Abel Test

This test on chemical stability was proposed by *Abel* in 1875. The test parameter determined is the time after which a moist potassium iodide starch paper turns violet or blue when exposed to gases evolved by one gram of the explosive at 82.2 °C (180 °F).

In commercial nitroglycerine explosives, for example, this coloration only develops after 10 min or more. In a more sensitive variant of the method, Zinc iodide – starch paper is employed.

The *Abel* test is still used in quality control of commercial nitrocellulose, but is currently no longer employed in stability testing of propellants.

Acceptor[1)]

Empfängerladung; *charge réceptrice*

A charge of explosives or blasting agent receiving an impulse from an exploding → *Donor* charge.

Acremite

This is the name given by the US inventor *Acre* to his mixture of about 94% ammonium nitrate with 6% fuel oil. This mixture was at first prepared in a primitive manner by the users themselves to obtain a very cheap explosive for open pit mining under dry conditions. Like → *ANFO*, the material has widely displaced conventional cartridged explosives.

Actuator

Mechanical device operated by a solid propellant.

Adiabatic

Processes or phenomena assumed to occur in a closed system without energy exchange with the surroundings.

adiabatic flame temperature

The temperature obtained by thermodynamics calculations for the products of combustion of energetic materials neglecting energy loss to the surroundings.

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1) Text quoted from glossary.

Explosives, 7. Edition, Rudolf Meyer, Josef Köhler, and Axel Homburg.

isobaric adiabatic flame temperature

Adiabatic flame temperature attained under constant pressure conditions.

isochoric adiabatic flame temperature

Adiabatic flame temperature attained under constant volume conditions.

adiabatic temperature

The temperature attained by a system undergoing a volume or pressure change in which no heat enters or leaves the system.

Adobe Charge

Auflegerladung; *pétardage*

Synonymous with → *Mud Cap*

ADR

Abbreviation for "Accord Européen Relatif au Transport des Marchandises Dangereuses par Route" (European Agreement Concerning the international Carriage of Dangerous Goods by Road). It is based on the Recommendations on the Transport of Dangerous Goods Model Regulations (United Nations).

Aerozin

A liquid fuel for rocket engines that is composed of 50% anhydrous hydrazine and 50% *asym*-dimethylhydrazine.

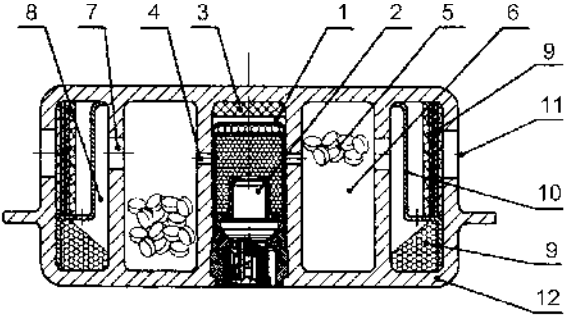
AGARD

Abbreviation for the NATO Advisory Group for Aeronautical Research and Development.

Airbag

Gasgenerator

The basic idea of the airbag as a passive restraint system in a motor vehicle was already patented for the first time in 1951 in Germany. However, it took nearly 20 years before development began on two basic types – pyrotechnic and hybrid gas generators. Both types are manufactured nearly exclusively in series production and were included in cars



1. Ignition chamber
2. Igniter unit
3. Pre-ignition unit
4. Nozzle holes
5. Gas mixture
6. Combustion chamber
7. Nozzle holes
8. Filter chamber
9. Filter
10. Deflector plate
11. Filter chamber apertures
12. Gas generator housing

Figure 1 Sectional diagram of a pyrotechnical gas generator for airbags.

starting in 1975. Mainstream applications of airbag restraint systems in almost every car started in 1990.

Nowadays four main types of gas generating principles are used for airbag inflators in cars. Pyrotechnic gas generators inflate the bag by gaseous combustion products of pyrotechnic compositions. Hybrid gas generators are based on a combination of pressurized gas and pyrotechnic (heating) charge to deliver the gas. Both types are widely used in driver, passenger, side and curtain airbag applications. So-called cold gas generators utilize pressurized helium for bag inflation and are usually used for knee and side airbag systems. The latest development in gas generating principles uses a combustible mixture of pressurized hydrogen, oxygen and inert gas being applied for driver and passenger applications. Hybrid and pyrotechnic gas generators are the most common types used and are described in detail below. Their construction is shown schematically in Figures 1 and 2.

In the *hybrid* system the pre-pressurized gas (nitrogen, argon/helium) is stored in pressure containers fitted with a burst disc. Opening this membrane by pyrotechnic means allows the gas to flow out into the airbag. The cooling of the expanding gas is compensated or even overcompensated by the pyrotechnic charge. Since the total amount of pyrotechnic mixture is small in quantitative terms, the compulsory threshold values of the toxic impurities contained in the working gas can be adhered to relatively easily. This fact, in addition to the ideal temperature of the working gas, is the main advantage of *hybrid* gas generators.

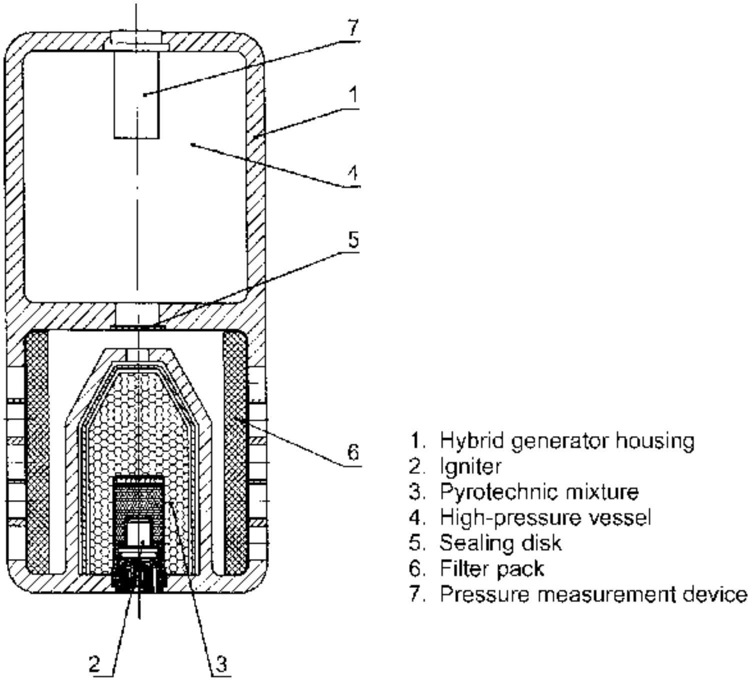


Figure 2 Sectional diagram of a hybrid gas generator for airbags.

The disadvantages are the larger weight compared to pyrotechnic gas generators, the more complex production technology needed and the subjection to pressure vessel regulation.

The unique feature of almost all *pyrotechnical gas generators* is the concentric assembly of three different chambers with designs corresponding to their pressure conditions and functions. The innermost chamber contains the booster unit consisting of a plug, squib and booster charge. An auto ignition charge is usually integrated in the booster setup, whose task is to ignite the pyrotechnic mixture without electric current in case of high temperatures, e.g. in case of fire. During standard electrical ignition the thin resistance wire of the igniter is heated and the ignition train started. The booster charge usually used in earlier times was boron/potassium nitrate. Nowadays pyrotechnic formulations with good ignition properties are used in pelletized grain design contributing noticeably to the overall gas yield of the generator. The hot gases and particles generated by this charge enter the concentrically arranged combustion chamber and ignite the pyrotechnic main charge. Both chambers are designed for high pressures up to 60 MPa. The pyrotechnic main charge consists generally of compressed pellets which

Table 1 Effluent gas limits according USCAR-24 regulation.

Effluent Gas	**Vehicle Level Limit (ppm)**	**Driver-Side Limit (ppm)**
Chlorine (Cl_2)	1	0.25
Carbon monoxide (CO)	461	115
Carbon dioxide (CO_2)	30 000	7500
Phosgene ($COCl_2$)	0.33	0.08
Nitric oxide (NO)	75	18.75
Nitrogen dioxide (NO_2)	5	1.25
Ammonia (NH_3)	35	9
Hydrogen chloride (HCl)	5	1.25
Sulphur dioxide (SO_2)	5	1.25
Hydrogen sulfide (H_2S)	15	3.75
Benzene (C_6H_6)	22.5	5.63
Hydrogen cyanide (HCN)	4.7	1.18
Formaldehyde (HCHO)	1	0.25

generate the working gas and slag residues by a combustion process. The products leave the combustion chamber through nozzles and enter the low pressure region of the filter compartment, where the slag is removed from the gas flow. The filter compartment is equipped with various steel filters and deflector plates. The gas then flows through the filter compartment nozzles into the bag.

The basic task of each gas generator is to provide sufficient nontoxic gas (see Table 1) within the required time frame of 11–30 ms to inflate the airbag to the specified pressure. The first pyrotechnic mixture used in airbag gas generators was based on sodium azide. During combustion, sodium azide reacts with oxidizing agents, which bond chemically the elemental sodium as the nitrogen is released. Established oxidizers were alkali and alkaline earth nitrates, metal oxides (e.g. CuO, Fe_2O_3), metal sulfides (MoS_2) and sulfur. If necessary slag forming agents (e.g. SiO_2, aluminosilicates) were also added. Advances in environmental awareness led consequently to the replacement of sodium azide, though pure nitrogen as a working gas was generated by this composition. Another factor to the detriment of sodium azide was the relative low specific gas yield and the unsolved disposal procedure for this type of pyrotechnic mixture.

With regard to azide-free gas mixtures, there have been numerous patents and initial applications since the early 1990s. These new gas mixtures generate more gas per gram (gas yields from gas mixtures containing NaN_3: 0.30–0.35 l/g) and thus enable smaller and to some extent a more lightweight construction of the gas generators.

They can be classified into two categories:

1. High-nitrogen organic compounds (C, H, O, N) are combined with inorganic oxidizers:
   The fuels are, for example, 5-aminotetrazole, azodicarbonamide, → *Guanidine nitrate*, → *Nitroguanidine*, dicyandiamide, → *Triaminoguanidine nitrate* and similar compounds, as well as salts of, for example, 5-nitrobarbituric acid, urea derivatives and also nitramines and similar compounds. The oxidizers are, for example, alkali or alkaline earth nitrates, → *Ammonium nitrate*, alkali or alkaline earth perchlorates and metal oxides.
   Gas yield of these mixtures: 0.50–0.65 l/g.
2. High-oxygen, nitrogen-free organic compounds (C, H, O) are blended with inorganic oxidizers. The fuels used are, for example, tri or dicarboxylic acids (e.g. citric acid, tartaric acid, fumaric acid) or similar compounds. The oxidizers used are especially perchlorates and chlorates with additional assistance from metal oxides. This enables any formation of NOx to be excluded. Gas yield of the mixture: 0.5–0.6 l/g.

The gas generator formulations are usually manufactured by grinding and blending the raw materials, which after a pre-compacting step are pressed into pellets or disks on rotary table presses. Some gas generator formulations using plastic (reactive) binders are manufactured by an extrusion process.

Air Blast

Druckwelle; *onde de choc*

The airborne acoustic or shock wave generated by an explosion → *Detonation*, → Fuel Air Explosives, → Thermobaric Explosives.

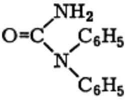
Air Loaders

Blasgeräte; *chargeurs pneumatiques*

Air loaders serve to charge prilled → *ANFO* blasting agents into boreholes. If the free-running prills cannot be charged by pouring, e.g. horizontal boreholes, boreholes with neglectable slope or boreholes with small diameters, they can be introduced by air loaders. This is done by loading the charge into a pressurized vessel and applying an air pressure of about 0.4 MPa; a valve at the lowest point of the machine, which can be controlled from the borehole to be filled, leads to a long hose; when the valve is opened, a stream of air containing the explosive charge in suspension is sent through it into the borehole. Other portable machines work on the injector principle.

Akardite I

diphenylurea; *Diphenylharnstoff*; *diphénylurée*



colorless crystals (molecular weight: 212.25 g/mol)
empirical formula: $C_{13}H_{12}N_2O$
energy of formation: −117.3 kcal/kg = −490.6 kJ/kg
enthalpy of formation: −138.2 kcal/kg = −578.2 kJ/kg
oxygen balance: −233.7%
nitrogen content: 13.21%
density: 1.276 g/cm^3

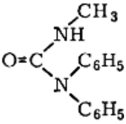
Akardite I serves as a → *Stabilizer* for gunpowders, in particular for → *Double-Base Propellants*.

Specifications

melting point:	at least 183 °C = 361 °F
moisture:	not more than 0.2%
ashes:	not more than 0.1%
chlorides:	not more than 0.02%
pH value:	at least 5.0
acid, 0.1 N NaOH/100 g:	not more than 2.0 cm^3

Akardite II

methyldiphenylurea; *Methyldiphenylharnstoff*; *N-méthyl-N′,N′-diphényl-urée*



colorless crystals
empirical formula: $C_{14}H_{14}N_2O$
molecular weight: 226.3 g/mol
energy of formation: −90.5 kcal/kg = −378.5 kJ/kg
enthalpy of formation: −112.7 kcal/kg = −471.5 kJ/kg
oxygen balance: −240.4%
nitrogen content: 12.38%
density: 1.236 g/cm^3

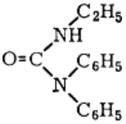
Akardite II is an effective → *Stabilizer* for double-base gunpowders

Specifications

same as for Akardite I,
except melting point at least 170–172 °C = 338–342 °F

Akardite III

ethyldiphenylurea; *Ethyldiphenylharnstoff*; *N-éthyl-N′,N′-diphénylurée*



colorless crystals
empirical formula: $C_{15}H_{16}N_2O$
molecular weight: 240.3 g/mol
energy of formation: −128.5 kcal/kg = −537.7 kJ/kg
enthalpy of formation: −151.9 kcal/kg = −635.5 kJ/kg
oxygen balance: −246.3%
nitrogen content: 11.65%
density: 1.128 g/cm^3

Akardite III is an effective → *Stabilizer* for double-base propellants. Both Akardite II and III are gelatinizers as well as → *Stabilizers*.

Specifications

same as for Akardite I,
except melting point at least 89 °C = 192 °F

Alex

Alex is an → aluminum powder formed by explosion of electrically heated aluminum wires in inert atmospheres with particle sizes between 50 and 200 nm. Due to a passivation layer of thickness between 2 and 4 nm, a substantial number of the particles are already converted to alumina, the formation of which should be avoided by *in situ* coating. In addition to the diffusion controlled oxidation at lower temperatures, a partial oxidation of the particles can occur by a fast chemically controlled reaction. Alex can increase the burning rate of solid composite rocket propellants up to a factor of two. An increase of detonation velocity is not confirmed but Alex might improve → *air blast* or fragment velocities of some high explosives, and viscosity increases in formulations with liquid binders.

Alginates

Salts of alginic acid which are capable of binding 200–300 times their own volume of water. They are added as swelling or gelling agents to explosive mixtures in order to improve their resistance to moisture and to → *Slurries* to increase viscosity.

All Fire

Mindestzündstrom; *ampèrage minime d'amorcage*

Minimum current that must be applied to an igniter circuit for reliable ignition of the primer charge without regard to time of operation.

Aluminum Powder

Aluminiumpulver; *poudre d'aluminum*

Aluminum powder is frequently added to explosives and propellants to improve their performance. The addition of aluminum results in considerable gain in heat of explosion because of the high heat of formation of aluminia (1658 kJ/mol, 16 260 kJ/kg) leading to higher temperatures of the fumes. Aluminum not reacted in the detonation front might be oxidized by atmospheric oxygen to induce post-heating in the fume zone and to increase the → *air blast* or even to initiate a delayed secondary explosion.

Widely used mixtures of explosives with aluminum powder include → *Ammonals*, → DBX, → HBX-1, → Hexal, → Minex, → Minol, → Torpex, → Trialenes, → Tritonal and *Hexotonal*. In addition, underwater explosives often contain aluminum powders.

The performance effect produced by aluminum powder is frequently utilized in → *Slurries*, also in → *Composite Propellants*.

Important characteristics of aluminum powders are shape and grain size of the powder granules. Waxed and unwaxed qualities are marketed. Propellant formulations often prescribe systematically varied grain sizes for obtaining optimal densities.

Amatex

A pourable mixture of trinitrotoluene, ammonium nitrate and RDX.

Amatols

Pourable mixtures of ammonium nitrate and trinitrotoluene of widely varying compositions (40 : 60, 50 : 50, 80 : 20). The composition 80 : 20 may be loaded into grenades, for example, using a screw press (extruder).

Ammonals

Compressible or pourable mixtures containing ammonium nitrate and aluminum powder; the pourable mixtures contain → *TNT*

Ammonium Azide

Ammoniumazid; *azoture d'ammonium*

NH_4N_3
colorless crystals
molecular weight: 60.1 g/mol
energy of formation: +499.0 kcal/kg = +2087.9 kJ/kg
enthalpy of formation: +459.6 kcal/kg = +1922.8 kJ/kg
oxygen balance: −53.28%
nitrogen content: 93.23%
density: 1.346 g/cm^3

Ammonium azide is prepared by introducing a solution of ammonium chloride and sodium azide into dimethylformamide at 100 °C. The solvent is then drawn off in vacuum. Owing to its high vapor pressure, this compound has not yet found any practical application.

Vapor pressure:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
1.3	29.2	84.6
7	49.4	121.0
13	59.2	138.6
27	69.4	157.0
54	80.1	176.2
80	86.7	188.1
135	95.2	203.4
260	107.7	225.9
530	120.4	248.7
1010	133.8	272.8

Ammonium Chloride

Ammoniumchlorid; *chlorure d'ammonium*

NH_4Cl
colorless crystals
molecular weight: 53.49 g/mol

energy of formation: −1371.6 kcal/kg = −5738.9 kJ/kg
enthalpy of formation: −1404.9 kcal/kg = −5878.1 kJ/kg
oxygen balance: −44.9%
nitrogen content: 26.19%
sublimation point: 335 °C = 635 °F

Ammonium chloride serves as a partner component to alkali nitrates in the so-called inverse salt-pair (ion-exchanged) explosives (→ *Permitted Explosives*).

Specifications

net content:	at least 99.5%
moisture:	not more than 0.04%
glow residue:	not more than 0.5%
Ca; Fe; SO_4; NO_3:	not more than traces
pH value:	4.6–4.9

Ammonium Dichromate

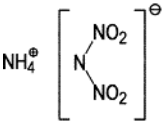
Ammoniumdichromat; *dichromate d'ammonium*

$(NH_4)_2Cr_2O_7$
orange red crystals
molecular weight: 252.1 g/mol
energy of formation: −1693.1 kcal/kg = −7083.9 kJ/kg
enthalpy of formation: −1713.1 kcal/kg = −7167.4 kJ/kg
oxygen balance: ±0%
nitrogen content: 11.11%
density: 2.15 g/cm^3

Ammonium dichromate decomposes on heating, but is not an explosive. It is a component of pyrotechnical charges, and is an effective additive that is introduced into ammonium nitrate-based propellants in order to catalyze the decomposition reaction. According to the → *REACH* regulation ammonium dichromate is identified as a substance of very high concern with carcinogenic, mutagenic and reproduction toxic properties. Therefore ammonium dichromate is included in the Annex XIV of the REACH regulation and after a transitional period it can no longer be placed on the market or used by any manufacturer, importer or downstream user unless authorization has been granted.

Ammonium Dinitramide

Ammoniumdinitramid; *ADN*



empirical formula: $H_4N_4O_4$
molecular weight: 124.06 g/mol
energy of formation: −259.96 kcal/kg = −1086.6 kJ/kg
enthalpy of formation: −288.58 kcal/kg = −1207.4 kJ/kg
oxygen balance: +25.8%
nitrogen content: 45.1%
volume of explosion gases: 1084 l/kg
heat of explosion
  (H_2O liq.): 3337 kJ/kg
  (H_2O gas): 2668 kJ/kg
specific energy: 843 kJ/kg
density: 1.812 g/cm^3 at 20 °C
melting point: 93.5 °C (decomposition starts at melting point)
impact sensitivity: 4 N m, friction sensitivity: 64 N

Ammonium dinitramide is obtained by ammonolysis of dinitroamines, which are formed by the step-wise nitration of urethanes, *β*,*β*-iminodipropionitrile or nitramide. The last nitration step in each case requires the most powerful nitration reagents, such as nitronium tetrafluoroborate or dinitrogen pentoxide. Other methods pass via the direct nitration of ammonia with dinitrogen pentoxide to a mixture of ADN and → *Ammonium Nitrate* or the nitration of ammonium sulfamate with nitric acid to a mixture of ADN and ammomium hydrogensulfate. On the basis of its good → *Oxygen Balance* and high → *Enthalpy of Formation*, ADN appears to be attractive as a halogen-free oxidizing agent for solid rocket propellants and is currently the subject of intensive studies.

Ammonium Nitrate

Ammoniumnitrat; *nitrate d'ammonium*; *AN*

NH_4NO_3
colorless crystals
molecular weight: 80.0 g/mol
energy of formation: −1058.3 kcal/kg = −4428.0 kJ/kg
enthalpy of formation: −1091.5 kcal/kg = −4567.0 kJ/kg
oxygen balance: +19.99%
nitrogen content: 34.98%
volume of explosion gases: 980 l/kg

heat of explosion
(H_2O liq.): 593 kcal/kg = 2479 kJ/kg
(H_2O gas): 345 kcal/kg = 1441 kJ/kg
melting point: 169.6 °C = 337.3 °F
lead block test: 180 cm^3/10 g
deflagration point:
begins decomposition at melting point,
complete at 210 °C = 410 °F
impact sensitivity: up to 5 kp m = 50 N m no reaction
friction sensitivity:
up to 36 kp = 353 N pistil load no reaction,
critical diameter of steel sleeve test: 1 mm

Ammonium nitrate is hygroscopic and readily soluble in water (the saturated solution contains about 65% NH_4NO_3). Transitions from one polymorph to another take place at 125.2, 84.2, 32.3 and −16.9 °C. The product shows a great tendency to cake. The difficulties therefore involved are avoided by transformation into → *Prills*. Ammonium nitrate is marketed as dense prills and as porous prills. Both can be introduced in industrial explosives after milling except → *ANFO* blasting agents, which need unmilled porous prills.

Ammonium nitrate is the most important raw material in the manufacture of industrial explosives. It also serves as a totally gasifiable oxygen carrier in rocket propellants.

Phase-stabilized ammonium nitrate (PSAN) and spray-crystallized ammonium nitrate (SCAN) are special qualities provided by the Fraunhofer ICT.

Specifications

net content (e.g. by N-determination):	at least 98.5%
glow residue:	not sandy, and not more than 0.3%
chlorides, as NH_4Cl:	not more than 0.02%
nitrites:	none
moisture:	not more than 0.15%
Ca; Fe; Mg:	not more than traces
reaction:	neutral
Abel test at 82.2 °C = 180 °F:	at least 30 min
pH:	5.9 ± 0.2
solubles in ether:	not more than 0.05%
unsolubles in water:	not more than 0.01%
acidity, as HNO_3:	not more than 0.02%

Specifications for prills

boric acid	0.14 ± 0.03%
density of grain:	at least 1.50 g/cm^3
bulk density:	at least 0.8 g/cm^3

Ammonium Nitrate Emulsion

ANE

Intermediate for →Emulsion (blasting) explosives. These emulsions are nonsensitized and are intended to produce an emulsion (a blasting) explosive only after further processing prior to use. Emulsions typically consist of ammonium nitrate (partly replaced by other inorganic nitrate salts), water, fuel, and emulsifier agents.

Ammonium Nitrate Explosives

Ammonsalpeter-Sprengstoffe; *explosifs au nitrate d'ammonium*

Ammonium nitrate explosives are mixtures of ammonium nitrate with carbon carriers such as wood meal, oils or coal and sensitizers such as → *Nitroglycol* or → *TNT* and → *Dinitrotoluene*. They also may contain → *Aluminum Powder* to improve the → *Strength*. Such mixtures can be cap-sensitive. The non-cap-sensitive ones are classed as → *Blasting agents*.

Mixtures of porous ammonium nitrate prills with liquid hydrocarbons, loaded uncartridged by free pouring or by means of → *Air Loaders* are extensively used under the name → ANFO blasting agents.

The resistance to moisture of powder-form ammonium nitrate explosives and blasting agents is low, but can be improved by addition of hydrophobic agents (e.g. calcium stearate). The densities of the powders are about 0.9–1.05 g/cm^3.

Higher density and better water resistance are obtained using gelatinous ammonium nitrate explosives. They are based on ammonium nitrate and 20–40% gelatinized nitroglycol or a nitroglycerine-nitroglycol mixture. The German ammongelites also contain low-melting TNT-dinitrotoluene mixtures. Ammonium nitrate gelatins have widely replaced the elder sodium nitrate nitroclycerine gelignites. The density of the gelatinous explosives is about 1.5–1.6 g/cm^3.

Water-containing ammonium nitrate mixtures with fuels are known as → *Slurries* and → *Emulsion Slurries*.

Many permitted explosives are ammonium nitrate in powder form or gelatinous explosives with added inert salts, such as sodium chloride or potassium chloride, which reduce their explosion temperature.

Ammonium Perchlorate

Ammoniumperchlorat; *perchlorate d'ammonium*; *APC*

NH_4ClO_4
colorless crystals
molecular weight: 117.5 g/mol
energy of formation: −576.5 kcal/kg = −2412.0 kJ/kg
enthalpy of formation: −601.7 kcal/kg = −2517.4 kJ/kg
oxygen balance: +34.04%
nitrogen content: 11.04%
volume of explosion gases: 799 l/kg
heat of explosion (H_2O liq.): 471 kcal/kg = 1972 kJ/kg
density: 1.95 g/cm^3
melting point: 244 °C; decomposition: 320 °C (10 K/min)
lead block test: 195 cm^3/10 g
deflagration point: 350 °C = 662 °F
impact sensitivity: 1.5 kp m = 15 N m

Ammonium perchlorate is prepared by neutralizing ammonia by perchloric acid. It is purified by crystallization.

Ammonium perchlorate is the most important oxygen carrier for → *Composite Propellants*. Unlike alkali metal perchlorates, it has the advantage of being completely convertible to gaseous reaction products.

Table 2 Specifications.

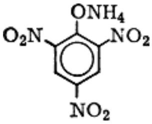
	Grade A	Grade B	Grade C
Net content: at least	99.0%	99.0%	98.8%
Water-insolubles: not more than	0.03%	0.01%	0.25%
Bromates, as NH_4BrO_3: not more than	0.002%	0.002%	0.002%
Chlorides, as NH_4Cl: not more than	0.15%	0.10%	0.15%
Chromates, as K_2CrO_4: not more than	0.015%	0.015%	0.015%
Iron, as Fe: not more than	0.003%	0.003%	0.003%
Residue from sulfuric acid fuming:			
Not more than	0.3%	0.3%	0.3%
Moisture: not more than	0.08%	0.05%	0.08%
Surface moisture: not more than	0.020%	0.015%	0.020%
Ash, sulfated: not more than	0.25%	0.15%	0.45%
Chlorate as NH_4ClO_3: not more than	0.02%	0.02%	0.02%
Na and K: not more than	0.08%	0.05%	0.08%
$Ca_3(PO_4)_2$:	none	none	0.15–0.22%
pH:	4.3–5.3	4.3–5.3	5.5–6.5

Granulation classes

Class 1	Through 420 and 297 micron sieve, retained on 74 micron sieve.
Class 2	Through 297 micron sieve.
Class 3	Through 149 micron sieve.
Class 4	50 to 70% through 210 micron sieve.
Class 5	Through 297 micron sieve, retained on 105 micron sieve.
Class 6	89 to 97% through 297 micron sieve.
Class 7	45 to 65% through 420 micron sieve.

Ammonium Picrate

ammonium-2,4,6-trinitrophenolate; *Ammonpikrat*; *picrate d'ammonium*; *explosive D*



yellow crystals
empirical formula: $C_6H_6N_4O_7$
molecular weight: 246.1 g/mol
energy of formation: −355.0 kcal/kg = −1485.2 kJ/kg
enthalpy of formation: −375.4 kcal/kg = −1570.7 kJ/kg
oxygen balance: −52.0%
nitrogen content: 22.77%
volume of explosion gases: 909 l/kg
heat of explosion
  (H_2O liq.): 686 kcal/kg = 2871 kJ/kg
  (H_2O gas): 653 kcal/kg = 2732 kJ/kg
density: 1.72 g/cm^3
melting point: 280 °C = 536 °F (decomposition)
lead block test: 280 cm^3/10 g
detonation velocity:
  7150 m/s = 23 500 ft/s at $\rho = 1.6$ g/cm^3
deflagration point: 320 °C = 608 °F
impact sensitivity: at 2 kp m = 19 N m no reaction

Ammonium picrate is soluble in water, alcohol and acetone, but is practically insoluble in ether. It is prepared by saturating an aqueous solution of picric acid with ammonia; a red form is formed first, which passes into the stable yellow form in the presence of water vapor, on prolonged storage or by recrystallization from water. Ammonium picrate has been employed as an explosive in military charges.

Amorces

This term denotes very small priming plates utilized in children's toys. They contain an impact-sensitive mixture of potassium chlorate and red phosphorus. The French word *amorce* means all initiating or inflaming devices.

ANFO

An abbreviation for ammonium nitrate fuel oil, a blasting agent composed of ammonium nitrate and liquid hydrocarbons. The application technique of these mixtures has now become very much easier owing to the fact that the material, which has a strong tendency to agglomeration, is commercially produced as porous prills. These are granules solidified from the liquid melt, sufficiently porous to take up about 6% of the oil, which is the amount needed to produce oxygen balance. The nitrate, and the explosive produced from it retain their free-flowing capacity (see also → Acremite).

The explosive must be utilized in the form of a continuous column, and must be ignited by a powerful primer. This means that it must be poured loose (not as cartridges) into the borehole, or else blown into it with an → *Air Loader*.

Its manufacture is very cheap, and may even take place on continuous mixers and wheels. The material has now almost completely replaced conventional explosives in cartridge form in open-pit mining and in potash mining.

density: 0.9 g/cm^3
weight strength: 75%

Heavy ANFO is a 50/50-mixture of ANFO and → *Emulsion Slurries*, which has higher loading densities than poured ANFO alone (→ bulk explosives).

AOP

Allied Ordnance Publication of NATO, which provides supporting guidance to a STANAG. For instance, AOP-39 provides guidance on the assessment and development of insensitive munitions (IM). The Agreement of NATO nations to use this AOP is recorded in → STANAG 4439.

APU

Auxiliary power unit. Propellant-powered device used to generate electric or fluid power.

Aquarium Test

The parameter measured in this test is the pressure of underwater explosion. Lead or copper membranes are employed and the membrane deformation as a function of the performance of the explosive and of the distance from the explosion site is estimated. The measuring apparatus, consisting of piston and anvil, resembles the *Kast* brisance meter. An alternative technique is to measure the deformation of diaphragms or copper discs accommodated inside an air-containing vessel such as a can.

In addition to the mechanical method described, there are also electromechanical measuring techniques in which the impact pressure is recorded by an oscillograph with the aid of a piezoquartz crystal.

The measurements can be carried out in natural waters. A basin, made of steel concrete and bulkhead steel, has a buffering floor made of foamed polystyrene. Air is blown in along the bulkhead walls for damping purposes, so that an air “curtain” is formed. → *Underwater Detonations*.

Argon Flash

Argon-Blitz; *éclair par détonation dans l’argon*

The intensity of the light appearing during a detonation is caused, primarily by compression of the surrounding air.

If the air is replaced by a noble gas such as argon, the light intensity increases considerably. The duration of the flash is only as long as that of the explosion, i.e. on the order of a few µs.

The recently developed ultra-short flash lamps work on the principle of detonation of an explosive in an argon medium. They are particularly suited to the illumination of detonation processes, since the detonation moment of the lamp can be accurately adjusted to the course of the detonation of the test specimen.

The intensity of the method can be considerably increased and the explosion time considerably reduced if the shock wave travelling from the explosive through the argon medium is reflected. This can be achieved by interposing a mass, which may be very small, such as a 0.2 mm-thick acetate foil, as an obstacle. The same effect can also be produced by using curved glass, such as a watch glass. It is mostly used in the orthogonal synchro-streak technique (OSST) to photograph the jet of a → shaped charge.

Armor Plate Impact Test

This is a test developed in the USA to study the behavior of a given explosive, employed as charge in a projectile, on impact against hard, solid targets. The explosive is charged into the test projectile and is fired from a "gun" against a steel plate. The impact velocity which causes the charge to detonate is determined. The test description: → *Susan Test*.

Armstrong Blasting Process

This is an extraction method used in coal mining in the USA. The highly compressed (71–81 MPa) air in the borehole is suddenly released by means of so-called blasting tubes equipped with bursting discs. The compressed air is generated underground by special compressors (see also → *Gas Generators*).

A similar method has received the name *Airdox*. The bursting elements in the blasting tubes have a different construction; the compressed air utilized in the method can be generated aboveground and distributed over a network of ducts.

ARDEC

US Army Armament Research, Development and Engineering Center; Picatinny Arsenal Dover, New Jersey, USA

Internationally acknowledged hub for the advancement of armament technologies and engineering innovation. As one of the specialized research, development and engineering centers within the US Army Materiel Command, the ARDEC has the responsibility for meeting this critical demand.

ASTROLITE

Stoichiometric mixture from hydrazine and ammonium nitrate. It was a spin-off from the US-rocket program in the 1960s. In 19th century, Sprengel (*Sprengel Explosives*) had already suggested that two nonexplosive components become cap sensitive after being mixed. Astrolite G and Astrolite A/A-1-5 (with 20% aluminum additive) are also called liquid landmines or binary explosives. The explosive strength of such mixtures is very high and even exceeds Nitroglycol in certain aspects. Detonation velocity of Astrolite G: 8600 m/s and Astrolite A/A-1-5: 7800 m/s.

Audibert Tube

Audibert-Rohr

This testing apparatus, which was first proposed by *Audibert* and *Delmas*, measures the tendency to → *Deflagration* of a permitted explosive. A cartridge containing the test sample is placed, with its front face open, in the tube and is packed tightly on all sides with coal dust. An incandescent spiral is placed in the cartridge opening; if the material is difficult to ignite (e.g. inverse salt-pair permissibles) the spiral is covered with a flammable igniter mixture. The tube is then closed by a perforated plate. The parameter measured is the minimum hole diameter at which the initiated deflagration arrives at the bottom of the cartridge.

In a modification of the method two cartridges placed coaxially one on top of the other are tested.

Aurol

T-Stoff; Ingolin

Concentrated (88–86%) hydrogen peroxide. It is employed in liquid fuel rocket engines as an → *Oxidizer* or, after catalytic decomposition, as → *Monergol*. For its explosive properties, see *Haeuseler*, Explosivstoffe 1, pp. 6–68 (1953).

Average Burning Rate

Mittlere Abbrandgeschwindigkeit; *vitesse moyenne de combustion*

The arithmetic mean (statistical average) burning rate of pyrotechnic or propellants at specific pressures and temperatures. Dimension: length/time or mass/time.

Azides

Azide; *azotures*

Azides are salts of hydrazoic acid (N_3H). Alkali metal azides are the most important intermediates in the production of → *Lead Azide*.

Sodium azide is formed by the reaction between sodium amide ($NaNH_2$) and nitrous oxide (N_2O). Sodium amide is prepared by introducing gaseous ammonia into molten sodium.

Ballistic Bomb

closed vessel; *ballistische Bombe*; *bombe pour essais ballistiques*

(→ *Burning Rate*)

The ballistic bomb (pressure bomb, manometric bomb) is used to study the burning behavior of a → *Gunpowder* or → *Propellant* charge powder. It consists of a pressure-resistant (dynamic loading up to about 1000 MPa (10 000 bar)) hollow steel body that can be bolted together and has a hole to adapt a piezoelectric pressure transducer. The pressure p in the bomb is measured as a function of time t.

As a rule, studies of powder in the pressure bomb are carried out in comparison with a powder of known ballistic performance. They are very useful both in the development of powders and in production monitoring.

If the dynamic liveliness L (= $1/p_{\max} \cdot \mathrm{d}\ln p/\mathrm{d}t$) is determined as a function of $p/p_{\max}$ from the primary measured signal, then for a defined powder geometry the parameters characterizing its burn-up, the linear burning rate $\dot{e}$ (→ *Burning Rate*) and the pressure exponent α can be determined. Pressure bomb shots of the same powder at different charge densities δ (= mass m_c of powder/volume V_B of the pressure vessel) enable the specific covolume η of the combustion gases from the powder and the force f (powder force) of the powder to be determined in addition. From these, if the → *Heat of Explosion* Q_{Ex} of the powder is known, the value of the average adiabatic coefficient æ (= $1 + f/Q_{Ex}$) of the combustion gases, which is of interest for the ballistic performance, can be derived.

Since the combustion gases of powders satisfy Abel's equation of state to a good approximation, it is possible to use the auxiliary parameters ρ_c (density of the powder):

$$\Delta := \frac{m_c}{V_B \cdot \rho_c} \quad \text{normalised charge density} \tag{1}$$

$$\chi := (1 - \eta\rho_c) \cdot \frac{\Delta}{1 - \Delta} \quad \text{real gas correction term} \tag{2}$$

$$\Phi := f\rho_c \frac{\Delta}{1 - \Delta} \quad \text{characteristic pressure} \tag{3}$$

to write the relationship between the pressure p in the manometric bomb and the burnt volume proportion z of the powder as

$$z\left(\frac{p}{p_{\max}}\right) = \frac{p/p_{\max}}{1 + \chi(1 - p/p_{\max})} \tag{4}$$

and

$$p(z) = \Phi \cdot \frac{z}{1 + \chi z} \tag{5}$$

Accordingly, the maximum gas pressure achieved at the end of burn-up ($z = 1$) is calculated as

$$p_{\max} = \frac{\Phi}{1 + \chi} \tag{6}$$

The dynamic liveliness L is calculated from

$$L = \frac{S(0)}{V(0)} \cdot \varphi(z) \cdot \frac{\dot{e}(p_{\mathrm{ref}})}{p_{\mathrm{ref}}} \cdot \left[\frac{p}{p_{\mathrm{ref}}}\right]^{\alpha-1} \cdot \frac{1 + \chi}{(1 + \chi z)^2} \tag{7}$$

$S(0)/V(0)$	is the ratio of the initial surface area to the initial volume of the powder,
$\varphi(z)$	is the shape function of the powder, which takes account of the geometrical conditions (sphere, flake, cylinder, n-hole powder) during the burn-up ($\varphi(z)$ = current surface area/ initial surface area)
$\dot{e}(p_{\mathrm{ref}})$	is the linear burning rate at the reference gas pressure p_{ref}
p_{ref}	is the reference gas pressure and
α	is the pressure exponent, which for many powders is close to 1.

To evaluate Eq. (7), z should be replaced by p/p_{max} using Eq. (4).

Figure 3 shows the time profile of the pressure in the manometric bomb for a typical 7-hole powder. Initially the pressure is increasingly steep, since burn-up takes place more quickly the higher the pressure and burning surface of the powder becomes greater as the burn-up progresses (progressive burn-up). Towards the end of the burn-up the pressure profile levels out rapidly because the burning surface area of the powder becomes drastically smaller as soon as approx. 88% of the powder has been burnt.

Figure 4, which shows the calculated profile of the dynamic liveliness as a function of p/p_{max}, again reflects essentially the shape of the form function for $p/p_{\mathrm{max}} > 0.2$ (see Figure 5). On the other hand for small values of p/pq_{max}, the dependence on $p^{\alpha-1}$ resulting for $\alpha = 0.9$ is dominant. The kink in the shapes of the form function and the dynamic liveliness at $p/p_{\mathrm{max}} = 0.87$ (disintegration of the powder granules into slivers) is greatly rounded off in the measured curves because not all of the gran-

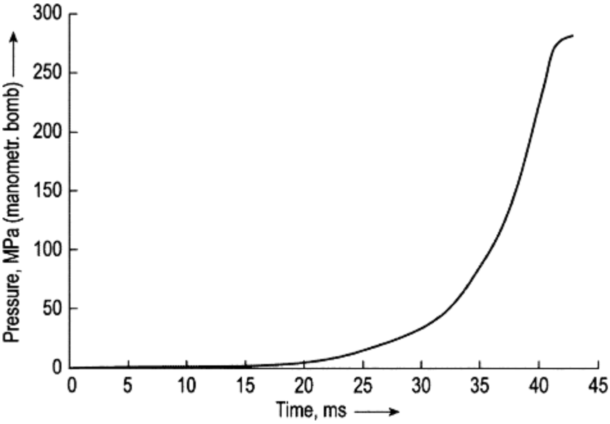


Figure 3 Pressure–time graph $p = f(t)$.

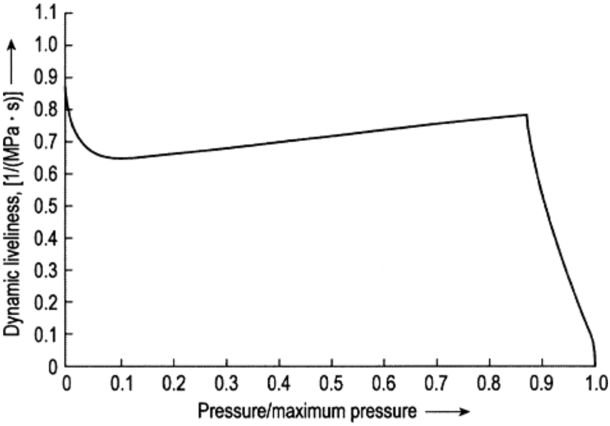


Figure 4 Dynamic liveliness as a function of p/p_{max}.

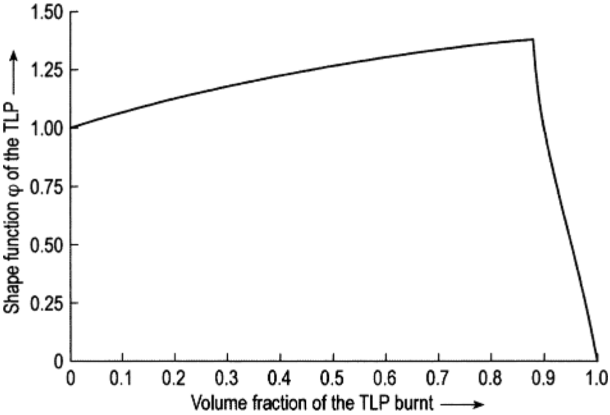


Figure 5 Form function of the powder as a function of the current surface area relative to the initial surface area.

ules burn up at exactly the same time and small differences in geometry always arise (manufacturing tolerances).

Ballistic Mortar

ballistischer Mörser; *mortier ballistique*

An instrument for comparative determinations of the performance of different explosives. A mortar, provided with a borehole, into which a snugly fitting solid steel projectile has been inserted, is suspended at the end of a 304.8 cm long pendulum rod. Ten grams of the explosive

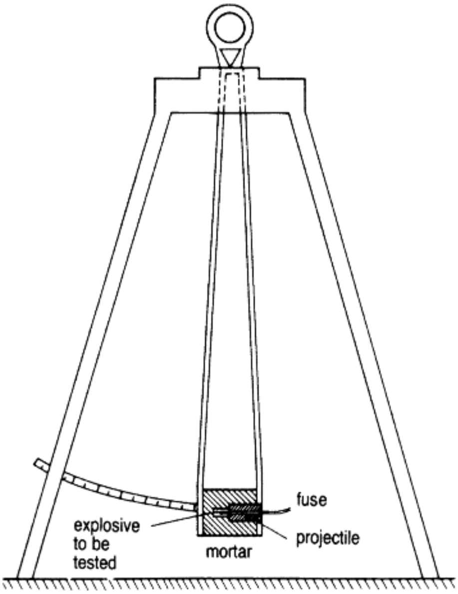


Figure 6 Ballistic mortar.

to be tested are detonated in the combustion chamber. The projectile is driven out of the mortar by the fumes and the recoil of the mortar is a measure of the energy of the projectile; the magnitude determined is the deflection of the pendulum. This deflection, which is also known as weight strength, is expressed as a percentage of the deflection produced by blasting gelatin (→ *Blasting Gelatin*), arbitrarily taken as 100. Also, relative values referring to the deflection produced by TNT are listed, especially for explosives of military interest.

This method, which is commonly employed in English-speaking countries and is suited for the experimental determination of the work performed by the explosive, has now been included in the list of standard tests recommended by the European Commission for the Standardization of Explosive Testing.

An older comparison scale is grade strength, which determines the particular explosive in standard "straight" dynamite mixtures (the mixtures contain ungelatinized nitroglycerine in different proportions, sodium nitrate and wood or vegetable flour (→ *Dynamites*)) and gives a pendulum deflection equal to that given by the test material. The percentage of nitroglycerine contained in the comparative explosive is reported as grade strength.

The grade strength percentage is not a linear indicator of the performance of the explosive; the performance of a 30% dynamite is more than half of the performance of a 60% dynamite, because the fuel-oxidizer mixtures as well as nitroglycerine also contribute to the gas- and heat-generating explosive reaction.

For comparison of weight strength values with other performance tests and calculations → *Strength*.

Ball Powder

Kugelpulver, Globularpulver; *poudre sphérique*

Ball powder is a propellant with ball-shaped particles, produced by a special method developed by *Mathieson* (USA). A concentrated solution of nitrocellulose in a solvent that is immiscible with water (e.g. ethyl acetate) is suspended in water by careful stirring so that floating spheres are formed. The solution is warmed at a temperature below the boiling point of the solvent and the latter gradually evaporates and the floating spheres solidify.

Since the spherical shape is unfavorable from internal ballistical considerations (very degressive), a thorough → *Surface Treatment* follows, the purpose of which is to sheathe the faster-burning core by using a slower-burning shell.

BAM

Bundesanstalt für Materialforschung und -prüfung, Unter den Eichen 87, 12200 Berlin (www.bam.de)

Federal Institute for Materials Research and Testing (including explosives). BAM sensitivity tests: → *Friction Sensitivity* → Heat Sensitivity and → *Impact Sensitivity*.

BAM is the German competent authority for Class 1 dangerous goods and notified body in compliance with EU directive 93/15.

Baratols

Pourable TNT mixtures with 10–20% nitrate.

Barium Chlorate

Bariumchlorat; *chlorate de barium*

$Ba(ClO_3)_2 \cdot H_2O$
colorless crystals
molecular weight: 304.2 g/mol

energy of formation: −789.3 kcal/kg = −3302.3 kJ/kg
enthalpy of formation: −2536.0 kJ/kg
oxygen balance: +31.55%
density: 3.18 g/cm^3
melting point: 414 °C = 779 °F

Barium chlorate and → *Barium Perchlorate* are used in pyrotechnical mixtures producing green flames.

Barium Nitrate

Bariumnitrat; *nitrate de barium: BN*

$Ba(NO_3)_2$
colorless crystals
molecular weight: 261.4 g/mol
energy of formation: −898.2 kcal/kg = −3758.1 kJ/kg
enthalpy of formation: −907.3 kcal/kg = −3796.1 kJ/kg
oxygen balance: +30.6%
nitrogen content: 10.72%
density: 3.24 g/cm^3
melting point: 592 °C = 1098 °F

Component in green-flame pyrotechnics and in ignition mixtures (with → *Lead Styphnate*). For specifications, see Table 3.

Barium Perchlorate

Bariumperchlorat; *perchlorate de barium*

$Ba(ClO_4)_2 \cdot 3H_2O$
colorless crystals
molecular weight: 336.24 g/mol
oxygen balance: +38.1%
density: 3.2 g/cm^3
melting point: 505 °C = 941 °F

Application in → *Pyrotechnical Compositions*.

Barricade

Schutzwall; *merlon, écran*

Barricades are grown-over earth embankments erected for the protection of buildings, which may be endangered by an explosion. The overall height of the barricade must be at least 1 m above the building to be protected. The required safety distances between explosive manufacture buildings or storage houses can be halved if the houses are barricaded.

Table 3 Specifications.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Net content by nitrogen analysis: at least	99.7%	99.0%	99.5%	99.5%	98.5%	99.5%
Sr: not more than	0.6%	–	0.6%	–	–	0.6%
Ca: not more than	0.05%	–	0.05%	–	–	0.05%
$Al_2O_3 + Fe_2O_3$: not more than	–	0.50%	–	–	–	–
Na, as Na_2O: not more than		0.15				0.15
Chloride, as $BaCl_2$, not more than	0.0075%	0.0075%	0.0075%	0.0075%	–	0.0075%
Grit: not more than	0.05%	0.05%	0.05%	0.05%	–	0.05%
Fe and other metals	none	none	none	none	none	none
Moisture: not more than	0.20%	0.10%	0.20%	0.20%	0.05%	0.10%
pH:	5.0–8.0	5.0–8.0	5.0–8.0	–	5.0–8.0	5.0–9.0
Insoluble matter: not more than	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%

Base-Bleed Propellants

Gas-generating elements inserted in the bottom of projectiles. The generated gas fills the subatmospheric pressure behind the projectile.

Base Charge

Sekundärladung; *charge de base de détonateur*

The main explosive charge in the base of a blasting cap, an electric blasting cap, or a nonelectric delay cap.

Bazooka

A shaped-charge anti-tank weapon first used by the Americans in the Second World War; → *Shaped Charges*. Its operating method is identical with that of the *Panzerfaust* developed in Germany at that time.

B-Black Powder

Sprengsalpeter; *poudre noir au nitrate de soude*

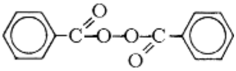
A → *Black Powder* mixture which contains sodium nitrate instead of potassium nitrate. It is marketed and utilized in the form of compressed cylinder-shaped grains, 25 and 30 mm in diameter, with a central hole 5 mm in diameter.

Bengal Fireworks

→ *Pyrotechnical Compositions*

Benzoyl Peroxide

Benzoylperoxid; *peroxyde de benzoyle*



colorless crystals
empirical formula: $C_{14}H_{10}O_4$
molecular weight: 242.1 g/mol
oxygen balance: −191.6%
melting and deflagration point: 107 °C = 225 °F
impact sensitivity: 0.5 kp m = 5 N m
friction sensitivity: at 12 kp = 120 N pistil load
decomposition: at 24 kp = 240 N pistil load crackling
critical diameter of steel sleeve test: 10 mm

Benzoyl peroxide is sparingly soluble in water and alcohol, but soluble in ether, benzene and chloroform. It can be prepared by reaction of benzoyl chloride with sodium peroxide.

The explosion strength of the product is low, but its sensitivity relatively high.

The organic peroxides serve as catalysts for polymerization reactions. They must be wetted or phlegmatized (→ *Phlegmatization*) for transportation and handling.

Benzoyl peroxide can also be used as a bleaching agent for oils and fats.

Bergmann–Junk Test

A method, developed by *Bergmann* and *Junk in* 1904, for testing the chemical stability of nitrocellulose; it was also subsequently employed for testing single-base powders. The test tube, which contains the specimen being tested and is equipped with a cup attachment, is heated at 132 °C = 270.4 °F for 2 h (nitrocellulose) or 5 h (single-base powders). At the end of the heating period the sample is extracted with water, and the test tube filled to the 50-ml mark with the water in the cup. The solution is filtered and the content of nitrous oxides is determined by the *Schulze–Tiemann* method on an aliquot of the filtrate.

The main disadvantage of the method is that nitrous compounds are only incompletely absorbed in water, especially since the atmospheric oxygen, which has remained behind in the tube, is expelled during heating or is displaced by the carbon dioxide evolved at the powder surface. Moreover, the results vary with the volume of the specimen employed, since differing volumes of water are required to fill the tube up to the mark in gelled and porous powders.

Siebert suggested the use of H_2O_2 rather than water as the absorption medium in 1942. He also suggested that the employed apparatus should be redesigned to avoid gas losses that occur when the cup attachment is taken off. In the new design, the cup is replaced by a large (over 50 ml) attachment resembling a fermentation tube, which need not be taken off during the extraction of the sample. In this way quantitative determination of the liberated nitrogen oxides, even in large amounts, becomes possible.

Siebert also suggested that the total acidity be determined by titration against 0.01 N NaOH in the presence of Tashiro's indicator. In this manner → *Double-Base Propellants* can also be tested; the test is carried out at 115 °C, the duration of heating being 8 or 16 h depending on the nitroglycerine content of the sample (or of similar products, e.g. → *Diethyleneglycol Dinitrate*).

Bichel Bomb

Bichel-Bombe; *bombe Bichel*

Used to study the composition and → *Volume of Explosion Gases*. It consists of a heavy steel case sealed by a screw cap. The construction withstands the dynamic shock of a detonating explosive sample. The gas developed can be vented by a valve in the screw cap for measurement of volume and for gas analysis.

The → *Lead Block Test* has been used for the same purpose: the block is sealed hermetically by a plug, and held in position by a steel construction. After detonation of the explosive sample in the block, the gas content has been vented by a special sealed drilling tool.

For computing the specific gas volume → *Thermo-dynamic Calculation of Decomposition Reactions*.

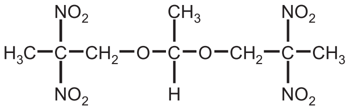
Billet

Monolithic charge of solid propellant of any geometry; term usually applied to a formed propellant prior to final shaping (→ *Grain*).

Binder

Compositions that hold together a charge of finely divided particles and increase the mechanical strength of the resulting propellant grain when it is consolidated under pressure. Binders are usually resins, plastics, or asphaltics, used dry or in solution (→ *Energetic Binders*).

Bis(2,2-dinitropropyl)acetal, BDNPA

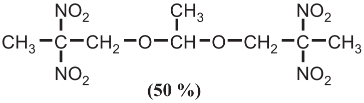


$$H_3C-\underset{NO_2}{\overset{NO_2}{C}}-CH_2-O-\underset{H}{\overset{CH_3}{C}}-O-CH_2-\underset{NO_2}{\overset{NO_2}{C}}-CH_3$$

solid
empirical formula: $C_8H_{14}N_4O_{10}$
molecular weight: 326.22 g/mol
oxygen balance: −63.76%
energy of formation: −607.14 kJ/mol
enthalpy of formation: −641.83 kJ/mol = −1967.46 kJ/kg
density: 1.36 g/cm^3
melting point: 33–35 °C
boiling point: 1150 °C

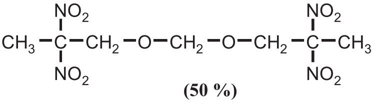
BDNPA is an ingredient of the energetic plasticizer → *BDNPA/F*.

Bis(2,2-dinitropropyl)acetal/formal, BDNPA/F



$$CH_3-\underset{NO_2}{\overset{NO_2}{C}}-CH_2-O-\overset{CH_3}{CH}-O-CH_2-\underset{NO_2}{\overset{NO_2}{C}}-CH_3$$

(50 %)



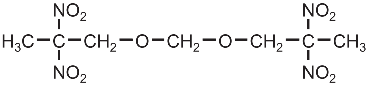
$$CH_3-\underset{NO_2}{\overset{NO_2}{C}}-CH_2-O-CH_2-O-CH_2-\underset{NO_2}{\overset{NO_2}{C}}-CH_3$$

(50 %)

liquid
empirical formula: $C_{7.5}H_{13}N_4O_{10}$
molecular weight: 319.21 g/mol
oxygen balance: −57.64%
energy of formation: −586.51 kJ/mol
enthalpy of formation: −620.03 kJ/mol = −1942.39 kJ/kg
density: 1.39 g/cm^3
melting point: −15 °C
boiling point: 150 °C

Plasticizers composed of → *BDNPA* and → *BDNPF* have found many applications in energetic formulations. For example, LOVA gun propellant uses BDNPA/F as an energetic ingredient. BDNPA/F plasticizer is typically a 50/50 mixture. The formal is solid, slightly less energetic than the acetal and the mixture is used to form a eutectic to lower the melting point.

Bis(2,2-dinitropropyl)formal, BDNPF



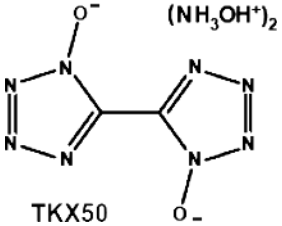
$$H_3C-\underset{NO_2}{\overset{NO_2}{C}}-CH_2-O-CH_2-O-CH_2-\underset{NO_2}{\overset{NO_2}{C}}-CH_3$$

solid
empirical formula: $C_7H_{12}N_4O_{10}$
molecular weight: 312.193 g/mol
oxygen balance: −51.25%
energy of formation: −564.84 kJ/mol
enthalpy of formation: −597.06 kJ/mol = −1912.46 kJ/kg
density: 1.41 g/cm^3
melting point: 31 °C
boiling point: 149 °C

BDNPF is an ingredient of the energetic plasticizer BDNPA/F.

Bishydroxylammonium-5,5′-bis(tetrazolate-1*N*-oxide)

Bishydroxylammonium-5,5′-bis(tetrazolat-1N-oxid); *TKX-50*

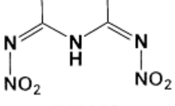


colorless crystals
empirical formula: $C_2H_8N_{10}O_4$
molecular weight: 236.2 g/mol
enthalpy of formation: +439 kJ/mol = +1859 kJ/kg
oxygen balance: −27.1%
density: 1.877 g/cm^3
deflagration point: 222 °C
detonation velocity: 9453 m/s at 1.8 g/cm^3
($P_{J\text{-}C}$: 354 kbar at 1.8 g/cm^3)
impact sensitivity: 20 N m
friction sensitivity: 120 N
electrostatic sensitivity: 0.1 J

TKX-50 (bishydroxylammonium 5,5′-bis(tetrazolate-1*N*-oxide)) is currently one of the promising ionic salts for a possible replacement for → RDX. TKX-50 can be prepared on a multigram scale by the reaction of 5,5′-(1-hydroxytetrazole) with dimethyl amine to form bis(dimethylammonium) 5,5′-(tetrazolate-1*N*-oxide) salt, which is then isolated, purified and subsequently reacted in boiling water with two equivalents of hydroxyammonium chloride to form TKX-50, dimethylammonium chloride and HCl.

Bis(nitramino)triazinone

Bis(nitramino)triazion; *DNAM*

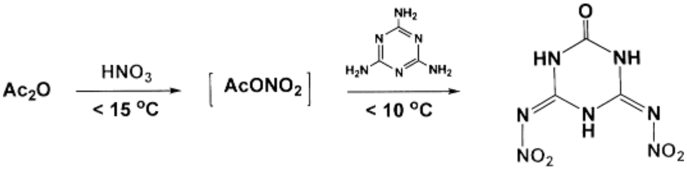


DNAM

empirical formula: $C_3H_3N_7O_5$
molecular weight: 217.1 g/mol

enthalpy of formation: −111 kJ/mol
density: 1.998 g/cm^3
melting point: 228 °C
detonation velocity: 9200 m/s
impact sensitivity: 82.5 N m
friction sensitivity: 216 N
electrostatic sensitivity: 0.25 J

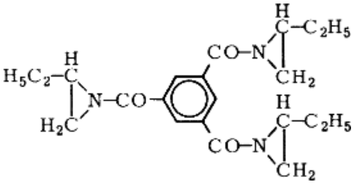
DNAM can be obtained in 50–60% yield by the nitration of melamine using $AcONO_2$ as the effective nitrating agent which is generated *in situ*, or by the direct nitration of melamine. One negative property of DNAM is its rapid hydrolysis at 80 °C, which results in the liberation of nitrous oxide (N_2O). This hydrolysis requires only one to two days at room temperature and is acid catalyzed.



DNAM

BITA

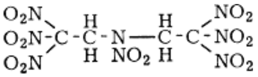
Abbreviation for an aziridine curing agent in → *Composite Propellants*



empirical formula: $C_{21}H_{27}N_3O_3$
molecular weight: 369.24 g/mol
density: 1.00 g/cm^3

Bi-trinitroethylnitramine

Di(2,2,2-trinitroethyl)nitramin; *di-trinitroéthylnitramine*;
BTNENA, HOX = high oxygen explosive

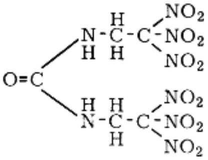


empirical formula: $C_4H_4N_8O_{14}$
molecular weight: 388.1 g/mol

energy of formation: +2.8 kcal/kg = +11.9 kJ/kg
enthalpy of formation: −17.0 kcal/kg = −71.2 kJ/kg
oxygen balance: +16.5%
nitrogen content: 28.80%
volume of explosion gases: 693 l/kg
heat of explosion
(H_2O liq.): 1299 kcal/kg = 5436 kJ/kg
(H_2O gas): 1248 kcal/kg = 5222 kJ/kg

Bi-trinitroethylurea

Di(2,2,2-trinitroethyl)-Harnstoff; *di-trinitroéthylurée*; *BTNEU*



empirical formula: $C_5H_6N_8O_{13}$
molecular weight: 386.1 g/mol
energy of formation: −178.5 kcal/kg = −746.7 kJ/kg
enthalpy of formation: −199.2 kcal/kg = −833.2 kJ/kg
oxygen balance: ±0%
nitrogen content: 29.02%
volume of explosion gases: 697 l/kg
heat of explosion
(H_2O liq.): 1543 kcal/kg = 6454 kJ/kg
(H_2O gas): 1465 kcal/kg = 6131 kJ/kg
density: 1.861 g/cm^3
melting point: 186 °C

Derivative of trinitroethylalcohol, addition product of → *Trinitromethane* and formaldehyde.

Black Powder

Schwarzpulver; *poudre noire*

Black powder is a mechanical mixture of potassium nitrate, sulfur and charcoal, which is mostly pressed, granulated and classified into definite grain fractions. It deflagrates faster than it detonates; it is thus classified as a low explosive, compared to the detonating high explosives.

The standard composition is: 75% potassium nitrate, 10% sulfur and 15% charcoal. There are also graded compositions containing 74, 70, 68 or 64% potassium nitrate. Corresponding compositions based on sodium nitrate are known as → *B-Black Powder*.

The starting components are finely ground, mixed and compacted in rolling mills and then pressed into cakes in hydraulic presses. The cakes are then broken and grain-classified; the resulting granules are polished with the application of graphite.

When in granulated form, black powder can be freely poured into boreholes.

Black powder is sensitive to impact, friction, and sparks. It is suitable for controlled blasting in which the treatment of stone must be mild, for example in the manufacture of roofing slates and in quarrying for paving stones.

It is employed in safety fuses, in pyrotechnics and in priming charges for smokeless powders. It is still the only suitable explosive for many purposes. It rapidly builds up pressure in relatively weak confinement. It does not detonate under normal conditions; the maximum rate of the explosion is about 500 m/s.

Blast Area

Sprengbereich (Absperrzone); *chantier de tir*

The area of direct blast impact. In addition, the adjacent areas that could be hit by flying debris (rocks, etc.).

Blaster

Sprengmeister; *boutefeu*

The qualified person in charge of, and responsible for, the loading and firing of a blast (same as *shot firer*).

Blasting Accessories

Sprengzubehör; *accessoires pour sautage*

Nonexplosive devices and materials used in blasting such as, but not limited to, cap crimpers, tamping bags, → *Blasting Machines*, → *Blasting Galvanometers*, and cartridge punches.

Blasting Agents

The notion of a blasting agent was conceived in the USA. Contrary to high explosives, which may contain nitroglycerine and which are sensitive to blasting caps, the term blasting agents denotes relatively low-sensitive explosives, usually based on ammonium nitrate, which are insensitive to blasting caps and do not contain any high explosives such as nitroglycerine or TNT. In many countries (not Germany) the safety regulations governing the transport and storage of blasting agents are considerably less severe than those applicable to high explosives. Nitricarbonitrate (NCN) is designated in the USA as an ammonium nitrate non-cap-sensitive explosive. The components are named by *nitro:* dinitrotoluene; by *carbo:* solid carbon carriers as fuel; by *nitrate:* ammonium nitrate. Meanwhile, NCN as a shipping name has been removed by the US Department of Transportation and replaced by the shipping name blasting agent. A blasting agent has to be non-cap-sensitive (→ *Cap Sensitivity*). → *ANFO* explosives and most → *Slurries* have to be classified as blasting agents.

Blasting Caps

Sprengkapseln; *détonateurs*

Blasting caps serve as initiators of explosive charges. They consist of a cylindrical copper or mainly aluminum capsule containing a primary charge of an initiating explosive or a mixture of initiating explosives (e.g. lead azide with lead trinitroresorcinate); in order to achieve a higher brisance, they also contain a secondary charge of a high explosive (e.g. → *Tetryl*; → *PETN*; → *Hexogen*).

A blasting cap can be ignited by the flame of a safety fuse or electrically. In the past, 10 standard types of blasting caps were marketed; these differed from each other by the quantity of the explosive in the charge and by their size. Currently, No. 8 blasting cap (0.3 g primary charge. 0.8 g secondary charge, 4–50 mm in length and 7.0 mm in external diameter) is, for all practical purposes, the main type of blasting cap on the market. Due to environmental and health issues modern blasting caps are based on lead-free primary explosives or even without primary explosives at all, using → DDT of PETN.

Blasting Galvanometer

→ *Circuit Tester*

Blasting Gelatin

Sprenggelatine; *dynamite-gomme*

This product is one of the strongest commercial explosives. It consists of 92–94% nitroglycerine, gelatinized with 6–8% soluble guncotton.

Since such a high explosive strength is rarely required, blasting gelatin is scarcely ever used in practice.

Blasting gelatin is used as a comparative explosive in determinations of relative weight strength (→ *Ballistic Mortar*).

Blasting Machines

Zündmaschinen; *exploseurs*

Blasting machines are used for electric firing of explosive charges by sending an electric pulse (indicated in mW s/Ω) through the firing circuit to the round of electric detonators connected in series. Except during the moment of actuation of the blasting machine, the entire electrical system is tensionless (unlike: → *Blasting Switch*).

In mines endangered by a potential firedamp explosion, the duration of the electric pulse must be limited to 4 ms with the aid of a triggering switch in the blasting machine, so that flying fragments cannot strike the firing circuit while the latter is still live and generate a short-circuit spark. Also, the housing must withstand an internal pressure of 1 MPa (10 atm), so that it cannot be destroyed by a burst due to intruded methane. These special conditions are only requested in blasting areas endangered by firedamp.

Two types of blasting machines are used:

1. blasting machines with direct energy supply, equipped with a self-induction or a permanent magnet generator, which are made to rotate with the aid of a twist knob, impact knob or a spring extension, and
2. blasting machines with an indirect energy supply, in which the generated electrical energy is stored in a capacitor and, after the discharge voltage has been attained, the breakthrough pulse is sent to a blasting train (CD Type). A misfire due to incorrect handling is impossible.

Capacitor machines have now superseded direct-generation machines. In order to set off → *Bridgewire Detonators*, which are connected in parallel, the output of the machines must be particularly high since more than 95% of the electric energy becomes lost in the blasting circuit. Special powerful machines are required to set off highly unsensitive (HU) detonators for blastings carried out in high mountain areas and in other locations endangered by high-voltage induction; a very strong (3000 mW s/Ω) priming pulse must be applied in such cases. → *Bridgewire Detonators*.

Blasting Mat

Sprengmatte; *réseau de fils d'acier*

A mat of woven steel wire, rope, scrap tires, or other suitable material or construction to cover blast holes for the purpose of preventing rock missiles against flying debris.

Blasting Switch

Zündschalter; *commande de tir*; *ignition switch*

Device which actuates electric primers by using main voltage – in open pit and potash mining, for example. The switch can be located in a surface stand (shelter outside a mine), e.g. if the danger of gas outbursts exists.

Blastmeter

Blastmeters are simple devices which are used to determine the maximum pressure of a shock wave (→ Detonation (Shock Wave Theory)). They consist of steel bodies into which holes of different diameters are drilled and covered with aluminum foil.

The smallest diameter is determined at which the foil covering is penetrated. The device can be calibrated by static pressure.

Bomb Drop Test

Serves to test the sensitivity of military explosives as bomb fillers. Bomb drops are made using bombs assembled in the conventional manner, as for service usage, but containing either inert or simulated fuzes. The target is usually reinforced concrete.

Boom Powder

A pyrotechnic ignition mixture designed to produce incandescent particles. A typical boom composition is:

Ingredient	**Part by weight %**
Iron oxide	50
Titanium (powdered)	32.5
Zirconium (powdered)	17.5

plus about 1 part cellulose nitrate as a binder.

Booster

Verstärkungsladung; *relais*

A device to ensure → *Initiation*. A booster can be a cap-sensitive cartridge or press molded cylinder for the initiation of non-cap-sensitive charges, e.g. blasting agents or cast TNT. A booster is, in rocketry, a rocket device that accelerates the missile to attain the required speed after the start.

Booster Sensitivity Test

The booster sensitivity test procedure is a scaled-up modification of the *Bruceton Test* (unconfined charge). The source of the shock consists of two tetryl pellets, each 1.57 in in diameter and 1.60 in long, of approximately 100 g total weight. The initial shock is degraded through wax spacers of cast Acrawax B, 15/8 in in diameter. The test charges are 15/8 in diameter by 5 in long. The value given is the thickness of wax in inches at the 50% detonation point. The weight of the tetryl pellet noted is the minimum that will produce detonation with the spacer indicated.

Bootleg

Bohrlochpfeife; *trou ayant fait canon*

That part of a drilled blast hole that remains when the force of the explosion does not break the rock completely to the bottom of the hole (→ *Large Hole Blasting*).

Boss

Messanschlüsse; *raccords de mesurage*

Outlets provided in the generator case for hot gas flow, igniter, pressure measurement, and safety diaphragm.

Break

Spalt; *fente*

Cleft in the rock formation, especially in coal mines, which endangers blasting in fire damp areas; → Permitted Explosives.

Breech

Patronenkammer; *chambre pour cartouche*

Reloadable pressure vessel used to contain a propellant cartridge.

Bridgewire Detonator

Brückenzünder; *amorce à pont*

Bridgewire detonators are used in industrial blasting operations for the initiation of explosive charges. They contain an incandescent bridge made of thin resistance wire, which is made to glow by application of an electric pulse. An igniting pill is built around the wire by repeated immersion in a solution of a pyrotechnical material followed by drying. The igniting flash acts directly onto the detonating surface in the case of instantaneous detonators; in delayed-action detonators it is sent over a delay device onto the detonating surface of a blasting cap which has been pressed onto the detonating pill so as to produce a water-tight bond with it. Nonarmed bridgewire detonators have an open casing, into which a blasting cap may be inserted.

The "U"-detonators that are now employed in mining in Germany need a pulse of 16 mW s/Ω; the earlier detonators required only 3 mW s/Ω. Thus new detonators afford much better protection against stray currents. Locations exposed to electrostatic stray charges (thunderstorms) and which are therefore particularly dangerous, are equipped with low-sensitivity detonators, which require as much as 2500 mW s/Ω for actuation and may therefore be considered safe ("HU"-detonators).

The delayed-action detonators may be set for a delay of half a second (half-second detonators) or for a delay of 2–34 ms (millisecond detonators). Blasting with the latter type of detonators results in a larger yield of blasted stone fragments; moreover, a smaller shock will be imparted to the ground around the explosion site.

In coal mining, only copper casings rather than the conventional aluminum casings are permitted because of the danger of firedamp. Explosive charges equipped with bridgewire detonators are fired by wire-connected → *Blasting Machines* from a safe location. If several charges have to be initiated at the same time, the detonators are connected in series with the connecting wire. Parallel connection of the detonators is used only in special cases (extremely wet conditions with danger of shunting); special blasting machines must be employed for this purpose.

Brisance

Brisanz

The performance of an explosive cannot be expressed by means of a single characteristic parameter. Brisance is the destructive fragmentation effect of a charge on its immediate vicinity. The relevant parameters are the detonation rate and the loading density (compactness) of the explosive, as well as the gas yield and the heat of explosion. The higher the loading density of the explosive (molding or pressing density), the higher its volume specific performance; also, the faster the reaction rate, the stronger the impact effect of the detonation. Moreover, an increase in density is accompanied by an increase in the detonation rate of the explosive, while the shock wave pressure in the detonation front (→ *Detonation*) varies with the square of the detonation rate. Thus it is very important to have the loading density as high as possible.

This is particularly true for → *Shaped Charges*.

Kast introduced the concept of brisance value, which is the product of loading density, specific energy and detonation rate.

Brisance tests are upsetting tests according to *Kast* and *Heß*; the compression of a copper cylinder is determined by actuating a piston instrument; alternatively, a free-standing lead cylinder is compressed by the application of a definite cylindrical load of the explosive being tested: → *Upsetting Tests*.

Bulk Density

Schüttdichte; *densité apparente, dénsite de versement*

The mass per unit volume of a bulk material, such as grain, cement, coal. Used in connection with packaging, storage or transportation.

Bulk Explosives

By far the largest part of explosives consumed is delivered in bulk form and used in mining, quarrying, tunnel building, and other construction operations. Bulk explosives are provided as → ANFOs or heavy ANFOs, → Emulsion Slurries or blends of these.

Bulk Mix

Sprengstoffmischung für unpatronierte Anwendung; *explosif en vrac*

A mass of explosive material prepared for use in bulk form without packaging.

Bulk Mix Delivery Equipment; Misch-Lade-Fahrzeug; véhicule mél-angeur-chargeur

Equipment (usually a motor vehicle with or without a mechanical delivery device) that transports explosives, blasting agents or ingredients for explosive materials in bulk form for mixing and/or loading directly into blast holes.

Bulk Strength

Cartridge Strength: Volume Strength

The strength per unit volume of an explosive calculated from its → *Weight Strength* and → *Density*.

Bulldoze

Auflegeladung; *pétardage*

A mud covered or unconfined explosive charge fired in contact with a rock surface without the use of a borehole. Synonymous with *Adobe Charge* and → *Mud Cap*.

Bullet Hit Squib

Filmeffektzünder; *Squib*

Bullet hit squibs are used in motion pictures and television to simulate ballistic impact of fired projectiles.

What is referred to here are small, pyrotechnic, electrical devices with varying charges and containing several milligrams of a compound consisting of → *Lead Azide*, → *Lead Styphnate*, → *Diazodinitrophenol* and tetrazole Derivatives.

The initiating explosive material must be specially treated and phlegmatized to avoid the undesired byproduct of smoke and flash. One method achieves this by using an admixture of alkaline earth sulfates or by means of micro-encapsulation of the explosive crystals.

These special electrical igniters are produced by the company J. Köhler Pyrotechnik in Schardenberg/Austria.

Bullet-Resistant

Kugelsicher; *résistant au balles*

Magazine walls or doors of construction resistant to penetration of a bullet of 150 grain (9.72 g) M2 ball ammunition having a nominal muzzle velocity of 2700 ft/s (∼ 823 m/s) fired from a .30-caliber rifle from a distance of 100 ft (∼ 30.5 m) perpendicular to the wall or door.

When a magazine ceiling or roof is required to be *Bullet-Resistant*, the ceiling or roof shall be constructed of materials comparable to the side walls or of other materials which will withstand penetration of the bullet above described when fired at an angle of 45° from the perpendicular.

Tests to determine bullet resistance shall be conducted on test boards or empty magazines which shall resist penetration of 5 out of 5 shots placed independently of each other in an area at least 3 ft by 3 ft (∼ 91 cm by ∼ 91 cm). If hardwood or softwood is used, the water content of the wood must not exceed 15%.

Bullet-Sensitive Explosive Material

Beschussempfindlicher Sprengstoff; *explosif sensible a l'impact de balles*

Explosive material that can be detonated by 150 grain (9.72 g) M2 ball ammunition having a nominal muzzle velocity of 2700 ft/s (∼ 823 m/s) when the bullet is fired from a .30 caliber rifle at a distance of not more than 100 ft (∼ 30.5 m) and the test material, at a temperature of 21,1 to 23,9 °C (70 to 75 °F), is placed against a backing material of 1/2 in steel plate.

(→ *Impact Sensitivity*)

Burden

Vorgabe; *distance entre 1 a charge et la surface du massif*

The dimension of a medium to be blasted measured from the borehole to the face at right angles to the spacing. It also means the total amount of material to be blasted by a given hole, usually measured in cubic yards or in tons.

Bureau of Alcohol, Tobacco and Firearms (BATF)

A bureau of the US Department of the Treasury having responsibility for the enactment and enforcement of regulations related to commerce in explosives under Part 181 of Title 26 of the Code of Federal Regulations.

Bureau of Explosives

A bureau of the Association of American Railroads with whom the US Department of Transportation may consult to classify explosive material for the purposes of interstate transportation.

Bureau of Mines

US Bureau of Mines.

Bureau of Mines Test

→ *Impact Sensitivity*.

Burning Rate

Abbrandgeschwindigkeit; *velocity of combustion*; *vitesse de combustion*

The linear burning rate of a propellant is the velocity with which a chemical reaction progresses as a result of thermal conduction and radiation (at right angles perpendicular to the current surface of the propellant). It depends on the chemical composition, the pressure, temperature and physical state of the propellant (porosity; particle size distribution of the components; compression). The gas (fume) cloud that is formed flows in a direction opposite to the direction of burning.

The burning rate describes the velocity with which the volume of the burning propellant changes. It is proportional to the linear burning rate and in addition it depends on the specific shape of the propellant (size of the powder elements and conformation, e.g. flakes, spheres, tubes, multi-perforated tubes, etc., extending to the most complicated shapes of rocket propellant charges).

In rocket engineering, burning rate means specifically the stationary progress of burning rate in the rocket chamber.

The following relationship exists between the burning rate $\mathrm{d}z/\mathrm{d}t$ and the linear burning rate $\dot{e}$:

$$\frac{\mathrm{d}z}{\mathrm{d}t} = \frac{S(0)}{V(0)} \cdot \varphi(z) \cdot \dot{e}$$

where $\dot{e}$ is given by

$$\dot{e} = \dot{e}(p_{\mathrm{ref}}) \cdot \left(\frac{p(z)}{p_{\mathrm{ref}}}\right)^{\alpha}$$

z	means the ratio of the volume burnt to that originally present $[V(0) - V]/V(0)$
$S(0)/V(0)$	means the ratio of the initial surface area to the initial volume of the powder,
$\varphi(z)$	means the shape function of the powder, which takes into account the geometrical conditions during burning rate (sphere, flake, cylinder, *n*-hole powder) ($\varphi(z)$ = current surface area/initial surface area)
$\dot{e}(p_{\mathrm{ref}})$	means the linear burning velocity at the reference gas pressure p_{ref}
p_{ref}	is the reference gas pressure and
α	is the pressure exponent.

The equation for the burning rate $\mathrm{d}z/\mathrm{d}t$ can also be written in the form

$$\frac{\mathrm{d}z}{\mathrm{d}t} = A \cdot \varphi(z) \cdot p^{\alpha}$$

and is then called Charbonnier's Equation.

The parameter

$$A = (S(0) \cdot V(0)) \cdot \varphi(z) \cdot \dot{e}\frac{p_{\mathrm{ref}}}{p_{\mathrm{ref}}^{\alpha}}$$

is called the vivacity or quickness factor.

The pressure exponent α typically has a value close to 1 for propellant charge powder (burning rate at high pressure level). At low pressure ranges (rocket burning rate) it can be brought close to zero (plateau burning rate) or even less than zero (mesa burning rate) by suitable additives to the propellant.

When the geometry of the propellant is known, the linear burning rate and the pressure exponent of a propellant can be determined experimentally in a → *ballistic bomb*.

If the gases flow continuously out, as in the case of a rocket motor, the pressure remains almost constant throughout the combustion period. The linear burning rate and its variation with the temperature and pressure may be determined in a → *Crawford Bomb*. The temperature coefficient of the burning rate is the variation per degree of temperature increase at constant pressure. The dependence on pressure is characterized by the pressure exponent (see above).

For details on relevant theoretical and practical relationships see: *Barrère, Jaumotte, Fraeijs de Veubeke, Vandenkerckhove:* "Raketenantriebe", Elsevier Publ. Co., Amsterdam 1961, p. 265ff.; *Dadieu, Damm, Schmidt:* "Raketentreibstoffe", Springer, Wien 1968.

Other relevant keywords are: → *Solid Propellant Rockets*, → *Specific Impulse*, → *Thermodynamic Calculation of Decomposition Reactions*, → *Thrust*.

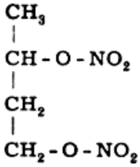
Bus Wire

Antenne für Parallelschaltung; *antenne pour le couplage en parallele*

Two wires that form an extension of the lead line and connecting wire and common to all caps in parallel. In parallel firing, each of the two wires of each electric blasting cap is connected to a different bus wire. For series in parallel firing each side of the series is connected to a different bus wire (→ *Parallel Connection*).

Butanediol Dinitrate

1,3-Butylenglykoldinitrat; *dinitrate de butyléneglycol*



$$\begin{array}{l} CH_3 \\ | \\ CH-O-NO_2 \\ | \\ CH_2 \\ | \\ CH_2-O-NO_2 \end{array}$$

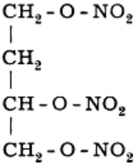
colorless liquid
empirical formula: $C_4H_8N_2O_6$

molecular weight: 180.1 g/mol
oxygen balance: −53.3%
nitrogen content: 15.56%
density: 1.32 g/cm^3
lead block test: 370 cm^3/10 g

Butanediol dinitrate is insoluble in water, but is soluble in solvents for nitroglycerine; it is more volatile than nitroglycerine. Soluble guncotton is readily gelatinized. The nitrate is formed by reaction of butylene glycol with a nitric acid-sulfuric acid mixture as in the nitroglycerine synthesis, but the product is very easily destroyed by oxidation; the reaction mixture decomposes generating heat and nitrous gases. The product cannot be obtained under industrial conditions and has not found practical application for this reason.

Butanetriol Trinitrate BTTN

1,2,4-Butantrioltrinitrat; *trinitrate de butanetriol*



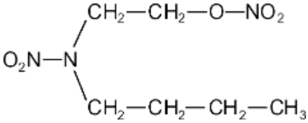
pale yellow liquid
empirical formula: $C_4H_7N_3O_9$
molecular weight: 241.1 g/mol
energy of formation: −379.2 kcal/kg = −1586.4 kJ/kg
enthalpy of formation: −402.5 kcal/kg = −1683.9 kJ/kg
oxygen balance: −16.6%
nitrogen content: 17.43%
refractive index: $n_D^{20} = 1.4738$
volume of explosion gases: 836 l/kg
heat of explosion
  (H_2O liq.): 1439 kcal/kg = 6022 kJ/kg
  (H_2O gas): 1327 kcal/kg = 5551 kJ/kg
density: 1.52 g/cm^3 (20/4)
solidification point: −27 °C = −17 °F
impact sensitivity: 0.1 kp m = 1 N m

1,2,4-Butanetriol is nitrated with a mixture of nitric and sulfuric acids. The nitrated product is very stable. It is, like nitroglycerine, gelatinized by nitrocellulose.

Butanetriol trinitrate was used in the manufacture of tropic-proof double-base powders. Isomers of butantriol trinitrate were also studied and utilized in practical work; these include methyl glycerol trinitrate and 1,2,3-butanetriol trinitrate, which have similar properties.

N-Butyl-*N*-(2-nitroxyethyl)nitramine

N-Butyl-2-nitratoethyl-nitramin; *BuNENA*



colorless liquid
empirical formula: $C_6H_{13}N_3O_5$
molecular weight: 207,19 g/mol
energy of formation: −803.34 kJ/kg
enthalpy of formation: −928.94 kJ/kg
oxygen balance: −104.25%
nitrogen content: 20.28%
density: 1.22 g/cm^3
melting point: −9 °C

This compound is prepared from *N*-butylethanolamine and nitric acid with acetic anhydride and a chloride source for catalysis. BuNENA is an energetic plasticizer for propellant formulations.

Calcium Nitrate

Calciumnitrat, Kalksalpeter; *nitrate de calcium*

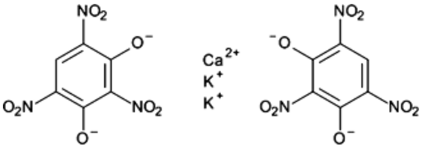
hydrated: $Ca(NO_3)_2 \cdot 4H_2O$
colorless crystals
anhydrous product: $Ca(NO_3)_2$
white powder

The following data refer to the anhydrous product:
molecular weight: 164.1 g/mol
energy of formation: −1352.1 kcal/kg = −5657.3 kJ/kg
enthalpy of formation: −1366.6 kcal/kg = −5717.7 kJ/kg
oxygen balance: +48.8%
nitrogen content: 17.07%
melting point: 561 °C = 1042 °F
very hygroscopic

Calcium nitrate can be used as an oxidizer component of → *Slurries*.

Calcium Potassium Styphnate

calcium potassium bis(2,4,6-trinitro-m-phenylene dioxide), 1,3-benzenediol-2,4,6-trinitro-, calcium potassium salt (2 : 1 : 2), calcium potassium styphnate; *Kalium-Calcium-Styphnat*; *Castyp*



pale yellow amorphous solid
CA registry number: 1265906-36-2
empirical formula: $C_{12}H_2CaK_2N_6O_{16}$
molecular weight: 604.5 g/mol
oxygen balance: −29%
nitrogen content: 13.9%
deflagration point: 345 °C
impact sensitivity: $>$ 0.2 N m
friction sensitivity: $>$ 0.5 N
electrostatic sensitivity: $>$ 0.4 mJ

Calcium potassium styphnate is formed by precipitation from an aqueous solution of potassium styphnate using a stoichiometric amount of calcium nitrate (DE 10 2006 060 145 A1).

It is practically insoluble in acetone and ethanol, but moderately soluble in cold and well soluble in hot water.

It shows low hygroscopicity.

Calcium potassium styphnate is used as a lead and heavy metal free primary explosive in priming mixtures used for small-caliber ammunition primers.

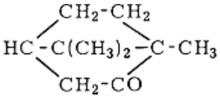
Due to its high deflagration temperature ($>$ 300 °C) it can also be applied within vehicle safety systems.

With respect to the sensitivities to impact and friction as well as the initiating properties calcium potassium styphnate is comparable to the common neutral lead styphnate.

In contrast, it is remarkably less sensitive to electrostatic discharge than lead styphnate, for which sensitivities of ca. 0.1 mJ are observed.

Camphor

Campher, Kampfer; *camphre*



empirical formula: $C_{10}H_{16}O$
molecular weight: 152.3 g/mol
energy of formation: −480 kcal/kg = −2008 kJ/kg
enthalpy of formation: −513 kcal/kg = −2146 kJ/kg
oxygen balance: −283.8%
density: 0.98–0.99 g/cm^3
melting point: 177–178 °C = 351–353 °F
boiling point: 209 °C = 408 °F

This compound is utilized in celluloid industry and also as gelatinizer in nitrocellulose gunpowders.

Specifications

net content:	not less than 99% (analysis by titration with hydroxylamine)
melting point:	not less than 176 °C = 350 °F
insolubles in alcohol and ether:	not more than 0.1%
chlorides:	not more than traces

Cap Sensitivity

Sprengkapsel-Empfindlichkeit; *sensibilité au choc détonateur*

Tests are carried out to determine the reaction of an explosive to a detonating cap. The results are used to determine the classification of the explosive as a transport hazard. The US Department of Transportation has placed → *Blasting Agents* into a hazard category subject to regulations similar to those applicable to the former NCN classification, i.e. much reduced in stringency. Explosives classified as blasting agents are those that cannot be initiated by means of an explosive cap.

In Germany the following test for sensitivity to explosive caps has been developed:

The explosive is placed into a cardboard tube, 200 mm long, inside diameter of 80 mm, wall thickness between 1.3 and 1.4 mm. One end of the tube is sealed by a thin cardboard disk, which is glued into position. The density of the filling charge is determined by weighing (increase in weight after filling volume 1005 cm^3). The cap sensitivity can be influenced by the density of the charge. The test sample is placed

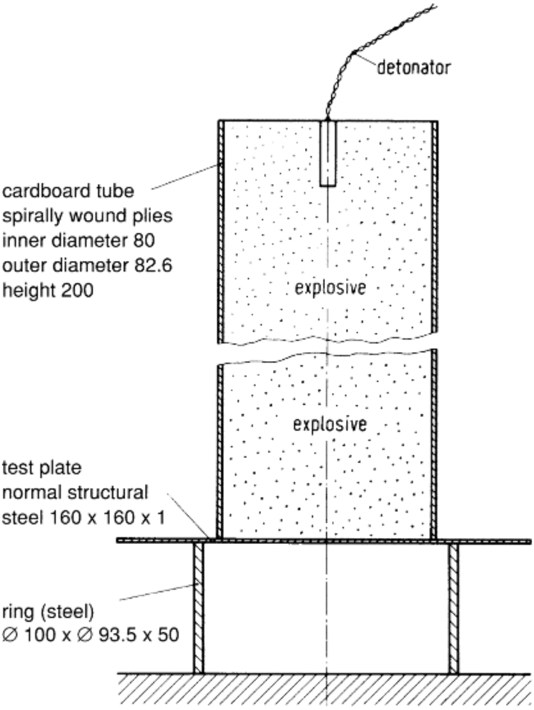


Figure 7 Cap test (dimensions in mm).

upright onto a steel plate of 1 mm thickness, which is placed on a steel ring 50 mm in height, inside diameter of 100 mm, and wall thickness of 3.5 mm. A European test fuse (0.6 g PETN secondary charge) is inserted from the top throughout the full length of the tube, and initiated. No change in the condition of the plate or denting with or without fissure is classed as nondetonation. A circular hole indicates detonation.

The results are unchanged when explosives are tested at increased temperatures (30 °C). An exception to this are the AN prills coated with DNT.

DNT diffuses into the pores, the explosive becomes more homogeneous and therefore more sensitive. No change occurs when the European test fuse is replaced by a No. 8 detonator (0.75 g Tetryl).

A similar test has been developed in the USA (according the deformation of a lead block, using commercial caps with 0.4–0.45 g PETN). It is advisable to classify according to test results and not, as was the custom in the USA, by the classification of NCN according to the explosive composition. As indicated above, ANFO's are not cap sensitive; mixtures of

Table 4 Cap test results.

Composition	Loading Density, (g/cm^3)	Test Result: Detonation
ANFO, porous prills	0.79–0.93	none
AN[a] cryst. with TNT and fuels	0.82–1.07	always +
AN cryst. with TNT, DNT and fuels	0.82–1.07	always +
AN cryst. with DNT and fuels (NCNs)	0.75–1.10	always +[b]
AN porous prills coated with DNT	0.82–0.84	none
AN cryst. with fuel	0.62–1.10	not at higher densities
AN cryst. with Al, earth alkaline nitrates, fuels and water (slurries)	1.13–1.26	+
(also with TNT)	1.37–1.60	none

a) AN = ammonium nitrate.
b) NCN explosives can be non-cap-sensitive at somewhat higher densities.

finely ground ammonium nitrate containing only 2% instead of 6% of oil or wax can, however, be cap sensitive.

Carbamite

Denomination frequently used in English for → *Centralite I*.

Cardox

A physical explosion process which, like the Armstrong process and Airdox process, operates on the principle of a sudden release of compressed gas by means of a bursting disc. In the Cardox process, condensed CO_2 is brought to a high vapor pressure by means of a heating cartridge.

Cartridge

Patrone; *cartouche*

This term denotes any quantity of an explosive material or functional formulations thereof, which has been sheathed in order to improve handling, loading or dosing; for ammunition, cartridge most often means an assembly of an → *Igniter*, a → *Propellant* charge and a projectile, which may itself contain a high explosive charge with ignition mechanism. As applied to industrial explosives, the term cartridge denotes the amount of the explosive – which may vary between 50 g and several kg – enclosed in an envelope which is usually cylindrical and is made of paper, cardboard or plastic.

Cartridge Density

Patronendichte; *densité de cartouche*

(→ *Loading Density*) In industrial explosives, the ratio between the weight of an explosive cartridge and its volume.

Some manufacturers indirectly give the cartridge density on the package by stating the number of standard 11/4 × 8″ (7 × 20, 3 cm) cartridges contained in a 50-pd (23 kg) case. The relationship is given in the following table:

Table 5 Cartridge density, weight of 11/4 × 8″ (7 × 20, 3 cm) cartridge and number of 11/4 by 8″ cartridges in 50-pd (23 kg) case.

Density (g/cm^3)	Weight of 11/4 × 8″ (7 × 20, 3 cm) cartridge (g)	Number of 11/4 × 8″ (7 × 20, 3 cm) cartridges in 50-pd (23 kg) case	Density (g/cm^3)	Weight of 11/4 × 8″ (7 × 20, 3 cm) cartridge (g)	Number of 11/4 by 8″ (7 × 20, 3 cm) cartridges in 50-pd (23 kg) case
0.62	100	227	1.18	190	120
0.68	110	206	1.24	200	114
0.75	120	189	1.31	210	108
0.81	130	175	1.37	220	103
0.87	140	162	1.43	230	99
0.93	150	151	1.49	240	95
0.99	160	142	1.55	250	91
1.06	170	134	1.62	260	87
1.12	180	126	1.68	270	84

Cartridge Strength

Synonymous with → *Bulk Strength*. Also → *Strength*; → Weight Strength.

Case

Brennkammer; *chambre de combustion*; *also: Kiste; caisse*

Pressure vessel designed to contain propellant charge before and during burning.

Also: a large shipping container for explosive materials.

Case Bonding

Kammerwandgebunden

This expression denotes a modern processing technique in the field of rockets driven by solid propellants. The pourable → *Composite Propellant* is cast directly into the combustion chamber, which has been pre-treated to produce a bonding and insulating layer and is allowed to harden (cure) in the chamber. Since temperature variations may be expected to produce major stresses, owing to the different values of thermal expansion coefficients, the success of the method depends to a large extent on the bonding forces acting between the bonding and insulating layer and the metal wall on the one hand, and the hardened propellant on the other, as well as on their elastomeric stress relaxation capability.

Caseless Ammunition

Hülsenlose Munition; *munition sans douille*

The requirement to improve portable firearms resulted in a reduction of the caliber (dimension 4–5 mm); and to reduce the ammunition weight led to the caseless ammunition project. Moreover, in the event of a crisis the problem of a worldwide shortage of nonferrous metals for cartridge cases will arise.

For a considerable time the caseless ammunition consisted of a compressed NC propellant body into which the bullet was inserted. However, this propellant tends to self-ignite even at relatively low temperatures (ca. 170 °C). Thus a "cook-off" may result, i.e. a premature ignition in a hot cartridge chamber that may occur with all automatic guns. In addition, with caseless ammunition the heat which is otherwise transferred to the cartridge case remains in the cartridge chamber. Therefore, in order to avoid the cook-off, high-ignition-temperature propellants (HITPs) have been developed worldwide. DNAG used such a propellant for the first time with caseless cartridges for a newly developed gun (G 11) from

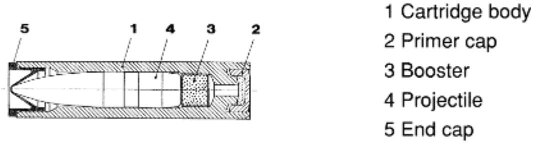


Figure 8 Sectional view of the caseless cartridge body (caliber 4.73 mm) for the G 11 weapon system.

Heckler & Koch. The essential innovations with regard to previous developments are the use of a high-temperature-resistant, noncrystalline explosive as binding material, a special granular shape for the main energy component and the possibility to adjust the interior ballistics by porosity and stability of the propellant body. Further new developments are the combustible primer and the booster. Beside the development of the G11-ammunition there are some other approaches for getting caseless ammunition. The Australian Voere VEC-91 hunting rifle uses 5.7-mm caseless ammunition. There are still some researchers involved in the development of caseless ammunition. One way is the compaction of spherical powder, which leads to a consolidated propellant, which can also be adapted for the use as caseless ammunition.

Besides this procedure, the technology of foamed propellants is developed for these reasons. Nitramines are incorporated in energetic polyurethane foams. Reaction injection molding (RIM) machinery is built up for the manufacture of the propellants at laboratory scale. The research is ongoing.

Casting of Explosives

Giessen von Sprengladungen; *coulée de charge de projectiles*

Since the brisance of an explosive largely depends on its loading density, the highest possible loading densities are employed, in particular for military explosives. This density is attained by casting or pressing. The pressing operation requires a technical device. A cast charge is easier to fit into shells, mines and bombs, which have rather complex-shaped internal profiles.

Since → *TNT* is pourable at 80 °C (176 °F), it is highly important in military technology. Since a considerable contraction takes place when the liquid explosive solidifies, good care must be taken during casting to ensure free access to all parts of the cast that have not yet solidified, in order to ensure proper replenishment of liquid material. Formerly, this was done by simple manual poking, but many automatic devices have been developed which do not involve any manual labor and which yield cavity-free casts.

Pure TNT tends to form very long, needle-shaped friable crystals, with a loose texture that does not correspond to the maximum density. Cast TNT charges must be fine-crystalline, mechanically firm and dense, with numerous crystallization nuclei; i.e. solid TNT must be finely dispersed in the cast. According to BOFORS, the texture of the cast can be improved by the addition of → *Hexanitrostilbene*. → DNAN is promising solid, used as TNT replacement in melt-cast formulations.

Casting of Propellants

Giessen von Treibsätzen; *coulée de propergols*

Casting processes are needed especially in rocketry for the shaping of large propellant grains. Unlike in the casting of explosives, processes which cause shrinking and yield friable crystals cannot be applied.

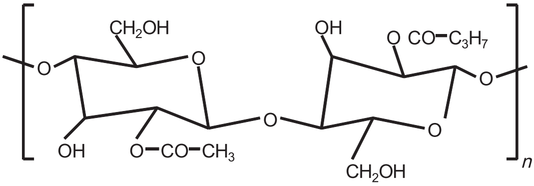
There are two solutions to this problem:

a) hardening of polycondensates (e.g. polyurethanes or epoxies) with mechanically incorporated oxidizers, e.g. ammonium perchlorate (→ *Composite Propellants*); the hardened plastic material acts as fuel for the oxidizer;
b) converting of pourable nitrocellulose granules by treatment with liquid nitrate esters (e.g. with nitroglycerine). The granules can be poured dispersed in the liquid (slurry casting), or filled in the rocket motor shell and gelled *in situ* with the added nitrate ester.

CDB Propellants

→ *Composite Propellants*.

Cellulose Acetate Butyrate, CAB



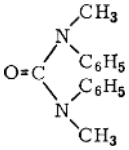
solid
empirical formula: $C_{10}H_{15.4}O_{5.2407}$
molecular weight: 219.48 g/mol
oxygen balance: −163.72%
energy of formation: −1237.75 kJ/mol

enthalpy of formation: −1263.32 kJ/mol = −5755.95 kJ/kg
density: 1.26 g/cm^3

CAB is a polymeric binder used in → LOVA gun propellants.

Centralite I

diethyldiphenylurea; *symm. Diethyldiphenylharnstoff*; *diéthyldiphénylurée*; *Ethyl Centralite; Carbamite*



colorless crystals
empirical formula: $C_{17}H_{20}N_2O$
molecular weight: 268.4 g/mol
energy of formation: −68.2 kcal/kg = −285.6 kJ/kg
enthalpy of formation: −93.5 kcal/kg = −391.5 kJ/kg
oxygen balance: −256.4%
nitrogen content: 10.44%
density: 1.112 g/cm^3
melting point: 71.5–72 °C = 161–162 °F
boiling point: 326–330 °C = 618–625 °F

Centralite I, II and III are used as → *Stabilizers* in gunpowders, especially in nitroglycerine powders (→ *Double-Base Propellants*). It is insoluble in water, but soluble in organic solvents.

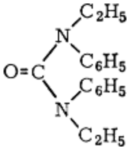
Centralites are not only stabilizers, but gelatinizers as well. The latter property is taken advantage of in solvent-free manufacture of double-base propellants.

Specifications

solidification point:	not less than 71 °C = 160 °F
molten material:	bright clear pale liquid
ashes:	not more than 0.1%
volatiles:	not more than 0.1%
acetone solution:	clear, no residue
secondary and tertiary amines:	not more than 0.1%
chlorides as HCl:	not more than 0.001%
reaction:	neutral
acidity:	not more than 0.04%

Centralite II

dimethyldiphenylurea; *Dimethyldiphenylharnstoff*; *diméthyldiphénylurée*



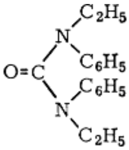
colorless crystals
empirical formula: $C_{15}H_{16}N_2O$
molecular weight: 240.3 g/mol
energy of formation: −37.3 kcal/kg = −156 kJ/kg
enthalpy of formation: −60.8 kcal/kg = −254 kJ/kg
oxygen balance: −246.3%
nitrogen content: 11.66%
melting point: 121–121.5 °C = 250–251 °F
boiling point: 350 °C = 662 °F

Specifications

same as for Centralite I,
except solidification point: not less than 119 °C = 246 °F

Centralite III

methylethyldiphenylurea; *Methylethyldiphenylharnstoff*; *méthyléthyldiphénylurée*



colorless crystals
empirical formula: $C_{16}H_{18}N_2O$
molecular weight: 254.3 g/mol
energy of formation: −94.7 kcal/kg = −396.1 kJ/kg
enthalpy of formation: −119.1 kcal/kg = −498.5 kJ/kg
oxygen balance: −251.7%
melting point: 57–58 °C = 135–138 °F

Specifications

same as for Centralite I,
except solidification point: 57 °C = 135 °F

Channel Effect

Kanaleffekt

Interruption in the detonation of an explosive column because of the compaction of the cartridges, which have not yet exploded due to the gas shock wave front in the borehole. This happens very often if the borehole cross-section is large as compared to that of the cartridges.

Chlorate Explosives

Chloratsprengstoffe; *explosifs chloratés*

Explosive mixtures of alkali metal chlorates with carbon-rich organic compounds such as wood dust, petroleum, oils, fats and nitro derivatives of benzene and toluene; they may also contain nitrate esters.

Their strength is lower than that of ammonium nitrate explosives in powder form. Chlorate explosives must not be stored together with ammonium nitrate explosives, since ammonium chlorate, which is formed when these two substances are brought into contact, decomposes and explodes.

Miedziankit is the name of absorbent potassium chlorate particles, which are impregnated with a liquid fuel just before use, and then acquire explosive properties. Following the development of → *ANFO*, this explosive is no longer of interest.

Cigarette-Burning

Stirnabbrand; *combustion en cigarette*

→ *Face Burning*

Circuit Tester (Ohmmeter)

Zündkreisprüfer; *éprouveur*; *blasting galvanometer*

Instrument for electrical testing of misconnected circuits. The current intensity used in the testing must be well below the → *No Fire* condition of the electric detonator; the circuit tester is accordingly equipped with resistances at both poles. Only officially approved testers should be employed. The testers are of two kinds: conduction testers which show, by means of a visual indicator, whether or not current is flowing in the circuit, and ohmmeters which measure the resistance of the priming circuit.

Class A, Class B and Class C Explosives

Classification defined by the US Department of Transportation:

Class A Explosives:

Explosives, which possess detonating or otherwise maximum hazard; such as dynamite, nitroglycerine, lead azide, TNT, Composition B, PBX, Octol, blasting caps and detonating primers.

Class B Explosives:

Explosives, which possess flammable hazard; such as, but not limited to, propellant explosives, photographic flash powders, and some special fireworks.

Class C Explosives:

Explosives, which contain class A or class B explosives, or both, as components but in restricted quantities.

Coal Dust

Kohlenstaub; *poussiére de charbon*

Mixtures of coal dust with air are explosive and their explosion by blasting must be prevented (→ *Permitted Explosives*).

Column Charge

Gestreckte Ladung; *file de cartouches*

A charge of explosives in a blast hole in the form of a long continuous unbroken column.

Combustible Cartridge Cases

Verbrennbare Kartuschhülsen; *douilles combustibles*

The propellant charge used for the shot from a weapon is introduced into cases or bags (cartouche bags); for metallic cartouche cases, the projectile is combined with the propellant charge and the propellant charge igniter to form a cartridge.

Now, combustible cartridge cases serve the purpose of making the case material contribute to the ballistic performance and to render unnecessary the removal of inert material from the weapon after the shot. Such case material has to be adapted to the combustion process of the powder. It consists of high-energy material, e.g. nitrocellulose, a structure-reinforcing additive, e.g. craft-paper pulp, binders of plastic material, and further additives, e.g. stabilizers contained in the powder itself. The cases are made by filtration from a pulp, pressing, molding and drying.

Caseless ammunition is also available for infantry weapons; as the ejector mechanism can be dispensed with, it is possible to raise the number of shots in machine guns. → *Caseless Ammunition*

Combustion

Verbrennung; *combustion*

Any oxidation reaction, including those produced by introduction of atmospheric oxygen; many explosives are capable of burning without detonation if unconfined. Moreover, the oxidation reaction taking place in propellants without introduction of oxygen is also designated as combustion: it is preferable to denote this process as burning (→ *Burning Rate*; → Deflagration).

Combustion Chamber

Brennkammer; *chambre de combustion*; *case*

In rocket technology, the chamber in which the reaction of the propellants takes place.

In solid fuel rockets, the propellant container also serves as the combustion chamber; in liquid fuel rockets it is the chamber in which the injected liquid components of the propellant to react with one another. The combustion chamber must withstand the predetermined working pressure and the temperatures developing at the chamber walls. In liquid fuel rockets the chamber wall is externally cooled in most cases; in solid fuel rockets, in which internal charges bonded to the chamber walls are often employed, the required protection is afforded by the propellant itself. These conditions determine the choice of a suitable chamber material. Since the weight of the combustion chamber has a decisive effect on the range of the rocket, the walls should be as thin as possible. The use of thermally insulating and reinforced (e.g. with fiberglass) inserts made of plastic materials has already proved successful.

Standard combustion chambers and laboratory combustion chambers 2) have been developed for testing the behavior of solid rocket fuels and for the determination of their characteristic properties.

Commercial Explosives

Gewerbliche Sprengstoffe; *explosifs pour usage industriel*

Explosives designed, produced and used for commercial or industrial applications other than military.

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2) Haeuseler, E. and Diehl, W. (1967) *Explosivstoffe*, **15**, 217.

Compatibility

Verträglichkeit; *compatibilité*

Ability of materials to be stored intimately without chemical reaction occurring.

Incompatibility may result in a loss of effectiveness or may be very hazardous. For example, → *Chlorate Explosives* and → *Ammonium Nitrate Explosives* are not compatible (formation of self-decomposing ammonium chlorate). For compatibility testing → *Vacuum Test*.

Compatibility Group

The so-called Orange Book edited by the UN comprises recommendations on the transport of dangerous goods and is an internationally harmonized manual of tests and criteria to be used for classifying chemical substances and articles. Part I contains classification procedures, test methods and criteria relating to explosives and explosives articles of class 1. Explosives and explosives articles of class 1 are further classified into one of thirteen compatibility groups (A to H, J, K, L, N or S), which are relevant for transportation and storage issues. Concerning the usability and handling instructions of explosives and explosives article are also classified into one of six hazardous division groups (1.1 to 1.6). Both assignments together imply special recommendations for the allowed/required way of packaging materials, the amounts, transportation and handling and labeling instructions, as well as the allowed way of clustered packaging, transportation and storage of the materials/articles.

Composite Propellants

Verbundtreibsätze; *poudres composites*

Composite propellants are solid rocket fuels, consisting of oxygen-donating inorganic salts and a binder made of plastic.

The high-polymeric binders in use today include polysulfides (PS), polybutadieneacrylic acid (PBAA), polybutadiene-acrylonitrile (PBAN), polyurethane (PU) and carboxyl- and hydroxyl-terminated polybutadiene (CTPB and HTPB).

Nitrates and perchlorates, → *Ammonium Perchlorate* in particular, are used as oxidizers.

These propellants can be manufactured by casting or by pressing. The grain size distribution of the salt affects the combustion properties to a significant extent. The mechanical (preferably rubber-elastic) properties of the plastic binders must satisfy special requirements.

CDB Propellants are combinations of composites with → *Double-Base Propellants*, which achieve plateaus (→ *Burning Rate*) otherwise difficult to attain.

For details about composite propellants see:

- *Zähringer, A. F.:* Solid Propellant Rockets, Wyandotte, New York 1958
- *Barrère, Jaumotte, Fraeijs de Veubeke, "Vandekerckhove":* Rocket Propulsions, Elsevier Publ. Amsterdam 1961
- *Dadieu, Damm, Schmidt:* Raketentreibstoffe, Springer, Wien 1968

Compositions A; A-2; A-3

Pressed charges made of phlegmatized → *Hexogen* differing from each other only by the various kinds of wax they contain.
detonation velocity, confined: 8100 m/s
at $\rho = 1.71$ g/cm^3

Compositions B; B-2

Hexolite; *Hexotol*

Castable mixtures of hexogen (RDX) and TNT in the proportion of 60 : 40; some of them contain wax as an additive. They are used as fillings for bombs, mines and → *Hollow (Shaped) Charges*.
density: about 1.65 g/cm^3 [3)]
detonation velocity, confined: 7800 m/s
at $\rho = 1.65$ g/cm^3

Composition C; C-2; C-3; C-4

Military plastic explosives, consisting of → *Hexogen* and a plasticizer, which itself may or may not be explosive. The respective formulations are:

Composition	RDX (%)	Plasticizer (%)	Type
C	88.3	11.7	nonexplosive
C-2	80.0	20.0	explosive
C-3	78	22.0	explosive
C-4	90 (selected grain fractions)	10.0	polyisobutylene

See also → *Plastic Explosives*

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3) Can be raised to > 1.7 g/cm^3 by application of special casting techniques.

Composition I; II

Eutectic mixtures of ammonium nitrate, sodium nitrate, dicyanodiamide and guanidine nitrate (Table 6).

Table 6 Composition of the mixtures (in percent).

	Composition	
	I	II
Ammonium nitrate	65.5	60
Sodium nitrate	10.0	24
Dicyanodiamide	14.5	8
Guanidine nitrate	10.0	8

Confined Detonation Velocity

Detonationsgeschwindigkeit unter Einschluss; *vitesse de détonation sous confinement*

The detonation velocity of an explosive or blasting agent in a container, such as a borehole, in contrast to detonating in the open (→ *Detonation Velocity*).

Confinement

Einschluss

Confinement is understood to mean an inert material of some strength and having a given wall thickness, situated in the immediate vicinity of an explosive. Priming or heating the explosive materials produces different results, according to whether they are located in a stronger or a weaker confinement. If confined by thick steel, almost any explosive will explode or detonate on being heated; on the other hand, they burn on contact with an open flame if unconfined (→ *Combustion*; → *Mass Explosion Risk*), except → *Initiating Explosives*.

The destructive (fragmentation) effect of an explosion becomes stronger if the explosive is confined (stemmed) in an enclosure such as a borehole. In the absence of natural confinement, the explosive charge is often embedded in an inert material such as clay. See also → *Mud Cap* and → *Stemming*.

Contained Detonating Fuze

Sprengschnur mit Schutzmantel; *cordeau détonant gainé*

Mild detonating fuze completely contained within a shock-absorbing sheath to prevent damage to the surroundings when the fuze is detonated.

Contour Blasting

Profilsprengen; *saulage en profil*

The purpose of controlled blasting is to produce an excavation contour, while leaving behind an intact, fissure-free formation (prenotching, presplitting off, notching, contour blasting). This is done by the application of diminished-strength explosive charges, using numerous boreholes driven exactly in parallel (vacant boreholes; firing in a cavity; charge diameters small as compared to the total diameter of the borehole; fissure-free roof firing in salt mines).

For further details see: *Rune Gustavson:* Swedish Blasting Technique. SPI, Gothenburg, Sweden (1972)

Copper Chromite

Kupferchromit; *chromite de cuivre*

$(CuO)_x(Cr_2O_3)_y$

dark brown to black powder

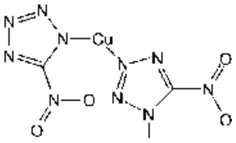
Copper chromite is the reaction product of copper oxide and chromium oxide. It is an important catalyst for the burning of rocket propellants and pyrotechnical compositions.

Specifications

sieve analysis:	
through mesh width 0.07 mm:	at least 98%
through mesh width 0.04 mm:	at least 90% net content
CuO:	at least 79%, not more than 85%
Cr_2O_3:	at least 13%, not more than 19%
Fe_2O_3:	not more than 0.35%
water-soluble matter:	not more than 0.5%

Copper(I) 5-Nitrotetrazolate

Kupfer(I)-5-Nitrotetrazolat, DBX-1



DBX-1

brown crystals
empirical formula: $C_2Cu_2N_{10}O_4$
molecular weight: 355.2 g/mol
enthalpy of formation: +99.8 kJ/mol = +281 kJ/kg
density (at 113 K): 2.584 g/cm^3
deflagration point: 329 °C
detonation velocity: 7000 m/s
impact sensitivity: 0.04 N m
friction sensitivity: 0.1 N
electrostatic sensitivity: 3 mJ

Copper(I) 5-nitrotetrazolate (DBX-1) was suggested as a possible environmentally compatible volumetric throw-in replacement for lead azide and has been extensively studied under the name **DBX-1** by Pacific Scientific EMC. DBX-1 has the empirical formula $C_2Cu_2N_{10}O_4$ and is a copper nitrotetrazolate salt. DBX-1 is thermally stable up to 325 °C (DSC), is stable at 180 °C for 24 h in air and for 2 months at 70 °C. The impact sensitivity of DBX-1 is 0.04 J (ball-drop instrument) compared to 0.05 J for LA. DBX-1 is prepared from NaNT and $CuCl_2$ in HCl/H_2O solution at elevated temperature. However, a better synthetic route for the preparation of DBX-1 in 80–90% yields is given by the following equation:

$$CuCl_2 + NaNT \xrightarrow{\text{reducing agent},H_2O,15\ \text{min},\Delta T} DBX\text{-}1$$

This primary explosive was first made by Dr. Walter Friederich (Dynamit Nobel AG, Troisdorf, Germany) and patented in 1960.

Cordite

Designation for double-base (nitroglycerine-nitrocellulose) gun propellants in the United Kingdom.

Coruscatives

This is the name given by the American worker *Zwicky* to pairs of materials (other than the well-known thermites, → *Delay compositions*) which react with each other without formation of gas.

The exothermal nature of certain components may be surprisingly high; the mixture Ti : Sb : Pb = 48 : 23 : 29 is primed at 570 °C (1060 °F), and the reaction temperature attains 1000 °C (1830 °F). Other combinations include magnesium-silicon, magnesium-tellurium, magnesium-tin and magnesium-phosphorus.

Coyote Blasting

Kammerminensprengungen; *sautage par grands fourneaux de mines*

In coyote blasting, which is practiced in open-pit mining and in stone quarries, tunnels are driven into the mine face and chambers are drilled that can accommodate large quantities (up to several tons) of explosives. The chambers – usually several chambers at once – are charged, stemmed and detonated. They must be primed with the aid of a → *Detonating Cord*.

Coyote blasting has now been almost completely displaced by → *Large Hole Blasting*, because the spaces accommodating the explosive can be produced more rationally in this way.

Crawford Bomb

A bomb used to determine the → *Burning Rate* of solid rocket propellants.

The propellant grains are in the form of thin rods (strands) which may have been cut or extruded and protected against surface burning by mantle insulation. The strand is placed in a bomb and electrically initiated at one end, after which its combustion rate is recorded with the aid of wire probes. Using compressed nitrogen, the pressure at which the combustion take place is adjusted in the bomb; standard values are 2, 4, 7, 10, 13, 18, and 25 MPa at a temperature between –40 and 60 °C.

Crimping

Anwürgen; *sertir*

The act of securing a blasting cap to a section of safety fuse by compressing the metal shell of the cap against the fuse by means of a cap crimper.

Critical Diameter

Kritischer Durchmesser; *diamètre critique*

The critical diameter is the minimum diameter of an explosive charge at which detonation can still take place. It is strongly texture-dependent, and is larger in cast than in pressed charges. Finely dispersed gas inclusions considerably reduce the critical diameter.

In the case of very insensitive materials – ammonium nitrate, for example – the critical diameter may be very large.

Cumulative Priming

Kumulative Zündung

Counter-current priming, in which the explosive charge is simultaneously primed at two or more places, so that the detonation waves travel to meet one another, and their effect becomes additive.

Curing

Härten, aushärten; *maturer*

Polymerization or polyaddition of prepolymer or monomer component of mixed propellants to increase mechanical strength.

Cushion Blasting

Hohlraumsprengen; *fir avec chambres d'expansion*

A method of blasting in which an air space is left between the explosive charge and the stemming, or in which the blast hole is purposely drilled larger than the diameter of the explosive cartridge to be loaded; → *Contour Blasting*.

Cut Off

Abschlagen einer Sprengladung; *decapitation*

Separation of a part of a borehole charge by the blast effect of another shot in electrical delay-firing circuits. Cut off can also occur to the whole burden of the borehole charge by previous shots; → *Permitted Explosives*.

Cutting Charges

Schneidladungen; *charge creuse pour découpage*

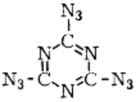
Cutting charges serve to cut through iron plates, cables, bridge trusses, etc. They are constructed on the principle of → *Shaped Charges*, but are not rotationally symmetrical; their shape is that of long channels (grooves).

The cutting depth of these charges depends to a considerable extent on the thickness and lining material of the angular or semi-circular groove; in addition, the optimum distance from the target must be determined in advance.

As in rotationally symmetrical hollow charges, a jet of highly accelerated gases and metal fragments is produced.

Cyanuric Triazide

Cyanurtriazid; triazide cyanurique, Triazine triazide, TTA



colorless crystals
empirical formula: C_3N_{12}
molecular weight: 204.1 g/mol
energy of formation: +1090.3 kcal/kg = +4561.9 kJ/kg
enthalpy of formation: +1072.9 kcal/kg = +4489.2 kJ/kg
oxygen balance: −47%
nitrogen content: 82.36%
melting point (under decomposition): 94 °C = 201 °F
lead block test: 415 cm^3/10 g
detonation velocity, unconfined: 5500 m/s at $\rho = 1.02$ g/cm^3
deflagration point (explosion): 200–205 °C = 390–400 °F
friction sensitivity: 0.01 kp = 0.1 N pistil load

This compound is prepared by slowly introducing powdered cyanogen chloride into an aqueous solution of sodium azide with efficient cooling.

Cyanuric triazide is an effective initiating explosive. It is not employed in practice owing to its high vapor pressure.

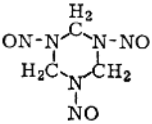
Triazine triazide (TTA), or cyanuric triazide, is being considered as a replacement for → Lead Azide (LA) in stab detonators in which LA is used as the transfer charge. In terms of explosive power, TTA is more powerful than LA which would make it an effective performer for medium and large detonators. However, since TTA has a slightly slower → DDT in comparison to LA, it may not be suitable for small detonator applications.

Cyclotol

The name given to RDX–TNT mixtures with compositions varying between 50 : 50 and 75 : 25 (→ *Compositions B*).

Cyclotrimethylene Trinitrosamine

trinitrosotrimethylenetriamine; *Cyclotrimethylentrinitrosamin*; *cyclotrimethylène trinitrosamine*



pale yellow crystals

empirical formula: $C_3H_6N_6O_3$
molecular weight: 174.1 g/mol
energy of formation: +417.9 kcal/kg = +1748.4 kJ/kg
enthalpy of formation: +392.4 kcal/kg = +1641.7 kJ/kg
oxygen balance: −55.1%
nitrogen content: 48.28%
volume of explosion gases: 996 l/kg
heat of explosion
  (H_2O liq.): 1081 kcal/kg = 4525 kJ/kg
  (H_2O gas): 1051 kcal/kg = 4397 kJ/kg
density: 1.508 g/cm^3
melting point: 102 °C = 216 °F
heat of fusion: 5.2 kcal/kg = 22 kJ/kg
detonation velocity, confined: 7300 m/s = 24 000 ft/s
  at $\rho = 1.49$ g/cm^3
melting point: 105.6 °C

Cyclotrimethylene trinitrosamine is soluble in acetone, alcohol chloroform and benzene, but is sparingly soluble in water.

This nitroso compound, which is related to hexogen, is prepared by treating hexamethylenetetramine with alkali metal nitrites in a dilute acid solution.

Since concentrated acid is not required in the preparation, large-scale manufacture of the product, under the name of R-salt, was under active consideration at one time during the Second World War. However, even though easily prepared and powerful, the explosive has not yet been used in practice owing to its limited chemical and thermal stability.

Cylinder Expansion Test

Experimental method to measure the effectiveness of an explosive. The radial expansion on detonation of a metallic cylinder (usually copper) filled with a high explosive is observed. A streak camera or a laser method might be used. The detonation velocity is determined simultaneously using, for example, time-of-arrival pins. The → *Equation of State* (EOS), which is often the Jones-Wilkins-Lee (JWL) EOS of the detonation products, is derived using Gurney theory.

Dangerous Goods Regulations

Gefahrgutverordnungen

Dangerous Goods Regulations, Rail (GGVE)

Dangerous Goods Regulations, Road (GGVS)

Dangerous Goods Regulations, Sea (GGVSea)

Dangerous Goods Regulations, Inland Waterways (GGVBinsch)

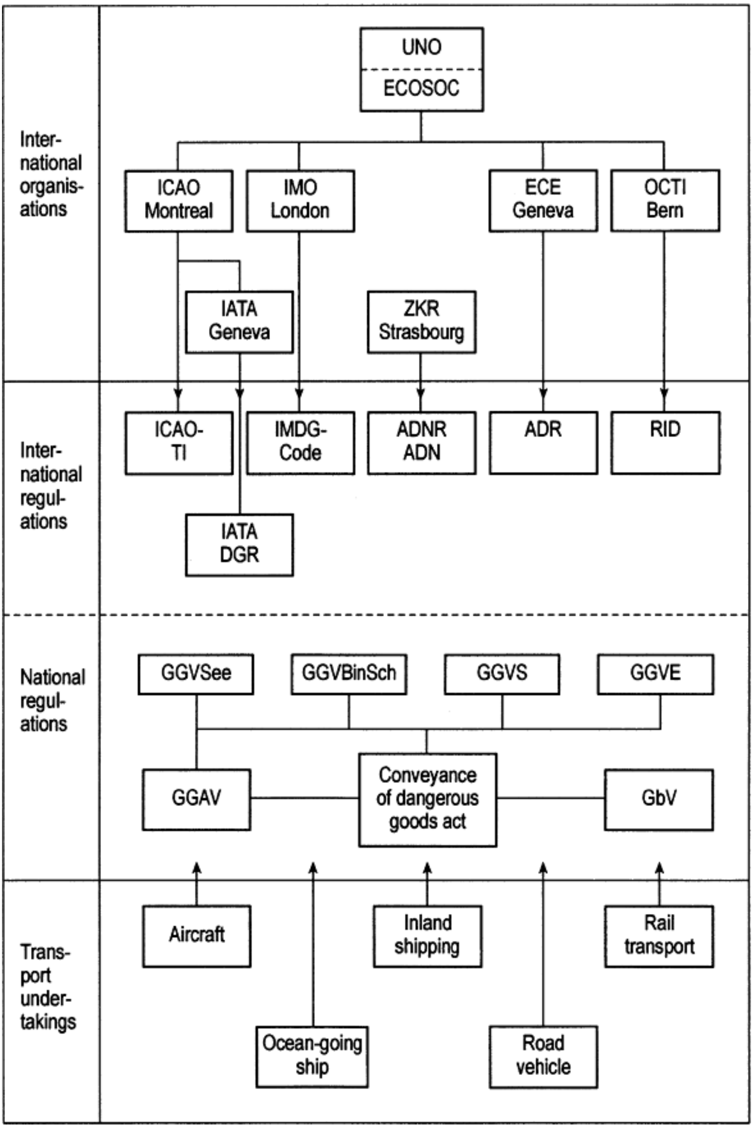


Figure 9 Organization of dangerous goods transport.

The Dangerous Goods Regulations are internationally harmonized regulations (*ADR*, → *RID*, → *IMDG Code*, *ADNR*, → *IATADGR*) for the transport of dangerous goods. All substances and articles that have defined explosive properties are assigned to Class 1 "Explosives and Articles with Explosive Substance". To classify into one of the six risk classes (subclasses of Class 1), the hazardous property of the substance or article is studied, including in its dispatch packing. This examination takes place in accordance with the test methods described in the "Recommendations on the Transport of Dangerous Goods; Manual of Tests and Criteria, United Nations". The → *BAM* (Federal German Materials Testing Laboratory, *WTD 91* for the military area) is the competent authority in Germany for classifying explosives, detonators, propellants, pyrotechnical mixtures and articles.

The purpose of the subclasses 1.1, 1.2, 1.3, 1.4, 1.5 and 1.6 is to characterize the explosive properties of the substances and articles in Class 1 with regard to their activity and to some extent their sensitivity as well. The 13 compatibility groups A, B, C, D, E, F, G, H, J, K, L, N and S reflect mainly the specific type of explosives. The Classification Code, consisting of the subclass and compatibility group (e.g. 1.1D for a mass-explodable detonating explosive or an article with such a substance), characterizes goods in Class 1.

Classification into a subclass and a compatibility group lead to particular rules specified in the Dangerous Goods Regulations for transporting these goods.

Dautriche Method

A method for the determination of the detonation rate. The test sample of the explosive is accommodated in a column, which may or may not be enclosed in an iron tube; the length of the detonating column to be measured is marked out by means of two blasting caps, one at each end. A loop made of a detonating cord with a known detonation rate is connected to the caps and is passed over a lead sheet in its middle part. The cord is successively ignited at both ends, and the meeting point of the two detonation waves advancing towards each other makes a notch on

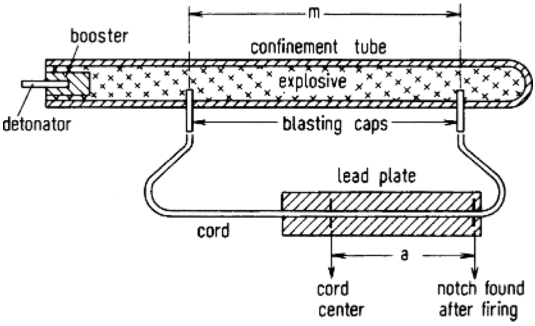


Figure 10 Dautriche method.

the lead sheet. The distance between this meeting point and the geometric center of the cord is a measure of the reciprocal detonation rate to be determined:

$$D_x = D \cdot \frac{m}{2a}$$

where D_x is the detonation rate of the sample, D is the detonation rate of the detonator cord, m is the length of the distance to be measured, and a is the distance between the notch and the center of the cord length.

The method is easy to carry out and no special chronometer is required.

DBX

A cast explosive charge, containing RDX, ammonium nitrate, TNT, and aluminum powder in the proportions 21 : 21 : 40 : 18.

Dead-pressing

Dead-pressing is a phenomenon that can occur if high pressures are used to press a material to achieve a higher density. If dead-pressing occurs the resulting material is hard to ignite, and if the material can be ignited it only burns without detonation occurring. Therefore, it is important to avoid pressing a primary explosive to a point where its capability to detonate is lost. This phenomenon is not observed for all primary explosives and some, such as many azides (including lead azide) are not easily dead-pressed. Others, however, such as MF (mercury fulminate), DDNP (diazodinitrophenol) and many peroxides can be very easily dead-pressed. In the case of MF, the pressure required for dead-pressing to occur is highly dependent on the MF crystal size. It is believed that due to the high pressure all air bubbles are squeezed out of the material and consequently no voids filled with air that could react as hotspots remain in the material.

Deckmaster

Trade name for primer charges with special delay inserts consisting of a sensor on one end and an aluminum shell delay cap on the other. Delay times: 0–500 ms in 25 ms intervals. The deckmaster unit has to be connected with detonating cord with no more than 30 gr/ft (→ *Miniaturized Detonating Cord*). For varied delay steps in the hole, only one downline detonating cord is needed.

Deflagration

Explosive materials often decompose at a rate below the sonic velocity of the material. This type of reaction is known as deflagration. It is propagated by the liberated heat of reaction, and the direction of flow of the reaction products is opposite to that of decomposition propagation (unlike in → *Detonation*). The burning of a powder or of a rocket charge is a deflagration process (→ *Burning Rate*). The mode of reaction of an explosive material – deflagration or detonation – depends on its mode of actuation (→ *Initiation*).

For transitions from deflagration to detonation (DDT) and vice versa see → *Detonation*.

It is important to prevent any deflagration of permitted explosives. Since the deflagration of an explosive proceeds at a much slower rate than its detonation, it may ignite methane-air and coal dust-air mixtures. This must be prevented by using suitable compositions (→ *Permitted Explosives*) and application techniques.

Deflagration Point

Verpuffungspunkt; *tempèrature de décomposition*

The deflagration point is defined as the temperature at which a small sample of the explosive, placed in a test tube and externally heated, bursts into flame, decomposes rapidly or detonates violently.

A 0.5-g sample (a 0.01-g sample in the case of → *Initiating Explosives*) is placed in a test tube and immersed in a liquid metal (preferably Wood's metal) bath at 100 °C (212 °F), and the temperature is raised at the rate of 20 °C/min until deflagration or decomposition takes place.

This method is identical with the official method laid down in *RID*. Nitrocellulose and nitrocellulose powder are tested in a stirred paraffin bath, heated at the rate of 5 °C/min.

Delay

Verzögerung; *retard*

A pyrotechnic, mechanical, electronic, or explosive train component that introduces a controlled time delay in some element of the arming or functioning of a fuze mechanism.

delay, arming

The time or distance interval between the instant a device carrying the fuze is launched and the instant the fuze becomes armed.

delay compositions

Verzögerungssätze; *compositions retardatrices*

Delay compositions are mixtures of materials which, when pressed into delay tubes, react without evolution of gaseous products and thus ensure the minimum variation in the delay period. Examples of such mixtures are potassium permanganate with antimony; lead dioxide with silicium; redox reactions with fluorides and other halides (also → *Coruscatives* and → *delay, gasless*).

delay element

An explosive train component normally consisting of a primer, a delay column, and a relay detonator or transfer charge assembled in that order in a single housing to provide a controlled time interval.

delay function

The time or distance interval between the initiation of the fuze and the detonation.

delay fuze

Verzögerungszünder; *fusée retardatrice*

In the military, delay fuses are complete shell fuses which set off the explosive charge a definite time after impact.

delay, gasless

Verzögerung, gaslos; *retard sans formation de gaz*

Delay elements consisting of a pyrotechnic mixture that burns without production of gases.

delayed initiation; delayed inflammation

Zündverzug, Anzündverzug

In hypergolic pairs of rocket propellants (→ *Hypergolic*), a delay in inflammation is understood to mean the time which elapses from the moment of contact between the reaction partners up to the initiation; this delay is on the order of a few milliseconds, and must not exceed a certain limiting value; thus, e.g. the inflammation delay of the reagent pair furfuryl alcohol-nitric acid is about 20 ms.

In the case of solid fuel rockets, the delay in inflammation, which is determined on a test stand, is understood to mean the time which elapsed between the moment of application of the initiation voltage to the electric inflammation element and the moment when about 10% of the maximum pressure has been attained. Clearly, the magnitude of this parameter depends both on the nature of the firing charge employed and on the ease with which the solid propellant can be initiated. The permitted initiation delay will depend on the objective of the firing.

Destressing Blasting[4)]

Entspannungssprengung; *sautage de détente*

Destressing blasting serves to loosen up the rock mass in order to distribute high compressive loads more uniformly and to counteract the hazard of rockbursts. Rockbursts are particularly violent fracture processes, accompanied by considerable earth tremors. They mainly consist of a sudden thrust or ejection of the rock involved (coal; salts; massive rocks) and abrupt closure of the excavation. In coal seams, the risk manifests itself by abnormally great amounts of debris when drilling small holes (so-called test drilling). Destressing blasting is performed by contained detonations.

Destruction of Explosive Materials

Vernichten von Explosivstoffen; *dèstruchon de matières explosives*

Destruction of explosives includes destruction of explosive materials and their waste, which present a danger of explosion, removal of explosive residues on machines, instruments, pipes etc., and handling objects with adhering explosives (for the evacuation and handling of ammunition → *Dismantling of Explosive Objects, Especially Ammunition*). The destruction of explosives must be carried out under the supervision of an expert, who must be in charge of the entire operation.

The following techniques may be used in the destruction of explosive materials:

1. Combustion: this technique is applicable to most explosives apart from initiating explosives. However, this destruction technique, while important per se, can only be carried out by the manufacturer. Burning of explosives by the user can be dangerous.
2. The explosive is poured into a large volume of water and is mixed with it. This technique can be applied to materials which are soluble totally in water (black powder, ANFO).
3. Treatment with chemicals (acids, alkalis, boiling with water): lead azide is destroyed by treatment with nitric acid in the presence of sodium nitrite; lead trinitroresorcinate by treatment with nitric acid; mercury fulminate by prolonged treatment with boiling nitric acid.
4. Exploding the material: blasting operations must be carried out in a barricaded area licensed for the purpose, located at least 1000 ft (ca.

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4) The article was made available by Dr. Bräuner, Bergbauverein Essen. Publications:
Bräuner, G. (1978) Möglichkeiten der Gebirgsschlagbekämpfung im Ruhrbergbau unter besonderer Berücksichtigung des Entspannungssprengens. *NOBEL-Hefte*, July–September, 91–97.
Bräuner, G. (1981) *Gebirgsdruck und Gebirgsschläge*, Verlag Glückauf, Essen.
Bräuner, G. (1991) *Gebirgsdruck und Gebirgsschläge*, Verlag Glückauf, Essen, 2nd edn.

305 m) away from any building which may be endangered by the explosion. A reinforced shelter is needed for protection of personnel; suitable protection from flying fragments (e.g. by walls; palisades) must be provided.

Deterrent

Propellant compositions in the small- and middle-caliber region are coated with an inert material (deterrent), which reduces the burning rate at the surface of the propellant grain and causes the propellant to burn progressively. Typical deterrents are dibutylphthalate, dinitrotoluene, ethylcentralite and paraplex.

Detonating Cord, Detonation Cord

detonating fuse, Primacord; *Sprengschnur*; *cordeau détonant*; *Cord-tex*

Detonating cords consist of a → *PETN* core (about 12 g/m) with wound hemp or jute threads and a plastic coating around it. The cord is initiated by a cap and its detonation velocity is about 7000 m/s. Special fuses for the safe initiation of → *ANFO* contain 40 and 100 g/m PETN.

Detonating fuses serve to initiate blasting charges; the initiation is safe if the cord is coiled several times around the cartridge. To initiate several charges, branch cords are attached to a main cord. In Germany, priming by detonating cords is mandatory in → *Large Hole Blasting* and in → *Coyote Blasting*.

Detonating cords are also employed for seismic shots in the desert and at sea. They are also used for clearing blasts in oil and gas wells, which restore the flow from blocked boreholes; special cords with a wire reinforced sheet are used for this purpose.

For the use of detonating cords in the determination of the detonation rate of explosives → *Dautriche Method*.

Transfer fuses which have no priming effect are manufactured in the USA. Those containing only a fraction of one gram of PETN per meter and a lead sheathing are known as mild detonating fuses. Cords containing about 2 g/m of the explosive inside a plastic-impregnated network are manufactured as Primadet.

Detonating Cord Downline; Zündabzweigung

The section of detonating cord that extends within the blast hole from the ground surface down to the explosive charge.

Detonating Cord MS Connectors; Millisekunden-Verzögerer

Nonelectric, short-interval (millisecond) delay devices for use in delaying blasts that are initiated by detonating cord.

Detonating Cord Trunirline; Leit-Sprengschnur; ligne de cordeau dètonant

The line of detonating cord that is used to connect and initiate other lines of detonating cord.

Detonation

Detonation; *détonation*

Detonation is a chemical reaction given by an explosive substance that produces a shock wave. High temperature and pressure gradients are generated in the wave front, so that the chemical reaction is initiated instantaneously. Detonation velocities lie in the approximate range of 1500–9000 m/s = 5000–30 000 ft/s; slower explosive reactions, which are propagated by thermal conduction and radiation, are known as → *Deflagration*.

1. Shock Wave Theory

Shock waves are also generated in nonexplosive media by a sudden change in pressure. The generation of a shock wave in air (as a nonexplosive gas) is illustrated by Figure 11, which has been taken from *R. Becker:*[5)]

Let a movable piston in a tube be suddenly accelerated from rest and then continue its motion at a constant rate (phase 1). The air in front of the piston must be compressed somewhat and warms up a little; the compression range is determined by the velocity of sound in the air.

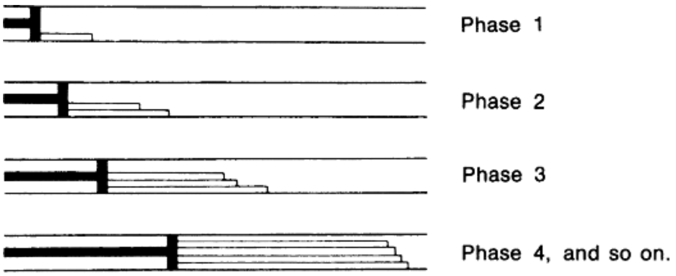

Figure 11 Generation of a plane shock wave.

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5) Becker, R. (1922) *Zeitschrift für Physik*, **8**, 321–362.

The increase in pressure and the range of the increase after a short time are symbolized by the line drawn in front of the piston. Now let the piston accelerate again and continue its motion at the new, higher rate. The new compression is imparted to the medium, some of which is already in motion, as shown in phase 2 of Figure 11; it is moving at a faster rate, the motion of the matter is superposed and, in addition, the sonic velocity has increased in the somewhat warmer medium. Phases 3, 4, etc. show that a steep pressure front is generated. A mathematical derivation of the relationships governing such a process would be beyond the scope of this book.

The state variables will be denoted as follows:

	Undisturbed medium	**Medium in shock compression**
Pressure	p_0	p_1
Temperature	T_0	T_1
Density	ρ_0	ρ_1
Specific volume ($v = 1/\rho$)	v_0	v_1
Internal energy	e_0	e_1
Sound velocity	c_0	c_1

If we limit our consideration to nearly ideal gases such as air, the following values for the rise in temperature, the speed of propagation of the shock wave *D*, and the rate of motion of matter behind the wave front *W* can be calculated as a function of the compression ratio p_1/p_0:

Table 7 .

p_1/p_0	T_1 (°C)	*D* (m/s)	*W* (m/s)
2	63	452	175
5	209	698	452
8	345	875	627
10	432	978	725
20	853	1369	1095

and further increasing values.

It is seen from Table 7 that even if the extent of compression is relatively small, the propagation rate becomes distinctly higher than the velocity of sound (330 m/s); at higher compression ratios the resulting temperatures are so high that glow phenomena occur even in the absence of an energy-supplying reaction. If the medium is an explosive gas mixture rather than air, it is obvious that an explosive reaction will be instantly initiated in front of the shock wave.

Owing to the sudden pressure effect, all explosions produce a shock wave in the surrounding air; this compression shock is the principle of the long-distance effect of explosions. If the propagation of the shock wave is nearly spherical, the compression ratio p_1/p_0 decreases rapidly, and so does the p_0 velocity of matter W; it becomes zero when the shock wave becomes an ordinary sound wave. If the explosion-generated shock wave is propagated in three-dimensional space, its effect decreases with the third power of the distance; this is the guideline adopted in the German accident prevention regulations, in which the safety distance (in meters) is calculated from the expression $f \cdot \sqrt[3]{M}$ where M is the maximum amount of explosives in kg which are present in the building at any time, whereas f is a factor which varies, according to the required degree of safety, from 1.5 (distance between two barricaded store houses) to 8 (distance from the nondangerous part of the plant). The f-value stipulated by the regulations may be as high as 20 for residential areas in the vicinity of the plant.

The shock wave theory is easier to understand if we consider a planar shock wave, such as the one shown in Figure 11, on the assumption that the tube is indestructible (such shock wave tubes are utilized as research instruments in gas dynamics and in solid-state physics; the shock sources are explosions or membranes bursting under pressure).

Comparative treatment of the behavior of the gas in the tube yields the following relationships.

From the law of conservation of mass:

$$\rho_0 D = \rho_1 (D - W) \quad \text{or} \quad v_1 D = v_0 (D - W) \tag{8}$$

From the law of conservation of momentum:

$$p_1 - p_0 = \rho_0 D W \quad \text{or} \quad v_0 (p_1 - p_0) = D W \tag{9}$$

From the law of conservation of energy:

$$p_1 W = \varrho_0 D \left(e_1 - e_2 + \frac{W^2}{2} \right) \tag{10}$$

Rearrangements yield the so-called *Hugoniot* equation:

$$e_1 - e_0 = \frac{1}{2}(p_1 + p_0)(v_0 - v_1) \tag{11}$$

Equation (11) represents a curve in the p–v diagram, the *Hugoniot* curve.

The following expression is obtained for the velocity D of the shock wave and for the velocity of matter W:

$$D = v_0 \sqrt{\frac{p_1 - p_0}{v_0 - v_1}} \tag{12}$$

and

$$W = \sqrt{(p_1 - p_0)(v_0 - v_1)} \tag{13}$$

These relationships are valid irrespective of the state of aggregation.

2. Detonation Wave Theory

If the medium is explosive, an explosive chemical reaction must be produced immediately in the wave front because of the drastic temperature and pressure conditions. The propagation of the shock wave is maintained by the energy of the reaction.

The equations developed above are still valid, but the meaning of the equation parameters are:

p_1 detonation pressure;
ρ_1 density of gaseous products in the front of the shock wave; this density is thus higher than the density of the explosive ρ_0;
D detonation rate;
W velocity of gaseous products (fumes).

Equation (8) remains unchanged.

Since p_0 is negligibly small as compared to the detonation pressure p_1, we can write Equation (9) as

$$p_1 = \rho_0 D W d^{6)} \tag{9d}$$

The detonation pressure in the wave front is proportional to the product of the density, the detonation rate, and the fume velocity, or – since the fume velocity is proportional to the detonation rate – to the square of the detonation rate. For a given explosive, the detonation velocity rises with increasing density. It is clearly seen from Equation (9d) that the detonation pressure increases very considerably if the initial density of the explosive can be raised to its maximum value, e.g. by casting or pressing or if the density of the explosive is intrinsically high (TNT 1.64; RDX 1.82; octogen 1.96). High density of the explosive is important if high

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6) Detonation wave theory equations are denoted by numbers corresponding to the respective equations of the shock wave theory with a suffix "d" (for detonation).

→ *Brisance* is needed, whereas the blasting performance (→ *Strength*) is less affected by it. The importance of the maximum possible compaction of explosives is demonstrated by the → *Hollow Charge* technique.

Conversely, the detonation pressure and detonation rate may be reduced by reducing ρ_0, i.e. by employing a more loosely textured explosive. This is done if the blasting has to act on softer rocks and if a milder thrust effect is required (see below: explanation of the concept of impedance).

The determination of the maximum detonation pressure p_1, in Equation (9d) has been studied by X-ray measurements. While the detonation velocity can be measured directly by electronic recorders or by the → *Dautriche Method*, there is no direct measurement possibility for the fume velocity W, but it can be estimated by the flow off angle of the fumes behind the wave front; this angle can be taken from X-ray flash photographs. The relation between D and W is[7]

$$W = \frac{D}{\gamma + 1}$$

γ is denoted as the polytrop exponent in the modified state equation $p = C\rho^{\gamma}\ C = \text{const.}$[8]

The value of γ is about 3, so that Equation (9d) can be written

$$p_1 = \rho_0 \frac{D^2}{4} \tag{2d}$$

Equation (2) above can be recalculated to

$$p_1 - p_0 \left(v_0 - v^1 \right) \rho_0^2 D^2 \tag{7d}$$

represented in the pressure–volume diagram (Figure 11) by a straight line with the slope – $\rho_0^2 D^2$, known as the *Rayleigh* line. The *Hugoniot* equation (11), applied to the detonation process involving the chemical energy of reaction q, becomes

$$e_1 - e_0 = \frac{1}{2}(p_1 + p_0)(v_0 + v_1) + q \tag{4d}$$

Equations (12) and (13) remain unchanged, but D now denotes the detonation rate, while W stands for fume velocity.

In a detonation process, the positions of the Hugoniot curve and the Rayleigh line on the p–v-diagram are as shown in Figure 12.

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7) The pressure maximum p_1 in the wave front is also called the Neumann spike, p_N.

8) A detailed report is given by Hornberg, H. (1978) The state of the detonation products of solid explosives. *Propellants and Explosives*, **3**, 97–106.

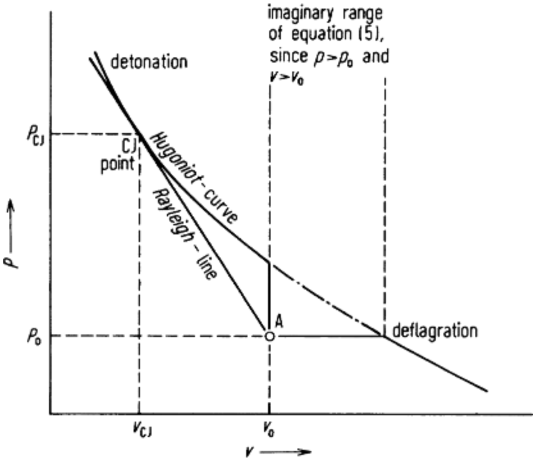

Figure 12 The *Hugoniot* curve and the Rayleigh line in the p–v diagram.

The dotted part of the Hugoniot curve shown in Figure 12 does not describe real detonation states, because here the term under the square root in Equation (10) becomes negative, and D contains the factor -1. The curve now consists of two separate segments: the one situated in the higher pressure area represents detonation, while the one located in the lower pressure area represents → *Deflagration*. The *Rayleigh* line is tangent to the Hugoniot curve at the *Chapman–Jouguet* (CJ) point[9] (all state parameters assigned to the CJ state are indexed CJ). These parameters describe a stable detonation, i.e. a detonation which, unlike a shock wave, can pass through the medium in a stationary manner, that is, at constant intensity and constant velocity. The following equation is then also valid

$$D_{CJ} = W_{CJ} + C_{CJ} \tag{8d}$$

i.e. the detonation rate is the sum of fume velocity and sound velocity.

All the equations given above involve no assumption as to the → *Equation of state* of the medium; they are thus valid irrespective of its state of aggregation. They yield no information as to the thickness of the reaction zone; as a matter of fact, the transitions from v_0 and p_0 to v_1 and p_1 are mathematically discontinuous. In reality, the thickness of the reaction zone is about 1 mm, and may be deduced from the effects of friction and thermal radiation, which were ignored in the treatment given above. The physical meaning of the imaginary part of the *Hugoniot* curve is that there is no continuous transition between detonation and defla-

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[9] *Chapman* and *Jouguet* are pioneers of shock wave theory development; also *Riemann, Hugoniot* and *Rayleigh*.

Table 8 Comparison of the reaction performance of nitroglycol.

	Deflagration	Detonation
Propagation rate D, m/s	3×10^{-4}	7.3×10^{3}
Mass reacted $m = \rho_0 D$, kg/(m² s)	4.5×10^{-1}	11×10^{6}
Reaction energy q per kg	460 kcal $= 1.93 \times 10^{-3}$ kJ	1600 kcal $= 6.7 \times 10^{3}$ kJ
Output, kcal/(m² s)	2.1×10^{2}	1.8×10^{10}
Output ratio deflagration:		
Detonation	about 1	10^{8}
width b of reaction zone, m	1×10^{-2}	1×10^{-3}
Energetic load of reaction zone mq/b, kcal/(m³ h)	7.5×10^{7}	6.6×10^{16}

gration. In practice, however, transition between these two phenomena may take place in either direction. Roth[10] compared both these types of reactions on → *Nitroglycol*. Table 8 is a comparison of the reaction performance of nitroglycol ($\rho_0 = 1.5 \times 10^3$ kg/m³ [11]) during detonation and deflagration respectively.

The value of 6.6×10^{16} kcal/(m³ h) for the energetic load may be compared with the maximum value of only 10^9 kcal/m³ that can be attained in chemical reactor technology.

The physical treatment of the detonation process involves yet another magnitude known as impedance[12]; this is the product of the density and the detonation rate and represents the material throughput. It has the dimension of a resistance, and reflects the fact that the progress of the detonation through the explosive medium becomes the more difficult, with increasing density of the explosive (i.e. if the density of the explosive has been increased by casting or pressing).

3. *Selective Detonation*

Selectivity in the course of a detonation process, as described by *Ahrens*, is noted when processes with very different sensitivities, and thus also

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[10] Roth, J.F. (1965) Sprengstoffe, in *Ullmanns Encyklopädie der technischen Chemie*, 3rd edn, Vol. 16, Urban & Schwarzenberg, München, p. 58.

[11] The unconventional dimension of kg/m³ is the result of our consistent application of the SI rather than the older CGS system of units. The fundamental SI units are meter, kilogram (mass), second, ampere, kelvin (K) and candela, while force, weight, pressure etc. are derived magnitudes. For conversion tables see the back flyleaf of this volume.

[12] Sprengtechnik – Begriffe, Einheiten, Formelzeichen. DIN 20163 (1973), Beuth-Vertrieb GmbH. *Roth*, Explosivstoffe, Vol. 6, p. 26 (1958)

with very different induction periods, participate in the intensive chemical reaction (*Detonation Wave Theory*) produced by the shock wave. If the intensity of the shock wave is very low owing to external conditions – explosion in an unconfined space, for example – the induction periods of less sensitive reactions may become infinite, i.e. the reaction may fail to take place.

This selectivity is important for ion-exchanged → *Permitted Explosives*. The proportion of the nitroglycerine-nitroglycol mixture in these types of permitted explosives is chosen so that it would just produce a detonation as if it were dispersed in an inert salt bed. The decomposition reaction of the ion exchanged salt pairs $NaNO_3$(or KNO_3) + NH_4Cl → NaCl (or KCl) + $N_2 + 2H_2O + 1/2O_2$ is insensitive and only takes place if the detonation process is favored by confinement; otherwise, the mixture will behave as an inert salt. Thus, if the explosive is detonated while unconfined (e.g. in angle-shot mortar test or because the confinement was destroyed in the previous blast), the only reaction which takes place is that of the nitroglycerine-nitroglycol mixture which is fast and is limited by its relative proportion and is thus firedamp safe. If the explosive is detonated in an undamaged borehole, double decomposition will take place, and the explosive can develop its full strength.

4. *Sympathetic Detonation*

gap test, flash-over; *Übertragung*; *coefficient de self-excitation*

These terms denote the initiation of an explosive charge without a priming device by the detonation of another charge in the neighborhood. The maximum distance between two cartridges in line is determined by flash-over tests, by which the detonation is transmitted. The transmission mechanism is complex: by shock wave, by hot reaction products, by flying metallic parts of the casing (if the donor charge is enclosed) and even by the → *Hollow Charge* effect.

In the EU, a method for determining the transmission of detonation is standardized as EN 13631-11. Two cartridges are coaxially fixed to a wooden rod with an air gap between them. Depending on the type of explosive the test is done with or without confinement (e.g. steel tube). One cartridge (donor) is initiated and it is noted whether the second cartridge (acceptor) detonates. The complete detonation of the acceptor is verified by measuring the velocity of detonation in it. The result of the test is the largest air gap in cm for which the detonation of the acceptor was recognized. For cartridged blasting explosives that will be used in the EU, a minimum transmission distance of 2 cm is required.

In Germany, the ion-exchanged → *Permitted Explosives* are also gap tested in a coal-cement pipe; these are cylinders made of a bonded mixture of cement with coal dust in the ratios of 1 : 2 and 1 : 20 and provided with an axial bore.

In the studies so far reported, donor and receiver cartridges consisted of the same explosive. The transmission of a standard donor cartridge through varying thicknesses of a stopping medium can also be employed to determine the sensitivities of different explosives. Recent practice in the United States is to insert cards (playing cards, perspex sheets etc.) between the donor cartridge and the receiver cartridge. Tests of this kind are named gap tests. In a more sophisticated method, the gap medium (e.g. a Plexiglas plate, see Figure 13 below) stops flying particles and directs heat transmission completely (shock-pass heat-filter). The shock wave is the only energy transmission to the acceptor charge.

For a 5-cm long and 5-cm diameter tetryl donor charge with a density of 1.51 g/cm^3, the pressure p in the Plexiglas as a function of the Plexiglas length d according to *M. Held*[13] is given by

$$p = 105e^{0.0358d}$$

p in kbar, d in mm.

The result of the gap test is recorded as the minimum pressure at which the acceptor charge detonates.

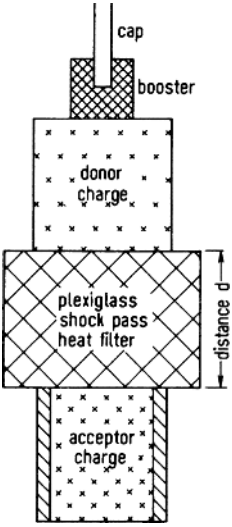

Figure 13 Gap test.

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[13] Held, M. (1968) Initiierung von Sprengstoffen, ein vielschichtiges Problem der Detonationsphysik. *Explosivstoffe*, **16**, 2–17 and Jaffe, J., Beaugard, R. and Amster, A. (1962) Determination of the shock pressure required to initiate detonation of an acceptor in the shock sensitivity test. *ARS Journal*, **32**, 22–25.

F. Trimborn[14)] described a simple method in which water is used as the heat blocking medium; the method can also be used to classify explosives which are hard to detonate and are insensitive to blasting caps.

The gap test explosive train is directed from bottom to top. The donor charge (hexogen with 5% wax) is placed into a Plexiglas tube and covered with water. The acceptor charge to be tested is introduced into the water column from above. The distance between the two charges can be easily varied.

A detonating cord, terminating on a lead plate, serves as evidence for detonation.

Some results:

Explosive	State	Density (g/cm^3)	Detonations at distance in water No (mm)	50% (mm)	100% (mm)	Initiating pressure for detonations (kbar)
Composition B	cast	1.68	18	17	16	17
Hexogen, 5% wax	pressed	1.63	22	21	20	12
PETN, 7% wax	pressed	1.60	29	28	27	7
Pentolite 50/50	cast	1.65	23	22	20	12
Picric acid	pressed	1.58	17	16	15	18
Tetryl	pressed	1.53	24	–	23	10
TNT	pressed	1.53	22	21	20	12
TNT	cast	1.58	7	6	5	38
TNT	cast	1.61	6	5; 4	2	43

Pressure values comply well with those published in other literature.

5. *Detonation Velocity*

Detonationsgeschwindigkeit; *vitesse de détonation*

The detonation velocity is the rate of propagation of a detonation in an explosive; if the density of the explosive is at its maximum value, and if the explosive is charged into columns which are considerably wider than the critical diameter, the detonation velocity is a characteristic of each individual explosive and is not influenced by external factors. It decreases with decreasing density of packing in the column. It is measured by ionization probes or fiber optical sensors.

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14) Trimborn, F. (1967) *Explosivstoffe*, **15**, 169–175.

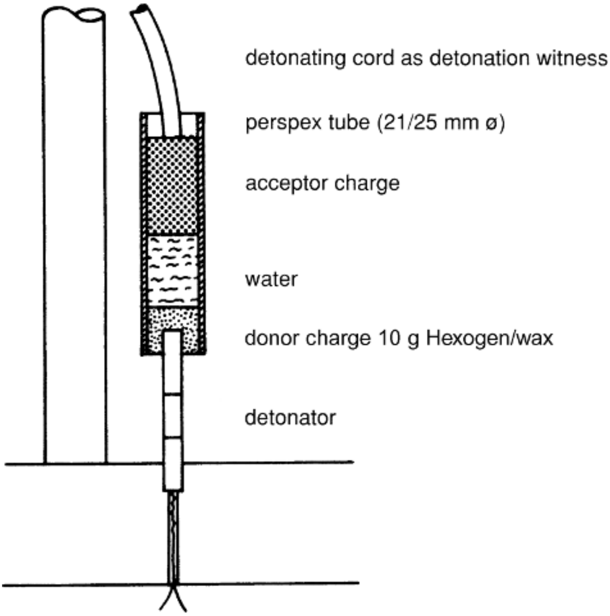

Figure 14 Gap test according to *Trimborn*.

The detonation velocities of confined and unconfined nitroglycerine and nitroglycol explosives have very different values; these values are known as upper and lower detonation velocities respectively. The velocity measured in a steel pipe confinement is not attained in a borehole. Special seismic explosives detonate at the same high detonation rate as measured in the steel pipe, whether confined or not.

6. Detonation Development Distance

Anlaufstrecke; *distance d'évolution de détonation*

A term denoting the distance required for the full detonation rate to be attained. In initiating explosives, this distance is particularly short.

The detonation development distance, especially that of less sensitive explosives, is strongly affected by the consistency, density and the cross-section of the charge.

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Detonator

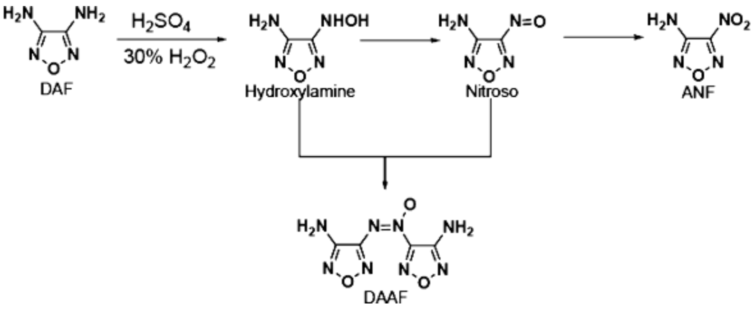
détonateur

Part of an explosive train which initiates the → *detonation* of high explosives, especially of insensitive ones. It may itself be triggered by a separate → *primer* of primary explosives or an integrated primer. Detonators are classified by the method of initiation: percussion, stab, electrical impulse, or flash. Laser initiation is also used. Depending on the application, detonators can include a delay mechanism. Explosive charge placed in certain equipment and set to destroy the equipment under certain conditions (→ *Initiator*).

3,3′-Diaminoazoxy-4,4′-Furazan (DAAF)

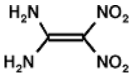
3,3′-Diaminoazooxy-4,4′-furazan, DAAF

3,3′-diaminoazoxy-4,4′-furazan (DAAF) is an *N*-oxide compound which has recently been suggested as a new, insensitive high explosive by LANL. Despite its low detonation velocity (7930 m/s) and detonation pressure (306 kbar at 1.685 g/cm^3), the low sensitivity (impact sensitivity $>$ 320 N m, friction sensitivity $>$ 360 N) and critical diameter of $<$ 3 mm make DAAF a promising compound. DAAF can be prepared by the route shown below.



1,1-Diamino-2,2-dinitroethylene

DADNE, DADE, FOX-7



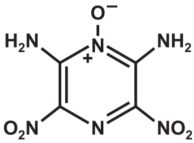
yellow crystals
empirical formula: $C_2H_4N_4O_4$
molecular weight: 148.08 g/mol
energy of formation: −119 kJ/mol
enthalpy of formation: −133.9 kJ/mol
oxygen balance: −21.61%
volume of explosion gases: 779 l/kg
heat of explosion (calculated)
(H_2O liq.): 4442 J/g
(H_2O gas): 4091 J/g
density:
α-polymorph 1.89 g/cm^3
β-polymorph 1.80 g/cm^3
specific energy: 1156 J/g
detonation velocity: 8869 m/s
deflagration point: 215 °C
friction sensitivity: $>$ 360 N
impact sensitivity: $>$ 25 N m

DADNE is a relatively new, low sensitive high explosive developed by the Swedish Defence Research Agency FOI. It is insoluble in cold water, slightly soluble in acetonitrile and cyclohexanone, soluble in DMSO, dimethylformamide and *N*-methylpyrrolidinone. It can cause allergic skin reactions.

DADNE is of interest for the development of IM-propellants and explosives. Three polymorphs α, β and γ were found by means of X-ray diffraction, but only the α-polymorph is stable at room temperature. Transitions occur on heating from α to β and β to γ at 113 and 173 °C, respectively.

2,6-Diamino-3,5-dinitropyrazine-1-oxide

3,5-Dinitro-2,6-pyrazinediamine-1-oxid, ANPZ-O, NPEX-1, LLM-105



solid
empirical formula: $C_4H_4N_6O_5$
molecular weight: 216.113 g/mol
oxygen balance: −37.02%
energy of formation: 5.65 kJ/mol
enthalpy of formation: −12.97 kJ/mol = −60.02 kJ/kg
density: 1.91 g/cm^3
melting point: 342 °C

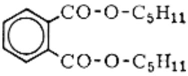
NPEX-1 is an insensitive explosive with an excellent thermal stability outranging the performance of → *TATB*.

NPEX-1 has a detonation velocity of 8730 m/s and a detonation pressure of 359 kbar – comparable with the values observed for → RDX (density = 1.80 g/cm^3, exptl. values: VoD = 8750 m/s, P_{CJ} = 347 kbar). However, NPEX-1 is much less impact-sensitive than RDX and, in addition, it is not sensitive towards electrostatics and friction.

NPEX-1 can be prepared through a variety of routes, most of which start from commercially available 2,6-dichloropyrazine, with oxidation of the intermediate in the final step to the 1-oxide (NPEX-1).

Diamyl Phthalate

Diamylphthalat; *phthalate diamylique*

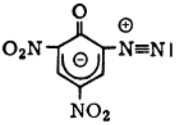


colorless liquid
empirical formula: $C_{18}H_{26}O_4$
molecular weight: 306.4 g/mol
energy of formation: −692.0 kcal/kg = −2895.2 kJ/kg
enthalpy of formation: −721.0 kcal/kg = −3016.5 kJ/kg
oxygen balance: −235.0%

Diamyl phthalate is used as an additive to gunpowders, both for the purpose of gelatinization and to affect → *Surface Treatment*.

Diazodinitrophenol

Dinol, Diazol; *diazodinitrophénol*; *DDNP*



red yellow amorphous powder
empirical formula: $C_6H_2N_4O_5$
molecular weight: 210.1 g/mol
energy of formation: +236.4 kcal/kg = +988.9 kJ/kg
enthalpy of formation: +220.8 kcal/kg = +924.0 kJ/kg
oxygen balance: −60.9%
nitrogen content: 26.67%
density: 1.63 g/cm^3
lead block test: 326 cm^3/10 g
detonation velocity, confined: 6600 m/s = 21 700 ft/s
  at $\rho = 1.5$ g/cm^3
deflagration point: 180 °C = 356 °F
impact sensitivity: 0.15 kp m = 1.5 N m

The compound is sparingly soluble in water, soluble in methanol and ethanol, and readily soluble in acetone, nitroglycerine, nitrobenzene, aniline, pyridine, and acetic acid. It rapidly darkens in sunlight. It is of interest for → *Lead-free Priming Compositions*.

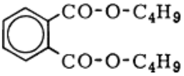
It is prepared by diazotization of → *Picramic Acid* with sodium nitrite in a hydrochloric acid solution with efficient cooling. The dark brown reaction product is purified by dissolution in hot acetone and reprecipitation with iced water.

In the USA, this diazo compound is used as an initiating explosive. It is more powerful than mercury fulminate and slightly less than lead azide.

For more information on diazophenols see: *Lowe-Ma, Ch., Robin, A.N.* and *William, S.W.*: Diazophenols – Their Structure and Explosive Properties, Naval Weapons Center, China Lake, CA 9355–6001; Rept.-Nr.: WC TP 6810 (1987).

Dibutyl Phthalate

Dibutylphthalat; *phthalate dibutylique*; *DBP*



colorless liquid
empirical formula: $C_{16}H_{22}O_4$
molecular weight: 278.4 g/mol
energy of formation: −696 kcal/kg = −2913 kJ/kg
enthalpy of formation: −723 kcal/kg = −3027 kJ/kg
oxygen balance: −224.2%
density: 1.045 g/cm^3
boiling point at 20 mmHg: 205 °C = 401 °F

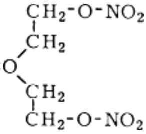
Dibutyl phthalate is insoluble in water, but is readily soluble in common organic solvents. It is used as a gelatinizer and to affect → *Surface Treatment* in gunpowder manufacturing. According to the → *REACH* regulation dibutyl phthalate is identified as a substance of very high concern with reproduction toxic properties. Therefore DBP is included in the Annex XIV of the REACH regulation and after a transitional period it can no longer be placed on the market or used by any manufacturer, importer or downstream user unless authorization has been granted.

Specifications

net content:	no less than 99% (analysis by saponification)
ashes:	not more than 0.02%
density:	1.044–1.054 g/cm^3
reaction in alcoholic solution:	neutral to phenolphthalein

Diethyleneglycol Dinitrate

Diglykoldinitrat, Dinitrodiglykol; *dinitrate de diéthylèneglycol, DEGN, DEGDN*



colorless oil
empirical formula: $C_4H_8N_2O_7$
molecular weight: 196.1 g/mol
energy of formation: −506.7 kcal/kg = −2120.0 kJ/kg
enthalpy of formation: −532.3 kcal/kg = −2227.3 kJ/kg
oxygen balance: −40.8%
nitrogen content: 14.29%
volume of explosion gases: 991 l/kg
heat of explosion
  (H_2O liq.): 1091 kcal/kg = 4566 kJ/kg
  (H_2O gas): 990 kcal/kg = 4141 kJ/kg
specific energy: 120.2 mt/kg = 1178 kJ/kg
density: 1.38 g/cm^3
refractive index: n_D^{25} = 1.4498
melting point:
  2 °C = 35.6 °F (stable modification)
  −10.9 °C = +12.4 °F (unstable modification)

vapor pressure:

Pressure (mbar)	Temperature (°C)	(°F)
0.0048	20	68
0.17	60	140

lead block test: 410 cm^3/10 g
detonation velocity, confined: 6600 m/s = 21 700 ft/s
at $\rho = 1.38$ g/cm^3
deflagration point: 190 °C = 374 °F
impact sensitivity: 0.01 kp m = 0.1 N m

This compound is miscible at ordinary temperatures with nitroglycerine, nitroglycol, ether, acetone, methanol, chloroform and benzene, and even with its precursor compound – the diglycol prior to nitration. It is not miscible with ethanol and is sparingly soluble in carbon tetrachloride. It has a low hygroscopicity and is sparingly soluble in water, but more soluble than nitroglycerin. Its vapors produce headaches, though these are not as strong as those produced by nitroglycol vapors.

Diethyleneglycol dinitrate, like nitroglycerine, is prepared by nitrating diethylene glycol with mixed acid in batches or continuously. The diglycol is produced by synthesis. Since the waste acid is unstable, special formulations of mixed acid must be employed, and the mixed acid must be denitrated at the end of the nitration stage.

Diglycol dinitrate was used extensively in the Second World War by the German side as one of the main components of → *Double-Base Propellants*. The explosion heat of diglycol in powder form can be kept lower than the heats of the corresponding nitroglycerine powders; they represented the first step towards the so-called cold powders. Diglycol dinitrate and triglycol dinitrate are also employed in double-base rocket propellants.

Specifications for diethyleneglycol as a nitration raw material

clear, colorless liquid	
density (20/4):	1.1157–1.1165 g/cm^3
reaction:	neutral
boiling analysis:	241 °C = 466 °F
beginning, fifth drop:	not below
distillation at:	246.5 °C = 475.5 °F
the end:	not above 250 °C = 482 °F

moisture:	not more than 0.5%
glow residue:	not more than 0.02%
acidity as H_2SO_4:	not more than 0.01%
chlorides:	traces only
saponification number:	not above 0.02%
reducing substance:	(test with ammoniacal solution of $AgNO_3$)
viscosity at 20 °C = 68 °F	35.7 cP

An additional specification was required in Germany:

content of (mono-)ethyleneglycol:	not more than 2%

determination: 4 cm^3 diethyleneglycol and 4 cm^3 NaOH solution (which contains NaOH 370 g/l) are mixed and cooled, and 2 cm^3 of copper sulfate solution (which contains $CuSO_4 \cdot 5H_2O$ 200 g/l) is added and shaken. The color is compared with the color obtained by standard mixtures of pure diethyleneglycol with 0.5, 1.5 and 2% ethyleneglycol after the same reaction.

Differential Thermal Analysis

Thermoanalyse; *analyse thermique différentielle*

All methods in which the sample to be analyzed is gradually heated and its calorimetric behavior studied. The method includes thermogravimetry (TG) and differential thermal analysis (DTA).

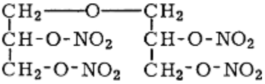
In thermogravimetry, the sample is placed in an oven and heated the desired rate; the loss in weight of the sample is then recorded. Such changes in weight can be due, for example, to the evaporation of hygroscopic moisture, evolution of gases, or chemical decomposition reactions. The thermal balance can also be applied in this manner to the study of thermal stability of explosive materials.

Thermal balance can also be combined with differential thermal analysis. DTA registers small temperature differences, which appear during simultaneous heating of the sample and a standard. In this way all physical and chemical processes, which are accompanied by an additional absorption or evolution of heat by the substance, are recorded. Examples of such processes are changes taking place in the crystal lattice, melting, evaporation, chemical reactions, and decompositions. Thus, the application of DTA gives more selective information about the behavior of explosive materials as a function of the temperature than does the determination of the → *Deflagration Point*.

See also: *Krien*, Explosivstoffe, Vol. 13, p. 205 (1965). An extensive report is given by Krien in an internal paper of the Bundesinstitut für Chemisch-Technische Untersuchungen: Thermoanalytische Ergebnisse der Untersuchung von Sprengstoffen, Az.: 3.0–3/3960/76 (1976).

Diglycerol Tetranitrate

Tetranitrodiglycerol, Tetranitrodiglycerin; *tetranitrate de diglycérine*



$$\begin{array}{lll} CH_2 & -O- & CH_2 \\ | & & | \\ CH{-}O{-}NO_2 & & CH{-}O{-}NO_2 \\ | & & | \\ CH_2{-}O{-}NO_2 & & CH_2{-}O{-}NO_2 \end{array}$$

yellow oil
empirical formula: $C_6H_{10}N_4O_{13}$
molecular weight: 346.2 g/mol
oxygen balance: −18.5%
nitrogen content: 16.18%
density: 1.52 g/cm^3
lead block test: 470 cm^3/10 g
impact sensitivity: 0.15 kp m = 1.5 N m

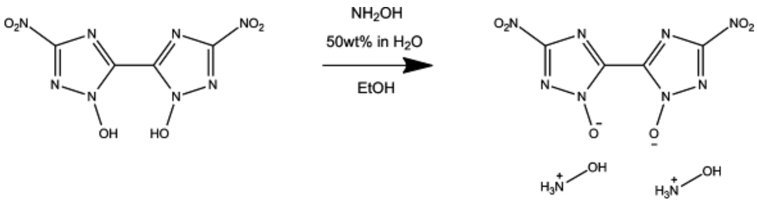
Pure tetranitrodiglycerol is a very viscous oil, which is nonhygroscopic, insoluble in water, and readily soluble in alcohol and ether. It has a lower explosive power than nitroglycerine, is less sensitive to impact, and its gelatinizing effect on nitrocellulose is not as satisfactory.

Prolonged heating of glycerol yields diglycerol and a small amount of other polyglycerols. If such mixtures of glycerol and diglycerol are nitrated, mixtures of nitroglycerol and tetranitroglycerol are obtained; they have a lower solidification temperature than pure nitroglycerine.

Tetranitrodiglycerol was used in the manufacture of nonfreezing dynamites when sufficient quantities of glycol from largescale industrial syntheses were not available.

Dihydroxylammonium-3,3′-dinitro-5,5′-bis(1,2,4-triazole)-1,1′-diolate

Dihydroxylammonium-3,3′-dinitro-5,5′-bis(1,2,4-triazole)-1,1′-diolat, MAD-X1



white crystyal
empirical formula: $C_4H_8N_{10}O_6$
molecular weight: 324.2 g/mol
energy of formation: +222 kJ/mol = 685 kJ/kg
density (25 ° C): 1.9 g/cm^3
deflagration point: 217 °C
detonation velocity: 8853 m/s at 1.8 g/cm^3 (P_{CJ}: 336 kbar)
impact sensitivity: $>$ 40 N m
friction sensitivity: $>$ 360 N
electrostatic sensitivity: 0.5 J

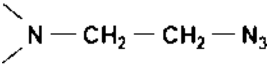
Dihydroxylammonium-3,3′-dinitro-5,5′-bis(1,2,4-triazole)-1,1′-diolate (**MAD-X1**) is a new high explosive belonging to the class of ionic high-nitrogen compounds. MAD-X1 is prepared by reaction of the corresponding diole compound with hydroxylamine.

Diluent

An additive, usually inert, used to regulate the burning rate or temperature.

2-Dimethylaminoethylazide

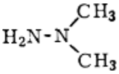
2-Dimethylaminoethylazid, DMAZ



2-Dimethylaminoethylazide (DMAZ) is of interest as a possible replacement for the bipropellant fuels monomethyl hydrazine (MMH) and dimethyl hydrazine (→ UDMH) which are highly toxic. DMAZ has been developed and is currently being produced by the company MACH I (PA). DMAZ is a covalent azide and shows hypergolic behavior with N_2O_4 and red fuming nitric acid.

Dimethylhydrazine, unsymmetrical

Dimethylhydrazin; *diméhylhydrazine*; *UDMH*



colorless liquid
empirical formula: $C_2H_8N_2$
molecular weight: 60.1 g/mol
energy of formation: +247 kcal/kg = +1035 kJ/kg

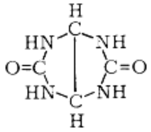
enthalpy of formation: +198 kcal/kg = +828 kJ/kg
density: 0.786 g/cm^3
melting point: −57.2 °C
boiling point: 62.3 °C

UDMH is used in liquid-fuel rockets.

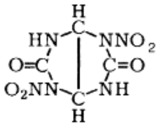
DINGU and Sorguyl 15)

dinitroglycolurile and tetranitroglycolurile; *glycolurile dinitramine et glycolurile tétranitramine*

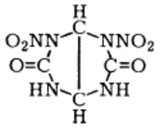
The reaction between glyoxal O=CH−CH=O and urea $H_2N-C=O-NH_2$ yields glycolurile with the structural formula



Dinitroglycoluril (DINGU) can be obtained by the nitration of glycouril using 100% nitric acid. DINGU is a member of the nitramine family of explosives and was first reported as far back as 1888.



or



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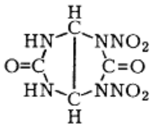


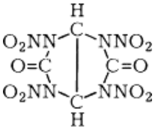
colorless crystals
empirical formula: $C_4H_4N_6O_6$
molecular weight: 232.1 g/mol
oxygen balance: −27.6%
nitrogen content: 36.21%
density: 1.94 g/cm^3
detonation velocity, confined: 7580 m/s = 24 900 ft/s
at ρ = 1.75 g/cm^3
misfire at maximum density
deflagration point: 225−250 °C = 437−482 °F
decomposition begins at 130 °C = 266 °F
impact sensitivity: 0.5−0.6 kp m = 5−6 N m
friction sensitivity: 20−30 kp = 20−300 N pistil load

---

15) DINGU and Sorguyl were developed by Société Nationale des Poudres et Explosivs, Sorgues, France.

The product is easily decomposed by alkaline hydrolysis. It is stable in contact with neutral or acid water. It is insoluble in most solvents and in molten TNT; it is soluble in dimethylsulfoxide (DMSO).

Nitration with a HNO_3-N_2O_5 mixture yields the tetranitramine Sorguyl:



colorless crystals
empirical formula: $C_4H_2N_8O_{10}$
molecular weight: 322.1 g/mol
oxygen balance: +5.0%
nitrogen content: 34.79%
density: 2.01 g/cm^3
detonation velocity, confined: 9150 m/s = 30 000ft/s
at $\rho = 1.95$ g/cm^3
deflagration point: 237 °C = 459 °F
impact sensitivity: 0.15–0.2 kp m = 1.5–2 N m

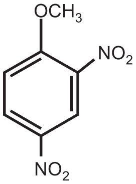
The product is interesting because of its high density and also high detonation velocity.

Sorguyl is not hygroscopic, but it decomposes easily by hydrolysis. It is insoluble in hydrocarbons and chlorinated hydrocarbons, but soluble in numerous solvents. DINGU and Sorguyl may be of interest as self-remediating energetic materials since they both show a higher hydrolytic activity.

It decomposes when mixed with molten → *TNT*.

2,4-Dinitroanisole

2,4-Dinitroanisol; *2,4-Dinitroanisole*; *DNAN*



pale yellow needles
empirical formula: $C_7H_6N_2O_5$
molecular weight: 198.1 g/mol
oxygen balance: −96.9%
energy of formation: −170.54 kJ/mol = −860.73 kJ/kg

enthalpy of formation: −186.65 kJ/mol = −942.03 kJ/kg
density: 1.546 g/cm^3
melting point: 94.5 °C
boiling point: 206 °C
friction sensitivity: $>$ 360 N
impact sensitivity: $>$ 50 N m

DNAN is a flammable solid, used as TNT replacement in melt-cast formulations. It is known since the Second World War (Amatol 40), but has raised new interest in recent years, as new compositions have been formulated on the basis of DNAN, such as the IMX or PAX family.

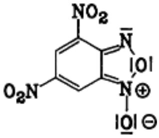
Review on melt-cast explosives, Ravi, P., Badgujar, D.M., Gore, G.M., Tewari, S.P., and Sikder, A.K. (2011) *Propellants Explos. Pyrotech.*, **36** (5), 393–403.

Dinitrobenzene

→ Metadinitrobenzene

4,6-Dinitrobenzofuroxan

4,6-Dinitrobenzfuroxan; *4,6-dinitrobenzofurazan-1-oxide*; *dinitro-dinitrosobenzene*



yellow-gold needles
empirical formula: $C_6H_2N_4O_6$
molecular weight: 226.1 g/mol
oxygen balance: −49.5%
nitrogen content: 24.78%
melting point: 172 °C
density: 1.79 g/cm^3

Dinitrobenzofuroxan is practically insoluble in water, alcohol and benzene. It is readily soluble in aromatic hydrocarbons and boiling acetic acid.

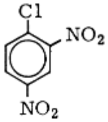
The compound is obtained by means of directly nitrating benzofurazan-1-oxide with concentrated nitric and sulfuric acid, or by heating → *Trinitrochlorbenzene* (*Picrylchloride*) with sodium azide in acetic acid in a water bath.

Dinitrobenzofuroxan has a somewhat more explosive power than *Picric Acid*, but due to its slightly acidic properties and its relatively high production cost it has yet to become widely used.

Of particular interest are the potassium and barium salts, both of which are thermally very stable and low → *Initiating Explosive* materials. In the categories of impact and friction sensitivity, the potassium-dinitrobenzofuroxan (KDNBF) falls between → *Mercury Fulminate* and → *Lead Azide*. It has been used mainly in the USA in explosive-initiating compositions for both military and commercial applications since the early 1950s.

Dinitrochlorobenzene

1,2,4-Chlordinitrobenzol; *dinitrochlorbenzène*



pale yellow crystals
empirical formula: $C_6H_3N_2O_4Cl$
molecular weight: 202.6 g/mol
energy of formation: −13.8 kcal/kg = −57.8 kJ/kg
enthalpy of formation: −28.6 kcal/kg = −120 kJ/kg
oxygen balance: −71.1%
nitrogen content: 13.83%
density: 1.697 g/cm^3
boiling point: 315 °C = 599 °F
solidification point: 43 °C = 109 °F (isomer mixture)
lead block test: 225 cm^3/10 g
deflagration point: evaporation without deflagration
impact sensitivity: up to 5 kp m = 50 N m no reaction
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: at 1 mm ∅ no reaction

Dinitrochlorobenzene is insoluble in water, but is soluble in hot ethanol, ether and benzene.

It is prepared by nitration of chlorobenzene, which yields a mixture of the 2,4- and the 2,6-isomers, with melting points of 53.4 °C (127.5 °F) and 87–88 °C (190–192 °F), respectively.

Dinitrochlorobenzene is not an explosive. It serves as an intermediate in many syntheses (→ *Hexanitrodiphenylamine*; → *Trinitrochlorobenzene*; → *Trinitroaniline*; etc.).

Dinitrodiazaalkanes (-pentane; -hexane; -heptane)

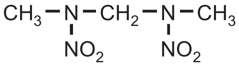
DNDA-57

empirical formula: $C_{36}H_{92}N_{40}O_{40}$
molecular weight: 1725.37 g/mol
oxygen balance: −72.33%
energy of formation: −363.09 kJ/mol = −210.44 kJ/kg
enthalpy of formation: −576.14 kJ/mol = −333.92 kJ/kg
density: 1.345 g/cm^3
melting point: −7−(−10) °C

DNDA-57 is a mixture of DNDA-5, -6, and -7. It is used as energetic plasticizer in propellant formulations. In seminitramine formulations with DNDA-57 a nearly temperature-independent burning behavior of the propellant can be reached.

2,4-Dinitro-2,4-diazapentane

2,4-Dinitro-2,4-diazapentan; *2,4-dinitro-2,4-diazapentane*; *DNDA-5*

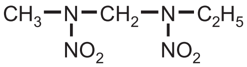


$CH_3-\underset{NO_2}{\underset{|}{N}}-CH_2-\underset{NO_2}{\underset{|}{N}}-CH_3$

empirical formula: $C_3H_8N_4O_4$
molecular weight: 164.121 g/mol
oxygen balance: −58.49%
energy of formation: −31.76 kJ/mol = −193.52 kJ/kg
enthalpy of formation: −51.59 kJ/mol = −314.33 kJ/kg
density: 1.389 g/cm^3
melting point: 54 °C

2,4-Dinitro-2,4-diazahexane

2,4-Dinitro-2,4-diazahexan; *2,4-dinitro-2,4-diazahexane*; *DNDA-6*

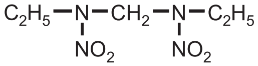


$CH_3-\underset{NO_2}{\underset{|}{N}}-CH_2-\underset{NO_2}{\underset{|}{N}}-C_2H_5$

empirical formula: $C_4H_{10}N_4O_4$
molecular weight: 178.148 g/mol
oxygen balance: −80.83%
energy of formation: −57.20 kJ/mol = −321.08 kJ/kg
enthalpy of formation: −79.5 kJ/mol = −446.24 kJ/kg
melting point: 33 °C

3,5-Dinitro-3,5-diazaheptane

3,5-Dinitro-3,5-diazapentan; *3,5-dinitro-3,5-diazapentane*; *DNDA-7*

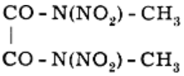


$$\underset{NO_2}{C_2H_5-\underset{|}{N}}-CH_2-\underset{NO_2}{\underset{|}{N}}-C_2H_5$$

empirical formula: $C_5H_{12}N_4O_4$
molecular weight: 192.175 g/mol
oxygen balance: −99.91%
energy of formation: −110.33 kJ/mol = −574.11 kJ/kg
enthalpy of formation: −135.1 kJ/mol = −703.01 kJ/kg
melting point: 75 °C = 167 °F

Dinitrodimethyloxamide

Dinitrodimethyloxamid; *dinitrodiméthyloxamide*



$$\begin{array}{l} CO-N(NO_2)-CH_3 \\ | \\ CO-N(NO_2)-CH_3 \end{array}$$

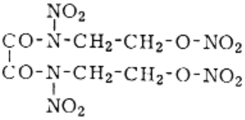
colorless needles
empirical formula: $C_4H_6N_4O_6$
molecular weight: 206.1 g/mol
energy of formation: −331.2 kcal/kg = −1385.8 kJ/kg
enthalpy of formation: −354.2 kcal/kg = −1482.0 kJ/kg
oxygen balance: −38.8%
nitrogen content: 27.19%
density: 1.523 g/cm^3
lead block test: 360 cm^3/10 g
detonation velocity, confined: 7100 m/s = 23 300 ft/s
  at $\rho = 1.48$ g/cm^3
impact sensitivity: 0.6 kp m = 6 N m

The compound is insoluble in water, sparingly soluble in ether and chloroform and soluble in acetone. It is chemically stable.

It is prepared by nitration of dimethyloxamide with a sulfuric acid and nitric acid mixture.

Dinitrodioxyethyloxamide Dinitrate

Dinitrodioxiethyloxamiddinitrat, Dinitrodiethanoloxamiddinitrat, Neno; dinitrate de dioxyéthyl-dinitroxamide; N,N′-dinitro-N,N′-bis(2-hydroxyethyl)-oxamide dinitrate



$$\begin{array}{l} \quad\ NO_2 \\ \quad\ \ | \\ CO-N-CH_2-CH_2-O-NO_2 \\ | \\ CO-N-CH_2-CH_2-O-NO_2 \\ \quad\ \ | \\ \quad\ NO_2 \end{array}$$

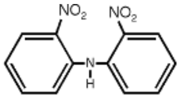
colorless flakes
empirical formula: $C_6H_8N_6O_{12}$

molecular weight: 356.2 g/mol
energy of formation: −355.5 kcal/kg = −1487.2 kJ/kg
enthalpy of formation: −377.1 kcal/kg = −1577.7 kJ/kg
oxygen balance: −18.0%
nitrogen content: 23.60%
melting point: 88 °C = 190 °F
density: 1.72 g/cm^3

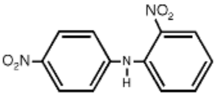
This compound is readily soluble in acetone and in hot alcohol, and is insoluble in cold water. It is prepared by nitration of diethanoloxamide, the latter being prepared by condensation of monoethanolamine with oxalic acid.

Dinitrodiphenylamine

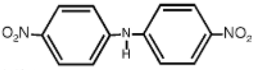
Dinitrodiphenylamin; *dinitrodiphénylamine*



2,2′-Dinitrodiphenylamine



2,4′-Dinitrodiphenylamine



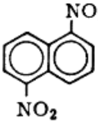
4,4′-Dinitrodiphenylamine

red crystals
empirical formula: $C_{12}H_9N_3O_4$
molecular weight: 259.2 g/mol
energy of formation: +39.4 kcal/kg = +165 kJ/kg
enthalpy of formation: +21.1 kcal/kg = +88.3 kJ/kg
oxygen balance: −151.2%
nitrogen content: 16.22%
density: 1.42 g/cm^3
melting point
  2,2′-isomer: 173 °C
  2,4-isomer: 220 °C
  2,4′-isomer: 156–167 °C
  2,6-isomer: 107 °C
  4,4′-isomer: 217–218 °C

Dinitrondiphenylamine is formed in nitrocellulose propellants stabilized by diphenylamine (→ *Stability*).

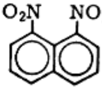
Dinitronaphthalene

1,5-; 1,8-Dinitronaphthalin; *dinitronaphthalène*; *Dinal*



1,5-

and



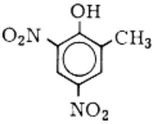
1,8-

grey yellow powder
empirical formula: $C_{10}H_6N_2O_4$
molecular weight: 218.2 g/mol
energy of formation:
  1,5-isomer: +49.7 kcal/kg = +208.1 kJ/kg
  1,8-isomer: +57.5 kcal/kg = +240.7 kJ/kg
enthalpy of formation:
  1,5-isomer: +33.5 kcal/kg = +140.0 kJ/kg
  1,8-isomer: +41.25 kcal/kg = +172.6 kJ/kg
oxygen balance: −139.4%
nitrogen content: 12.84%
volume of explosion gases: 488 l/kg
heat of explosion (H_2O liq.):
  1,5-isomer: 725 kcal/kg = 3031 kJ/kg
  1,8-isomer: 732 kcal/kg = 3064 kJ/kg
specific energy: 58 mt/kg = 569 kJ/kg
melting point:
  1,5-isomer: 216 °C = 421 °F
  1,8-isomer: 170 °C = 338 °F
deflagration point: 318 °C = 605 °F

This material is prepared by a two-step nitration of naphthalene with nitric acid. The commercial product, which is a mixture of isomers, melts above 140 °C = 276 °F. It is readily soluble in benzene, xylene, and acetone and is sparingly soluble in alcohol and ether. It has been used in French explosive mixtures (schneiderites) as fuel mixed with ammonium nitrate.

Dinitroorthocresol

Dinitro-o-kresol; *dinitroorthocrésol*

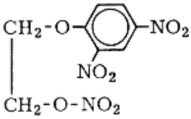


yellow crystals
empirical formula: $C_7H_6N_2O_5$
molecular weight: 198.1 g/mol
energy of formation: −221.8 kcal/kg = −928.1 kJ/kg
enthalpy of formation: −241.3 kcal/kg = −1009.4 kJ/kg
oxygen balance: −96.9%
nitrogen content: 14.51%
volume of explosion gases: 832 l/kg
heat of explosion (H_2O liq.): 724 kcal/kg = 3027 kJ/kg
specific energy: 70.5 mt/kg = 691 kJ/kg
density: 1.486 g/cm^3
melting point: 86 °C = 187 °F
impact sensitivity: up to 5 kp m = 50 N m no reaction
friction sensitivity: up to 36 kp = 353 N pistil load no reaction

o-Dinitrocresol is prepared by introducing *o*-nitrophenylglycerylether into mixed acid at 25–30 °C = 77–85 °F. It is insoluble in water and readily soluble in acetone; it is a poor gelatinizer of nitrocellulose.

Dinitrophenoxyethylnitrate

Dinitrophenylglykolethernitrat; *nitrate de 2,4-dinitrophénoxyéthyle*



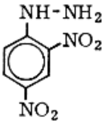
pale yellow crystals
empirical formula: $C_8H_7N_3O_8$
molecular weight: 273.2 g/mol
energy of formation: −236.8 kcal/kg = −990.6 kJ/kg
enthalpy of formation: −256.3 kcal/kg = −1072.2 kJ/kg
oxygen balance: −67.4%
nitrogen content: 15.38%
density: 1.60 g/cm^3
solidification point: 64 °C = 147 °F
lead block test: 280 cm^3/10 g
detonation velocity, confined: 6800 m/s = 22 300 ft/s
at $\rho = 1.58$ g/cm^3
deflagration point: over 300 °C = 570 °F
impact sensitivity: 2 kp m = 20 N m

The compound is insoluble in water, but soluble in acetone and toluene. It is prepared by dissolving phenyl glycol ether in sulfuric acid and pouring the reaction mixture into mixed acid at 10–20 °C (50–68 °F).

It is a nitrocellulose gelatinizer.

Dinitrophenylhydrazine

Dinitrophenylhydrazin



empirical formula: $C_6H_6N_4O_4$
molecular weight: 198.1 g/mol
energy of formation: +81.2 kcal/kg = +339.6 kJ/kg
enthalpy of formation: +60.3 kcal/kg = +252.1 kJ/kg
oxygen balance: −88.8%
nitrogen content: 28.28%

According to the studies performed by the Bundesanstalt für Materialprüfung (BAM), Germany, this compound may explode when dry, but in the presence of 20% water there is no longer any danger of explosion. It is widely used in analytical organic chemistry for the preparation of dinitrophenylhydrazone and its derivatives from ketones and aldehydes.

Dinitrosobenzene

Dinitrosobenzol; *dinitrosobenzène*

empirical formula: $C_6H_4N_2O_2$
molecular weight: 136.1 g/mol
oxygen balance: −141%
nitrogen content: 20.58%
melting point: decomposition
lead block test: 138 cm^3/10 g
deflagration point: 178–180 °C = 352–355 °F
impact sensitivity: 1.5 kp m = 15 N m
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 2 mm

This substance is explosive despite its low oxygen content. It will explode in a 1-in steel pipe if actuated by a primer.

4,10-Dinitro-2,6,8,12-tetraoxa-4,10-diazaisowurtzitane

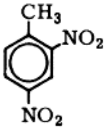
4,10-Dinitro-2,6,8,12-tetraoxa-4,10-diazaisowurtzitan; *TEX*

white crystals
empirical formula: $C_6H_6N_4O_8$
molecular weight: 262.1 g/mol
enthalpy of formation: −541 kJ/mol = −2064 kJ/kg
density: 2.008 g/cm^3
decomposition point: 285–304 °C
detonation velocity: 8180 m/s at 1.9 g/cm^3
(*P*$_{CJ}$ at 1.9 g/cm^3 : 294 kbar
impact sensitivity: 15–19 N m
friction sensitivity: > 360 N
electrostatic sensitivity: 0.08 J

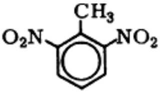
TEX is a very insensitive high explosive which was first described by Ramakrishnan and coworkers in 1990. TEX has a structure that is closely related to that of → Hexanitrohexaazaisowurtzitane, and has one of the highest densities of all nitramines (2.008 g/cm^3).

Dinitrotoluene

Dinitrotoluol; *dinitrotoluène*; *DNT*



2,4-isomer



2,6-isomer

yellow needles
empirical formula: $C_7H_6N_2O_4$
molecular weight: 182.1 g/mol
energy of formation:
2,4-isomer: −70.0 kcal/kg = −292.8 kJ/kg
2,6-isomer: −38.1 kcal/kg = 159.5 kJ/kg
enthalpy of formation:
2,4-isomer: −89.5 kcal/kg = −374.7 kJ/kg
2,6-isomer: −57.6 kcal/kg = −241.2 kJ/kg
oxygen balance: −114.4%
nitrogen content: 15.38%

volume of explosion gases: 807 l/kg
heat of explosion
2,4-isomer, (H_2O liq.): 763 kcal/kg = 3192 kJ/kg
(H_2O gas): 729 kcal/kg = 3050 kJ/kg
2,6-isomer, (H_2O liq.): 795 kcal/kg = 3325 kJ/kg
(H_2O gas): 761 kcal/kg = 3183 kJ/kg
specific energy: 70 mt/kg = 687 kJ/kg
density
2,4-isomer: 1.521 g/cm^3
2,6-isomer: 1.538 g/cm^3
melting point
pure 2,4-isomer: 70.5 °C = 159 °F
natural isomer mixture: about 35 °C = 95 °F
vapor pressure of the 2,4-isomer:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
0.014	35	95
0.11	70	158 (melting point)
0.83	100	212
8.5	150	302
50.5	200	392
223	250	482
300	300	572

heat of fusion
2,4-isomer: 26.1 kcal/kg = 109 kJ/kg
2,6-isomer: 22.5 kcal/kg = 94 kJ/kg
lead block test: 240 cm^3/10 g
deflagration point: ignition at 360 °C = 680 °F
impact sensitivity: up to 5 kp m = 50 N m no reaction
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter steel sleeve test: 1 mm

Dinitrotoluene is sparingly soluble in water, alcohol and ether, but readily soluble in acetone and benzene. It is formed as an intermediate in → *TNT* Synthesis.

The product, which is obtained as a low-melting mixture of six isomers, is an important component in the manufacture of both gelatinous and powdery commercial explosives. Owing to its negative oxygen balance, it also serves as a carbon carrier. It is readily miscible with nitroglycerine and gelatinizes soluble guncotton.

A purer product, consisting mainly of the 2,4-isomer, is also employed as a component of gunpowder.

Table 9 Data for the other DNT isomers.

Dinitrotoluene isomer	**Density (g/cm^3)**	**Melting point**		**Energy of formation**		**Enthalpy of formation**	
		(°C)	**(°F)**	**(kcal/kg)**	**(kJ/kg)**	**(kcal/kg)**	**(kJ/kg)**
2,3-	1.2625	59.5	139	−1.1	−4.6	−20.9	−87.5
2,5-	1.2820	50.5	123	−25.3	−106	−45.0	−188
3,4-	1.2594	59.5	139	0	0	−19.2	−80.4
3,5-	1.2772	93	199.5	−37.3	−156	−57.1	−239

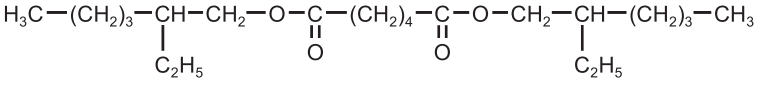
According to the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation, dinitrotoluol is identified as a substance of very high concern with carcinogenic properties. Therefore DNT is included in annex XIV of the REACH regulation and, after a transitional period, it can no longer be placed on the market or used by any manufacturer, importer or downstream user unless an authorization has been granted.

Specifications

moisture:	not more than 0.25%
benzene insolubles:	not more than 0.10%
acidity as H_2SO_4:	not more than 0.02%
tetranitromethane:	none
solidification point gunpowder grade:	68.0 ± 2.5 °C (154 °F)
for industrial explosives:	as low as possible

Dioctyl Adipate

DOA



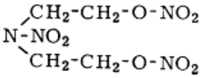
$$H_3C-(CH_2)_3-\underset{\displaystyle C_2H_5}{\underset{|}{CH}}-CH_2-O-\underset{\displaystyle O}{\underset{\|}{C}}-(CH_2)_4-\underset{\displaystyle O}{\underset{\|}{C}}-O-CH_2-\underset{\displaystyle C_2H_5}{\underset{|}{CH}}-(CH_2)_3-CH_3$$

liquid
empirical formula: $C_{22}H_{42}O_4$
molecular weight: 370.57 g/mol
oxygen balance: −263.37%
energy of formation: −1158.05 kJ/mol
enthalpy of formation: −1215.03 kJ/mol = −3278.8 kJ/kg
density: 0.925 g/cm^3
melting point: −67.8 °C
boiling point: 417 °C

DOA is an inert plasticizer used in gun propellants.

Dioxyethylnitramine Dinitrate

Nitrodiethanolamindinitrat; *dinitrate de dioxydthylnitramine*; *DINA*



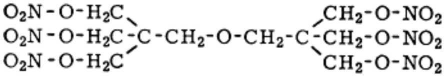
colorless crystals
empirical formula: $C_4H_8N_4O_8$
molecular weight: 240.1 g/mol
energy of formation: −249.8 kcal/kg = −1045.1 kJ/kg
enthalpy of formation: −274.4 kcal/kg = −1148.2 kJ/kg
oxygen balance: −26.6%
nitrogen content: 23.34%
volume of explosion gases: 924 l/kg
heat of explosion
  (H_2O liq.): 1304 kcal/kg = 5458 kJ/kg
  (H_2O gas): 1201 kcal/kg = 5025 kJ/kg
specific energy: 133 mt/kg = 1306 kJ/kg
density: 1.488 g/cm^3
melting point: 51.3 °C = 124.3 °F
detonation velocity, confined: 7580 m/s = 25 000 ft/s
  at $\rho = 1.47$ g/cm^3
impact sensitivity: 0.6 kp m = 6 N m

This compound is prepared from diethanolamine and nitric acid with acetic anhydride as a dehydrating agent and in the presence of hydrochloric acid as a catalyst. The nitration product is stabilized by boiling in water, followed by dissolution in acetone and reprecipitation with water.

It is a satisfactory gelatinizer for nitrocellulose and is a powerful explosive, comparable to hexogen and PETN. Double-base propellants based on DINA instead of nitroglycerine are called Albanites.

Dipentaerythritol Hexanitrate

Hexanitrodipentaerythrit; *hexanitrate de dipentaérythrite*; *DIPEHN*



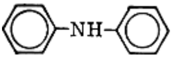
colorless crystals
empirical formula: $C_{10}H_{16}N_6O_{19}$
molecular weight: 524.2 g/mol
energy of formation: −424.2 kcal/kg = −1771 kJ/kg
enthalpy of formation: −446 kcal/kg = −1867 kJ/kg
oxygen balance: −27.5%

nitrogen content: 16.03%
volume of explosion gases: 878 l/kg
heat of explosion
  (H_2O liq.): 1229 kcal/kg = 5143 kJ/kg
  (H_2O gas): 1133 kcal/kg = 4740 kJ/kg
specific energy: 125 mt/kg = 1223 kJ/kg
density: 1.63 g/cm^3
melting point: 72 °C = 162 °F
detonation velocity, confined: 7400 m/s = 24 300 ft/s
  at $\rho = 1.6$ g/cm^3
deflagration point: 200 °C = 392 °F
impact sensitivity: 0.4 kp m = 4 N m

The compound is soluble in acetone, but insoluble in water. When technical grade pentaerythritol is nitrated, a certain amount of dipentaerythritol hexanitrate is formed as a by-product.

Diphenylamine

Diphenylamin; *diphénylamine*



colorless crystals
empirical formula: $C_{12}H_{11}N$
molecular weight: 169.2 g/mol
energy of formation: +204.6 kcal/kg = +856.0 kJ/kg
enthalpy of formation: +183.6 kcal/kg = +768.2 kJ/kg
oxygen balance: −278.9%
nitrogen content: 8.28%
density: 1.16 g/cm^3
melting point: 54 °C = 129 °F
boiling point: 302 °C = 576 °F

Diphenylamine is sparingly soluble in water, but is readily soluble in alcohol and acids. It may be used as reagent for nitric acid and nitrates. Its use as a → *Stabilizer* is particularly important.

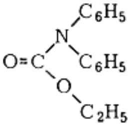
Specifications

solidification point:	51.7–53 °C = 125–127.4 °F
insolubles in benzene:	not more than 0.02%
moisture:	not more than 0.2%
solution in ether-alcohol:	clear

ashes:	not more than 0.05%
aniline:	not more than 0.1%
acidity, as HCl:	not more than 0.005%
alkalinity, as NaOH:	not more than 0.005%

Diphenylurethane

Diphenylurethan; *diphénylurethane*



empirical formula: $C_{15}H_{15}NO_2$
molecular weight: 241.3 g/mol
energy of formation: −256.0 kcal/kg = −1071.1 kJ/kg
enthalpy of formation: −278.1 kcal/kg = −1163.5 kJ/kg
oxygen balance: −235.4%
nitrogen content: 5.81%
melting point: 72 °C

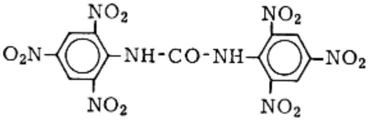
Diphenylurethane is used as a gunpowder stabilizer and gelatinizer.

Specifications

snow-white powder	
solidification point:	not less than 70 °C = 158 °F
melt:	clear, colorless
volatiles:	not more than 0.1%
ashes:	not more than 0.1%
insolubles in ether:	none
chlorides, as NaCl:	not more than 0.02%
reaction:	neutral
acidity, 0.1 N NaOH/100 g:	not more than 0.1 cm^3

Dipicrylurea

Hexanitrocarbanilid; *dipicrylurée*



pale yellow crystals
empirical formula: $C_{13}H_6N_8O_{13}$

molecular weight: 482.2 g/mol
oxygen balance: −53.2%
nitrogen content: 23.24%
melting point: 208−209 °C = 406−408 °F
deflagration point: 345 °C = 655 °F

Dipicrylurea is prepared by nitration of carbanilide in one or more stages.

Dismantling of Explosive Objects, Especially Ammunition

A principal distinction must be made between two kinds of ammunition: ammunition of known origin, which has been properly stored and which has to be separated out for routine reasons such as aging or replacement by other types of ammunition; and ammunition found lying around or acquired as booty. The latter kind of ammunition may have been exposed to strong corrosive agents, and its delayed-action fuses may no longer be controllable. Handling abandoned ammunition is one of the most dangerous tasks in explosive handling and must be left to top experts in this field (familiarity with the regulations concerning explosive substances is not enough). This includes the first attempt to move the ammunition while still *in situ*. A detailed discussion of the deactivation of abandoned ammunition is beyond the scope of this book.

Explosive objects are classified according to the potential danger they present. The criteria of such a classification include the nature of the explosive object, whether or not it contains detonators or primers, and whether or not it presents a → *Mass Explosion Risk*. Dangerous mechanical tasks, such as unscrewing the detonators or sawing them off, cutting, milling or sawing, must be performed under remote control.

Fusible explosives such as TNT and TNT mixtures may be melted out of their containers (grenades, bombs, mines) after removal of detonators and booster charges. The material thus obtained may be purified and re-used for nonmilitary purposes.

Case-bonded → *Composite Propellants* are unloaded from their casing by a remote-controlled lathe or water gun.

See also → *Case Bonding*

See also → *Destruction of Explosive Materials*

Ditching Dynamite

A mixed dynamite, containing about 50% nongelatinized nitroglycerine, used for ditch blasting. This explosive displays a particularly strong tendency to flash over. Usually only the first charge is initiated by the cap. The following charges for the excavation of the ditch are exploded by the shock wave of the first detonation. See also → *Detonation*

See also → Detonation, 4. Sympathetic Detonation

Dithekite

A US trade name for an explosive liquid mixture of nitric acid, nitrobenzene and water.

Donor Charge

Geberladung; *charge excitatrice*

An exploding charge producing an impulse that impinges upon an explosive acceptor charge.

Double-Base Propellants

nitroglycerine powders; *poudres a base de la nitroglycérine*

This term denotes propellants containing two main components: nitrocellulose, and nitroglycerine or other liquid nitrate esters. Double-base propellants are also important for solid rocket applications.

Double-base compositions can be manufactured without the application of organic solvents by heated rolling and pressing of → *Paste*.

Drop Hammer

Fallhammer; *mouton de choc*

Drop hammer instruments are used to determine the → *Impact Sensitivity* of explosives.

Drop Test

See also → *Bomb Drop Test*

Dutch Test

Holland Test

A method developed in 1927 by the Dutchman Thomas for the determination of the chemical stability of propellants. The parameter determined is the weight loss that takes place after 72 h of heating at 105 °C (221 °F) for multibase propellants, or at 110 °C (230 °F) for single-base propellants. This loss, after subtracting the loss occurring after the first 8 h of heating, must not exceed 2%.

An advantage of this test is that not only nitrogen oxides, but also all the other decomposition products of the propellants – in particular CO_2

and N_2 – are determined by it. In order to work under reproducible experimental conditions, precision-stoppered tubes of an identical type, equipped with calibrated capillaries, are employed.

Since the heating temperature is high, especially for multi-base powders, Siebert proposed determining the weight loss at a lower temperature and not limiting the duration of heating, but to continue it until some auto-catalytic or other decomposition becomes apparent. This test, which should be carried out at 90, 75 and 65 °C may also be employed to indicate the loss of stability in storage (otherwise known as shelf life) of a propellant.

Dwell Time

In press loading of powders into cavities, the dwell time is the interval of time that the powder is held at the full loading pressure.

Dynamite LVD; MVD

Compositions for defined detonation velocities:

LVD (low-velocity dynamite):	
RDX	17.5%
TNT	67.8%
PETRIN	8.6%
binder (Vistac and DOS)	4.1%
acetyl cellulose	2.0%
MVD (medium-velocity dynamite):	
RDX	75%
TNT	15%
starch	5%
oil	4%
Vistanex oil gel	1%

Dynamites

Dynamite was the first trade name for a commercial explosive invented by Alfred Nobel; it was nitroglycerine absorbed in kieselguhr (guhr dynamite). Bonding of nitroglycerine by gelatinization with nitrocellulose was discovered by Nobel at a later date.

At first, active absorbents such as a mixture of sodium nitrate with wood dust were employed instead of the inert kieselguhr. The result was the development of nitroglycerine-sensitized powdery explosives, which are still known as dynamites in English-speaking countries. (See also → *Ditching Dynamite*)

Variations in the concentration of gelatinized nitroglycerine (the concentrated product is known as blasting gelatin) by the addition of sodium nitrate and wood dust or cereal meal yielded gel dynamites, which are known as gelignites in English-speaking countries; in Germany, the old designation of dynamite has been retained. In the meantime, they have been replaced by ammonium-nitrate-based Ammongelit. These products contain nitroglycol rather than nitroglycerine, with improvement in the safety of handling and transportation.

Dynamites are no longer manufactured in Germany.

Ednatol

A cast explosive charge employed in the USA. It consists of a mixture of → *Ethylenedinitramine* and TNT in the ratio of 55 : 45.

casting density:	1.62 g/cm^3
detonation velocity at casting density, confined:	7300 m/s = 23 900 ft/s

EED

Electro-explosive device; *elektrischer Zünder*

Any detonator or initiator initiated by an electric current.

A 1-A/1-W initiator is an EED that will not fire when one ampere of current at one watt of power is supplied to a bridgewire for a specified time.

Emulsion Slurries

Emulsion Explosives

Emulsion slurries *(see also → Slurries*) are based on a water-in-oil emulsion that is formed from a saturated nitrate solution and a mineral oil phase. Additions controlling the density (through the formation of gas bubbles or → *Microballoons*) are used to achieve a density that can be adjusted within an range between primer sensitivity (booster charge) and cap sensitivity.

The density is slightly higher when compared with water gels and results in higher performance; explosion temperature and detonation pressure are higher. There is a positive oxygen balance. Due to the fact that the mixture is substantially more intimate, there are differences in detonation kinetics compared to water gels. The blasting efficiency is higher, particularly in hard rock.

Emulsion slurries can be applied using mobile pumping and mixing devices (in large hole blasting), as well as in the form of cartridges of varying length and diameter. In cartridge form, the emulsion slurries replace the classic nitroglycerine-nitroglycol-based gelatinous explosives (see also → bulk explosives).

End of Burning

Brennschluss; *fin de combustion*

The moment at which emission of the gas jet by a rocket ends. In solid propellant rockets this moment corresponds to a complete burnout of the propellant; in liquid-fuel and hybrid rockets, reignition can take place.

End Burning Velocity

Brennschlussgeschwindigkeit; *vitesse en fin de combustion*

Velocity attained by a rocket at the moment at which combustion ceases. It is a function of the → *Gas Jet Velocity*, the → *Mass Ratio* and the burning time.

Endothermal

Reaction that occurs with the absorption of heat (opposite of → *Exothermal*).

Energetic Binders

Energetische Binder, Aktive Binder; *active binders*

In the realm of modern, nitric-ester-free → *LOVA Gun Propellants*, the widely used inert binders consume energy and to some extent have an undesirably high overall phlegmatizing effect on the explosive material. The high filler content of an explosive substance has a detrimental effect on the mechanical strength of this type of propellant.

An active binder would be a preferable alternative if it combined a high energy content with favorable mechanical properties, together with a thermal stability higher than that of → *Nitrocellulose* or of → *Polyvinylnitrate* while remaining relatively uncomplicated to process.

At present, the difficult task of developing such improved active binders has yielded only two usable compositions:

1. → *Polynitropolyphenylene*, a noncrystalline explosive material that withstands high temperatures. This polymer is a gelatinous type of binder and is combined with small amounts of softeners, inert binders and → *Hexogen* or → *Octogen*. By means of organic solvents, it is processed into the corresponding LOVA composition.

2. → *Glycidyl Azide Polymer (GAP)*; a gas-producing glycerin derivate. The glycidyl azide polymer belongs to the group of reactive polymers (thermoset materials) and is processed together with a main energy conductor, small amounts of softener, inert binders, curing agents and, where necessary, accelerating agents. → *PolyNIMMO* is an alternative binder to GAP with a better oxygen balance. → *PolyGlyn* is an alternative binder to GAP with a higher energy content.

See also → Energetic Thermoplastic Elastomers (ETPE)

Energy of Formation; Enthalpy of Formation

Bildungsenergie, Bildungsenthalpie; *chaleur de formation*

These thermodynamic concepts denote the energy that is bound during the formation of a given compound from its constituent elements at constant volume (energy of formation) or at constant pressure (enthalpy of formation, which includes the mechanical work performed at the standard state of 25 °C (77 °F) and a pressure of 1 bar. The data are tabulated in accordance with thermodynamic convention: if the formation of a compound from its elements is accompanied by a release of energy, the energy of formation is considered to be negative.

The knowledge of the energies of formation of an explosive or an inflammable mixture on one hand, and of the energies of formation of the presumed reaction products on the other, makes it possible to calculate the → *Heat of Explosion* (see also → *Thermodynamic Calculation of Decomposition Reactions*). The values for selected components of explosives and propellants are given in Table 28. An extensive collection of tabulated data for energies and enthalpies of formation, including source references, was published by the Fraunhofer Institut für Chemische Technologie (ICT), Berghausen, 1972. These values were incorporated into the ICT-Database of Thermochemical Values, which includes data from more than 14 000 substances. The database is available from the Fraunhofer ICT.

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Environmental Seal

Schutzmembran; *diaphragme de protection*

Diaphragm having very low moisture vapor transmission rate, used over generator outlets to provide a hermetic seal.

Eprouvette

An instrument to determine the performance of → *Black Powders*. It is a small mortar, positioned vertically upwards. A known amount (10 g) of the black powder sample is charged and set off with the aid of a fuse passing through a priming hole. The mortar is closed with a projectile guided upwards by two steel rods. The projectile gains its maximum height and is then locked. The height of the locked projectile is determined. This is a measure of the performance of the black powder sample.

Equation of State

Zustandsgleichung; *l'équation d'état*; *EOS*

The internal ballistic pressure resulting from an explosion of a powder propellant can reach up to 600 MPa and a temperature of up to 4000 K. Under such conditions of extreme pressure and temperature, the calculation of thermodynamic data is possible only using a suitable equation of state, whereby pressure (P), temperature (T), the density of Gas (ρ) and the specific number of moles (n_s) are associated.

For internal ballistics one ordinarily uses a truncated virial equation, which breaks off after the third term and is in the form:

$$P = n_s \cdot R \cdot T \cdot \rho \left[(1 + n_s) \cdot \rho \cdot \left(B + n_s^2\right) \cdot \rho^2 \cdot C\right]$$

P: pressure (Pa), n_s: specific number of moles (kmol/kg), R: gas constant (J/(kmol K)), T: explosion temperature (K), ρ: density of gas (kg/m^3), B: second viral coefficient (m^3/kmol), C: third virial coefficient (m^6/kmol^2).

The temperature-dependent second and third virial coefficient describe the increasing two- and three-particle collisions between the gas molecules and their accompanying increase in gas density. The virial coefficients are calculated using a suitable intermolecular potential model (usually a 12-6 Lennard-Jones potential) from rudimentary statistical thermodynamics.

The detonation pressure behind the → *Shock Wave* of a liquid or solid explosive substance is between 2 and 50 GPa; the temperature at the wave front can reach up to 5000 K.

In addition to the Chapman–Jouget theory, during the last 50 years the principal methods of calculating detonation pressure and the velocity of flat detonation waves have been the Becker–Kistiakowsky–Wilson (BKW), the Lennard-Jones–Devonshire (LJD) and the Jacobs–Cowperthwaite–Zwisler (JCZ) equations of state.

All of these methods employ model equations that do not quite satisfactorily yield the condition of the highly dense and heated detonation products. This is shown in particular in the semi-empirical BKW equation of state, which, in addition to five parameters for the calibrating of experimental measurements values, requires two separate sets of data for the calculations, involving explosives of either an extremely high or slightly negative oxygen balance or a positive oxygen balance.

The LJD and the JCZ equations of state represent methods that, when used in conjunction with an intermolecular potential rudiment, employ lattice models.

With lattice models it is assumed that the molecules in the fluid phase sit on the lattice points of a three dimensional lattice, while entering into an exchange effect with the adjacent molecules.

Among the more recent and theoretically based equations of state in detonation physics are the perturbation-theoretical methods. First used by R. Chirat and G. Pittion-Rossillion, these methods were considerably improved later by F. Ree.

The perturbation theory is one of the processes that have achieved the most significant advances in the area of statistical thermodynamics in the last 15 years.

R. Chirat and G. Pittion-Rossillion employ a simplified Weeks–Chandler–Andersen (WCA) perturbation theory while F. Ree uses the Mansoori–Canfield–Rasaiah–Stell (MCRS) hard-sphere variational theory. Both methods build on the α-Exp-6 potential and yield the theoretical Chapman–Jouget detonation velocities and pressures, which for a large number of explosives lie within the measurement accuracy of practically obtained values.

Despite the advances made over the last several decades in the field of detonation physics, there still exist many phenomena that quantitatively are not understood. Among these in particular are the unstationary, multidimensional detonation processes of gaseous, liquid or condensed bodies.

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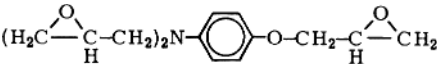
Epoxyaliphatic Resin

Epoxyaliphatic resin for the formation of binders in → *Composite Propellants*.



empirical formula: $C_{15}H_{19}NO_4$
molecular weight: 277.16 g/mol
density: 1.20–1.21 g/cm^3

Erosion

Wearing away of a material due to high gas velocities and entrained particles. Erosion in gun tubes is caused by reaction of atomic hydrogen H (*in status nascendii*), which reacts with the carbon of the steel to CH_4.

Erosive Burning

Erosiver Abbrand; *combustion érosive*

Term used in solid fuel rocket technology to describe the anomalous increase in the burning rate. This increase is thought to originate from turbulent instead of laminar gas flow along the burning surface, which leads to a higher feedback of heat energy onto this surface, and thus a higher rate of burning. Mechanical erosion may also take place by gases enriched with solid particles, such as Al_2O_3.

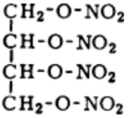
Resonance combustion is defined as the generation of pressure maxima in the combustion chamber and the consequent irregularity of the burning rate. These maxima originate from the interaction between the gas stream and the flame and become apparent as a kind of vibration.

Star-shaped grooves in case-bonded charges tend to equalize the pressure and suppress the tendency to resonate.

See also → *Burning Rate*, → *Solid Propellant Rockets*

Erythritol Tetranitrate

Tetranitroerythrit; *tétranitrate d'érythrite*



$$\begin{array}{l} CH_2\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH_2\text{-}O\text{-}NO_2 \end{array}$$

colorless crystals
empirical formula: $C_4H_6N_4O_{12}$
molecular weight: 302.1 g/mol

oxygen balance: +5.3%
nitrogen content: 18.55%
volume of explosion gases: 704 l/kg
heat of explosion
  (H_2O liq.): 1519 kcal/kg = 6356 kJ/kg
  (H_2O gas): 1421 kcal/kg = 5943 kJ/kg
specific energy: 111 mt/kg = 1091 kJ/kg
density: 1.6 g/cm^3
melting point: 61.5 °C = 143 °F
deflagration point: 154–160 °C = 309–320 °F (violent explosion)
impact sensitivity: 0.2 kp m = 2 N m

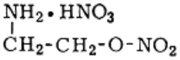
Erythrol tetranitrate is insoluble in cold water, but is soluble in alcohol and ether. It is prepared by dissolving erythrol in concentrated nitric acid with efficient cooling, and precipitating the product by concentrated sulfuric acid. It crystallizes out of alcohol as colorless plates.

Erythritol tetranitrate serves as an effective cardial medicine (in a low percentage mixture with milk sugar).

The pure substance is extremely sensitive to shock and friction.

Ethanolamine Dinitrate

Monoethanolamindinitrat; *dinitrate d'éthanolamine*; *2-nitratoethylammonium nitrate*



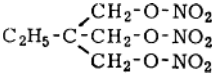
$$\begin{array}{l} NH_2 \cdot HNO_3 \\ | \\ CH_2\text{-}CH_2\text{-}O\text{-}NO_2 \end{array}$$

colorless crystals
empirical formula: $C_2H_7N_3O_6$
molecular weight: 169.1 g/mol
oxygen balance: −14.2%
nitrogen content: 24.85%
volume of explosion gases: 927 l/kg
heat of explosion
  (H_2O liq.): 1254 kcal/kg = 5247 kJ/kg
  (H_2O gas): 1089 kcal/kg = 4557 kJ/kg
specific energy: 118.8 mt/kg = 1165 kJ/kg
density: 1.53 g/cm^3
melting point: 103 °C = 217 °F
lead block test: 410 cm^3/10 g
deflagration point: 192 °C = 378 °F

This compound is readily soluble in water, sparingly soluble in cold alcohol, and somewhat hygroscopic. It is prepared by dissolution of monoethanolamine in concentrated nitric acid and precipitation from alcohol or ether with cooling.

Ethriol Trinitrate

trimethylolethylmethane trinitrate, trimethylolpropane trinitrate; trinitrate de trimethylolethylméthane

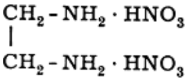


colorless crystals
empirical formula: $C_6H_{11}N_3O_9$
molecular weight: 269.4 g/mol
energy of formation: −401 kcal/kg = −1678 kJ/kg
enthalpy of formation: −426 kcal/kg = −1783 kJ/kg
oxygen balance: −50.5%
nitrogen content: 15.62%
volume of explosion gases: 1009 l/kg
heat of explosion
  (H_2O liq.): 1014 kcal/kg = 4244 kJ/kg
  (H_2O gas): 936 kcal/kg = 3916 kJ/kg
density: 1.5 g/cm^3
melting point: 51 °C = 124 °F
lead block test: 415 cm^3/10 g
detonation velocity, confined: 6440 m/s = 21 100 ft/s
  at $\rho = 1.48$ g/cm^3

This compound is prepared by nitrating trimethylolpropane (obtained by condensing formaldehyde with butyraldehyde in the presence of lime) with a mixture of nitric acid and sulfuric acid.

Ethylenediamine Dinitrate

dinitrate d'éthylène diamine: PH-Satz; EDD



$$\begin{array}{l} CH_2-NH_2\cdot HNO_3 \\ | \\ CH_2-NH_2\cdot HNO_3 \end{array}$$

colorless crystals
empirical formula: $C_2H_{10}N_4O_6$
molecular weight: 186.1 g/mol
energy of formation: −807.4 kcal/kg = −3378.2 kJ/kg
enthalpy of formation: −839.2 kcal/kg = −3511.3 kJ/kg
oxygen balance: −25.8%
nitrogen content: 30.11%
volume of explosion gases: 1071 l/kg
heat of explosion
  (H_2O liq.): 912 kcal/kg = 3814 kJ/kg
  (H_2O gas): 739 kcal/kg = 3091 kJ/kg

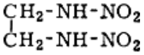
density: 1.577 g/cm^3
melting point: 188 °C = 370 °F
volume of detonation gases: 945.5 l/kg
lead block test: 350 cm^3/10 g
detonation velocity, confined: 6800 m/s = 22 300 ft/s
at $\rho = 1.53$ g/cm^3
deflagration point: 370–400 °C = 700–750 °F
impact sensitivity: 1.0 kp m = 10 N m
friction sensitivity: at 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 2 mm

Ethylenediamine dinitrate is somewhat hygroscopic and is readily soluble in water. It is prepared by saturating an aqueous solution of ethylenediamine with nitric acid.

It forms a eutectic mixture (melting point 100 °C = 212 °F) when mixed with an equal amount of ammonium nitrate.

Ethylenedinitramine

N,N,-dinitroethylene diamine; *éthylène dinitramine*; *haleite; halite; EDNA*



$$\begin{array}{l} CH_2\text{-}NH\text{-}NO_2 \\ | \\ CH_2\text{-}NH\text{-}NO_2 \end{array}$$

empirical formula: $C_2H_6N_4O_4$
molecular weight: 150.1 g/mol
energy of formation: −137.7 kcal/kg = −576.2 kJ/kg
enthalpy of formation:−165.3 kcal/kg = −691.6 kJ/kg
oxygen balance: −32.0%
nitrogen content: 37.33%
volume of explosion gases: 1017 l/kg
heat of explosion
(H_2O liq.): 1123 kcal/kg = 4699 kJ/kg
(H_2O gas): 1023 kcal/kg = 4278 kJ/kg
density: 1.71 g/cm^3
melting point: 176.2 °C = 349.2 °F (decomposition)
lead block test: 410 cm^3/10 g
detonation velocity, confined: 7570 m/s = 24 800 ft/s
at $\rho = 1.65$ g/cm^3
deflagration point: 180 °C = 356 °F
impact sensitivity: 0.8 kp m = 8 N m

This compound behaves as a dibasic acid and forms neutral salts. It is insoluble in ether, sparingly soluble in water and alcohol and soluble in dioxane and nitrobenzene. It is not hygroscopic.

It has considerable brisance, combined with a high chemical stability and relatively low mechanical sensitivity.

Ethylenedinitramine is prepared by nitration of ethylene urea with mixed acid to yield dinitroethylene-urea. The latter compound liberates carbon dioxide and forms ethylenedinitramine.

Ethylene-urea is prepared by reacting ethylene diamine to ethyl carbonate under elevated pressure.

Pourable mixtures of ethylenedinitramine with TNT are known in the USA as Ednatol.

Ethyl Nitrate

Ethylnitrat; *nitrate d'éthyle*

$C_2H_5—O—NO_2$

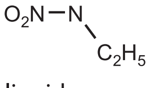
empirical formula: $C_2H_5NO_3$
molecular weight: 91.0 g/mol
energy of formation: −470.4 kcal/kg = −1968 kJ/kg
enthalpy of formation: −499.5 kcal/kg = −2091 kJ/kg
oxygen balance: −61.5%
nitrogen content: 15.24%
volume of explosion gases: 1101 l/kg
heat of explosion (H_2O liq.): 993 kcal/kg = 4154 kJ/kg
density: 1.10 g/cm^3
melting point: −102 °C = −152 °F
lead block test: 420 cm^3/10 g
detonation velocity, confined: 5800 m/s = 19 000 ft/s
at $\rho = 1.1\ g/cm^3$

This compound is a colorless, mobile liquid with a pleasant smell. It is practically insoluble in water, but is soluble in alcohol and in most organic solvents. Ethyl nitrate vapors readily form explosive mixtures with air even at room temperature; the lower explosion limit is at 3.8% ethyl nitrate.

Ethyl nitrate explodes when brought into contact with alkali metals.

N-Ethyl-*N*-(2-nitroxyethyl)nitramine

EtNENA



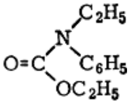
liquid
empirical formula: $C_4H_9N_3O_5$
molecular weight: 179.1 g/mol

oxygen balance: −66.99%
energy of formation: −156.86 kJ/mol
enthalpy of formation: −177.9 kJ/mol = −993.14 kJ/kg
density: 1.32 g/cm^3
melting point: 5 °C
boiling point: 200 °C

EtNENA is an energetic plasticizer for propellant applications.

Ethylphenylurethane

Ethylphenylurethan; *éthylphénylinréthane*



colorless liquid
empirical formula: $C_{11}H_{15}NO_2$
molecular weight: 193.2 g/mol
energy of formation: −492.5 kcal/kg = −2060.5 kJ/kg
enthalpy of formation: −520.1 kcal/kg = −2175.9 kJ/kg
oxygen balance: −227.7%
nitrogen content: 7.25%

Ethylphenylurethane is a gelatinizing → *Stabilizer* especially for → *Double-Base Propellants*.

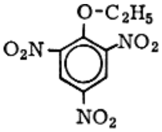
Specifications

clear, colorless liquid

density at 20 °C (68 °F):	1.042−1.044 g/cm^3
refractive index n_D^{20}:	1.504–1.507
boiling analysis at 760 Torr:	252−255 °C = 485−491 °F
acidity, as HCl:	not more than 0.004%
reaction:	neutral

Ethyl Picrate

2,4,6-trinitrophenetol; *Ethylpikrat*; *picrate d'ethyle*

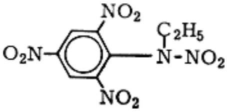


pale yellow needles
empirical formula: $C_8H_7N_3O_7$
molecular weight: 257.2 g/mol
energy of formation: −167.1 kcal/kg = −699 kJ/kg
enthalpy of formation: −186.7 kcal/kg = −781 kJ/kg
oxygen balance: −77.8%
nitrogen content: 16.34%
volume of explosion gases: 859 l/kg
heat of explosion
  (H_2O liq.): 840 kcal/kg = 3515 kJ/kg
  (H_2O gas): 805 kcal/kg = 3369 kJ/kg
specific energy: 86 mt/kg = 847 kJ/kg
density: 1.52 g/cm^3
melting point: 78 °C = 172 °F
detonation velocity, confined: 6500 m/s = 21 300 ft/s
  at ρ = 1.55 g/cm^3

The preparation of this compound resembles that of → *Trinitroanisole*.

Ethyltetryl

2,4,6-trinitrophenylethylnitramine; *trinitrophényléthylnitramine*



green-yellow crystals
empirical formula: $C_8H_7N_5O_8$
molecular weight: 301.2 g/mol
energy of formation: +5.4 kcal/kg = +22.5 kJ/kg
enthalpy of formation: −14.3 kcal/kg = −59.8 kJ/kg
oxygen balance: −61.1%
nitrogen content: 23.25%
volume of explosion gases: 874 l/kg
heat of explosion
  (H_2O liq.): 970 kcal/kg = 4058 kJ/kg
  (H_2O gas): 939 kcal/kg = 3930 kJ/kg
specific energy: 109 mt/kg = 1069 kJ/kg
density: 1.63 g/cm^3
melting point: 95.8 °C = 204.4 °F
heat of fusion: 18.7 kcal/kg = 78 kJ/kg
lead block test: 325 cm^3/10 g
impact sensitivity: 0.5 kp m = 5 N m
friction sensitivity: up to 36 kp = 353 N pistil load no reaction

The properties of this compound resemble those of tetryl; it can be prepared from mono- or diethylaniline.

Since the melting point of ethyltetryl is lower than that of tetryl, the former can be more readily employed in energy-rich pourable mixtures.

ETPE

Abbreviation for energetic thermoplastic elastomers. They are based on polyoxetans or polyoxirans having energetic side groups like azido, nitrato or nitro.

GAP-ETPE: energetic thermoplastic elastomer based on glycidylazidopolymer.

AMMO-BAMO-ETPE: energetic thermoplastic elastomer based on copolymers of azidomethylmethyloxetane (AMMO) and bis(azidomethyl)-oxetane (BAMO).

Similar to thermoplastic elastomers (→ *TPE*) they perform thermoplastic and elastomeric properties and are suitable binders for propellants and explosives. They release additional energy during the combustion reaction and can therefore increase the performance of the energetic material.

Reference: *A.K. Sikder* and *S. Reddy:* Review on Energetic Thermoplastic Elastomers (ETPEs) for Military Science, Propellants, Explosives, Pyrotechnics, 2013, 38, 14–28

European Defence Agency (EDA)

EDA’s mission is to support the efforts of its participating member states to improve military capabilities for the European security and defense policy. Working and investing together on collaborative projects can save money for national budgets, simply because the financial burden is spread over a greater number of member states. At the same time cooperation contributes to increasing standardization and interoperability between Europe’s armed forces.

Exothermal

Process characterized by the evolution of heat (opposite of → *Endothermal*).

Explode

Explodieren; *exploser*

To be changed in chemical or physical state, usually from a solid or liquid to a gas (as by chemical decomposition or sudden vaporization), so as to suddenly transform considerable energy into the kinetic form. *(See also → Explosion*)

Exploding Bridgewire

Detonator or initiator that is initiated by capacitor discharge that explodes (rather than merely heats) the bridgewire. Cannot be initiated by any normal shock or electrical energy.

Exploding Bridgewire Detonator (EBW)

An initiating device that utilizes the shock energy from the explosion of a fine metallic wire to directly initiate a secondary explosive train. Invented by Luis Alvarez for the Manhattan Project in the early 1940s, the basic EBW consists of a fine wire (typically gold, 0.038 mm in diameter, 1 mm long), next to a secondary explosive such as → *PETN* or → *RDX*. A large, fast current pulse (> 200 A in approximately 1 μs) through the wire causes it to rapidly vaporize generating a shock wave of about 1500 MPa. This intense shock wave is sufficient to directly initiate the low density explosive next to the exploding wire. The low density explosive is than used to initiate a higher density explosive output pellet which in turn can initiate main charge explosives.

Exploding Foil Initiator (EFI; slapper)

Similar in some respects to an → *Exploding Bridgewire Detonator*, the Exploding Foil Initiator uses a high electrical current to vaporize a foil and accelerate a dielectric flyer down a short barrel (typically about 0.2 mm long). The kinetic energy of the flyer is sufficient to initiate high density secondary explosives such as HNS directly. Invented in 1965 by John Stroud of the Lawrence Livermore National Laboratory.

Explosion

An explosion is a sudden increase in volume and release of energy in a violent manner, usually with generation of high temperatures and release of gases. An explosion causes pressure waves in the local medium in which it occurs. Explosions are categorized as deflagrations if these waves are subsonic and → *Detonations* if they are supersonic (shock waves).

Explosion Heat

See → *Heat of Explosion*

Explosion Temperature

Explosionstemperatur; *température d'explosion*

Explosion temperature is the calculated temperature of the fumes of an explosive material if detonated while confined in a shell that is indestructible and impermeable to heat. The calculation is based on the → *Heat of Explosion* and on the decomposition reaction, with allowance for the dissociation equilibria and the relevant gas reaction (see also → *Thermodynamic Calculation of Decomposition Reactions*). The real detonation temperature in the front of the shock wave of a detonating explosive can be estimated on the strength of the hydrodynamic shock wave theory, and is higher than the calculated explosion temperature.

Explosive Bolt

Sprengriegel; *verrou destructif*

A bolt that is intended to be fractured by a contained or inserted explosive charge.

Explosive Forming and Cladding

Metallbearbeitung durch Sprengstoffe; *traitement des métaux par explosion*

The utility of explosive materials for metal forming have been studied with three different objectives in view: sheet forming and matrix forming of flat items by pressure impact, metal plating, and surface hardening of manganese hard steel.

The application of the pressure shock of an explosive to form very large workpieces is primarily intended to achieve the shaping of a workpiece without using presses, which are very expensive. The transmission of the pressure impact takes place underwater. Preliminary experiments have given encouraging results, but a large-scale industrial application has not yet been developed.

The development of explosive cladding is very much more advanced. The metal sheet to be cladded is exploded onto the base material, parallel to it or at a certain angle. In this way it is possible to perform cladding tasks that would be impossible with manual welding, owing to the formation of brittle intermediate alloys between the plating material and the base material – as, for instance, in plating titanium onto a steel surface.

On the surface of manganese steel, the impact of the explosive layer onto the steel surface results in hardening. The only application of this process is to enable repair work on railway tracks in remote regions, with no need to convey the defective parts over long distances. In densely populated areas, forming explosions are difficult to perform.

Explosive Loading Factor

Spezifischer Sprengstoffverbrauch; *consommation specitique d'explosits*

The amount of explosive used per unit of rock, usually expressed as pounds of explosives per cubic yard of rock, or tons of rock per pound of explosives, or their reciprocals.

Explosive Materials

Sprengmittel; *materiaux explosif*

(See also Table 10)

These include explosives, blasting agents and detonators. The term includes, but is not limited to, dynamite and other high explosives, slurries and water gels, blasting agents, black powder pellet powder, initiating explosives, detonators, safety fuses, squibs, detonating cords, igniter cords and igniters. A list of explosive materials determined to be within the coverage of 18 USC Chapter 40, *Importation, Manufacture, Distribution and Storage of Explosive Materials* is issued at least annually by the Director of the Bureau of Alcohol, Tobacco and Firearms of the Department of the Treasury.

The United States Department of Transportation classifications of explosive materials used in commercial blasting operations are not identical with the statutory definitions of the Organized Crime Control Act of 1970, title 18 USC, section 841. To achieve uniformity in transportation, the definitions of the United States Department of Transportation in Title 49 Transportation CFR, Parts I-999 subdivides these materials into:

→ Class A Explosives	– Detonating, or otherwise maximum hazard
→ Class B Explosives	– Flammable hazard
→ Class C Explosives	– Minimum hazard
Oxidizing Material	– A substance that yields oxygen readily to stimulate the combustion of organic matter (see also → *Oxidizer*)

A list of energetic materials is also available from the German BAM.

Explosive Train

A train of combustible and explosive elements arranged in order of decreasing sensitivity. The explosive train accomplishes the controlled augmentation of a small impulse into one of suitable energy to actuate a main charge. A fuze explosive train may consist of a primer, a detonator, a delay, a relay, a lead and booster charge, one or more of which may be either omitted or combined. If the bursting charge is added to the foregoing train it becomes a bursting charge explosive train. A propelling charge explosive train might consist of a primer, igniter or igniting charge, usually black powder, and finally, any of the various types of propellants.

See also → *Igniter Train*

Explosives

Explosivstoffe; *explosifs*

1. Definition

Explosives are solid or liquid[16] substances, alone or mixed with one another, which are in a metastable state and are capable, for this reason, of undergoing a rapid chemical reaction without the participation of external reactants such as atmospheric oxygen. The reaction can be initiated by mechanical means (impact → *Impact Sensitivity*; friction → *Friction Sensitivity*), by the action of heat (sparks, open flame, red-hot or white-hot objects), or by detonating shock (→ *Blasting Cap* with or without a → *Booster Charge*). The resistance of the metastable state to heat is known as → *Stability*. The ease with which the chemical reaction can be initiated is known as → *Sensitivity*.

The reaction products are predominantly gaseous (see also → *Fumes*). The propagation rate from the initiation site outwards through the explosive material may be much slower than the velocity of sound (see also → *Deflagration*; → *Gunpowder*) or may be supersonic (see also → *Detonation*). Explosives are solid, liquid, or gelatinous substances, or mixtures of individual substances, which have been manufactured for blasting or propulsion purposes. (For their effectiveness, see also → *Strength*; → *Burning Rate*; → *Brisance*)

Materials that are not intended to be used for blasting or shooting may also be explosive. They include, for example, organic peroxide catalysts, gas-liberating agents employed in the modern manufacture of plastic materials and plastic foams, certain kinds of insecticides, etc. Figure 15 gives an overview of explosive materials.

2. Important Explosives

Of the many explosive chemicals discussed in this book, the following are, at present, of industrial or military importance:

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16) Of course, gases and gaseous mixtures can also be explosive. Explosive mixtures are often generated spontaneously (such as by leaks in gas pipes or solvent tanks, or firedamp in coal mining).

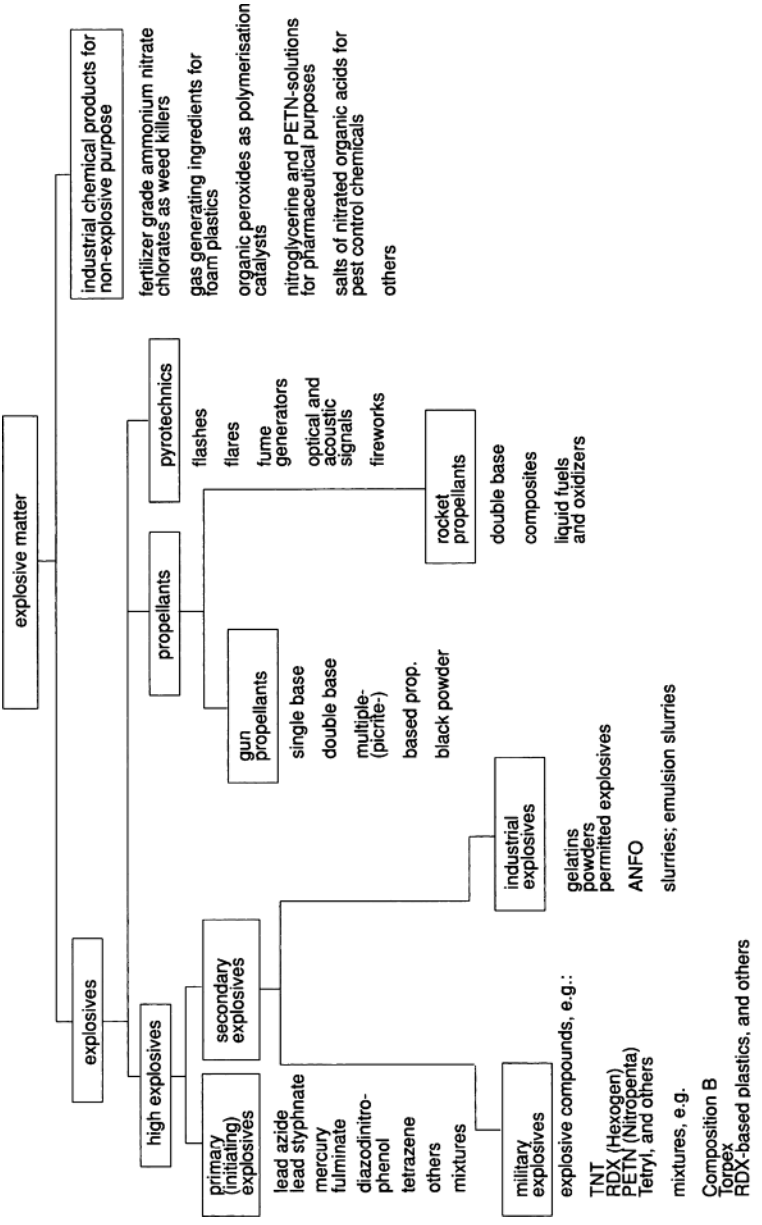

Figure 15 Explosive Materials and their Application.

Nitro compounds: → *TNT* in various degrees of purity, as defined by the solidification point of the material; pure 2,4- and 2,6-isomers of dinitrotoluene (as propellant components) and low-melting isomer mixtures (for commercial explosives).

Aromatic nitramines: → *Tetryl* (trinitrophenylnitramine) for booster charges and secondary blasting cap charges.

Aliphatic nitramines: → *Hexogen* (RDX) and → *Octogen* (HMX) as components for high-brisance compositions (see also → *Compositions B*; → *Hollow Charges*). → *Nitroguanidine* as the main component in powders with low explosion heat and in rocket propellants.

Nitrate esters: → *Nitroglycerine*, which is still of primary importance in commercial explosives, smokeless powders and rocket propellants. → *Nitroglycol* in commercial explosives only[17]. → *PETN* as a high-brisance component, which is phlegmatized and pressed for booster charges. It is also employed as a secondary charge of blasting caps and as a detonating cord charge.

→ *Diethyleneglycol Dinitrate* for smokeless (cold) powders. → *Nitrocellulose*, which is the most important component of single-base and double-base powders and multibase rocket propellants. It is also used to gelatinize commercial explosives. Outside the explosives industry, it is also used in the manufacture of lacquers and varnishes.

Initiating explosives: → *Mercury Fulminate*, and other fulminates, which are now used to a much smaller extent. → *Lead Azide*, alone and in mixtures with *Lead Trinitroresorcinate*, as primary charges in blasting caps, for firedamp-proof cooper caps in coal mining, and in military primers of all kinds. → *Lead Styphnate (Lead Trinitroresorcinate)* mixtures, which may contain → *Tetrazene*, for percussion caps.

Many nitro-derivatives of benzene and naphthalene were of importance in the past, since toluene – the starting compound in the manufacture of TNT – could only be prepared by distillation of coal. Owing to advances in petrochemistry, toluene is now available in practically unlimited amounts. The bulk of the toluene now produced is employed as the starting material for the preparation of toluene diisocyanate (TDI), used in the production of plastics.

3. *Quality Requirements for Industrial and Military Explosives*

The quality requirements for industrial explosives are quite different from those for military explosives. It follows that their compositions and the mode of their preparation must be different as well. Table 10 gives an overview.

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17) Nitroglycol-based gelatinous explosives have been replaced by → *Emulsion Slurries*.

Table 10 Requirements on Industrial and Military Explosives.

	Industrial explosives	**Military explosives**
Performance	Large gas volume and high heat of explosion = high strength high detonation velocity not needed, except: special gelatins for seismic prospecting	According to the purpose of the weapon: mines, bombs, mine projectiles, rocket war head charges: high gas impact large gas volume high heat of explosion (high detonation velocity not needed) grenades: high speed splinter formation high loading density high detonation velocity medium strength is sufficient shaped (hollow charge effect): extremely high values for density and detonation velocity (HMX best component) high strength + high brisance
Sensitivity	Safe in handling cap-sensitive (except: blasting agents and slurries) safe flash over capacity in long columns	As unsensitive as possible firing safety impact safety → projectile impact safety
Stability and behavior on storage	Storage life about 6 months or longer neutral (e.g. no nitric acid as component)	Storage life 10 years or longer neutral no reaction with metals such as picrate formation
Water resistance	When cartridged, should withstand 2 h in stagnant water (for seismic prospecting shots even longer)	Completely waterproof, at least when loaded in the weapon
Consistency	Formable (gelatinous or powder form) to be able to introduce the cap	Castable or pressible
Thermal behavior	Must not freeze above −25 °C (−13 °F) must withstand about +60 °C (140 °F) for several hours (e.g. in deep mining)	Fully functional between −40 °C (−40 °F) and 60 °C (140 °F) or even higher for special purposes.

The combustion behavior of propellants (see also → *Burning Rate*), which is affected by the ignition and by the design of the grain configuration in the combustion chamber, must be exactly reproducible.

Primary explosives, when set off by a flame, must detonate immediately, and their detonation development distance must be as short as possible.

4. Acquisition, Handling, and Storage

Almost every country has its own laws and regulations governing the acquisition and utilization of explosives. These laws were passed in order to protect the public and to make the use of explosives for criminal purposes a heavily punishable offence. Generally speaking, buyers and users must prove their competence to the authorities and are obliged by law to keep a storage record. The manner of construction of the buildings serving as storerooms, the permissible stacking height, and the minimum distance between residential buildings and buildings in which explosives are stored (or produced) are in most cases officially specified.

In order to estimate the safe distance required for an amount (M) of the explosive, it may be assumed that this distance increases with the cube root of M; we thus have $f \cdot \sqrt[3]{M}$. If M is given in kilograms, and the safe distance is to be obtained in meters, then f is about 16 for the distance to inhabited buildings, about 8 for the distance between dangerous and safe areas of the explosive-manufacturing plant, and about 1.5 for the distance between one storehouse and another. (For transport regulations for dangerous materials, see also → *RID*.)

See also → IATADGR; → IMO; → Mass Explosions Risk

Exudation

Ausschwitzen; *exsudation*

The separation of oily ingredients out of explosives during prolonged storage, especially at elevated temperatures. It may be caused by low-melting eutectics of isomers or primary products of the explosive material or by added ingredients. Exudation may particularly be anticipated in TNT shell charges. Accordingly, the chemical purity standards of the product (→ *TNT*, specifications) are particularly important.

In propellant charges, exudation occurs if the percentage of e.g. nitroglycerine, aromatic compounds, gelatinizers or Vaseline is high. The propellant grains will agglomerate and ignition will suffer. The same disadvantage may be caused by crystalline separation of stabilizers. The ballistic performance can also be affected.

Prolonged storage, especially in wet climates, may cause exudation of gelatinous nitroglycerine explosives. Mostly, the exudated liquid consists of a watery ammonium nitrate solution; initiation sensitivity and performance may be affected. Particularly dangerous is the exudation of unbonded nitroglycerine. This occurs when the gelatinization with nitrocellulose (blasting soluble) is faulty or the nitrocellulose is of bad quality.

Face Burning

"Cigarette-Burning"; *Stirnabbrand*; *combustion en cigarette*

In rocket technology, a design of the propellant charge that results in the combustion process being restricted to the cross-section of the combustion chamber. This type of combustion is produced by coating all other surfaces with a nonflammable layer. In such rockets, long combustion times (10 min or more) at a nearly constant thrust can be achieved.

Federation of European Explosives Manufacturers (FEEM)

The Federation of European Explosives Manufacturers (FEEM) is a non-governmental organization created in 1976 by European industrial explosives manufacturers. The main objectives of the Federation, which are embodied in its Articles of the Constitution, are to encourage best practice in the industry and to make the public aware of the importance of different uses of industrial explosives in creating its infrastructure and environment.

Further objective of the FEEM is the advancement of the commercial explosives industry in the widest sense and with particular regard to the improvement of:

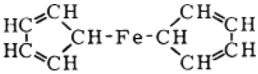
- safety, quality and security in methods of manufacture of explosives and working conditions;
- safety and security of civil explosives during transport, handling, storage and use.

In addition FEEM undertakes to maintain high-quality standards in its products and to advance the welfare and standing of the explosives industry.

A prime function of FEEM is to ensure proper and adequate representation of the European Explosives Industry with both International and National regulating bodies and at conferences, where matters concerning the regulation of this trade are discussed.

Ferrocene

Ferrocen; *Bis-cyclopentadienyl-eisen*; *ferrocène*



empirical formula: $C_{10}H_{10}Fe$
molecular weight: 186.0 g/mol
energy of formation: +214.9 kcal/kg = +899.2 kJ/kg
enthalpy of formation: +199.0 kcal/kg = +832.6 kJ/kg
oxygen balance: −223.6%

Ferrocene is a combustion-modifying additive especially for → *Composite Propellants*.

Firedamp

Schlagwetter; *grisou*

Firedamp is an explosive mixture of marsh gas (methane, CH_4) with air. These mixtures are explosive at normal temperatures and pressures, and the explosion is propagated over large distances if the mixture contains 5–14% methane. A methane-air mixture containing 8.5–9.5% methane is prescribed for official tests of permissibles. The danger of explosion is greatest in this concentration range.

See also → *Permitted Explosives*

Firing Current

Zündstrom; *courant de mise à feu*

An electric current of recommended magnitude to sufficiently energize an electric blasting cap or a circuit of electric blasting caps.

Firing Line

Zündkabel; *ligne de tir*

The wire(s) connecting the electrical power source with the electric blasting cap circuit.

First Fire

Igniter composition used with pyrotechnic devices that is loaded in direct contact with main pyrotechnic charge. Pyrotechnic first fire composition is compounded to produce high temperature. Composition must be readily ignitable, and be capable of igniting the underlying pyrotechnic charge.

Flame

Flamme; *flamme*

Chemical reaction or reaction product, partly or entirely gaseous, that yields heat and emits light. State of blazing combustion. The flame profile maybe be represented by the temperature profile. Flame temperature is the calculated or determined temperature of the flame.

Flame Shield

Flammenschild; *boinclier contre l'érosion*

Thin metal shield adjacent to case insulation to prevent erosion of the insulation and to prevent objectionable insulation pyrolysis products from entering the gas stream.

Flare

Fackel; *flambeau*

A pyrotechnic device designed to produce a single source of intense light or radiation for relatively long durations for target or airfield illumination, signaling, decoy for guided missiles, or other purposes.

Flash Over

Übertragung; *détonation par influence*

Flash over means the transmission of detonation from one cartridge to another one in line. Explosives with extremely high flash-over tendency can be initiated by the shock wave from one charged borehole to the next one, even at large distances (see also → *Ditching Dynamite*).

See also → *Detonation, 4. Sympathetic Detonation*

Flash Point

Flammpunkt; *point d'inflammation*

The lowest temperature at which vapors above a volatile combustible substance ignite in air when exposed to flame.

Fly Rock

Steinflug; *projections de roche*

Rocks propelled from the blast area by the force of an explosion.

Fragmentation Test

Splittertest; *epreuve de fracture*

A USA standard test procedure for explosives of military interest.

The weight of each empty projectile and the weight of water displaced by the explosive charge is determined, from which the density of the charge is calculated. All 3-in and 90-mm projectiles are initiated by M20 booster pellets, and those used with 3-in HE, M42AI, Lot KC-5 and 90-mm HE, I1II71, Lot WC-91 projectiles are controlled in weight and height as follows: 22.50 + 0.10 g, and 0.480–0.485 in.

The projectile assembled with fuze, actuated by a blasting cap, Special, Type II (Spec. 49-20) and booster, is placed in boxes constructed of half-inch pine. The 90-mm projectiles are fragmented in boxes 21 × 10.5 × 10.5 in^3 and the 3-in projectiles in boxes 15 × 9 × 9 in^3 external dimensions. The box with projectile is placed on about 4 ft of sand in a steel fragmentation tub, the detonator wires are connected, and the box is covered with approximately 4 ft more of sand. The projectile is fired and the sand runs onto a gyrating 4-mesh screen on which the fragments are recovered.

Fragment Velocity

Charges 10-1/8 in long and 2 in in diameter, containing a booster cavity filled by a 72-g tetryl pellet (1.375 in diameter, 2 in long, average density 1.594), are fired in a model projectile of Shelby seamless tubing (2 in ID, 3 in OD, SAE 1020 steel, with a welded-on cold-rolled steel base). The projectile is fired in a chamber, connected to a corridor containing velocity stations (protected sites for high-speed measuring equipment), so that a desired wedge of projectile casing fragments can be observed. The fragment velocities are determined by shadow photographs, using flash bulbs and rotating drum cameras, each behind three slits. The drum cameras have a writing speed of 30 m/s.

Free-Flowing Explosives

Rieselfähige Sprengstoffe; *explosifs pulvérulents*

Noncartridged commercial explosives which can be poured into boreholes, mostly ammonium nitrate explosives containing anticaking agents. When ammonium nitrate became commercially available as → *Prills* (porous pellets), → *ANFO* blasting agents could also be utilized in the free-flowing form.

See also → *Pellets*

Freezing of Nitroglycerine-Based Explosives

Gefrieren von Nitroglycerin-Sprengstoffen; *congélation d'explosifs à base de la nitroglycerine*

Nitroglycerine may freeze at +10 °C. The frozen cartridges are unsafe to handle, and improvised thawing operations are risky. Freezing is prevented by adding nitroglycol to the nitroglycerine.

Friction Sensitivity

Reibempfindlichkeit; *sensitiveness to friction*; *sensibilité au frottement*

The sensitivity to friction can be determined by rubbing a small quantity of the explosive in an unglazed porcelain mortar. The sample being tested is compared with a standard specimen. The friction sensitivity of secondary explosives is very dependent on the grain sizes of the material.

In the USA, the friction procedure is made by the friction pendulum test:

A 0.7-g sample of explosive, 5–100 mesh, is exposed to the action of a steel or fiber shoe swinging as a pendulum at the end of a long steel rod. The behavior of the sample is described qualitatively (e.g. the most energetic reaction is explosion), and in decreasing order: snaps, cracks, and unaffected. An improved method, developed by the Bundesanstalt für Materialforschung und -prüfung (→ *BAM*[18)]), Germany, yields reproducible numerical values.

Sensitiveness of friction

This method is the recommended test method in the UN recommendations for the transport of dangerous goods and it is standardized as EN 13631-3 as a so-called Harmonized European Standard.

Procedure

The sample is placed on a roughened 25 × 25 × 5 mm^3 porcelain plate, which is rigidly attached to the sliding carriage of the friction apparatus. A cylindrical porcelain peg, 10 mm in diameter and 15 mm in height, with a roughened spherical end (radius of curvature 10 mm), is placed on top of the sample. The rod is tightly clamped and may be loaded with different weights with the aid of a loading arm. The load on the peg may vary between 0.01 and 1 kp in a small apparatus and between 0.5 and 36 kp in a large apparatus. The porcelain plate moves forward and back under the porcelain peg; the stroke length is

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18) Koenen, H. and Ide, K.H. (1961) *Explosivstoffe*, **9**, 4 and 10.

10 mm in each direction. The two ends of the peg will serve for two trials and the two friction surfaces of the plate will serve for three trials each.

(Gelatins with a low content of nitroglycerine or nitroglycol, powder-form explosives, slurries and permitted explosives, ammonium nitrate; dinitrobenzene; nitroglycol; nitroglycerine, nitrocellulose up to 13.4% N, picric acid and TNT do not react up to a pistil load of 36 kp.)

Table 11

Explosive	**Pistil load** **(kp)**	 **(N)**
A. Initiating explosives, small machine		
Lead azide	0.01	0.1
Lead styphnate	0.15	1.5
Mercury fulminate, gray	0.3	3
Mercury fulminate, white	0.5	5
Tetrazene	0.8	8
B. Secondary explosive materials, large machine		
PETN (nitropenta)	6	60
RDX (hexogen)	12	120
HMX (octogen)	12	120
Tetryl	36	353
C. Industrial explosives, large machine		
Blasting gelatin	8	80
Gelignite, 60% nitroglycerine	12	120
Ammongelit, 38% nitroglycol	24	240

Friction sensitivity of explosive materials

(Sensitiveness to explosive materials)

The figure reported is the smallest load of the peg which causes deflagration, crackling or explosion of the test sample at least once in six consecutive trials. The quantity of the test sample is 10 mm^3.

Fraunhofer ICT

Fraunhofer-Institut für Chemische Technologie 76327 Pfinztal-Berghausen (www.ict.fraunhofer.de)

German research institute for propellants, explosives and energetic materials and organizer of international meetings at Karlsruhe, Germany.

Fuel

Brennstoff; *combustible*

Most explosives and pyrotechnical compositions are prepared by a mixture of → *Oxidizers* and fuels. Fuel means any substance capable of reacting with oxygen and oxygen carriers (oxidizers) with the evolution of heat. Hence, the concept of fuel here has a wider significance than that of fuel in everyday language; thus, for instance, ammonium chloride in ion-exchanged → *Permitted Explosives* can act as a fuel.

Fuel Air Explosives

FAE; *explosifs combustible-air*; *Brennstoff-Luft-Sprengstoffe, Druckwellensprengstoffe*

First experiments for fuel air explosives were done during the end of Second World War by the Austrian physicist Mario Zippermayer. His system used air/liquid oxygen together with coal dust/methane to generate strong and enduring blast waves suggested for use in the first surface-to-air missiles like HS 117 Schmetterling or the self-propelled Flakmine V7. At the beginning of the 1970s, the first useable FAE were developed at the US Naval Air Warfare Centre Weapons Division NAWCWPNS, California. They are considered as the strongest non-nuclear chemical explosives. Primarily, ethylene oxide (EO) or propylene oxide (PO) serve as fuels. These substances are atomized by explosive charges and ignited after mixing with air. After intramolecular decomposition the fuel reacts with atmospheric oxygen and starts a detonation with velocities about 2000 m/s. Peak pressure under the detonating cloud reaches up to 3 MPa. The effectiveness of the blast wave exceeds TNT more than fivefold, calculated for equivalent masses.

As a result of the rapid oxidation of surrounding oxygen a very strong suction phase is generated, which is expressed by the term 'vacuum bomb'. EO and PO are toxic and carcinogenic, which has led to the development of innocuous FAE in the last fifteen years (see also → *Thermobaric Explosives*).

For optimizing pressure wave propagation FAE are ignited similar to nuclear-weapons in a defined distance above ground zero. So they often produce an atomic-mushroom-like smoke signature and blast characteristics making them look like mini Nukes.

Fields of deployment for FAE are the rapid removal of antipersonal (AP) mines and the production of highly effective blast waves. Being exposed to these long, enduring pressure and suction phases may lead to heavy internal injuries up to lung rupture. Modern infantry troops have much better fragment protection than in former days, but there is currently no effective protection against the effects of such strong blast waves. Recently, the use in Hyper Sonic Planes travelling with velocities up to Mach 10 became an important spinoff for FAE near fuels and technologies.

Fumes

Schwaden; *fumées de tir*

The composition of the fumes produced by the detonation of an explosive can be determined by calculation (→ *Thermodynamic Calculation of Decomposition Reactions*) or by detonating a cartridge of the explosive in a closed vessel (→ *Bichel Bomb*) followed by gas analysis of the fumes.

In the case of industrial explosives containing an excess of oxygen (→ *Oxygen Balance*), it is conventionally assumed for the calculated values that only CO_2, but no CO, and also that only H_2O, N_2 and excess O_2 are contained in the fumes. In reality the reaction is much more complex, and the product may in fact include CO, NO, NO_2, CH_4 and many other substances, if the explosive contains sulfur and/or chlorine compounds.

It must always be assumed that explosive fumes and propellant fumes are to some extent toxic. Excess oxygen causes the formation of nitrogen oxides, deficiency carbon monoxide, both toxic. In the United States, the following classification of toxic fume components has been accepted: a 1.25 by 8″ (20.32 cm) cartridge in its cartridge paper is detonated in a → *Bichel Bomb*, and the fume composition is analyzed in the following tables (Table 12 and 13). Toxic gases means the sum of $CO + H_2S$ (NO and NO_2 are not considered) in m^3/kg explosive.

Table 12 Fume composition for classes A–C.

Fume class	Toxic gases (m^3/kg)	Toxic gases (l/kg)
A	less than 0.08	78
B	0.08–0.16	78–156
C	0.01–0.02	156–234

Table 13 Fume composition for classes 1–3.

Fume class	Toxic gases (m^3/kg)	Toxic gases (l/kg)
1	less than 0.01	10
2	0.01–0.02	10–21
3	0.02–0.04	21–42

In the European Community the Standard EN 13631-16 Detection and Measurement of Toxic Gases specifies a method for quantification of nitrogen oxides and carbon oxides produced by the detonation of explosives for use in underground works.

The test is carried out in a blast chamber with a minimum volume of 15 m^3, which is designed to withstand forces during the detonation of high explosives and to prevent a significant loss of blasting fumes. The chamber is equipped with a thick-walled steel tube (inner diameter of 150 mm, length of 1400 mm) and with an effective mixing system to ensure a homogeneous gas phase. The chamber has ports for gas sampling and for measuring the ambient temperature and pressure. Cartridged explosives and bulk explosives in glass or aluminum tubes can be used. The explosive charge should have the minimum diameter for application and a length of 700 mm or at least seven times the diameter. The explosive mass-to-chamber volume ratio should be between 30 and 50 g/m^3.

The explosive charge is placed centrally in the bore of the steel tube and fired there. The initiation is done as recommended by the manufacturer. If booster charges are necessary their proportion in the fumes produced has to be considered in the calculation.

For sampling a gas extraction system has to be used, which prevents the condensation of water vapor and the subsequent dissolving of nitrous oxides.

The quantity of CO, CO_2, NO and NO_2 is measured simultaneously and continuously over a period of 20 min. The concentration of CO and CO_2 are constant over the entire measuring period, provided the blast chamber is sufficiently gas tight. Since NO and NO_2 give subsequent secondary reactions, measured concentration is extrapolated to obtain the initial concentration. From the initial concentrations determined, the volume of the chamber and the amount of the explosive fired, the amount of each toxic gas is calculated in liter per kilogram of explosive (at standard temperature and pressure). The test is performed three times.

Limits for the toxic gases are not required in the European Standard. However, the measured amounts can be used by national authorities for regulations of the underground use of explosives.

Functioning Time

Ignition delay; *Anzündverzugszeit*; *retard d'allumage*

Lapsed time between the application of firing current to the start of pressure rise.

Fuse

An igniting or explosive device in form of a cord, consisting of a flexible fabric tube and a core of low or high explosive. Used in blasting and demolition work, and in certain munitions. A fuse with a black powder or other low explosive core is called a safety fuse or blasting fuse. A fuse with a → *PETN* or other high explosive core is called a detonating cord or primacord.

Fuze

Zünder, Anzünder; *fusée*

A device with explosive or pyrotechnic components designed to initiate a train of fire or detonation.

Fuze, delay: any fuze incorporating a means of delaying its action. Delay fuzes are classified according to the length of time of the delay.

Fuze, long delay: a type of delay fuze in which the fuze action is delayed for a relatively long period of time, depending upon the type, from minutes to days.

Fuze, medium delay: a type of delay fuze in which the fuze action is delayed for a period of time between that of short delay and long delay fuzes, normally 4–15 s.

Fuze Head

Zündschraube, Anzündschraube

A device for the ignition of a gun propellant. It consists of a percussion cap, containing a small amount of black powder booster in front, and a threaded armature part screwed into the base of the cartridge.

Gap Test

See → *Detonation*; *Sympathetic Detonation*; *Flash Over*.

Gas Generators

gaserzeugende Ladungen; *charges génératrices de gaz*

Pyrotechnic or propellant device in which propellant is burned to produce a sustained flow of gas at a given pressure on demand. Gas generating units are employed in blasting operations conducted in mines without recourse to brisant explosives. The device consists of a nondetonating, gas-generating material and a priming or a heating charge, which are confined together in a steel pipe. The heating charge evaporates the gas-generating substance such as liquid CO_2 (→ *Cardox*). Another possibility is for the primer to initiate an exothermal chemical reaction (Chemecol process, Hydrox process). The gas-generating reaction may be the decomposition of nitrogen-rich compounds such as ammonium nitrate, or nitrate mixtures, or nitroguanidine in the presence of carbon carriers and sometimes in the presence of catalysts. When a given pressure has been reached, a bursting disc releases the gases in the pipe. The sudden gas expansion taking place in the borehole has an effect similar to that of an explosion.

Gas Jet Velocity

Nozzle Velocity; *Ausströmgeschwindigkeit*; *vélocité à jet de gaz*

In rocket technology, the velocity of the combustion gases discharged from the combustion chamber and passing the nozzle into the atmosphere. The jet velocity and the mass flow serve to calculate the → *Thrust*. The jet velocity will increase with the pressure in the combustion chamber, i.e. with the expansion ratio under passage through the → *Nozzle*. The pressure in the combustion chamber should not be adjusted too high, otherwise the wall thickness of the chamber (i.e. its weight) will become too great (see also → *Mass Ratio*).

In accordance with the *Saint-Venant* and *Wantzel* formula

$$a = \sqrt{2\frac{k}{k-1}\frac{RT}{M}\left[1-\left(\frac{P_0}{P_1}\right)^{\frac{k-1}{k}}\right]}$$

where: P_0 is the gas pressure at the nozzle exit (atmospheric pressure); P_1 is the pressure in the combustion chamber; k is the coefficient of specific heat; R is the ideal gas constant measured in absolute units; T is the flame temperature (in kelvin); M is the mean molecular weight of the combustion gases.

The jet velocity is proportional to the square root of the combustion temperature and inversely proportional to the square root of the mean molecular weight of the combustion gases.

Other details can be deduced from the formula.

See also → *Propellant Area Ratio*; → *Solid Propellant Rockets*

Gas Pressure

Gasdruck; *pression de gaz*

The pressure generated in the chamber of a weapon. Its value depends to a large extent on the nature of the weapon and the powder selected. Standard determinations of gas pressure are carried out with the aid of a crusher (measuring egg) – a copper cylinder or a copper pyramid – the compression of which is a measure of the gas pressure.

A complete transient gas pressure curve can be plotted with the aid of piezo-quartz or other pressure transducer with an oscillograph (see also → *Ballistic Bomb*).

Gelatins; Gelatinous Explosives; Gelignites

These are dough-like → *Explosives* based on nitroglycerine/nitroglycol gelatinized by nitrocellulose. Gelatins are being replaced by cartridged → *Emulsion Slurries* and → *Plastic Explosives*.

Gelled Propellants

Gelled propellants combine the major advantages of solid and liquid fuels and therefore enable the construction of engines with controllable thrust combined with easy handling and storage capabilities. At rest, the gels behave like a solid in the tank, but under sufficiently high applied shear stress they can be liquefied to a large extent due to their non-Newtonian shear-thinning behavior. The energy content of the gelled propellants can be increased, for example by adding metal particles, without these particles forming sediments in the tank. Moreover, in addition to monergolic fuels, diergolic or hypergolic systems can also be used without causing direct contact of the components in case of leakages.

GGVE

Gefahrgutverordnung, Eisenbahn

German transport regulation.

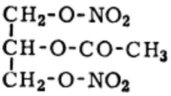
See also → *RID*

Globally Harmonized System (GHS)

The Globally Harmonized System of Classification and Labelling of Chemicals addresses worldwide classification of chemicals by types of hazard and proposes harmonized hazard communication elements, including labels and safety data sheets. It aims at ensuring that information on physical hazards and toxicity from chemicals be available to enhance the protection of human health and environment during the handling, transport and use of chemicals. (www.unece.org)

Glycerol Acetate Dinitrate

Acetyldinitroglycerin; *acétate-dinitrate de glycérine*



$$\begin{array}{l}CH_2\text{-}O\text{-}NO_2\\ |\\ CH\text{-}O\text{-}CO\text{-}CH_3\\ |\\ CH_2\text{-}O\text{-}NO_2\end{array}$$

pale yellow oil
empirical formula: $C_5H_8N_2O_8$
molecular weight: 224.1 g/mol
oxygen balance: −42.86%
nitrogen content: 12.50%
density: 1.412 g/cm^3
lead block test: 200 cm^3/10 g
deflagration point: 170−180 °C = 338−356 °F

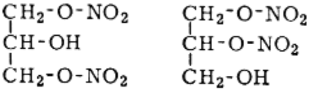
This compound is insoluble in water, but is readily soluble in alcohol, ether, acetone, and concentrated HNO_3.

It may be prepared by nitration of acetylglycerol with mixed acid containing a very large proportion of nitric acid.

Glycerol acetate dinitrate has been proposed as an additive to nitroglycerine in order to depress the solidification point of the latter. It has so far not been employed in practice.

Glycerol Dinitrate

Dinitroglycerin, Glycerindinitrat; *dinitrate de glycérine*



$$\begin{array}{l}CH_2\text{-}O\text{-}NO_2\\ |\\ CH\text{-}OH\\ |\\ CH_2\text{-}O\text{-}NO_2\end{array}\qquad\begin{array}{l}CH_2\text{-}O\text{-}NO_2\\ |\\ CH\text{-}O\text{-}NO_2\\ |\\ CH_2\text{-}OH\end{array}$$

α β

pale yellow oil
empirical formula: $C_3H_6N_2O_7$
molecular weight: 182.1 g/mol
oxygen balance: −17.6%
nitrogen content: 15.38%
density: 1.51 g/cm^3
solidification point: −30 °C = −22 °F
lead block test: 450 cm^3/10 g

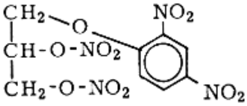
deflagration point: 170 °C = 338 °F
impact sensitivity: 0.15 kp m = 1.5 N m

Glycerol dinitrate is a viscous liquid, but is more volatile and more soluble in water than nitroglycerine. It is hygroscopic and may be used as a gelatinizer of certain types of nitrocelluloses. It is more stable than glycerol trinitrate. Its vapors are toxic and cause headaches.

It is prepared by nitration of glycerol with nitric acid. Such nitrations mostly yield mixtures of di- and trinitroglycerine.

Glycerol-2,4-Dinitrophenyl Ether Dinitrate

Dinitrophenylglycerinetherdinitrat;
dinitrate de glycérine-dinitrophényléther; *Dinitryl*

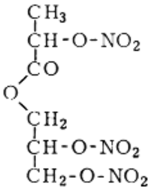


pale yellow crystals
empirical formula: $C_9H_8N_4O_{11}$
molecular weight: 348.2 g/mol
oxygen balance: −50.6%
nitrogen content: 16.09%
density: 1.60 g/cm^3
melting point: 124 °C = 255 °F
lead block test: 320 cm^3/10 g
deflagration point: 205 °C = 400 °F
impact sensitivity: 0.8 kp m = 8 N m

This compound is prepared by reacting glycerol nitrophenyl ether with a nitric acid – sulfuric acid mixture at 25–30 °C. It is insoluble in water, but is readily soluble in acetone. It is a poor gelatinizer of nitrocellulose.

Glycerol Nitrolactate Dinitrate

Dinitroglycerinnitrolactat; *dinitrate-nitrolactate de glycérine*



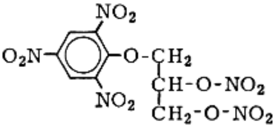
colorless liquid
empirical formula: $C_6H_9N_3O_{11}$
molecular weight: 299.2 g/mol

oxygen balance: −29.7%
nitrogen content: 14.05%
density: 1.47 g/cm^3
refractive index: $n_D^{25} = 1.464$
deflagration point: 190 °C = 374 °F

Dinitroglycerol nitrolactate is practically insoluble in water, readily soluble in alcohol and ether, and is a good gelatinizer of nitrocellulose. It is more resistant to heat and less sensitive to impact than nitroglycerine.

Glycerol Trinitrophenyl Ether Dinitrate

Trinitrophenylglycerinetherdinitrat; *dinitrate de trinitrophenyl-glycérine-éther*



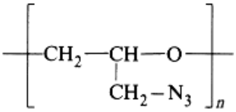
the diole substituted prepolymer forms yellowish,
light-sensitive crystals
empirical formula: $C_9H_7N_5O_{13}$
molecular weight: 393.2 g/mol
oxygen balance: −34.6%
nitrogen content: 17.81%
solidification point: 128.5 °C = 263.3 °F
lead block test: 420 cm^3/10 g
deflagration point: 200–205 °C = 392–400 °F
impact sensitivity: 0.4 kp m = 4 N m

Glycerol trinitrophenyl ether dinitrate is insoluble in water, but is readily soluble in acetone. It does not gelatinize nitrocellulose.

It is prepared by nitration of phenyl glycerol ether with a nitric acid-sulfuric acid mixture.

Glycidyl Azide Polymer

Glycidylazidpolymer; *GAP*



$$\left[-CH_2-\underset{\displaystyle CH_2-N_3}{CH}-O-\right]_n$$

light-yellowish, viscous liquid
empirical formula of structural unit: $C_3H_5N_3O$
molecular weight of structural unit: 99.1 g/mol

mean molecular weight: 2000 g/mol
energy of formation: +1535.2 kJ/kg = +366.9 kcal/kg
enthalpy of formation: 114 kJ/mol = 1150 kJ/kg
oxygen value: −121.1%
nitrogen content: 42.40%
specific energy: 808 kJ/kg
explosion heat (H_2O liq.): 3429 kJ/kg = 820 kcal/kg
normal volume of gases: 946 l/kg
viscosity: 4.28 Pa s
density: 1.29 g/cm^3
deflagration temperature: 216 °C
impact sensitivity: 7.9 N m = 0.8 kp m
sensitivity to friction: at 360 N = 37 kp pin load, no reaction

Glycidyl azide polymer is produced in a two-step process. First, epichlorohydrin in the presence of bortriflouride is polymerized into polyepichlorohydrin. Using dimethylformamide as a solvent, the polymer is then processed with sodium azide at high temperature. Nearly all the inorganic components as well as the solvent are removed, leaving the raw final product free of low molecular weight compounds.

Glycidyl azide polymer was originally developed in the USA as an → *Energetic Binder* for → *Composite Propellants*. The gas-producing component releases at the composition large amounts of nitrogen and thermal energy. It has been used in recent years as an energetic binder compound in → *LOVA* gun propellant and in gas generating propellants, and it has potential for use in fast burning rocket propellants. The disadvantage of GAP is a glass transition point of −45 °C.

Grain

A single mass of solid propellant of the final geometric configuration as used in a gas generator or rocket motor.

Also used as a mass unit for gun propellants. 1 gr = 0.0648 g.

Granulation

Size and shape of granules of pyrotechnic or propellant ingredients. See also → *Grist*

Graphite

C

atomic weight: 12.01

serves for surface smoothing of flake-grained → *Gunpowder* and of → *Black Powder*.

Specifications

moisture:	not more than 0.5%
reaction:	neutral
glow residue in natural graphite:	not more than 25%
scratching parts	not admitted
silicic acid:	none

Green Propellants

In the past, the production, processing and use of many energetic materials has led to the release of substances that can be harmful to humans or the environment and can accumulate in nature. Therefore the use of several defense-important materials has already been restricted or banned, such as → *Dibutyl Phthalate* and → *Dinitrotoluene*.

This fact has resulted in research efforts aimed at developing sustainable green propellants with no impact on human health and the environment.

As a green oxidizer to replace → *Ammoniumperchlorate* (AP) in solid propellants, → *Ammoniumdinitramide* (ADN) is very attractive. The development of green propellants based on ADN is currently the subject of intensive studies.

Reference:

T. Brinck, Green Energetic Materials, 2014, John Wiley & Sons Ltd.

Grist

Particle size of pyrotechnic material.

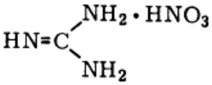
See also → *Granulation*

GSX

Cheap mixture of ammonium nitrate, water, aluminum powder and polystyrene adhesive as a bonding agent. First used in the 6.75 t free fall bomb BLU-82 (Daisy cutter or aerosol bomb). The peak pressure of the bomb ignited approximately 1 m above ground reaches 7 MPa in a radius of 30 m. GSX has been used for mine field clearing and to create instant helicopter landing zones in the Vietnam jungle-war.

Guanidine Nitrate

Guanidinnitrat; *nitrate de guanidine*



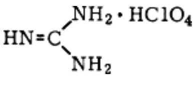
colorless crystals
empirical formula: $CH_6N_4O_3$
molecular weight: 122.1 g/mol
energy of formation: −726.1 kcal/kg = −3038 kJ/kg
enthalpy of formation: −757.7 kcal/kg = −3170.1 kJ/kg
oxygen balance: −26.2%
nitrogen content: 45.89%
volume of explosion gases: 1083 l/kg
heat of explosion
  (H_2O liq.): 587 kcal/kg = 2455 kJ/kg
  (H_2O gas): 447 kcal/kg = 1871 kJ/kg
specific energy: 72.6 mt/kg = 712 kJ/kg
density: 1.436 g/cm^3
melting point: 215 °C = 419 °F
heat of fusion: 48 kcal/kg = 203 kJ/kg
lead block test: 240 cm^3/10 g
deflagration point: 270 °C = 518 °F (decomposition)
impact sensitivity: up to 5 kp m = 50 N m no reaction
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 2.5 mm

Guanidine nitrate is soluble in alcohol and water. It is the precursor compound in the synthesis of → *Nitroguanidine*. It is prepared by fusing dicyanodiamide with ammonium nitrate.

Guanidine nitrate is employed in formulating fusible mixtures containing ammonium nitrate and other nitrates. Such mixtures were extensively used during the war as substitutes for explosives, for which the raw materials were in short supply. However, a high explosive such as → *Hexogen* must usually be added to the mixtures. It was also proposed that guanidine nitrate be used in → *Double-Base Propellants* and gas generating propellants.

Guanidine Perchlorate

Guanidinperchlorat; *perchlorate de guanidine*



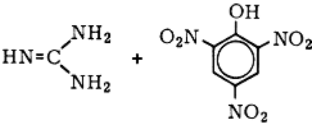
empirical formula: $CH_6N_3O_4Cl$
molecular weight: 159.5 g/mol
energy of formation: −440.1 kcal/kg = −1841.4 kJ/kg
enthalpy of formation: −466.1 kcal/kg = −1950.0 kJ/kg

oxygen balance: −5.0%
nitrogen content: 26.35%
density: 1.82 g/cm^3
melting point: 240 °C = 464 °F
lead block test: 400 cm^3 / 10 g

This compound is prepared from guanidine hydrochloride and sodium perchlorate.

Guanidine Picrate

Guanidinpikrat; *picrate de guanidine*

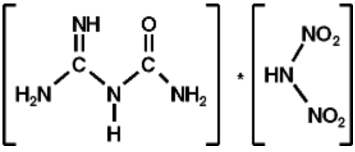


yellow crystals
empirical formula: $C_7H_8N_6O_7$
molecular weight: 288.1 g/mol
oxygen balance: −61.1%
nitrogen content: 29.16%
melting point: 318.5–319.5 °C= 605–606 °F (decomposition)
deflagration point: 325 °C = 617 °F

Guanidine picrate is sparingly soluble in water and alcohol. It is prepared by mixing solutions of guanidine nitrate and ammonium picrate.

Guanylureadinitramide

GUDN; *Guanylureadinitramide*; *N-Guanylharnstoffdinitramid, FOX-12*



white crystals
empirical formula: $C_2H_7N_7O_5$
molecular weight: 209.12 g/mol
energy of formation: −332 kJ / mole
enthalpy of formation: −356 kJ / mole
oxygen balance: −19.13%
volume of explosion gases: 785 l/kg
heat of explosion (calculated)
  (H_2O gas): 2998 kJ/kg
  (H_2O liq.): 3441 kJ/kg

density: 1.75 g/cm^3
specific energy: 950 kJ/kg
melting point: 215 °C
Friction sensitivity (BAM): $>$ 360 N
Impact sensitivity (BAM): 31 N m

GUDN is a high explosive developed by the Swedish Defence Research Agency FOI. It provides good thermal stability, low water solubility and no hygroscopicty. It is used as a fuel in gas-generating compositions, and may be used for LOVA applications.

Guar Gum

Guarkernmehl; *farine de guar*

Guar gum is a water soluble paste made from the seeds of the guar plant *Cyanopsis tetragonoloba*. The product gels with water in the cold. It is added to commercial powder explosives to protect them against water in wet boreholes. Guar gum gelled with water produces a barrier layer that prevents any further penetration of water.

See also → *Water Resistance*; → *Slurries*

Gunpowder

propellant; *Schiesspulver*; *poudre*

The propellant that has exclusively been used for a long time in conventional military weapons is the smokeless (or, more accurately, low-smoke) powder. According to its composition, it can be classified as a single-base powder (e.g. nitrocellulose), a double-base powder (e.g. nitroglycerine) or a triple-base powder (e.g. nitrocellulose plus nitroglycerine (or diglycol dinitrate) plus nitroguanidine powders).

The main component of nitrocellulose powders is nitrocellulose, a mixture of guncotton (13.0–13.4% nitrogen) and soluble guncotton (11–13% nitrogen content). To manufacture the powder, the nitrocellulose mixture is gelatinized with the aid of solvents – mostly alcohol and ether. Additives – stabilizers in particular – can be incorporated at this stage. The plastic solvent-wet mass thus obtained is then shaped in extrusion presses to give strips or tubes and is cut to the desired length by a cutting machine. The residual solvents in the powder are removed by soaking the powder in water and drying. The dried powder is then polished in drums and is graphitized. A surface treatment is performed at the same time, using alcoholic solutions of centralite, dibutyl phthalate, camphor, dinitrotoluene, or other phlegmatization agents.

To make nitroglycerine powder, nitrocellulose is suspended in water, the suspension is vigorously stirred, and nitroglycerine is slowly introduced into the suspension, until practically all of it is absorbed by the nitrocellulose. The bulk of the water (residual water content 25–35%) is then centrifuged off or squeezed out, and the powder paste is ground. It is then mixed by mechanical kneading with nitroglycerine-insoluble additives and is gelatinized on hot rollers, as a result of which the water evaporates, leaving behind a residual water content of about 1%.

This product, which is thermoplastic, can then be geometrically shaped as desired, in accordance with the type of the powder, using finishing rollers, cutting and punching machines, or hydraulic extrusion presses.

This solventless processing avoids variations in the characteristics of the products due to the presence of residual solvents. No prolonged drying operations are needed for ballistic stability of the gunpowder.

If the use of solvents is required in the production process of double- and triple-base propellants, the nitroglycerine can be introduced in the mixtures in the form of a master mix, a gelatinized mixture consisting of 85% nitroglycerine and 15% alcohol-wet nitrocellulose of the same type as the prescribed powder component.

Depending on their intended use, nitroglycerine powders have a nitroglycerine content between 25 and 50%.

In the USA and United Kingdom, a large amount of nitroglycerine and nitroguanidine powders are still produced with the aid of solvents. Acetone is added to nitroglycerine in order to facilitate the kneading and pressing operations, but must be subsequently removed by drying.

A number of liquid nitrate esters other than nitrocellulose have been recently used, including diglycol dinitrate, metriol trinitrate, and butanetriol trinitrate, of which diglycol dinitrate has been the most extensively employed. Powders prepared with diglycol dinitrate or triglycol dinitrate are lower in calories. This fact is relevant to the service life of the gunbarrels in which these powders are utilized. Such powders are known as cold propellants.

Further research for gunbarrel-saving propellants led to the development of nitroguanidine powders, in which → *Nitroguanidine* (picrite) is the third energy-containing component, beside nitroglycerine (or diglycol dinitrate or triglycol dinitrate) and nitrocellulose. Powders containing more than 40% nitroguanidine can be made only with the aid of solvents.

Another special processing method is used for the manufacture of → *Ball Powder*. Floating spheres of concentrated nitrocellulose solutions are cautiously suspended in warm water. The solvent evaporates gradually and the floating spheres solidify. Finally, an intensive surface treatment is needed to reach the desired ballistic behavior. The ballistic properties of a powder are affected not only by its chemical composition, but also by its shape. Thus, in conventional weapons, it ought to bring about progressive burning, or at least ensure that the surface area of the grain remains constant during combustion.

The following geometric forms of powder grains are manufactured:

perforated long tubes
multi perforated tubes
strips
cubes
rings
perforated tubes, cut short
flakes
ball powder
rods, cut short

Finer-grained powders are used for portable firearms; tubular powder is mostly employed for guns; powders in the form of flakes and short tubes are employed for mortars, howitzers, and other high-angle firearms.

Finer-grained powders can be improved in their ballistic behavior by → *Surface Treatment*. Phlegmatizers are infiltrated in the outer layer of the powder grains; the burning rate in the weapon chamber begins slowly and turns progressive.

Gurney Energy

The energy E_G per unit mass available for the acceleration of fragments of detonating explosives. It consists of the kinetic energies of the moving accelerated fragments and fumes.

Gurney Velocity

The velocity of fragments of explosives extrapolated to zero mass.

$$V_\mathrm{G} = \sqrt{2E_\mathrm{G}}$$

Hangfire

Spätzündung; *explosion tardive*

The detonation of an explosive charge at some nondetermined time after its normally designed firing time. This can be a dangerous phenomenon.

Hansen Test

In this stability test, which was proposed by Hansen in 1925, 8 samples of the material to be tested are heated up to 110 °C (230 °F). Every hour one of the samples is taken out of the oven, extracted with CO_2-free water, and the pH of the filtrate determined. Since the decomposition of propellants based on nitrates is usually accompanied by the liberation of CO_2, which interferes with the potentiometric determination, the results obtained are unsatisfactory and the test is now hardly ever used.

HBX, HBX-1 etc.

These are pourable mixtures of TNT, hexogen and aluminum (→ *Torpex*) containing phlegmatizing additives.

Heat of Combustion

Verbrennungswärme; *chaleur de combustion*

Unlike the heat of explosion, the heat of combustion represents the caloric equivalent of the total combustion energy of the given substance. It is determined in a calorimetric bomb under excess oxygen pressure. The heat of combustion is usually employed to determine the heat of formation.

The heat of combustion depends only on the composition of the material and not on any other factor, such as loading density or other factors.

Heat of Explosion

Explosionswärme; *chaleur d'explosion*

The heat of explosion of an explosive material, an explosive mixture, gunpowder or propellant is the heat released during its explosive decomposition. Its magnitude depends on the thermodynamic state of the decomposition products; the data used in practical calculations usually have water (which is a product of the explosion) in the form of vapor as the reference compound.

The heat of explosion may be both theoretically calculated and experimentally determined. The calculated value is the difference between the energies of formation of the explosive components (or of the explosive itself if chemically homogeneous) and the energies of formation of the explosion products (for more details see → *Thermodynamic Calculation of Decomposition Reactions*). The advantage of the calculation method is that the results are reproducible if based on the same energies of formation and if the calculations are all conducted by the same method; this is often done with the aid of a computer.

The values of heats of explosion can also be more simply calculated from the → *Partial Heats of Explosion* of the components of the propellant.

The calculated values do not exactly agree with those obtained by experiment. If the explosion takes place in a bomb, the true compositions of the explosion products are different and, moreover, vary with the loading density. In accurate calculations these factors must be taken into account. In difficult cases (strongly oxygen-deficient compounds and side reactions, such as the formation of CH_4, NH_3, HCN, or HCl), the only solution is to analyze the explosion products. For standard values of heats of formation at constant volume or constant pressure see → *Energy of Formation*.

The experimental determination takes place in a calorimetric bomb. The bomb volume is usually 20 cm^3, but can also be 300 cm^3. The sample quantity is usually chosen to obtain a loading density of 0.1 g/cm^3. If a powder refuses to explode – as is often the case if the heat of explosion is smaller than 800 cal/g – a "hot" powder with a known heat of explosion is added, and the heat of explosion of the sample powder is calculated from that of the mixture and that of the hot powder.

The heat of detonation under CJ conditions (see → *Detonation*) can differ from the explosion value, because the chemical reaction can be influenced by the conditions in the wave front (for example by the loading density of the explosive)19).

Moreover, the detonation energy is related to H_2O in the gaseous state. The calorimetric values as well as the calculated values given for the individual explosives in this book are based on H_2O in the liquid state as a reaction product.

Partial Heat of Explosion

partielle Explosionswärme; *chaleur partielle d'explosion*

A. Schmidt proposed a simplified way of estimating the probable heat of explosion of a propellant. In this method, a partial heat of explosion is assigned to each component of the powder. Materials with high negative oxygen balances (e.g. stabilizers and gelatinizers) are assigned negative values for the partial heat of explosion. The explosion heat of the propellant is calculated by the addition of the partial values weighted in proportion to the respective percentage of the individual components.

A number of such values have been tabulated. The value for trinitroglycerine is higher than its heat of explosion, since the excess oxygen reacts with the carbon of the other components.

The values refer to water in the liquid state as a reaction product.

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19) Ornellas, D.L. (1974) The heat and products of detonation in a calorimeter of CNO, HNO, CHNF, CHNO, CHNOF, and CHNOSi explosives. *Combustion and Flame*, **23**, 37–46.

Table 14 Values for the partial heat of explosion.

Component	Partial heat of explosion (kcal/kg)	(kJ/kg)
Akardite I	−2283	−9559
Akardite II	−2300	−9630
Akardite III	−2378	−9957
Ammonium nitrate	+1450	+6071
Barium nitrate	+1139	+4769
Barium sulfate	+132	+553
Butanetriol trinitrate (BTN)	+1400	+5862
Camphor	−2673	−11 192
Candelilla wax	−3000	−12 561
Carbon black	−3330	−13 942
Centralite I	−2381	−9969
Centralite II	−2299	−9626
Centralite III	−2367	−9911
Cupric salicylate	−1300	−5443
Basic cupric salicylate	−900	−3768
Diamyl phthalate (DAP)	−2187	−9157
Dibutyl phthalate (DBP)	−2071	−8671
Dibutyl tartrate (DBT)	−1523	−6377
Dibutyl sebacate (DBS)	−2395	−10 028
Diethyleneglycol dinitrate (DEGN, DEGDN)	+1030	+4313
Dioxyethylnitramine dinitrate (DINA)	+1340	+5610
Diethyl phthalate (DEP)	−1760	−7369
Diethyl sebacate (DES)	−2260	−9463
Diisobutyl adipate (DIBA)	−2068	−8658
Dimethyl phthalate (DMP)	−1932	−8089
Dinitrotoluene (DNT)	−148	−620
Dioctyl phthalate (DOP)	−2372	−9931
Diphenylamine (DPA)	−2684	−11 238
Diphenyl phthalate (DPP)	−2072	−8675
Diphenylurea	−2227	−9324
Diphenylurethane	−2739	−11 468
Ethyleneglycol dinitrate	+1757	+7357
Ethylphenylurethane	−1639	−6862
Glycol	−889	−3722
Graphite	−3370	−14 110
Lead acetyl salicylate	−857	−3588
Lead ethylhexanoate	−1200	−5024

Table 14 Continued.

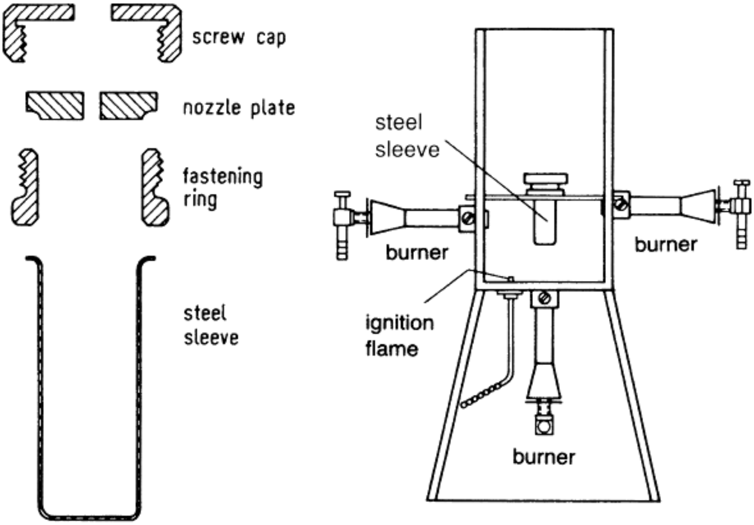
Component	Partial heat of explosion (kcal/kg)	(kJ/kg)
Lead salicylate	−752	−3149
Lead stearate	−2000	−8374
Lead sulfate	+150	+628
Methyl methacrylate (MMA)	−1671	−6996
Metriol trinitrate (MTN)	+1189	−4978
Mineral jelly	−3302	−13 825
Nitrocellulose, 13.3% N	+1053	+4409
Nitrocellulose, 13.0% N	+1022	+4279
Nitrocellulose, 12.5% N	+942	+3944
Nitrocellulose, 12.0% N	+871	+3647
Nitrocellulose, 11.5% N	+802	+3358
Nitroglycerine (NG)	+1785	+7474
Nitroguanidine (picrite)	+721	+3019
Pentaerythritol tetranitrate (PETN)	+1465	+6134
Pentaerythritol trinitrate (PETRIN)	+1233	+5163
Polyethylene glycol (PEG)	−1593	−6670
Poly methacrylate (PMA)	−1404	−5879
Polyvinyl nitrate (PVN)	+910	+3810
Potassium nitrate	+1434	+6004
Potassium perchlorate	+1667	+6980
Potassium sulfate	+300	+1256
Triacetin (TA)	−1284	−5376
Triethyleneglycol dinitrate (TEGN)	+750	+3140
Trinitrotoluene (TNT)	+491	+2056

Heat Sensitivity

thermische Sensibilität; *sensitiveness to heat*; *sensibilité au chauffage*

Heat sensitivity is determined by testing the flammability of explosives brought into contact with glowing objects, flame, sparks, the initiating flame of a black powder safety fuse, a red-hot iron rod or a flame.

RID (Règlement International concernant le Transport des Marchandises Dangereuses) describes a method in which a sample of about 500 g of the explosive, accommodated in a metal can of given dimensions, is exposed to a wood fire, and its behavior (combustion, intense decomposition or detonation) is observed.



Parts of the steel sleeve

The steel sleeve in the burner support

Figure 16 Steel sleeve test (Koenen test).

In response to a suggestion made by *Koenen* (Bundesanstalt für Materialprüfung, Berlin, Germany), these tests, which are carried out with the purpose of evaluating the safety during transport, were improved as described below; the method is known as the steel sleeve test (Koenen test).

Koenen Test Procedure

The sample substance is introduced into a cylindrical steel sleeve (25 mm dia. × 24 mm dia. × 75 mm) up to a height of 60 mm, and the capsule is closed with a nozzle plate with a central hole of a given diameter. The diameter of the hole can vary between 1 and 20 mm; when the plate is not employed, the effect is equivalent to that of a 24-mm hole. The charged sleeve is placed inside a protective box and is simultaneously heated by four burners; the time elapsed up to incipient combustion and the duration of the combustion itself are measured with a stop watch. The plate perforation diameter is varied, and the limiting perforation diameter corresponding to an explosion caused by accumulation of pressure inside the steel sleeve is determined. Explosion is understood to mean fragmentation of the sleeve into three or more fragments or into a greater number of smaller fragments.

In this way, reproducible numerical data are obtained which allow classification of different explosives according to the explosion danger they represent.

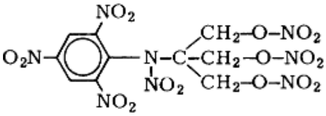
The parameter reported is the largest diameter of the circular perforation in mm (limiting diameter) at which at least one explosion occurs in the course of three successive trials.

Table 15 Results of steel sleeve test.

Explosive material	Limiting diameter (mm)	Time to ignition (s)	Time of combustion (s)
A. Homogeneous explosives			
Nitroglycerine	24	13	0
Nitroglycol	24	12	10
Nitrocellulose, 13.4% N	20	3	0
Nitrocellulose, 12.0% N	16	3	0
Hexogen	8	8	5
Ammonium perchlorate	8	21	0
PETN	6	7	0
Tetryl	6	12	4
TNT	5	52	29
Picric acid	4	37	16
Dinitrotoluene	1	49	21
Ammonium nitrate	1	43	29
B. Industrial explosives			
Blasting gelatin	24	8	0
Guhr dynamite	24	13	0
Gelignite	20	7	0
Ammonium nitrate gelatin	14	10	0
Ammonium-nitrate-based powder-form explosives	1.5–2.5	25	40
Nitrocarbonitrates	2	25	4
ANFO blasting agents	1.5	33	5
Gelatinous permitted explosives	14	12	0
Ion-exchanged powder-form permitted explosives	1	35	5

Heptryl

N-(2,4,6 Trinitrophenyl-N-nitramino)-trimethylolmethane trinitrate; *Trinitrate de trinitrophényl-nitramino-triméthylolméthane*



yellow crystals
empirical formula: $C_{10}H_8N_8O_{17}$
molecular weight: 512.24 g/mol
energy of formation: −96.8 kcal/kg = −405.0 kJ/kg
oxygen balance: −21.9%
nitrogen content: 21.9%
volume of explosion gases: 787 l/kg
specific energy: 1261 kJ/kg
melting point: 154 °C = 309 °F (decomposition)
deflagration point: 180 °C = 356 °F
heat of combustion: 2265.9 kcal/kg

Heptryl is comparable in power and sensitivity to PETN. It can be prepared by nitrating 2,4-dinitroanilinotrimethylolmethane with mixed nitric-sulfuric acid and purified by reprecipitation from acetone.

HEX

Abbreviation for high energy explosive. The HEX series comprises modifications of → *Torpex*.

Hexachloroethane

Hexachlorethan, HC

Hexachlorethane (HC) was previously one component of ZnO/Al/hexachlorethane (HC) mixtures used in (white) smoke and fog generating munitions. In these mixtures, $ZnCl_2$ (and graphite) is formed as an intermediate which then quickly hydrolyses to form HCl and ZnO. Formulations of this type are no longer used by NATO armies, since some of the side-products of the reactions have been found to be toxicologically and ecologically undesirable (e.g. hexachlorobenzene, hexachlorobutadiene, chlorinated dibenzofurane and dibenzodioxine).

Hexal

Mixture of hexogen, aluminum powder and wax as phlegmatizer. It is used, press-molded, as a filling for anti-aircraft gunshells. Owing to the aluminum component, both an incendiary and an explosive effect are obtained.

Hexamethylene Diisocyanate

Hexamethylendiisocyanat; *diisocyanate d'hexaméthyléne*

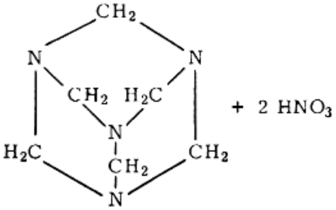
$O{=}C{=}N{-}(CH_2)_6{-}N{=}C{=}O$
colorless liquid
empirical formula: $C_8H_{12}N_2O_2$
molecular weight: 168.2 g/mol
energy of formation: −468 kcal/kg = −1961 kJ/kg
enthalpy of formation: −496 kcal/kg = −2078 kJ/kg
oxygen balance: −205.4%
nitrogen content: 16.66%
density 20/4: 1.0528 g/cm^3
boiling point at 0.013 bar: 124 °C = 255 °F

The compound acts as a hydroxy curing agent in the formation of polyurethane binders of → *Composite Propellants*.

See also → *Casting of Propellants*

Hexamethylenetetramine Dinitrate

exametylentetramindinitrat; *dinitrate d'hexaméthylene tétramine*



colorless crystals
empirical formula: $C_6H_{14}N_6O_6$
molecular weight: 266.2 g/mol
energy of formation: −309.9 kcal/kg = −1296.6 kJ/kg
enthalpy of formation: −338.8 kcal/kg = −1417.7 kJ/kg
oxygen balance: −78.3%
nitrogen content: 31.57%
volume of explosion gases: 1081 l/kg
heat of explosion
(H_2O liq.): 631 kcal/kg = 2642 kJ/kg
(H_2O gas): 582 kcal/kg = 2434 kJ/kg

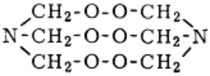
specific energy: 76.4 mt/kg = 749 kJ/kg
density: 1.57 g/cm^3
melting point: 158 °C = 316 °F (decomposition)
lead block test: 220 cm^3/10 g
impact sensitivity: 1.5 kp m = 15 N m
friction sensitivity: at 24 kp = 240 N pistil load reaction

This salt is soluble in water, but insoluble in alcohol, ether, chloroform, and acetone.

Hexamethylenetetramine dinitrate can be prepared from hexamethylenetetramine and nitric acid of medium concentration. It is an important precursor of hexogen manufactured by the Bachmann method.

Hexamethylenetriperoxide Diamine

Hexamethylentriperoxiddiamin; *hexamethylenetriperoxyde diamine*; *HMTD*



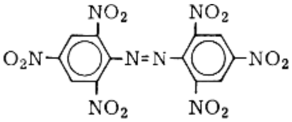
colorless crystals
empirical formula: $C_6H_{12}N_2O_6$
molecular weight: 208.1 g/mol
energy of formation: −384.3 kcal/kg = −1608 kJ/kg
enthalpy of formation: −413.7 kcal/kg = −1731 kJ/kg
oxygen balance: −92.2%
nitrogen content: 13.46%
volume of explosion gases: 1075 l/kg
heat of explosion
  (H_2O liq.): 825 kcal/kg = 3450 kJ/kg
  (H_2O gas): 762 kcal/kg = 3188 kJ/kg
specific energy: 87.3 mt/kg = 856 kJ/kg
density: 1.57 g/cm^3
lead block test: 330 cm^3/10 g
detonation velocity: 4500 m/s = 15 000 ft/s
deflagration point: 200 °C = 390 °F
beginning of decomposition: 150 °C = 300 °F
impact sensitivity: 0.06 kp m = 0.6 N m
friction sensitivity: at 0.01 kp = 0.1 N pistil load reaction

This peroxide is practically insoluble in water and in common organic solvents. It is prepared from hexamethylenetetramine and hydrogen peroxide in the presence of citric acid, with efficient cooling.

It is an effective initiating explosive. Nevertheless, it cannot be employed in practice owing to its poor storage properties. The thermal and mechanical stability is low.

Hexanitroazobenzene

Hexanitroazobenzol; *hexanitroazobenzène*

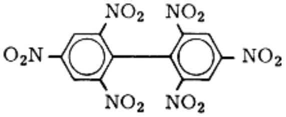


orange red crystals
empirical formula: $C_{12}H_4N_8O_{12}$
molecular weight: 452.2 g/mol
oxygen balance: −49.7%
nitrogen content: 24.78%
melting point: 221 °C = 430 °F

This compound can be prepared from dinitrochlorobenzene and hydrazine. The tetranitrohydrazobenzene, which is obtained as an intermediate product, is treated with mixed acid, yielding hexanitroazobenzene by simultaneous oxidation and nitration. It is a more powerful explosive than → *Hexanitrodiphenylamine*.

2,4,6,2′,4′,6′-Hexanitrobiphenyl

Hexanitrobiphenyl; hexanitrobiphényle

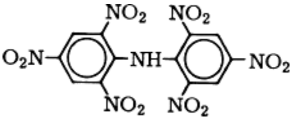


pale yellow crystals
empirical formula: $C_{12}H_4N_6O_{12}$
molecular weight: 424.2 g/mol
oxygen balance: −52.8%
nitrogen content: 19.81%
density: 1.6 g/cm^3
melting point: 263 °C = 505 °F
lead block test: 344 cm^3/10 g
deflagration point: 320 °C = 610 °F

Hexanitrobiphenyl is insoluble in water, but is soluble in alcohol, benzene, and toluene. It is a rather heat-insensitive explosive.

2,4,6,2′,4′,6′-Hexanitrodiphenylamine

dipicrylamine; Hexanitrodiphenylamin; hexanitrodiphenylamine; hexyl; hexite; HNDPhA: HNDP



yellow crystals
empirical formula: $C_{12}H_5N_7O_{12}$
molecular weight: 439.2 g/mol
energy of formation: +38.7 kcal/kg = +162 kJ/kg
enthalpy of formation: +22.5 kcal/kg = +94.3 kJ/kg
oxygen balance: −52.8%
nitrogen content: 22.33%
volume of explosion gases: 791 l/kg
heat of explosion
  (H_2O liq.): 974 kcal/kg = 4075 kJ/kg
  (H_2O gas): 957 kcal/kg = 4004 kJ/kg
specific energy: 1098 kJ/kg
density: 1.64 g/cm^3
melting point: 240–241 °C = 464–466 °F (decomposition)
lead block test: 325 cm^3/10 g
detonation velocity, confined: 7200 m/s = 23 600 ft/s
  at $\rho = 1.60$ g/cm^3
deflagration point: 250 °C = 480 °F
impact sensitivity: 0.75 kp m = 7.5 N m
friction sensitivity: up to 353 N no reaction
critical diameter of steel sleeve test: 5 mm

This explosive is toxic (the dust attacks the skin and mucous membranes) and light-sensitive. It is insoluble in water and most organic solvents. It forms sensitive acid salts.

It is prepared by nitration of *asym*-dinitrodiphenylamine with concentrated nitric acid. *Asym*-dinitrodiphenylamine is formed by condensation of dinitrochlorobenzene with aniline.

Its stability and brisance, as well as its sensitivity, are somewhat higher than those of picric acid.

Hexanitrodiphenylamine has been employed in underwater explosives in the form of pourable mixtures with TNT and aluminum powder. Since hexanitrodiphenylamine is toxic and is strongly colored, such mixtures are usually replaced by better ones, such as → *Torpex* or → *HBX*.

By itself hexanitrodiphenylamine is an explosive with a relatively low sensitivity to heat.

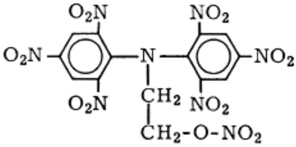
The compound has been used as a precipitant for potassium.

Specifications

melting point:	not less than 230 °C = 446 °F
insolubles in 1 : 3 pyridine acetone mixture:	not more than 0.1%

Hexanitrodiphenylaminoethyl Nitrate

Hexanitrodiphenylaminoethylnitrat; *nitrate d'hexanitrodiphényleamino-éthyle*

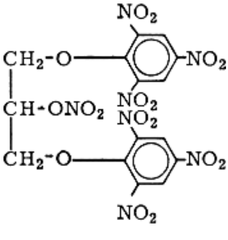


pale yellow platelets

empirical formula: $C_{14}H_8N_8O_{15}$
molecular weight: 528.3 g/mol
oxygen balance: −51.5%
nitrogen content: 21.21%
melting point: 184 °C = 363 °F
deflagration point: 390−400 °C = 735−750 °F

Hexanitrodiphenylglycerol Mononitrate

Heptanitrophenylglycerin; *mononitrate d'hexanitrodiphényleglycérine*



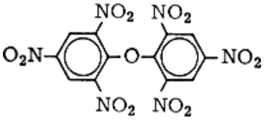
yellow crystals
empirical formula: $C_{15}H_9N_7O_{17}$
molecular weight: 559.3 g/mol
oxygen balance: −50.1%
nitrogen content: 17.22%
melting point: 160−175 °C = 320−347 °F
lead block test: 355 cm^3 / 10 g
impact sensitivity: 2.3 kp m = 23 N m

This compound is soluble in glacial acetic acid, sparingly soluble in alcohol, and insoluble in water.

It is prepared by dissolving glyceryl diphenyl ether in nitric acid and pouring the resulting solution into mixed acid.

2,4,6,2′,4′,6′-Hexanitrodiphenyl Oxide

Hexanitrodiphenyloxid; *hexanitrodiphényloxyde*

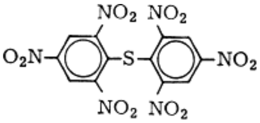


yellow crystals
empirical formula: $C_{12}H_4N_6O_{13}$
molecular weight: 440.2 g/mol
oxygen balance: −47.3%
nitrogen content: 19.09%
density: 1.70 g/cm^3
melting point: 269 °C = 516 °F
lead block test: 373 cm^3/10 g
detonation velocity, confined: 7180 m/s = 23 600 ft/s
at $\rho = 1.65$ g/cm^3
impact sensitivity: 0.8 kp m = 8 N m

Hexanitrodiphenyl oxide is insoluble in water, but is sparingly soluble in alcohol and ether. It is a very stable compound, which is less sensitive to impact, but is a more powerful explosive than picric acid. It is prepared by nitrating dinitro-, trinitro-, tetranitro- and pentanitro-substituted diphenyl ether with mixed acid.

2,4,6,2′,4′,6′-Hexanitrodiphenylsulfide

Hexanitrodiphenylsulfid; Picrylsulfid; hexanitrodiphenylsulfide



reddish-yellow granular powder
empirical formula: $C_{12}H_4N_6O_{12}S$
molecular weight: 456.2 g/mol
oxygen balance: −56.1%
nitrogen content: 18.42%
density: 1.65 g/cm^3

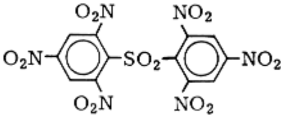
melting point: 234 °C = 453 °F
lead block test: 320 cm^3/10 g
detonation velocity, confined: 7000 m/s = 23 000 ft/s
at $\rho = 1.61$ g/cm^3
deflagration point: 305–320 °C = 580–610 °F
impact sensitivity: 0.5 kp m = 6 N m

This explosive is not toxic, and its technological blasting performance resembles that of hexanitrodiphenylamine. It is sparingly soluble in alcohol and ether, but is readily soluble in glacial acetic acid and acetone.

It is prepared by reacting trinitrochlorobenzene with sodium thiosulfate in alkaline solution. It is relatively heat-insensitive.

2,4,6,2′,4′,6′-Hexanitrodiphenylsulfone

Hexanitrosulfobenzid; hexanitrodiphenylsulfone

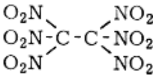


pale yellow crystals
empirical formula: $C_{12}H_4N_6O_{14}S$
molecular weight: 488.2 g/mol
oxygen balance: −45.8%
nitrogen content: 17.22%
melting point: 307 °C = 585 °F

Hexanitrodiphenylsulfone is soluble in acetone, but sparingly soluble in benzene and toluene. Its stability is satisfactory. It is prepared by oxidation of hexanitrodiphenylsulfide.

Hexanitroethane

Hexanitroethan; *hexanitroéthane*; *HNE*

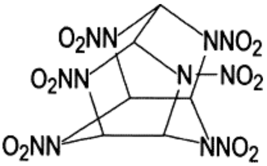


colorless powder
empirical formula: $C_2N_6O_{12}$
molecular weight: 300.1 g/mol
energy of formation: +101.8 kcal/kg = +425.9 kJ/kg
enthalpy of formation: +63.3 kcal/kg = +264.9 kJ/kg
oxygen balance: +42.7%
nitrogen content: 28.01%
volume of explosion gases: 734 l/kg

heat of explosion: 689 kcal/kg = 2884 kJ/kg
specific energy: 80.5 mt/kg = 789 kJ/kg
density: 1.85 g/cm^3
melting point: 147 °C = 297 °F
vapor pressure is relatively high
transformation point: 17 °C = 63 °F
lead block test: 245 cm^3/10 g
detonation velocity, confined: 4950 m/s = 16 240 ft/s
  at $\rho = 0.91$ g/cm^3
deflagration point: 175 °C = 347 °F
friction sensitivity: 240 N

Hexanitrohexaazaisowurtzitane

Hexanitrohexaazaisowurtzitan; *HNIW; CL-20; 2,4,6,8,10,12-(hexanitrohexaaza)-tetracyclododecane*



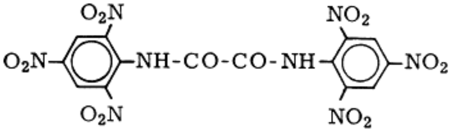
empirical formula: $C_6H_6N_{12}O_{12}$
molecular weight: 438.19 g/mol
energy of formation: +240.3 kcal/kg = +1005.3 kJ/kg
enthalpy of formation: +220.0 kcal/kg = +920.5 kJ/kg
oxygen balance: −10.95%
nitrogen content: 38.3%
heat of explosion
  (H_2O liq.): 1509 kcal/kg = 6314 kJ/kg
  (H_2O gas): 1454 kcal/kg = 6084 kJ/kg
specific energy: 134.9 mt/kg = 1323 kJ/kg
density: 2.04 g/cm^3 (epsilon phase)
melting point: > 195 °C (decomposition)
impact sensitivity: 0.4 kp m = 4 N m
friction sensibility: 4.9 kp = 48 N

Hexanitrohexaazaisowurtzitane is obtained by condensing glyoxal with benzylamine to yield hexabenzylhexaazaisowurtzitane. Next the benzyl groups are replaced under reducing conditions by easily removable substituents such as acetyl or silyl groups. Nitration to form hexanitrohexaazaisowurtzitane takes place in the final reaction step. Hexanitrohexaazaisowurtzitane exists in various crystal modifications; only the ε-modification is of interest because of its high density and detonation velocity of more than 9000 m/s.

Being one of the most energy-rich organic explosives, CL-20 is attractive for many energetic systems.

Hexanitrooxanilide

Hexanitrodiphenyloxamid; *HNO*

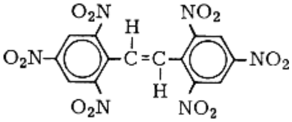


empirical formula: $C_{14}H_6N_8O_{14}$
molecular weight: 510.1 g/mol
oxygen balance: −53.3%
nitrogen content: 21.97%
melting point: 295−300 °C = 565−570 °F
decomposition temperature: 304 °C = 579 °F

This compound is prepared by nitration of oxanilide. It is of interest because it is relatively stable at high temperatures. The decomposition reaction above 304 °C is endothermic.

Hexanitrostilbene

Hexanitrostilben; *hexanitrostilbène*; *HNS*

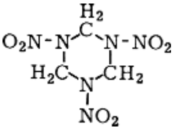


yellow crystals
empirical formula: $C_{14}H_6N_6O_{12}$
molecular weight: 450.1 g/mol
energy of formation: +57.3 kcal/kg = +239.8 kJ/kg
enthalpy of formation: +41.5 kcal/kg = +173.8 kJ/kg
oxygen balance: −67.6%
nitrogen content: 18.67%
volume of explosion gases: 766 l/kg
heat of explosion
  (H_2O liq.): 977 kcal/kg = 4088 kJ/kg
  (H_2O gas): 958 kcal/kg = 4008 kJ/kg
density: 1.74 g/cm^3
melting point: 318 °C = 604 °F (decomposition)
lead block test: 301 cm^3/10 g
impact sensitivity: 0.5 kp m = 5 N m
friction sensitivity: > 240 N

HNS is a heat-resistant high explosive used in aerospace applications, for ammunition, and in oil and gas exploration, when a high thermal stability is required. It is commercially produced by oxidizing → *Trinitrotoluene* with a solution of sodium hypochlorite.

Hexogen

cyclo-1,3,5-trimethylene-2,4,6-trinitramine; Cyclonite; *Trimethylentrinitramin*; *hexogène*; *RDX; T 4*



colorless crystals
empirical formula: $C_3H_6N_6O_6$
molecular weight: 222.1 g/mol
energy of formation: +401.8 kJ/kg
enthalpy of formation: +301.4 kJ/kg
oxygen balance: −21.6%
nitrogen content: 37.84%
volume of explosion gases: 903 l/kg
heat of explosion (calculated)[20]
  (H_2O liq.): 5647 kJ/kg
  (H_2O gas): 5297 kJ/kg
heat of detonation:[21] (H_2O liq.): 6322 kJ/kg
specific energy:1375 kJ/kg
density: 1.82 g/cm³
melting point: 204 °C
heat of fusion: 161 kJ/kg
vapor pressure:

Pressure (Pa)	**Temperature (°C)**
0.0 54	110
0.1 4	121
0.3 4	131
0.5 3	138.5

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[20] Computed by ICT-Thermodynamic-Code.

[21] Value quoted from Dobratz, B.M. (1981) *Properties of Chemical Explosives and Explosive Simulants*, University of California, Livermore.

lead block test: 480 $cm^3/10$ g
detonation velocity, confined: 8750 m/s at $\rho = 1.76\,g/cm^3$
impact sensitivity: 7.5 N m
friction sensitivity: 120 N
critical diameter of steel sleeve test: 8 mm

Hexogen is soluble in acetone, insoluble in water and sparingly soluble in ether and ethanol. Cyclohexanone, nitrobenzene and glycol are solvents at elevated temperatures.

Hexogen is currently probably the most important high-brisance explosive; its brisant power is high owing to its high density and high detonation velocity. It is relatively insensitive (compared to → *PETN*, which is an explosive of a similar strength). It is very stable. Its performance properties are only slightly inferior to those of the homologous → *Octogen* (HMX).

The classical method of production (Henning, 1898) is the nitration of hexamethylene tetramine ($C_6H_{12}N_4$) to hexogen ($C_3H_6O_6N_6$) using concentrated nitric acid; the concentrated reaction mixture is poured into iced water, and the product precipitates out. The structural formula shows that three methylene groups must be destroyed or split off by oxidation. As soon as this problem and the attendant dangers had been mastered, industrial-scale production became possible, and during Second World War, hexogen was manufactured in large quantities on both sides, using several mutually independent chemical methods.

S-H process (inventor Schnurr): continuous nitration of hexamethylenetetramine using highly concentrated nitric acid, accompanied by a decomposition reaction under liberation of nitrous gases, without destruction of the hexogen formed. The reaction mixture is then filtered to separate the product from the waste acid, followed by stabilization of the product by boiling under pressure and, if required, recrystallization.

K process (inventor Knöffler): an increased yield is obtained by the addition of ammonium nitrate to the nitration mixture of hexamethylene tetramine and nitric acid, followed by warming. The formaldehyde as a by-product forms more hexamethylenetetramine with the added ammonium nitrate and is converted by the nitric acid into hexogen.

KA process (inventors Knöffler and Apel; in USA Bachmann): hexamethylenetetramine dinitrate is reacted with ammonium nitrate and a small amount of nitric acid in an acetic anhydride medium. Hexogen is formed in a similar manner as in the E process. The waste acetic acid thus formed is concentrated, subjected to the so-called ketene process, recycled, and the regenerated acetic anhydride is re-used.

E process (inventor Eble): paraformaldehyde and ammonium nitrate are reacted in an acetic anhydride medium with formation of hexogen (precursor of KA process).

W process (inventor Wolfram): potassium amidosulfonate and formaldehyde are reacted to give potassium methyleneamidosulfonate ($CH_2{=}N{-}SO_3K$), which is then nitrated to cyclonite by a nitric acid-sulfuric acid mixture.

Phlegmatized and pressed hexogen is used as a highly brisant material for the manufacture of → *Booster* and → *Hollow Charges*. Nonphlegmatized hexogen in combination with TNT is also used as a pourable mixture for hollow charges and brisant explosive charges (→ *Compositions B*); mixtures of Cyclonite with aluminum powder are used as torpedo charges *(Hexotonal*, → *Torpex*, → *Trialen*). Hexogen may also be used as an additive in the manufacture of smokeless powders.

Manufacturing explosive charges which are required to have a certain mechanical strength or rubber-elastic toughness, hexogen is incorporated into curable plastic materials such as polyurethanes, polybutadiene or polysulfide and the mixture is poured into molds (see → *Plastic Bonded Explosives*).

Specifications

melting point:	at least 200 (°C)
for products prepared by the acetic anhydride method:	at least 190 (°C)
acidity, as HNO_3:	not more than 0.05%
acetone-insolubles:	not more than 0.025%
ashes:	not more than 0.03%
sandy matter:	none

HMX

An abbreviation for High Melting Explosive, High-velocity Military Explosive or His/Her Majesty Explosive. Homocyclonite, the US name for → *Octogen*.

Hollow Charge

Hohlladung

See → *Shaped Charge*.

Hot-Needle Test

The Hot-Needle (or Köhler) Test is a simple method that can be used to estimate whether a new compound might show a fast DDT and could therefore be a possible new primary explosive. In this test, a few milligrams of the compound are placed on a paper sheet and confined by covering it with cellotape. A hot needle (heated in a Bunsen burner) is then placed on the cellotape. An immediate and sharp bang provides the first indication that the compound may be a primary explosive.

Hotspots

This term denotes the increase of the detonation sensibility of explosives by finely dispersed air bubbles. The loss in sensitivity to detonation of gelatinous nitroglycerine explosives by long storage has been known since the time of Alfred Nobel; it is due to the loss or coagulation of the air bubbles that may have been left in the explosive by the manufacturing process. This effect can be explained by the adiabatic compression and heating of the air inclusions as the detonation wave is passing (see → *Detonation Wave Theory*). This effect was used to make the recently developed, cap sensitive → *Emulsion Slurries*. Conservation and independence from pressure of the air inclusions can be achieved by so-called → *Microballoons*.

Hot Storage Tests

Warmlagertest; *épreuves de chaleur*

These tests are applied to accelerate the decomposition of an explosive material, which is usually very slow at normal temperatures. They are able to evaluate the stability and the expected service life of the material from the kind and the amount of the decomposition products. Various procedures, applicable at different temperatures, may be employed for this purpose.

1. Methods in which the escaping nitrous gases can be recognized visually or by noting the color change of a strip of dyed filter paper. The former methods include the qualitative tests at 132, 100, 75, and 65.5 °C (270, 212, 167, and 150 °F). These tests include the US supervision test, the methyl violet test, the Abel test, and the Vieille test.
2. Methods involving quantitative determination of the gases evolved. Here we distinguish between tests for the determination of acidic products (nitrous gases) only, such as the Bergmann–Junk test, and methods that determine all the decomposition products, including manometric methods and weight loss methods.
3. Methods which give information on the extent of decomposition of the explosive material (and thus also on its stability), based on the kind and the amount of the decomposition products of the stabilizer formed during the storage. These include polarographic, thin-layer chromatographic and spectrophotometric methods.

4. Methods providing information on the stability of the explosive based on the heat of decomposition evolved during storage (such as the silvered vessel test).
5. Methods in which stability can be estimated from the physical degradation of a nitrocellulose gel (viscometric measurements).

The tests actually employed vary with the kind of explosive tested (explosives, single-base, double-base or triple-base powders, or solid propellants) and the temporal and thermal exposure to be expected (during rapid railway transportation or many years' storage under varying climatic conditions). In the case of propellants about to be transported by train, only short-time testing is required. However, to obtain an estimate of the expected service life, the so-called long-time tests must be performed at 75 °C (167 °F) and below. The duration of such storage is up to 24 months, depending on the propellant type. Short-time tests – the Bergmann–Junk test, the Dutch test, the methyl violet test, the Vieille test, and, very rarely, the Abel test – are mostly employed in routine control of propellants of known composition, i.e. propellants whose expected service life may be assumed to be known. In selecting the test to be applied, the composition of the propellant and the kind and amounts of the resulting decomposition products must also be considered.

Contrary to the common propellants, which contain nitrates, the so-called composite propellants cannot be tested in the conventional manner owing to the relatively high chemical stability of the incorporated oxidants, e.g. ammonium perchlorate. In such cases the stability criterion of the propellants is the condition of the binder and its chemical and physical change.

HU-Zünder

HU-detonators have a high safety against static electricity, stray currents and energy from lightning discharge. They are safe against 4 A and 1100 mJ/Ω. All-fire current is 25 A; all-fire energy is 2500 mJ/Ω. They were developed by Dynamit Nobel as instantaneous detonators and as 20-ms and 30-ms short-period delays (18 delays each), and as 250-ms long-period delays (24 delays).

The corresponding blasting machines (HU-Zündmaschinen) were developed by ZEB Zünderwerke Ernst Brün GmbH, Haltern, Germany.

Hybrids

lithergoles

Hybrids is the name given in rocket technology to systems in which a solid fuel in the form of a case-bonded charge with a central perforation is reacted with a liquid oxidant. Hybrids with solid oxidant and liquid fuel also exist. Hybrids can be thrust-controlled during combustion and can even be re-ignited if hypergolic components are incorporated in the formulation of the fuel charge.

Hydan

Smokeless binary liquid explosive based on hydrazine hydrate and → *Ammonium Nitrate* $(NH_2)_2 \cdot H_2O/NH_4NO_3$, developed by A. Kappl at Dynamit Nobel Wien in 1994. Some characteristic values for a 50/50 mixture:

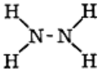
Hydan II:	oxygen balance	[%]	–4.0
	heat of explosion	[kJ/kg]	3879
	fume volume	[l/kg]	1112
	explosion temperature	[°C]	2400
	specific energy	[mt/kg]	112.3
	brisance (Kast)	$[10^6]$	105.3
	specific weight ρ	$[g/cm^3]$	1.36
	detonation velocity	[m/s]	7150[a)]

a) Ignition with 2 g → *Pentrit-Booster*.

Despite a favorable price, high security, and stability when stored separately, these explosive mixtures have no civilian market due to the handling problems of hydrazine hydrate (it is corrosive and toxic). It can be used as a liquid, cold-burning monergole propellant (→ *Monergol*) with a low smoke signature. Japanese and US institutions have worked on similar mixtures for use in ship artillery (see → *Liquid Propellants*).

Hydrazine

Hydrazin; *hydrazine*

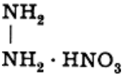


colorless liquid
empirical formula: H_4N_2
molecular weight: 32.05 g/mol
energy of formation: +433.1 kcal/kg = +1812 kJ/kg
enthalpy of formation: +377.5 kcal/kg = +1580 kJ/kg
oxygen balance: −99.9%
nitrogen content: 87.41%
density: 1.004 g/cm^3
melting point: 2.01 °C
boiling point: 114.2 °C

Hydrazine and alkylhydrazines are important propellants in rocket engines, especially for flight control rockets which are actuated only for short periods of time during space travel. In the presence of special catalysts, hydrazine can be made to decompose within milliseconds (see also → *Dimethylhydrazine*). Hydrazine and its derivatives are toxic.

Hydrazine Nitrate

Hydrazinnitrat; *nitrate d'hydrazine*



$$\begin{array}{l} NH_2 \\ | \\ NH_2 \cdot HNO_3 \end{array}$$

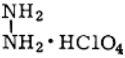
colorless crystals
empirical formula: $H_5N_3O_3$
molecular weight: 95.1 g/mol
energy of formation: −586.4 kcal/kg = −2453 kJ/kg
enthalpy of formation: −620.7 kcal/kg = −2597 kJ/kg
oxygen balance: −8.6%
nitrogen content: 44.20%
volume of explosion gases: 1001 l/kg
heat of explosion
  (H_2O liq.): 1154 kcal/kg = 4827 kJ/kg
  (H_2O gas): 893 kcal/kg = 3735 kJ/kg
specific energy: 108 mt/kg = 1059 kJ/kg
density: 1.64 g/cm^3
melting point: stable modification: 70.7 °C = 159.3 °F
unstable modification: 62.1 °C = 143.8 °F
lead block test: 408 cm^3/10 g
detonation velocity, confined: 8690 m/s = 28 500 ft/s
  at $\rho = 1.60$ g/cm^3
decomposition temperature: 229 °C = 444 °F
impact sensitivity: 0.75 kp m = 7.4 N m
critical diameter of steel sleeve test: 6 mm

Hydrazine nitrate is readily soluble in water.

The high detonation velocity of the salt is interesting. Mixtures with → *Octogen*, pressed to high density, reach more than 9000 m/s.

Hydrazine Perchlorate

perchlorate d'hydrazine



$$\begin{array}{l} NH_2 \\ | \\ NH_2 \cdot HClO_4 \end{array}$$

colorless crystals
empirical formula: $H_5N_2O_4Cl$
molecular weight: 132.5 g/mol
energy of formation: −291 kcal/kg = −1216 kJ/kg
enthalpy of formation: −318 kcal/kg = −1331 kJ/kg
oxygen balance: +24.1%
nitrogen content: 21.14%
volume of explosion gases: 838 l/kg
heat of explosion
  (H_2O liq.): 882 kcal/kg = 3690 kJ/kg
  (H_2O gas): 725 kcal/kg = 3033 kJ/kg
density: 1.83 g/cm^3
melting point: 144 °C = 291 °F
lead block test: 362 cm^3/10 g
deflagration point: 272 °C = 522 °F
impact sensitivity: 0.2 kp m = 2 N m
friction sensitivity: at 1 kp = 10 N pistil load no reaction
critical diameter of steel sleeve test: 20 mm

The product is thus very sensitive.

Hygroscopicity

Hygroskopizität; *hygroscopicité*

Tendency of a substance to absorb moisture from its surroundings; specifically, absorption of water vapor from atmosphere.

Hypergolic

Liquid propellant system based on two or more substances capable of spontaneous ignition on contact.

IATADGR

International Air Transport Association Dangerous Goods Regulations. Contains regulations for the transport of dangerous goods by air.

ICAO TI

International Civil Aviation Organisation Technical Instructions for the Safe Transport of Dangerous Goods by Air. Contains the conditions under which it is permissible to transport dangerous goods by commercial aircraft.

Igniter

Anzünder; *allumeur*

A pyrotechnic and/or propellant device used to start burning of propellant.

Igniter Cord

Anzündlitze; *corde d'allumage*

An igniter cord is a safety fuse which burns at a fast rate (6–30 s/m) and with an open flame. The cord can be ignited by an open flame or with by a conventional safety fuse (guide fuse) with a connector. Its function is to ignite the cords in the desired sequence.

Igniter Cord Connector

Anzündlitzenverbinder

Igniter cord connectors ensure a safe transmission of the sparking combustion of the igniter cord into the gunpowder core of a connected safety fuse.

Igniter Safety Mechanism

Zündsicherung; *dispositif de securite d'allumage*

Device for interrupting (safing) or aligning (arming) an igniter train of an energetic device, i.e. a rocket motor or gas generator.

Igniter Train

Anzündkette; *chaine d'allinmage (d'amorcage)*

Step-by-step arrangement of charges in pyrotechnic or propellant by which the initial fire from the primer is transmitted and intensified until it reaches and sets off the main charge. Also called *burning train* or *explosive train*.

Ignitibility

Anzündwilligkeit; *inflammabilité*

Statement of ease with which burning of a substance may be ignited.

Ignition

Ignite; *anzünden*; *inflammer; allumer*

The mode of ignition affects the manner in which an explosive reacts, detonating (→ *Detonation*) or deflagrating (→ *Deflagration*). The effect of flame ignition differs from that of a brisant initiation produced by a blasting cap or by a booster. The nonbrisant ignition is termed inflammation.

The sensitivity of explosives to inflammation varies widely. Black powder can be exploded by a spark from a spark-producing tool; smokeless powders are ignited by the brief flame jet produced by striking a percussion cap. On the other hand, the combustion of an ion-exchanged → *Permitted Explosive*, ignited by a gas flame, is extinguished as soon as the flame source is removed. → *Initiating Explosives* always detonate when inflamed.

Ignition System

Zündanlage; *système d'allumage*

Arrangement of components used to start the combustion of the propellant charge of a gas generator (→ *Igniter Train*).

Illuminant Composition

Leuchtsatz; *composition lumineuse*

A mixture of materials used in the candle of a pyrotechnic device to produce a high intensity light as its principal function. Materials used include a fuel (reducing agent), an oxidizing agent, a binder plus a color intensifier and waterproofing agent. The mixture is loaded under pressure in a container to form the illuminant charge. Basic formulations contain sodium nitrate, magnesium and a binder.

IM

Technological advances in the design of explosive ordnance are making possible the development of insensitive munitions (IM) or munitions à risques atténués (MURAT), which are less dangerous than previous weapons when subjected to accidental and combat stimuli. Introduction of IM into service is intended to enhance the survivability of logistic and tactical combat systems, minimize the risk of injury to personnel, and provide more cost effective and efficient transport, storage, and handling of munitions. Guidance for the assessment and development of IM are provided by → AOP-39.

IMDG Code

International Maritime Dangerous Goods Code. It contains the regulations for the transport of dangerous goods by ocean-going ships, inter alia, their classification, packaging and stowing.

IME (Institute of Makers of Explosives)

A nonprofit trade association representing leading US producers of commercial explosive materials and dedicated to safety in the manufacture, transportation, storage, and use of explosive materials.

IMO

Abbreviation for International Maritime Organisation, London, with the International Maritime Dangerous Goods (IMDG Code) contains texts of international conventions on classification, compatibility, packing, storage, etc. during transportation by sea; explosives and primers belong to class 1 of the code.

Immobilization

Festlegung; *immobilisation*

Method of fixing propellant grain in definite position relative to generator case.

Impact Sensitivity

Schlagempfindlichkeit; *sensitiveness to impact*; *sensibilité à l'impact*

The impact sensitivity of solid, liquid, or gelatinous explosives is tested by the drop hammer method. Samples of the explosives are subjected to the action of falling weights of different sizes. The parameter to be determined is the drop height at which a sufficient amount of impact energy is transmitted to the sample to decompose or to explode. The friction sensitivity of secondary explosives depends on the grain sizes of the used material.

The US standard procedures are:

- Impact sensitivity test for solids: a sample ($\approx$ 0.02 g) of explosive is subjected to the action of a falling weight, usually 2 kg. A 20-milligram sample of explosive is always used in the Bureau of Mines (BM) apparatus when testing solid explosives. The weight of the sample used in the Picatinny Arsenal (PA) apparatus is indicated in each case. The impact test value is the minimum height at which at least one of 10 trials results in explosion. In the BM apparatus, the explosive is held between two flat, parallel hardened steel surfaces; in the PA apparatus it is placed in the depression of a small steel die-cup, capped by a thin brass cover, in the center of which a slotted, vented, cylindrical steel plug is placed, with the slotted side downwards. In the BM apparatus, the impact impulse is transmitted to the sample by the upper flat surface; in the PA, by the vented plug. The main differences between the two tests are that the PA test involves greater confinement, distributes the translational impulse over a smaller area (due to the inclined sides of the die-cup cavity), and involves a frictional component (against the inclined sides).

The test value obtained with the PA apparatus depends greatly on the sample density. This value indicates the hazard to be expected on subjecting the particular sample to an impact blow, but is of value in assessing a material's inherent sensitivity only if the apparent density (charge weight) is recorded along with the impact test value. The samples are screened between 50 and 100 mesh, U.S. where single-component explosives are involved, and through 50 mesh for mixtures.

- Impact sensitivity test for liquids: the PA impact test for liquids is run in the same way as for solids. The die-cup is filled, and the top of the liquid meniscus is adjusted to coincide with the plane of the top rim of the die-cup. To date, this visual observation has been found adequate to assure that the liquid does not wet the die-cup rim after the brass cup has been set in place. Thus far, the reproducibility of data obtained in this way indicates that variations in sample size obtained are not significant.

In the case of the BM apparatus, the procedure that was described for solids is used with the following variations:

1. The weight of explosives tested is 0.007 g.
2. A disc of desiccated filter paper (Whatman No. 1) 9.5 mm diameter is laid on each drop, on the anvil, and then the plunger is lowered onto the sample absorbed in the filter paper.

The drop hammer method was modified by the German Bundesanstalt für Materialprüfung (BAM), so as to obtain better reproducible data[22]. The sample is placed in a confinement device, which consists of two coaxial cylinders placed one on top of the other and guided by a ring. The cylinders have a diameter of $10^{-0.003}_{-0.005}$ mm and a height of 10 mm, while the ring has an external diameter of 16 mm, a height of 13 mm and a bore of $10^{+0,005}_{+0,01}$ mm; all parts, cylinders and rings, must have the

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[22] Koenen, H. and Ide, K.H. (1961) *Explosivstoffe*, **9**, 4 and 30.

Table 16 Impact sensitivities given as the product of drop weight (N) and drop height (m). In the following table the kp m values are listed at which at least one of six tested samples explodes.

Explosive	**Drop weight**		**Drop height**	**Drop energy**	
	(kp)	**(N)**	**(m)**	**(kp m)**	**(N m)**
A. Homogeneous explosives					
Nitroglycol	0.1	1	0.2	0.02	0.2
Nitroglycerine	0.1	1	0.2	0.02	0.2
Tetrazene	1	10	0.2	0.2	2
Mercury fulminate	1	10	0.2	0.2	2
PETN	1	10	0.3	0.3	3
Tetryl	1	10	0.3	0.3	3
Nitrocellulose 13.4% N	1	10	0.3	0.3	3
Nitrocellulose 12.2% N	1	10	0.4	0.4	4
Lead azide	5	50	0.15	0.75	7.5
Hexogen	5	50	0.15	0.75	7.5
Picric acid	5	50	0.15	0.75	7.5
TNT	5	50	0.30	1.5	15
Lead styphnate	5	50	0.30	1.5	15
Ammonium perchlorate	5	50	0.50	2.5	25
Dinitrobenzene	10	100	0.50	5	50
B. Industrial explosives					
Guhr dynamite	1	10	0.10	0.1	1
Gelignite	1	10	0.10	0.1	1
Seismic gelatins	1	10	0.10	0.1	1
Blasting gelatin	1	10	0.20	0.2	2
Ammonium nitrate nitroglycol gelatin	1	10	0.20	0.2	2
Gelatinous permitted explosives	1	10	0.30	0.3	3
Nitroglycerine-sensitized powders and permitted explosives	5	50	0.20	1.0	10
Powder-form explosives without nitroglycerine	5	50	0.40	2.0	20

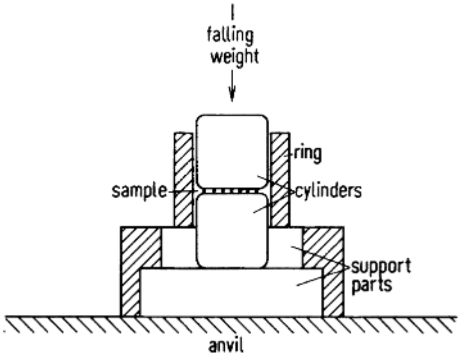

Figure 17 Drop hammer confinement device.

same hardness[23]. Cylinders and rings are renewed for each falling test procedure. If the sample is a powder or a paste, the upper cylinder is slightly pressed into the charged confinement device as far as it will go without flattening the sample. If liquids are tested, the distance between the cylinders is 2 mm. The charged device is put on the anvil of the drop hammer apparatus, and the falling weight, guided by two steel rods, is unlocked. For sensitive explosives such as primary explosives, a small drop hammer is used. For insensitive explosives, a large hammer is used. The small hammer involves the use of fall weight of up to 1000 g, while the fall weights utilized with the large hammer are 1, 5 and 10 kg. The fall heights are 10–50 cm for the 1-kg weight, 15–50 cm for the 5-kg weight and 35–50 cm for the 10-kg weight. This method is the recommended test method in the UN-recommendations for the transport of dangerous goods and it is standardized as EN 13631-4 as a so-called Harmonized European Standard.

The influence of friction test results is thus eliminated. Standardized procedures are described in STANAG 4489 – Explosive Impact Sensitivity Tests.

For explosives of high critical diameter, *Eld, D.* and *Johansson, C.H.* described an impact testing method[24] by shooting the explosive sample (unconfined; filled in bakelite tubes 30-mm diameter; 30-mm length and covered with paper or plastic foil) with brass cylinders (15-mm diameter; 15-mm length; 19 g) and varying their velocity. They are accelerated in

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23) The ground and hardened cylinders and rings are standard parts for ball bearings; they are commercially available.

24) Eld, D. and Johansson, C.H. (1963) Shooting test with plane surface for determining the sensitivity of explosives. *Explosivstoffe*, **11**, 97 and Johansson-Persson (1970) Detonics of High Explosives, Academic Press, London and New York, p. 108ff.

a gun by means of compressed air or gunpowders. The front of them is plane, the back concave for better flight stability. A pendulum bearing a shock acceptance plate, hanging at about one yard from the shooting line, and the observation of the appearance of light and of smell are used to determine reaction of the explosive sample.

Results see Tables 17 and 18.

Table 17 Low → *Critical Diameter* (< 40 mm).

Explosive	**Projectile velocity (m/s)**	**Pendulum (deg)**	**Smell**	**Light**
Dynamite 1.34 g/cm^3	186	15	+	+
	143	16	+	+
	116	15	+	+
	88	19	+	+
	73	19	+	+
	62	15	+	+
	55	12	+	+
	53	17	+	+
Limit:			+	+
	49	0	–	–
	49	0	–	–
	47	0	–	–
	45	0	–	–
	43	0	–	–
Test explosive 0.84 g/cm^3	377	17	+	+
60% PETN/40% NaCl	316	19	+	+
	238	15	+	+
	222	12	+	+
	195	0	–	–
	189	14	+	+
Limit:				
	174	0	–	–
	174	0	–	–
	170	0	–	–
	164	0	–	–

Table 18 High critical diameter (40–132 mm).

Explosive	Projectile velocity (m/s)	Pendulum (deg)	Smell	Light
ANFO 0.91 g/cm^3	1110	3	+	+
(94% ammonium nitrate;	765	2	+	+
6% liquid hydrocarbon)	675	3	+	+
	520	2	+	+
	460	1	+	+
	440	1	+	+
	435	0	+	+
	415	0	+	+
Limit:				
	390	0	–	–
	380	0	–	–
	350	0	–	–
	320	0	–	–

For impact sensitivity of confined explosive charges thrown against a steel target → *Susan Test*.

Impulse

Product of thrust and by time (see also → *Specific Impulse*).

Incendiary

Designates a highly exothermic composition or material that is primarily used to start fires.

Inert

Nonreacting material.

Inhibited Propellant, Restricted Propellant

Oberflächenbehandelter Treibsatz; *propellant traité de surface*

A propellant grain in which a portion of the surface area has been treated to control the burning Deterred Propellant.

Restrictor:

Material applied to selected areas of propellant charge to prevent burning in these areas.

Initiating Explosives

primary explosives; *Initialsprengstoffe*; *explosifs d'amorçage; explosifs primaires*

Primary explosives can detonate by the action of a relatively weak mechanical shock or by a spark; if used in the form of blasting caps, they initiate the main explosive. They are also filled in percussion caps mixed with friction agents and other components.

An initiating explosive must be highly brisant and must have a high triggering velocity. The most important primary explosives are mercury fulminate, lead azide, lead trinitroresorcinate, silver azide, diazodinitrophenol, tetrazene, and the heavy metal salts of 5-nitrotetrazole, which is used as an additive in primers. Initiating charges must be transported only if they are already pressed into capsules; the latter are usually made of aluminum, and sometimes of copper, while plastic capsules are used for special purposes (→ *Blasting Caps*; → *Bridgewire Detonators*; → *Bullet Hit Squib*).

Initiation

Zündung; *mise à feu*

Initiation means to set off explosive charges. The decomposition of an explosive can undergo → *Deflagration* (subsonic propagation rate) or → *Detonation* (supersonic propagation rate), depending on the manner and intensity of the ignition and on the amount of → *Confinement*.

Nonbrisant, i.e. flame ignition, is known as inflammation. Brisant initiators include blasting caps, electric detonators, → *Primers* and → *Detonating Cords*. The initiating shock can be intensified by interposition of → *Boosters*, when the charge is insensitive.

In rocketry, initiation means the functioning of the first element in an → *Igniter Train*.

Initiator

A device used as a primary stimulus component in all explosive or pyrotechnic devices, such as detonator primer or squib, which, on receipt of proper mechanical or electrical impulse, produces burning or detonating action. Generally an initiator contains a small quantity of sensitive explosive (→ *Squib*; → Detonator; → Primer; → Bullet Hit Squib).

Insensitive Munition

Insensitive Munition, IM

Insensitive munition (IM) is a term that is used to describe munition which is particularly safe to handle and difficult to accidentally initiate, but at the same time has the power and reliability to fulfill the requirements needed to complete the specified mission. The sensitivity of munition can be tested and can be classified into six categories, with I indicating the most sensitive and NR indicating the least sensitive.

Categories for insensitive munition:

	German	English
NR	Keine Reaktion	No reaction
V	Abbrand	Burning
IV	Deflagration	Deflagration
III	Explosion	Explosion
II	Teilweise Detonation	Partial detonation
I	Vollständige Detonation	Detonation

In order for a specific munition to be classified into one of the six categories of this system, six tests must be performed on each substance. The standardized tests which must be used are briefly summarized in the table below. The results of these tests can range from no reaction (least sensitive category) to complete detonation (most sensitive category). Since this area is so important, NATO has founded a Munitions Safety Information Analysis Center (MSIAC).

Insensitive Munition Explosive (IMX)

Family of insensitive melt cast formulations bases on the binder → DNAN; e.g. IMX-101 is an insensitive high explosive mixture developed by BAE Systems and the United States Army to replace TNT in artillery or other large-caliber munitions, and IMX-104 is a melt cast explosive, e.g. for mortar applications, which contains DNAN, and the explosives → NTO and → RDX (31.7/53/15.3).

Instantaneous Detonator

Momentzünder; *détonateur instantané*

A detonator that has a firing time essentially of zero seconds as compared to delay detonators with firing times of several milliseconds to several seconds.

Scenario	IM test	Test procedure	Allowed response for IM
Small-arms attacks	BI	attack (bullet impact) with three 12.7-mm bullets with 850 m/s	V – burning
Fragmenting munitions attacks	FI	attack with five 16–250-g fragments with 2530 m/s	V – burning
Magazine, store, plane, ship or truck in fuel fire	FCO	fast cook-off test, simulation of a fuel fire	V – burning
Fire in adjacent magazine, store or vehicle	SCO	slow cook-off test (SCO) with a heat rate of 3.3 °C/h	V – burning
Shaped-charge weapon attack	SCI	Impact of a shaped charge between 50 and 62 mm	III – no detonation
Detonation in magazine, plane, truck etc.	SR	Reaction to detonation of a neighboring charge (sympathetic reaction)	III – no detonation

Insulation

Isolierung; *isolement*

Thermal barrier designed to prevent excessive heat transfer from hot combustion products to case of rocket.

Ion Propellants

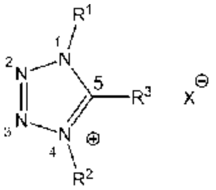
Ionentreibstoffe

In vacuo, i.e. under space travel conditions, ions, which are atomic carriers of electric charges, can be accelerated by electric fields and bunched to give a single beam. The discharge velocity thus attained is of a higher order than that of gaseous products from chemical reactions. For this reason, very high values of specific impulse can be produced.

The preferable ion propellant is cesium owing to its high molecular weight and to the fact that it is easily ionized.

Ionic Liquid

Ionische Flüssigkeit, IL



R^1, R^2 = Me, Et, $CH_2CH_2{-}N_3$, NH_2

R^3 = H, Me, NH_2, $CH_2{-}N_3$

X = NO_3^-, $N(NO_2)_2^-$, ClO_4^-, N_3^-

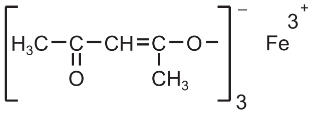
Ionic liquid (IL) is a term which refers to liquids that contain exclusively ions (i.e. liquid salts). As a rule, for a salt to be classified as an IL, it must be a liquid at temperatures below 100 °C. For a salt to be an IL, it is important that the size and the symmetry of the participating ions prevents the formation of a strong crystal lattice, meaning that only small amounts of thermal energy are needed to overcome the lattice energy and break up the highly ordered solid crystal lattice structure. Examples of suitable cations are alkylated imidazolium, pyridinium, ammonium or phosphonium ions. Recently reported energetic ionic liquids (EILs) include imidazole salts 1,2,4-triazole or tetrazole salts.

To enable ionic liquids to be used as fuels in bipropellants, suitable anions must be found. ILs would have the advantage over currently used fuels such as MMH and UDMH, of possessing a negligibly low vapor pressure, which would consequently considerably reduce the inhalation toxicity of methyl hydrazine-based fuels. The dicyanamide anion, $[N(CN)_2]^-$, in combination with the 1-propargyl-3-methyl-imidazolium cation is a promising candidate for use as an ionic liquid for rocket propulsion. If WFNA is used as the oxidizer, the ignition delay is 15 ms, in comparison with 1 ms for the MMH/NTO and 9 ms for MMH/WFNA.

ILs should also be suitable as monopropellants. However, the IL salt must contain both the oxidizer and fuel, or salt mixtures must be used in which both oxidizing and reducing salts are present. These mixtures can be classified as monopropellants, since they are homogeneous systems in which both the oxidizer and fuel is present. Salt mixtures with lower toxicities and vapor pressures than hydrazine are of particular importance and are labeled “green” propellants. Nitrate or the dinitramide anions are suitable components for such salts.

Iron Acetylacetonate

Eisenacetylacetonat; *acétylacetonate de fer*



$$\left[H_3C-\underset{\underset{O}{\|}}{C}-CH=\underset{\underset{CH_3}{|}}{C}-O-\right]_3^{-} \quad Fe^{3+}$$

empirical formula: $C_{15}H_{21}O_6Fe$
molecular weight: 353.2 g/mol
energy of formation: −836 kcal/kg = −3498 kJ/kg
enthalpy of formation: −859 kcal/kg = −3593 kJ/kg
oxygen balance: +163.1%
density: 1.34 g/cm^3

Iron(III) acetylacetonate is a curing catalyst for polymethane binders with combustion-modifying abilities for AP containing → *Composite Propellants*.

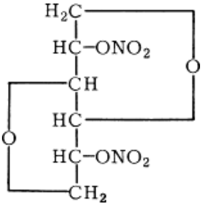
ISL

Institut Franco-Allemand de Recherches de St. Louis; *Deutsch-Französisches Forschungsinstitut St. Louis, France, 5 rue du Général Cassagnou, 68300 SAINT-LOUIS – France*

German-French research institute especially for ballistics and detonation physics.

Isosorbitol Dinitrate

Isosorbitdinitrat; *dinitrate d'isosorbitol*



white microcrystals
empirical formula: $C_6H_8N_2O_8$
molecular weight: 236.1 g/mol
oxygen balance: −54.2%
nitrogen content: 11.87%
melting point: 70 °C = 158 °F (decomposition)
lead block test: 311 cm^3/10 g
detonation velocity, confined: 5300 m/s at $\rho = 1.08\ g/cm^3$
deflagration point: 173 °C = 343 °F
impact sensitivity: 1.5 kp m = 15 N m
friction sensitivity: over 16 kp = 160 N pistil load crackling

Isosorbitol dinitrate serves as an effective cardial medicine (in low percentage mixture with milk sugar). The pure substance is a strong explosive; it is more effective than → *PETN*.

ITAR

International Traffic in Arms Regulations. These United States government regulations control the export and import of defense-related materials and services.

JA2

Is a double-base conventional tank gun propellant.

Jet Tappers

Abstichladungen; *ouvreuses explosives de percée*

Jet tappers are used in tapping Siemens–Martin (open hearth) furnaces. They are hollow charges, which are insulated from heat by earthenware jackets; when detonated, the tapping channel is produced. Other shaped charges are used to break up blast furnace hang-ups.

Kamlet–Jacobs Equation

Kamlet-Jacobs-Gleichungen

The Kamlet–Jacobs equation is an empirical relationship between the detonation velocity and the detonation pressure, in which the detonation velocity D is proportional to the loading density, whereas the detonation pressure p_{CJ} scales with the square of the loading density ρ_0 (in g/cm^3):

$$p_{\mathrm{CJ}}\ [\mathrm{kbar}] = K\rho_0^2\Phi$$

$$D\ [\mathrm{mm/\mu s}] = A\Phi^2(1 + B\rho_0)$$

The constants K, A and B are defined as follows: $K = 15.88$, $A = 1.01$, $B = 1.30$.

The value Φ is therefore

$$\Phi = N(M)^{0.5}(Q)^{0.5}$$

where N is the moles of gas released per gram of explosive, M is the mass of gas in in g/mol of gas and Q is the heat of explosion in cal/g.

Kelly

A hollow bar attached to the top of the drill column in rotary drilling; also called grief joint, kelly joint, kelly stem, or kelly bar.

KDN (Potassium Dinitramide)

Kalium-Dinitramid

Potassium dinitramide (KDN) has the formula $K^+N(NO_2)_2^-$ and is the potassium salt of dinitraminic acid. Ammonium dinitramide is the ammonium salt of dinitraminic acid. KDN is a very useful synthetic reagent for introducing the dinitramide ion into energetic compounds. For example, in the synthesis of diaminotetrazolium dinitramide, the dinitramide ion is introduced by KDN via ion exchange with the corresponding energetic perchlorate salt.

Kneisl-Test

To estimate the thermal long-term stability of an explosive, the Kneisl-Test can be used. This is a simple method which is used for primary explosives in particular. In the Kneisl-Test, a defined quantity (e.g. 100 mg) of a particular substance is sealed under air in a glass ampoule which is then placed in an oven for 100 h, at the temperature for which the thermal stability should be determined. After the heating-time has elapsed, the ampoule is opened and the mass of the substance remaining in the ampoule is weighed. In addition, if any gaseous decomposed products are formed, they are analyzed using IR and/or MS and/or GC-MS. If the mass of substance which was lost on heating due to decomposition is less than 2%, then the substance is defined as having passed the test.

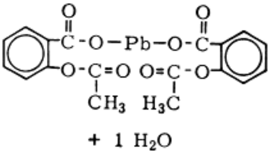
Large Hole Blasting

Großbohrloch-Sprengverfahren; *sautage à grand trou*

In large-scale blasting processes in open pit mining and quarrying, rows of nearly vertical boreholes are drilled parallel to the quarry face; the diameter of each borehole is 3–8 in (in Germany it is more often 3–4 in), while the borehole length is over 12 m. The holes are filled with explosive and stemmed. → *Free-flowing Explosives* or pumped → *Slurries* can be applied.

Lead Acetylsalicylate

Bleiacetylsalicylat; *acétylsalicylate de plomb*



colorless, fine crystals
empirical formula: $C_{18}H_{14}O_8Pb \cdot H_2O$
molecular weight: 583.5 g/mol
energy of formation: −810 kcal/kg = −3391 kJ/kg
enthalpy of formation: −823 kcal/kg = −3444 kJ/kg
oxygen balance: −98.7%

Lead acetylsalicylate is a combustion-modifying additive, especially so in → *Double-Base Propellants* for rockets.

Lead Azide

Bleiazid; *azoture de plomb*

$Pb(N_3)_2$
colorless crystals; microcrystalline granules, if dextrinated
molecular weight: 291.3 g/mol
energy of formation: +397.5 cal/kg = +1663.3 kJ/kg

enthalpy of formation: +391.4 cal/kg = +1637.7 kJ/kg
oxygen balance: −5.5%
nitrogen content: 28.85%
volume of explosion gases: 231 l/kg
explosion heat: 391 kcal/kg = 1638 kJ/kg
density: 4.8 g/cm^3
lead block test: 110 cm^3/10 g
detonation velocity, confined:
  4500 m/s = 14 800 ft/s at $\rho = 3.8$ g/cm^3
  5300 m/s = 17 400 ft/s at $\rho = 4.6$ g/cm^3
deflagration point: 320−360 °C = 600−680 °F
impact sensitivity
  pure product: 0.25−0.4kpm = 2.5−4 N m
  dextrinated: 0.3−0.65 kp m = 3−6.5 N m
friction sensitivity: at 0.01−1 kp = 0.1−1 N pistil load explosion

Lead azide is insoluble in water, is resistant to heat and moisture, and is not too hygroscopic. It is prepared by reacting aqueous solutions of sodium azide and lead nitrate with each other. During the preparation, the formation of large crystals must be avoided, since the breakup of the crystalline needles may produce an explosion. Accordingly, technical grade product is mostly manufactured with 92–96% $Pb(N_3)_2$ and is precipitated in the presence of dextrin, polyvinyl alcohol, or other substances which interfere with crystal growth. Lead azide is employed as an initiating explosive in blasting caps. When used as a primary charge, it is effective in smaller quantities than mercury fulminate, has a higher triggering rate and, unlike mercury fulminate, cannot be dead-pressed by even relatively low pressures. In order to improve its flammability, an easily flammable additive, such as lead trinitroresorcinate, is added. Lead azide is decomposed by atmospheric CO_2, with evolution of hydrazoic acid.

Lead azide detonators for use in coal mining have copper capsules; for all other blastings, aluminum caps are used.

Specifications

net content (by determination as $PbCrO_4$):	not less than 91.5%
moisture:	not more than 0.3%
mechanical impurities:	none
water solubles:	not more than 1%
lead content:	at least 68%
copper:	none
reaction:	neutral, no acid
bulk density:	at least 1.1 g/cm^3
deflagration point:	not below 300 °C = 572 °F

Lead Block Test

Bleiblockausbauchung; essai au bloc de plomb, coefficient d'utilisation pratique, c. u. p.

The *Trauzl* lead block test is a comparative method for the determination of the → *Strength* of an explosive. Ten grams of the test sample, wrapped in tinfoil, are introduced into the central borehole (125-mm deep, 25 mm in diameter) of a massive soft lead cylinder, 200 mm in diameter and 200-mm long. A copper blasting cap No. 8 with an electric primer is introduced into the center of the explosive charge, and the remaining free space is filled with quartz sand of standard grain size. After the explosion, the volume of the resulting bulge is determined by filling it with water. A volume of 61 cm^3, which is the original volume of the cavity, is deducted from the result thus obtained.

In France the lead block performance value is given by the coefficient d'utilisation pratique (c.u.p.): if m_x is the mass of the tested explosive, which gives exactly the same excavation as 15 g of picric acid, the ratio

$$\frac{15}{m_x} \cdot 100 = \%\text{c.u.p}$$

is the coefficient d'utilisation pratique. Also, 10 g of picric acid can be applied as a standard comparison explosive. For the relationship with other testing procedures → *Strength*.

Another modification of the lead block test is recommended by BAM (Bundesanstalt für Materialprüfung, Germany). The test sample is prepared as follows: a special instrument wraps the sample in tinfoil and molds it into a cylinder with 11-ml capacity (24.5 mm in diameter, 25 mm in height, with a coaxial cavity 7 mm in diameter and 20-mm long for the blasting cap), whereby the resulting density should be only slightly higher than the pour (bulk) density. Liquids are filled into thin-walled cylindrical glass ampoules or, in special cases, directly into the cavity of the lead block.

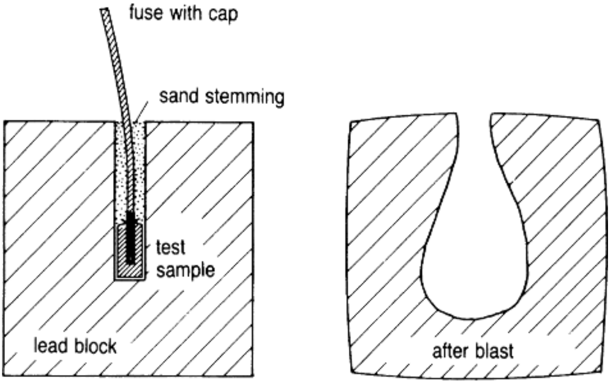


Figure 18 Lead block test.

The initiation is effected with an electric copper blasting cap No. 8 containing 0.4 g of high-pressed (380 kp/cm^2) and 0.2 g of low-pressed → *PETN* as the secondary charge and 0.3 g of lead azide as the initiating charge.

Table 19 Lead block excavation values.

A. Homogeneous explosives

Explosive	**Test value (cm^3 / 10 g)**	**Explosive**	**Test value (cm^3 / 10 g)**
Nitroglycol	610	Picric acid	315
Methylnitrate	600	Trinitroaniline	311
Nitroglycerine	530	TNT	300
PETN	520	Urea nitrate	272
RDX	483	Dinitrophenol	243
Nitromethane	458	Dinitro benzene	242
Ethylnitrate	422	DNT	240
Tetryl		Guanidine nitrate	
nitrocellulose	410	Ammonium	240
13.4% N	373	perchlorate	194
Ethylenediamine		Ammonium nitrate	178
dinitrate	350		

B. Industrial explosives

Explosive	**Density (g / cm^3)**	**Test value (cm^3 / 10 g)**
Blasting gelatin	1.55	600
Guhr dynamite	1.35	412
Gelignite 65% Nitroglycerine	1.53	430
Ammonium-nitrate-based gelatins, 40% nitroglycerine	1.47	430
Powder-form ammonium-nitrate-based explosives	1.0	370
ANFO	0.9	316
Gelatinous permitted explosive	1.69	130
Ion-exchanged permitted explosive	1.25	85

The empty space above the test sample is filled with dried, screened quartz sand (grain size 0.5 mm), as in the original method.

The volume of the excavation is determined by filling it with water; after 61 ml have been deducted from the result, the net bulge corresponding to the weight of the compressed sample is obtained. In accordance with the international convention, this magnitude is recalculated to a 10-g sample.

The European Commission for the Standardization of Testing of Explosive Materials[25] recalculated the results for a 10-ml test sample, using a calibration curve established by *Kurbalinga* and *Kondrikov*, as modified by *Ahrens*; the reported value refers to the mixture of PETN with potassium chloride which gives the same result as the test sample under identical experimental conditions.

Since this regulation is still recent, the values given in the following table, as well as the values given under the appropriate headings of the individual explosive materials, are still based on the older method, in which a 10-g sample is employed. Other conventional methods for the determination of the explosive strength are the ballistic mortar test and the sand test.

For further details, including descriptions of other tests, → *Strength*.

Lead Chromate

Bleichromat; *Blei(II)-chromat*; *chromate de plomb(II)*
solid
empirical formula: $PbCrO_4$
molecular weight: 323.194 g/mol
oxygen balance: 7.43%
energy of formation: −894.62 kJ/mol
enthalpy of formation: −899.56 kJ/mol = −2783.34 kJ/kg
density: 6.12 g/cm^3 (15 °C)
melting point: 844 °C

Lead chromate is used in pyrotechnic elements. According to the → *REACH* regulation lead chromate is identified as a substance of very high concern with carcinogenic and teratogenic. Therefore lead chromate is included in the Annex XIV of the REACH regulation and after a transitional period it can no longer be placed on the market or used by any manufacturer, importer or downstream user unless an authorization has been granted.

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25) Now: International Study Group for the Standardization of the Methods of Testing Explosives. Secretary: Dr. Per-Anders Persson, Swedish Detonic Research Foundation, Box 32058, S 12611 Stockholm, Sweden.

Lead Dioxide

Bleidioxid; *dioxide de plomb*

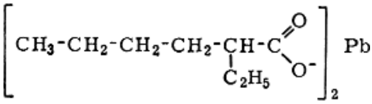
O=Pb=O

dark brown powder
empirical formula: PbO_2
molecular weight: 239.2 g/mol
energy of formation: −274.7 kcal/kg = −1149.4 kJ/kg
enthalpy of formation: −277.2 kcal/kg = −1159.8 kJ/kg
oxygen balance: +6.7%
density: 9.38 g/cm^3

Lead dioxide serves as an oxidizer in primer and pyrotechnic compositions, and in crackling stars.

Lead Ethylhexanoate

Bleiethylhexanoat; *éthylhexanoate de plomb*



technical product: brownish, nearly amorphous
empirical formula: $C_{16}H_{30}O_4Pb$
molecular weight: 493.6 g/mol
energy of formation: −703 kcal/kg = −2940 kJ/kg
enthalpy of formation: −724 kcal/kg = −3027 kJ/kg
oxygen balance: −142.6%

Lead ethylhexanxoate is a combustion-modifying additive, especially in → *Double-Base Propellants* for rockets.

Lead-Free Priming Compositions

Air contamination with health-impairing pollutants gave rise to the demand for sport ammunition free from lead, barium and mercury. → *SINTOX Primer Composition*.

Lead Nitrate

Bleinitrat; *nitrate de plomb*

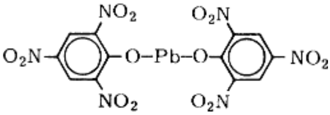
$Pb(NO_3)_2$
colorless crystals
molecular weight: 331.2 g/mol
energy of formation: −318.9 kcal/kg = −1334.4 kJ/kg
enthalpy of formation: −326.1 kcal/kg = −1364.3 kJ/kg

oxygen balance: +24.2%
nitrogen content: 8.46%
density: 4.53 g/cm^3
beginning of decomposition: 200 °C = 390 °F

Lead nitrate is employed as an oxidizer in initiating mixtures in which a particularly high density is required.

Lead Picrate

Bleipikrat; *picrate de plomb*



yellow crystals
empirical formula: $C_{12}H_4N_6O_{14}Pb$
molecular weight: 663.3 g/mol
oxygen balance: −31.4%
nitrogen content: 12.7%
density: 2.4 g/cm^3

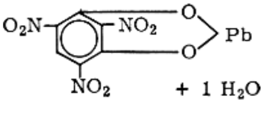
Lead picrate is insoluble in water, ether, chloroform, benzene and toluene, and sparingly soluble in acetone and alcohol. It is prepared by precipitation with a solution of lead nitrate in a solution of sodium picrate and picric acid.

It can be used as an active component in initiating mixtures, e.g. for electrical squibs in bridgewire detonators. It is more powerful and more sensitive than → *Lead Styphnate*.

The unintentional formation of picrates by reaction of picric acid with the surrounding metals must be strictly avoided.

Lead Styphnate

lead trinitroresorcinate; *Bleitrizinat*; *trinifroresorcinate de plomb*



orange-yellow to dark brown crystals
empirical formula: $C_6H_3N_3O_9Pb$
molecular weight: 468.3 g/mol
energy of formation: −417.6 kcal/kg = −1747.2 kJ/kg
enthalpy of formation: −427.1 kcal/kg = −1786.9 kJ/kg
oxygen balance: −18.8%

nitrogen content: 8.97%
density: 3.0 g/cm^3
lead block test: 130 cm^3/10 g
detonation velocity, confined: 5200 m/s = 17 000 ft/s
at $\rho = 2.9$ g/cm^3
heat of explosion: 347 kcal/kg = 1453 kJ/kg
deflagration point: 275–280 °C = 527–535 °F
impact sensitivity: 0.25–0.5 kp m = 2.5–5 N m

Lead trinitroresorcinate is practically insoluble in water (0.04%), and is sparingly soluble in acetone and ethanol; it is insoluble in ether, chloroform, benzene and toluene. It is prepared by precipitation with a solution of lead nitrate from a solution of magnesium trinitroresorcinate, while maintaining certain concentration relationships and working in a given temperature and pH range, with stirring, in a reaction vessel which can be heated or cooled. The magnesium trinitroresorcinate solution required for the precipitation of lead trinitroresorcinate is obtained as a brown-to-black solution in a dissolving vessel by reacting an aqueous suspension of trinitroresorcinol with magnesium oxide powder while stirring.

Lead trinitroresorcinate is mostly employed as an initiating explosive in the form of a mixture with lead azide forming the detonator charge; it is particularly suited for this purpose, since it has a high ignition sensitivity, and its hygroscopicity is low. It is also employed as the main component of sinoxide charges in noneroding percussion caps; these charges also contain the usual additives and a low percentage of tetrazene.

In the absence of any admixtures, lead trinitroresorcinate readily acquires an electrostatic charge, easily causing explosion. According to the REACH regulation lead styphnate is identified as a substance of very high concern (SVHC) with teratogenic. Therefore lead styphnate is included on the SVHC list of the REACH regulation.

Specifications

net content:	not less than 98%
moisture:	not more than 0.15%
lead content (determination as $PbCrO_4$):	43.2–44.3%
heavy metals other than lead:	not more than 0.05%
Ca + Mg:	not more than 0.5%
Na:	not more than 0.07%
pH:	5–7
nitrogen content:	at least 8.8%
bulk density:	1.3–1.5 g/cm^3
deflagration point:	not below 270 °C = 518 °F

Leading Lines

Leading Wires; *Zündkabel*; *ligne de fir*

The wire(s) connecting the electrical power source with electric blasting cap circuit.

Leg Wires

Zünderdrähte; *fils du défonaleur*

The two single wires or one duplex wire extending out from an electric blasting cap.

Linear Burning Rate

Linear Regression Rate; *lineare Brenngeschwindigkeit*; *velocité de combustion linéaire*

Distance normal to any burning surface of pyrotechnic or propellant burned through in unit time; → *Burning Rate*.

Liquid Explosives

flüssige Sprengstoffe; *explosifs liquides*

Numerous explosive materials are liquid. This applies primarily to several nitric acid esters such as → *Nitroglycerine*, → *Nitroglycol*, → *Diethyleneglycol Dinitrate*, → *Triethyleneglycol Dinitrate*, → *Butanetriol Trinitrate* and many more. Most of them are so highly sensitive to impact that they are converted to the less sensitive solid state, e.g. by gelatinization with nitrocellulose; as is well known, such processes formed the subject of the pioneering patents of *Alfred Nobel*. It was shown by *Roth* that the impact sensitivity of explosive liquids is considerably enhanced if they contain air bubbles. Nitrocellulose gelatinization increases the minimum explosion-producing impact energy in drop hammer tests performed on nitroglycerine from 0.2–2 N m.

→ *Nitromethane* is considerably less sensitive. The volatility of the compound is high, and the handling of the constituent explosion-producing liquids is complicated. Nevertheless, nitromethane was used in the USA for preliminary studies to the big nuclear explosions (e.g. Pre-Gondola). It has also been used in stimulation explosions carried out in gas wells and oil wells. Picatinny Liquid Explosive (PLX) consists of 95% nitromethane and 5% ethylenediamine.

It has been proposed that liquid oxidizers (highly concentrated nitric acid, nitrogen tetroxide, tetranitromethane) be incorporated into the explosive mixture only on the actuation site or in the weapon itself so as to produce an approximately equalized oxygen balance and thus attain a higher degree of transport safety. Well known liquid explosives include Panklastites (nitrogen tetroxide with nitrobenzene, benzene, toluene, or gasoline) and Hellhoffites (concentrated nitric acid with dinitrobenzene or dinitrochlorobenzene). The mixture, under the name Boloron, was still a recommended procedure in Austria after the Second World War. Similar explosives are known as → *Dithekite*. The explosive strength of these mixtures is very high. However, since the components are corrosive, their handling is very unpleasant; when mixed together, the product becomes highly sensitive. For all these reasons they are no longer employed in practice.

For mud-like ammonium nitrate explosives → *Slurries* and → *Emulsion Slurries*.

Liquid Oxygen Explosives

Flüssigluft-Sprengstoffe; *Oxyliquit*; *explosifs à l'oxygene liquide*

Liquid oxygen explosives are made by impregnating cartridges made of combustible absorbent materials such as wood dust, cork meal, peat dust, Carbene, etc., with liquid oxygen. They must be exploded immediately after the impregnation and loading, which are carried out *in situ*. They are energy-rich and cheap, but their manner of utilization does not permit rational working, such as detonating a large number of charges in one priming circuit. They are, accordingly, hardly ever employed in practice.

Liquid Propellants

Flüssigtreibstoffe; *propergols liquides*; *(Monergol; Hypergolic)*

Combinations of pairs of liquids that react with each other (fuels and oxidizers in the most general sense of the word) and release energy in the form of hot gaseous reaction products; the → *Gas Jet Velocity* builds up the → *Thrust*. The caloric yield and the possible magnitude of the specific impulse may be higher than in one-component systems – i.e. higher than those of → *Monergols*, homogeneous propellants, and composite propellants.

Examples of fuels are alcohol, hydrocarbons, aniline, hydrazine, dimethylhydrazine, liquid hydrogen, liquid ammonia.

Examples of oxidizers are liquid oxygen, nitric acid, concentrated H_2O_2, N_2O_4, liquid fluorine, nitrogen trifluoride, chlorine trifluoride.

Certain pairs of the reacting liquids are → *Hypergolic*.

The liquid-propellant technique was developed for rocketry, but it is also considered today for small-caliber cannons (e.g. 30 mm in diameter).

Lithium Nitrate

Lithiumnitrat; *nitrate de lithium*

$LiNO_3$
molecular weight: 68.95 g/mol
oxygen balance: +58.1%
nitrogen content: 20.32%
density: 2.38 g/cm^3
melting point: 256 °C = 493 °F

Lithium nitrate is soluble in water and is highly hygroscopic. It is used is as a flame-coloring oxidizer in pyrotechnical formulations.

Lithium Perchlorate

Lithiumperchlorat; *perchlorate de lithium*

$LiClO_4$
colorless crystals
molecular weight: 106.4 g/mol
oxygen balance: +60.2%
density: 2.43 g/cm^3
melting point: 239.0 °C = 462 °F
decomposition point: 380 °C = 716 °F

Lithium perchlorate is soluble in water and alcohol and is very hygroscopic. The hydrated salt melts at 95 °C (203 °F).

Lithium perchlorate is prepared by saturating perchloric acid with lithium hydroxide or lithium carbonate. It is also used in batteries.

Loading Density

Ladedichte; *densité de chargement*

The ratio between the weight of the explosive and the explosion volume, i.e. the space in which the explosive is detonated. In a similar manner, the loading density of a powder is the ratio between the maximum weight of the powder and the space into which it is loaded.

Loading density is a very important parameter, both in propellant powders (owing to the necessity of ensuring the strongest possible propellant effect in the loaded chamber, whose shape and size are mostly limited by the design of the weapon) and in brisant explosives (→ *Brisance*).

It is often essential to attain the maximum possible loading density (especially in shaped charges). This is done by casting and pressing methods, such as vacuum, sedimentation, and mold-casting processes.

LOVA

An abbreviation for low-vulnerability ammunition. This term is descriptive of the trend towards choosing substances for both explosive and propellant charges which are as intensive as possible even if losses in effectivity have to be accepted. The development of → *Shaped Charges* has made it possible to hit stored ammunition with simple tactical weapons even behind armored walls.

The sensitivity of high-brisance explosives, e.g. → *Hexogen*, can be reduced by embedding them in rubberlike plastics (→ *Plastic Explosives*).

Low-sensitivity propellants, too, are based on plastic compounded nitramines. Another example of an insensitive explosive and propellant is → *Nitroguanidine*.

LOVA Gun Propellant

LOVA-Treibladungspulver; *LOVA-poudre*

Since 1970, in addition to the various well-known → *Gunpowders*, LOVA gun propellants have been developed and used in the production of propellants. The acronym LOVA stands for (Low Vulnerability Ammunition) which has come to represent a type of gun propellant.

This name expresses the unique characteristics of this type of munitions and those of gun propellants. That is, under external influences from the bullet casing, a hollow charge or fire, or a possible reaction, can at most, lead to combustion, but not to → *Deflagration* or → Detonation. Nevertheless, the ballistic capability of traditional gunpowders must be equaled and surpassed.

To meet this challenge, one can use standard → *Explosives* imbedded in a matrix of → *Energetic* or inert *Binders*, so that the explosive is desensitized allowing a regular combustion.

The most widely-used explosives are → *Hexogen* and → *Octogen* and to an extent → *Triaminoguanidine Nitrate*. Depending on the desired purpose, → *Nitroguanidine*; → *Guanidine Nitrate* and → *Ammonium Perchlorate* can also be used.

As a binder system polymers are utilized. If the binders contain energy or gas-producing pending groups ($-NO_2$, $-N_3$), one classifies the binders as → *Energetic Binders* (e.g. polynitropolyphenylene, glycidyl azide polymer, polyvinyl nitrate and nitrocellulose). If these groups are not present, the binders are classified as inert binders.

Depending on available processing methods, binder types such as thermoset material, thermoplast or gelatinizers can be used. They can then be formed and cured by chemical or physical means.

For thermoset materials, reactive polymers such as polyesters or polybutadiene derivatives combined with curing agents (e.g. isocyanates) are utilized. For thermoplasts one uses long-chained, partially branched polyether (Movital) or polymeric flouridated hydrocarbons (Fluorel). An example of a gelatin binder type is celluloseacetobutyrat (CAB), which is normally used in combination with nitrocellulose.

The production of LOVA powders is dependant on the chosen binder type. When thermoset materials are used, the system of energy carrier/binders/curing agents is kneaded together. The same is true when gelatins are used, however in this case, gelatinizing solvents (usually alcohol and ether) are added.

Thermoplasts, after being combined with energy carriers, are processed on hot rollers into a plastic material. The subsequent shaping is achieved by means of hydraulic mold presses and cutting machines. Depending on the binder type, the resulting powder kernels are cured (thermoset material), cooled (thermoplast), or dried by the removal of solvents (gelatin).

The possible forms of LOVA powders correspond to those of traditional → *Gunpowder* and are adapted according to the desired ballistic characteristics.

LX

Code of Lawrence Livermore National Laboratory for designated formulations in production. Examples[26] are:

LX	**Synonym**	**HMX (%)**	**Additive**	**Detonation confined**		**Velocity, at $\rho =$**	
				(%)	**(m/s)**	**(ft/s)**	**(g/cm^3)**
–04–1	PBHV-85/15	85	Viton A	15	8460	27 740	1.86
–07–2	RX-04-BA	90	Viton A	10	8640	28 330	1.87
–09–0	RX-09-CB	93	DNPA	7	8810	28 890	1.84
–10–0	RX-05-DE	95	Viton A	5	8820	28 920	1.86
–11–0	RX-04-P1	80	Viton A	20	8320	27 280	1.87
–14–0		95	Estane	5	8837	28 970	1.83

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[26] Data quoted from the publication UCRL-51319 of the US Department of Commerce: Properties of Chemical Explosives and Explosive Stimulants, edited and compiled by *Brigitta M. Dobratz*, University of California (1974).

Magazine

Sprengstofflager; *dépôt*

Any building or structure approved for the storage of explosive materials.

Magazine Keeper; Lagerverwalter; agent du dépôt

A person responsible for the safe storage of explosive materials, including the proper maintenance of explosive materials, storage magazines and areas.

Magazine, Surface; Übertage-Lager; dépôt superficiel

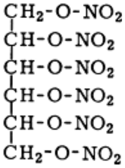
A specially designed structure for the storage of explosive materials aboveground.

Magazine, Underground; Untertage-Lager; dépôt souterrain

A specially designed structure for the storage of explosive materials underground.

Mannitol Hexanitrate

nitromannitol; *Nitromannit*; *hexanitrate de mannitol*; *Hexanitromannit; MHN*



$$\begin{array}{l} CH_2\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH_2\text{-}O\text{-}NO_2 \end{array}$$

colorless needles
empirical formula: $C_6H_8N_6O_{18}$
molecular weight: 452.2 g/mol
energy of formation: −336.2 kcal/kg = −1406.8 kJ/kg
enthalpy of formation: −357.2 kcal/kg = −1494.4 kJ/kg
oxygen balance: +7.1%
nitrogen content: 18.59%
volume of explosion gases: 694 l/kg
heat of explosion (H_2O gas): 1399 kcal/kg = 5855 kJ/kg
specific energy: 110 mt/kg = 1078 kJ/kg
density: 1.604 g/cm^3
melting point: 112 °C = 234 °F
lead block test: 510 cm^3/10 g
detonation velocity, confined: 8260 m/s = 27 100 ft/s
at $\rho = 1.73$ g/cm^3

deflagration point: 185 °C = 365 °F
impact sensitivity: 0.08 kp m = 0.8 N m

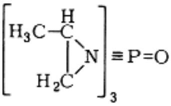
Nitromannitol is insoluble in water, but is soluble in acetone, ether and hot alcohol; it is difficult to stabilize.

It is prepared by dissolving mannitol in cold concentrated nitric acid and precipitating it with cold concentrated sulfuric acid. The crude product is washed with a dilute bicarbonate solution and with water, and is then recrystallized from hot alcohol.

In the USA nitromannitol was used as a filling for → *Blasting Caps*.

MAPO

Methylaziridine phosphine oxide



empirical formula: $C_9H_{18}N_3OP$
molecular weight: 215.14 g/mol
density: 1.08 g/cm^3
boiling point at 0.004 bar: 120 °C = 248 °F

MAPO is a bonding agent for AP containing → *Composite Propellants*.

Mass Explosion Risk

Massen-Explosionsfähigkeit, Massen-Explosionsgefährlichkeit; *danger d'explosion en masse*

A term describing the behavior of explosive materials and items (chiefly ammunition) in bulk. The question to be answered is whether a local explosion or fire will or will not detonate the entire bulk of the explosive (a truckload, or even a shipload of explosives). A number of tests have been laid down, in which first a parcel, then a case, and finally a caseload – in the form in which it is to be dispatched – are primed or inflamed in the manner in which this is to be done in actual service. When testing a caseload, the cases are arranged in predetermined locations, covered by inert cases of identical construction, and ignited.

Mass explosion risk does not depend solely on the properties of the explosive material, but also on the stacking height (in extreme cases, an entire shipload), on the nature of the confinement (e.g. buildings, lightly or heavy built, or trucks), and on the mode of packing and packing arrangements.

Mass Ratio

Massenverhältnis; *relation des masses*

In rocket technology, the ratio between the initial mass of the rocket and its final mass, after the propellant has burnt out. The relation between the end-velocity of a rocket projectile (theoretical value, without considering friction by the atmosphere) and the mass ratio is described by the equation

$$v_b = I_s \cdot g \cdot \ln \frac{1}{1 - \frac{M_e}{M_i}}$$

v_b: velocity of projectile at the end of burning, I_s: specific impulse, g: gravitation constant, M_e: mass of the rocket projectile after propellant has burnt out, M_i: mass of charged missile at beginning of burning.

Other keywords in this context: → *Rocket Motor*; → *Solid Propellant Rocket*; → *Specific Impulse*.

Mercury Fulminate

Knallquecksilber; *fulminate de mercure*

$Hg{=}(ONC)_2$
colorless crystals
empirical formula: $C_2N_2O_2Hg$
molecular weight: 284.6 g/mol
energy of formation: +229 kcal/kg = +958 kJ/kg
enthalpy of formation: +225 kcal/kg = +941 kJ/kg
oxygen balance: −11.2%
nitrogen content: 9.84%
heat of explosion: 415 kcal/kg = 1735 kJ/kg
density: 4.42 g/cm^3
deflagration point: 165 °C = 330 °F
impact sensitivity: 0.1−0.2 kp m = 1−2 N m

Mercury fulminate is toxic and is practically insoluble in water. When dry, it is highly sensitive to shock, impact, and friction, and is easily detonated by sparks and flames. It can be phlegmatized by the addition of oils, fats, or paraffin, and also by press-molding under very high pressure.

Mercury fulminate is prepared by dissolving mercury in nitric acid, after which the solution is poured into 95% ethanol. After a short time, vigorous gas evolution takes place and crystals are formed. When the reaction is complete, the crystals are filtered by suction and washed until neutral. The mercury fulminate product is obtained as small, brown to grey pyramid-shaped crystals; the color is caused by the presence of colloidal mercury.

If small amounts of copper and hydrochloric acid are added to the reaction mixture, a white product is obtained. Mercury fulminate is stored underwater. It is dried at 40 °C shortly before use. Owing to its excellent priming power, its high brisance, and to the fact that it can easily be detonated, mercury fulminate was the initial explosive most frequently used prior to the appearance of lead azide. It was used in compressed form in the manufacture of blasting caps and percussion caps. The material, the shells, and the caps are made of copper.

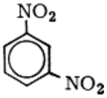
Mesa Burning

Mesa-Abbrand

→ *Burning Rate*.

Metadinitrobenzene

m-Dinitrobenzol; *métadinitrobenzéne*



pale yellow needles
empirical formula: $C_6H_4N_2O_4$
molecular weight: 168.1 g/mol
energy of formation: −21.1 kcal/kg = −88.1 kJ/kg
enthalpy of formation: −38.7 kcal/kg = −161.8 kJ/kg
oxygen balance: −95.2%
nitrogen content: 16.67%
volume of explosion gases: 907 l/kg
heat of explosion
  (H_2O liq.): 637 kcal/kg = 2666 kJ/kg
  (H_2O gas): 633 kcal/kg = 2646 kJ/kg
specific energy: 79.7 mt/kg = 781 kJ/kg
density: 1.5 g/cm^3
solidification point: 89.6 °C = 193.3 °F
lead block test: 242 cm^3/10 g
detonation velocity, confined: 6100 m/s = 20 000 ft/s
  at $\rho = 1.47$ g/cm^3
deflagration point: evaporation at 291 °C = 556 °F;
  no deflagration
impact sensitivity: 4 kp m = 39 N m
friction sensitivity: up to 36 kp = 353 N no reaction
critical diameter of steel sleeve test: 1 mm

Dinitrobenzene is sparingly soluble in water. It is prepared by direct nitration of benzene or nitrobenzene. It is an insensitive explosive. For purposes of official transport regulations, the sensitivity and the reactivity of dinitrobenzene are just on the limit between high-explosive and the nondangerous zone.

Dinitrobenzene is toxic and produces cyanosis.

The maximum permissible concentration of this compound in the air at the workplace is 1 mg/m^3. The compound is of no interest as an explosive, since toluene – from which → *TNT* is produced – is available in any desired amount.

Methylamine Nitrate

Methylaminnitrat; *nitrate de méthylamine*; *MAN*

$CH_3{-}NH_2 \cdot HNO_3$
colorless crystals
empirical formula: $CH_6N_2O_3$
molecular weight: 94.1 g/mol
energy of formation: −862 kcal/kg = −3604 kJ/kg
enthalpy of formation: −896 kcal/kg = −3748 kJ/kg
oxygen balance: −34%
nitrogen content: 29.77%
volume of explosion gases: 1191 l/kg
heat of explosion
  (H_2O liq.): 821 kcal/kg = 3437 kJ/kg
  (H_2O gas): 645 kcal/kg = 2698 kJ/kg
specific energy: 95.3 mt/kg = 934 kJ/kg
density: 1.422 g/cm^3
melting point: 111 °C = 232 °F
lead block test: 325 cm^3/10 g

Methylamine nitrate is considerably more hygroscopic than ammonium nitrate. Its sensitivity to impact is very low. It can be employed as a flux component in castable ammonium nitrate mixtures, but requires incorporation of brisant components. Methylamine nitrate is also employed as a component in → *Slurries*.

Methyl ethyl ketone peroxide

Methyl-ethylketon-peroxid, MEKP

MEKP is an example of an organic peroxide that contains more than one peroxo group per molecule and is therefore related to → TATP and → HMTD.

MEKP can be prepared by the reaction of 2-butanone with hydrogen peroxide (50% aqueous solution) at 0 °C using catalytic amounts of acid and is a colorless oily liquid. MEKP is a highly explosive compound and has caused many accidental injuries in accidental explosions since it can be thermally initiated at the relatively low temperature of 110 °C and is incompatible with Fe^{2+} or Fe^{3+} ions and alkaline or acidic substances which lower the thermal decomposition temperature of MEKP. MEKP is, however, thermally more stable than → TATP.

MEKP is extremely sensitive and has an impact sensitivity of 35 mJ. MEKP is an important industrial chemical which is used in dilute solution as a catalyst in resins and in the plastic industry.

Methyl Nitrate

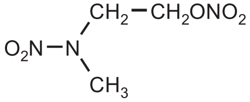
Methylnitrat; *nitrate de méthyle*

$CH_3{-}O{-}NO_2$
colorless volatile liquid
empirical formula: CH_3NO_3
molecular weight: 77.0 g/mol
energy of formation: −456.7 kcal/kg = −1911 kJ/kg
enthalpy of formation: −483.6 kcal/kg = −2023.6 kJ/kg
oxygen balance: −10.4%
nitrogen content: 18.19%
volume of explosion gases: 873 l/kg
heat of explosion
  (H_2O liq.): 1613 kcal/kg = 6748 kJ/kg
  (H_2O gas): 1446 kcal/kg = 6051 kJ/kg
specific energy: 123 mt/kg = 1210 kJ/kg
density: 1.217 g/cm^3
boiling point: 65 °C = 149 °F
lead block test: 610 cm^3
detonation velocity, confined: 6300 m/s = 20 700 ft/s
  at $\rho = 1.217$ g/cm^3
deflagration: evaporation, no deflagration
impact sensitivity: 0.02 kp m = 0.2 N m
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 18 mm

Methyl nitrate is a highly volatile liquid, and its brisance is about equal to that of nitroglycerine. Its vapors are both flammable and explosive and produce headaches. Methyl nitrate dissolves nitrocellulose, yielding a gel, from which it rapidly evaporates.

It can be prepared by introducing methyl alcohol into a nitrating mixture at a low temperature or by distilling methanol with medium-concentrated nitric acid.

N-Methyl-*N*-(2-nitroxyethyl)nitramine, MeNENA

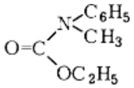


solid
empirical formula: $C_3H_7N_3O_5$
molecular weight: 165.1 g/mol
oxygen balance: −43.61%
energy of formation: −160.71 kJ/mol
enthalpy of formation: −179.28 kJ/mol = −1085.87 kJ/kg
density: 1.55 g/cm^3
melting point: 37–39 °C
boiling point: 205 °C

MeNENA is an energetic plasticizer for propellant applications.

Methylphenylurethane

Methylphenylurethan; *Ethyl-N,N-Phenylmethylcarbamat*; *methylphenylurethane*



colorless liquid
empirical formula: $C_{10}H_{13}O_2N$
molecular weight: 179.2 g/mol
boiling point: 250 °C = 482 °F
refractive index n_D^{20}: 1.515 58
energy of formation: −538.5 kcal/kg = 2253 kJ/kg
enthalpy of formation: −564.7 kcal/kg = −2363 kJ/kg
oxygen balance: −218.7%
nitrogen content: 7.82%
density: 1.09 g/cm^3

Methylphenylurethane is a gelatinizing → *Stabilizer* especially for → *Double-Base Propellants*.

Specifications

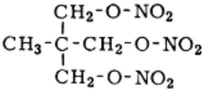
density (20/4):	1.071−1.090 g/cm^3
boiling analysis:	248−255 °C = 478−491 °F
reaction:	neutral

Methyl Violet Test

In this test, which was developed in the USA about 50 years ago from another test known as the German test (testing for visible nitrous gases at 135 °C), visual inspection of the nitrous gases is replaced by testing with a strip of paper, impregnated with methyl violet. This test is performed at 134.5 °C for nitrocellulose and single-base powders and at 120 °C for multibase propellants. At the end of the test the violet dye changes color to blue-green and then to salmon-pink. For single-base powder, this color change should not take place after less than 30 min and for a multibase powder after less than 60 min. Only highly unstable powders can be detected by this test, therefore the latter is now rarely used.

Metriol Trinitrate

methyltrimethylolmethane trinitrate; *Metrioltrinitrat; Nitropentaglycerin*; *trinitrate de triméthylolméthylméthane*; *TMETN*



$$CH_3-\overset{\displaystyle CH_2-O-NO_2}{\underset{\displaystyle CH_2-O-NO_2}{\overset{|}{\underset{|}{C}}}}-CH_2-O-NO_2$$

pale-colored, oily substance
empirical formula: $C_5H_9N_3O_9$
molecular weight: 255.1 g/mol
energy of formation: −373.8 kcal/kg = −1564.1 kJ/kg
enthalpy of formation: −398.2 kcal/kg = −1666.1 kJ/kg
oxygen balance: −34.5%
nitrogen content: 16.47%
volume of explosion gases: 966 l/kg
heat of explosion
  (H_2O liq.): 1182 kcal/kg = 4945 kJ/kg
  (H_2O gas): 1087 kcal/kg = 4549 kJ/kg
specific energy: 124 mt/kg = 1215 kJ/kg
density: 1.460 g/cm^3
solidification point: −15 °C = +5 °F
lead block test: 400 cm^3/10 g
deflagration point: 182 °C = 360 °F
impact sensitivity: 0.02 kp m = 0.2 N m

The oil is practically insoluble in water and is chemically very stable. When mixed with nitrocellulose, it can be gelatinized on rollers only to a moderate extent and only at an elevated temperature. The volatility of the trinitrate is low.

Metriol trinitrate can be prepared by nitration of methyltrimethylolmethane (metriol) with mixed acid. Metriol is prepared by condensation of propanal with formaldehyde in a manner similar to that employed in the synthesis of pentaerythritol.

During the Second World War, mixtures of metriol trinitrate with triglycol dinitrate (a good gelatinizer of nitrocellulose) were processed together with nitrocellulose to produce tropic-proof propellants. They were also distinguished by good mechanical strength for employment in rocket motors. TMETN is an excellent plasticizer for GAP or other energetic polymer binders.

Microballoons

Microspheres

Microballoons are bubbles with an average diameter of 40 μm (range 10–100 μm). They were originally used as a filler to control the density of plastic products. They are available as glass or plastic material.

Microballoons have proved to produce a fine gas bubble distribution in low-sensitivity explosives, particularly in emulsion slurries. Finely distributed gas bubbles considerably increase the sensitivity to detonation (hotspots). In the form of microballoons, gas distribution stabilizes; gas distributions without enclosure may experience a loss in effectiveness as a result of coagulation into coarse bubbles, or by escape.

Millisecond Delay Blasting

Millisekunden-Sprengen; *tir à microretard*

The explosive charges are successively initiated at time intervals as short as 20–100 ms with the aid of millisecond detonators (→ *Bridgewire Detonators*).

Experience shows that rock fragmentation is better with this technique, and a smaller amount of explosive is required to produce the same blasting effect since there is better mutual support of the charges.

Minex

A cast explosive charge used in the USA consisting of RDX, TNT, ammonium nitrate, and aluminum powder.

Miniaturized Detonating Cord

Mild detonating fuse; *nicht-sprengkräftige detonierende Zündschnur*;
cordeau détonant miniaturé

Detonating cord with a core load of five or less grains of explosive per foot (≤ 0.1 g/m).

Minol

A pourable mixture of TNT, ammonium nitrate, and aluminum powder (40 : 40 : 20).

casting density: 1.70 g/cm^3
detonation velocity at casting density, confined:
6000 m/s = 19 700 ft/s

Misfire

Versager; *raté*

An explosive material charge that fails to detonate after an attempt of initiation.

Missile

Raketenflugkörper; *roquette*

The integral functional unit consisting of initiator and igniter devices, rocket engine, guiding equipment, and useful payload. → *Rocket Motor*. Missiles are, in principle, guided rocket projectiles.

Mock Explosives

Sprengstoff-Attrappen; *factices*

Mocks27) are nonexplosive simulants for high explosives. They duplicate the properties for test purposes without hazard. The required properties to copy need different mocks, e.g. for physical properties, for density, or for thermal behavior.

Monergol

In rocket technology the name for liquid or gelled homogeneous propellants, which require no other reaction partner for the formation of gaseous reaction products. Gas formation can be due to catalytic decomposition (on concentrated H_2O_2 or anhydrous hydrazine) or to an intramolecular reaction, e.g. by decomposition of propylnitrate generating N_2, CO, CO_2, NO, etc., → *Liquid Propellants*.

Motor

Motor; *moteur*

Generic term for solid propellant gas generator or rocket.

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27) For more details see *Dobratz, B.M.*, Properties of Chemical Explosives and Explosive Simulants, UCRL-51319, Rev. 1, University of California.

MOX

Abbreviation for metal oxidizer explosives (USA). For compositions see Table 20.

Table 20 Composition of metal oxidizer explosives.

MOX	1 (%)	2B (%)	3B (%)	4B (%)	6B (%)
Ammonium perchlorate	35	35	–	–	–
Aluminum (fine grain)	26.2	52.4	47	47	49.2
Magnesium (fine grain)	26.2	–	–	–	–
Tetryl	9.7	–	–	–	–
RDX	–	5.8	29.1	29.1	28.7
TNT	–	3.9	2.0	2.0	–
Potassium nitrate	–	–	18	–	–
Barium nitrate	–	–	–	18	–
Copper oxide	–	–	–	–	19.7
Wax	–	–	0.9	0.9	0.9
Calcium stearate	1.9	1.9	2.0	2.0	–
Graphite	1.0	1.0	1.0	1.0	1.5

Muckpile

Haufwerk; *déblai*

The pile of broken burden resulting from a blast.

Mud Cap

Auflegerladung; *pétardage*

Mud caps are explosive charges which have a strong destructive effect even when not placed in a confining borehole. They are used for the demolition of boulders and concrete structures. (Synonymous with *Adobe Charge* and *Bulldoze*).

A highly brisant explosive is required for this purpose. Mud caps are usually covered with mud in order to enhance their brisance. It is often desirable to use charges of definite shape (→ *Shaped Charges*; → *Cutting Charges*).

Munroe Effect

The effect of shaped charges is known in the USA as the Munroe effect after *Munroe*, who described it in 1888. The terms cavity effect and lined-cavity effect are also employed (→ *Shaped Charges*).

Muzzle Flash

Mündungsfeuer; *lueur à 1 a bouche*

Muzzle flash is the appearance of a flame at the muzzle of a barrel or a tube during the shot. The flash is a secondary effect which takes place when the still flammable explosion gases (CO, H_2) become mixed with air on emerging from the barrel.

The reasons for the appearance of the flash are not yet fully clear; it is also unclear why the flash can be suppressed by introducing certain additives to the powder (probably catalytic termination of chain reactions). It is certain that muzzle flash is promoted by the high temperature of the combustion gases, the high gas pressure and the high velocity of the gas emerging from the muzzle.

In a given weapon, fast-burning powders have a lower tendency to flash than slow-burning powders. Weapons with a high ballistic performance (high projectile velocity and high gas pressure) give a larger flash, which is more difficult to suppress than that given by firearms with a lower performance.

In general, alkali metal salts damp muzzle flash better than alkaline earth salts. It is also fairly certain that the flash-damping effect in the alkali metal group increases from lithium to cesium. In the First World War, bags filled with sodium chloride placed in front of the propellant charge, was used as a muzzle flash damper.

Subsequently, potassium salts, in particular the sulfate, nitrate and bitartrate, proved to be more effective. Other muzzle flash dampers, used with varying degrees of success, are oxalates, phosphates, and bicarbonates.

Nanoenergetic Materials

Nanosized energetic materials possess desirable combustion characteristics, such as high heats of combustion and fast energy release rates. Because of their capability to enhance performance, various metals have been introduced in solid propellants formulations, gel propellants, and solid fuels. Besides, shortened ignition delay and burn times, enhanced heat transfer rates, greater flexibility in design and the use of nanomaterials as gelling agent stimulate current research activities.

Navy Insensitive Low Erosion Propellant

NILE

NILE (Navy Insensitive Low Erosion Propellant) is an example of the newly developed class of high-nitrogen gun propellant charges. NILE is based on triaminoguanidinium azotetrazolate and has very similar performance values for M1/NILE but a much reduced erosion coefficient (N_2/CO) which is due to the reduced CO and increased N_2 content in the products: $f_E = 0.942/0.895\,kJ/g$; $b_E = 1.076/1.190\,cm^3/g$, $T_c = 2537/2175\,K$; $N_2/CO = 0.25/ > 100$.

A typical composition for a high-nitrogen gun propellant is shown below:

Ingredient	Amount (wt. %)
RDX	40
High-N compound[a)]	20
FOX-12	16
Cellulose acetate	12
BDNPA/F[b)]	8
NC (13.25)	4

a) High-N compound = triaminoguanidinium azotetrazolate or triaminoguanidinium bistetrazolate.

b) Bis(dinitropropyl)acetal (BDNPA) : Bis(dinitropropyl)formal (BDNPF) = 50 : 50

NENA

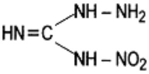
The abbreviation for nitratoethylnitramin. NENAs are a class of energetic plasticizers, which differ from each other in the chain length of the alkyle rest bonded to the nitramine. → *N-Butyl-N-(2-nitroxyethyl)nitramine*, *BuNENA*; → *N-Ethyl-N-(2-nitroxyethyl)nitramine*, *EtNENA*; → *N-Methyl-N-(2-nitroxyethyl)nitramine*, *MeNENA*

Neutral Burning

Burning of a propellant grain in which a reacting surface area remains approximately constant during combustion (→ *Burning Rate*, *Progressive Burning* and *Regressive Burning*).

Nitroaminoguanidine

Nitraminoguanidin; N′-Nitro-N-aminoguandine, 1-Amino-3-nitroguanidine, NAGu



empirical formula: $CH_5N_5O_2$
molecular weight: 119.09 g/mol
energy of formation: +74.2 kcal/kg = +310.2 kJ/kg
enthalpy of formation: +44.3 kcal/kg = +185.5 kJ/kg
oxygen balance: −33.6%
nitrogen content: 58.2%
heat of explosion
 (H_2O liq.): 895.2 kcal/kg = 3746 kJ/kg
 (H_2O gas): 816.9 kcal/kg = 3418 kJ/kg
specific energy: 114.5 mt/kg = 1124 kJ/kg
density: 1.71 g/cm^3
deflagration point: 188 °C
impact sensitivity: 0.3 kp m = 3 N m
friction sensibility: 25 kp = 240 N
critical diameter of steel sleeve test: 12 mm

Nitroaminoguanidine is obtained by reacting → *nitroguanidine* with hydrazine in aqueous solution. Nitroaminoguanidine has gained a certain attractiveness as a reduced carbon monoxide propellant because of its ready ignitability and its burn-up properties.

Nitrocarbonitrate

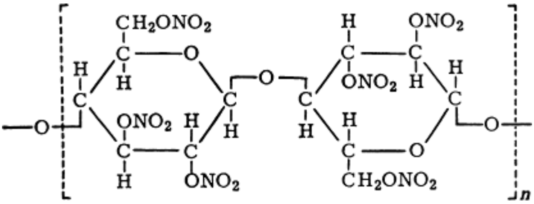
NCN

Nitrocarbonitrates are relatively low-sensitive explosives, usually based on ammonium nitrate, which do not contain any high explosives such as nitroglycerine or TNT. The components are named by *nitro:* dinitrotoluene; by *carbo:* solid carbon carriers as fuel: by *nitrate:* ammonium nitrate.

NCN as a classification for dangerous goods has been removed by the US Department of Transportation and replaced by blasting agent as a shipping name (→ *Blasting Agents*).

Nitrocellulose

Nitrocellulose; *nitrocellulose*; *NC*



white fibers
empirical formula of the structural unit: $C_{12}H_{14}N_6O_{22}$
nitrogen content referring to the theoretical maximum[28] nitration grade = 14.14%
nitrogen content, practical maximum value: ca. 13.4%
molecular weight of the structure unit: 324.2 g/mol (N-content 14.14%)
energy of formation and enthalpy of formation in relation to the nitrogen content:

	Energy of formation		**Enthalpy of formation**	
(% N)	**(kcal/kg)**	**(kJ/kg)**	**(kcal/kg)**	**(kJ/kg)**
13.3	−556.1	−2327	−577.4	−2416
13.0	−574.6	−2404	−596.1	−2494
12.5	−605.6	−2534	−627.2	−2624
12.0	−636.5	−2663	−658.4	−2755
11.5	−667.4	−2793	−689.6	−2885
11.0	−698.4	−2922	−720.7	−3015

the following data refer to 13.3% N
oxygen balance: −28.7%
volume of explosion gases: 871 l/kg
heat of explosion
  (H_2O liq.): 1031 kcal/kg = 4312 kJ/kg
  (H_2O gas): 954 kcal/kg = 3991 kJ/kg
density: 1.67 g/cm^3
  (maximum value attainable by pressing: 1.3 g/cm^3)
lead block test: 370 cm^3/10 g
impact sensitivity: 0.3 kp m = 3 N m
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 20 mm

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[28] Nitrogen content >13.5% may be reached in the laboratory by use of acid mixtures with anhydrous phosphoric acid as a component.

Nitrocellulose is the commonly employed designation for nitrate esters of cellulose (cellulose nitrates). Nitrocellulose is prepared by the action of a nitrating mixture (a mixture of nitric and sulfuric acids) on well-cleaned cotton linters or on high-quality cellulose prepared from wood pulp. The concentration and composition of the nitrating mixture determine the resulting degree of esterification, which is measured by determining the nitrogen content of the product.

The crude nitration product is first centrifuged to remove the bulk of the acid, after which it is stabilized by preliminary and final boiling operations. The spent acid is adjusted by addition of concentrated nitric acid and anhydrous sulfuric acid and recycled for further nitration operations. The original form and appearance of the cellulose remains unchanged during the nitration. Subsequent boiling of the nitrocellulose under pressure finally yields a product with the desired viscosity level. The nitrated fibers are cut to a definite fiber length in hollanders or refiners. Apart from the numerous types of lacquer nitrocelluloses, which include ester- and alcohol-soluble products with a nitrogen content of 10.3–12.3% at all viscosity levels used in technology, standard nitrocellulose types are manufactured and blended to the desired nitrogen content. Blasting soluble nitrocotton (dynamite nitrocotton; 12.2–12.3% N) is held at a high viscosity to maintain good gelatinizing properties.

All nitrocelluloses are soluble in acetone. The viscosity of the solutions is very variable. (For its adjustment by pressure boiling see above.)

Nitrocellulose is transported in tightly closed drums or in pasteboard drums lined with plastic bags inside, which contain at least 25% of a moisturizing agent (water, alcohol, isopropanol, butanol, etc.). Spherical NC particles are precipitated from solution under vigorous stirring, and preferably used for manufacturing of cast or composite double-base propellants.

Specifications

The specified nitrogen content, solubility in alcohol, ether-alcohol mixtures and esters, as well as viscosity, etc., all vary in various types of nitrocellulose. The nitrogen content should not vary more than +0.2% from the specified value. The following specifications are valid for all types:

Bergmann–Junk-Test at 132 °C (270 °F):	not more than 2.5 cm^3 /g NO
ashes:	not more than 0.4%
insolubles in acetone:	not more than 0.4%
alkali, as $CaCO_3$:	not more than 0.05%
sulfate, as H_2SO_4:	not more than 0.05%
$HgCl_2$:	none

Nitrocellulose for gelatinous explosives must gelatinize nitroglycerine completely within 5 min at 60 °C (140 °F).

Linters (cotton fibers) as raw material

$(C_6H_{10}O_5)_n$
white fibers
molecular weight of structure unity: 162.14 g/mol

Specifications

α-cellulose content (insoluble in 17.5% NaOH):	at least 96%
fat; resin (solubles in CH_2Cl_2):	not more than 0.2%
moisture:	not more than 7.0%
ash content:	not more than 0.4%
appearance:	homogenous, white or pale yellow, free of impurities (knots; rests of capsules)

Nitroethane

Nitroethan; *nitroéthane*

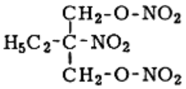
$CH_3{-}CH_2{-}NO_2$
colorless liquid
empirical formula: $C_2H_5NO_2$
molecular weight: 75.07 g/mol
energy of formation: −426.7 kcal/kg = −1785.3 kJ/kg
enthalpy of formation: −458.3 kcal/kg = −1917.4 kJ/kg
oxygen balance: −95.9%
nitrogen content: 18.66%
heat of explosion
  (H_2O liq.): 403 kcal/kg = 1686 kJ/kg
  (H_2O gas): 384 kcal/kg = 1608 kJ/kg
specific energy: 75.3 mt/kg = 738 kJ/kg
density: 1.053 g/cm^3
boiling point: 114 °C = 237 °F

Nitroparaffins are produced by vapor phase nitration with nitric acid vapor. Nitroethane is also prepared in this way. The individual reaction products (nitromethane, nitroethane, nitropropane) must then be separated by distillation.

All these products can be reacted with formaldehyde; polyhydric nitroalcohols are obtained, which can be esterified with nitric acid.

Nitroethylpropanediol Dinitrate

Nitroethylpropandioldinitrat; *dinitrate d'éthyl-nitropropandiol*



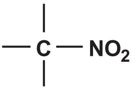
$$H_5C_2{-}\overset{\displaystyle CH_2{-}O{-}NO_2}{\underset{\displaystyle CH_2{-}O{-}NO_2}{C}}{-}NO_2$$

empirical formula: $C_5H_9N_3O_8$
molecular weight: 239.2
oxygen balance: −43.5%
nitrogen content: 17.57%
volume of explosion gases: 1032 l/kg
heat of explosion (H_2O liq.): 1037 kcal/kg = 4340 kJ/kg
specific energy: 122 mt/kg = 1193 kJ/kg
density: 1.44 g/cm^3

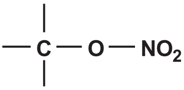
The product is prepared by condensing nitropropane with formaldehyde and by nitration of the resulting nitroethylpropanediol.

Nitrogen-Rich Compounds

Stickstoffreiche Verbindungen



A



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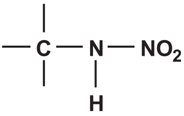

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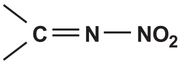
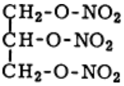


D

By definition, nitrogen rich molecules have a nitrogen content of >65% and are of importance due to the high energy content in the N–N bonds. Often new energetic materials are nitrogen-rich compounds (> 60% N) which also contain oxidizing groups (e.g. nitro: $-NO_2$, nitrimino: $=N-NO_2$), in order to achieve the best oxygen balance (Ω) as possible. This enables the oxidizer and fuel to be combined in *one* molecule (in contrast to mixtures) which results – in general – in superior detonation parameters such as a higher detonation velocity and detonation pressure, without resulting in a worse thermal stability or higher sensitivity than → RDX shows.

Nitroglycerine

glycerol trinitrate; *Nitroglycerin*; *nitroglycérine*; *trinitrate de glycérine; NG; Ngl*



$$\begin{array}{l} CH_2\text{-}O\text{-}NO_2 \\ | \\ CH\text{-}O\text{-}NO_2 \\ | \\ CH_2\text{-}O\text{-}NO_2 \end{array}$$

yellow oil
empirical formula: $C_3H_5N_3O_9$
molecular weight: 227.1 g/mol
energy of formation: −368.0 kcal/kg = −1539.8 kJ/kg
enthalpy of formation: −390.2 kcal/kg = −1632.4 kJ/kg
oxygen balance: +3.5%
nitrogen content: 18.50%
volume of explosion gases: 716 l/kg
heat of explosion
  (H_2O liq.): 1594 kcal/kg = 6671 kJ/kg
  (H_2O gas): 1485 kcal/kg = 6214 kJ/kg
specific energy: 106.6 mt/kg = 1045 kJ/kg
density: 1.591 g/cm^3
solidification point
  +13.2 °C = 55.8 °F (stable modification)
  +2.2 °C = 35.6 °F (unstable modification)
specific heat: 0.32 kcal/kg = 1.3 kJ/kg
vapor pressure:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
0.000 33	20	68
0.009 7	50	122
0.13	80	176
0.31	90	194

lead block test: 520 cm^3/10 g
detonation velocity, confined: 7600 m/s = 25 000 ft/s
  at $\rho = 1.59$ g/cm^3
impact sensitivity: 0.02 kp m = 0.2 N m
friction sensitivity: up to 36 kp = 353 N pistil load
  no reaction critical
diameter of steel sleeve test: 24 mm

Nitroglycerine is almost insoluble in water, but is soluble in most organic solvents; it is sparingly soluble in carbon disulfide. It readily dissolves a large number of aromatic nitro compounds and forms gels with soluble guncotton. Its volatility is negligible, but is still sufficient to cause headaches.

The acid-free product is very stable, but exceedingly sensitive to impact. The transportation of nitroglycerine and similar nitrate esters is permitted only in the form of solutions in nonexplosive solvents or as mixtures with fine-powdered inert materials containing not more than 5% nitroglycerine. To avoid dangers, internal transport within the factories is made by water injection (→ *Water-driven Injector Transport*). Transport of pure nitroglycerine and similar products outside factory premises is difficult; in the USA, special vessels have been developed in which the oil is bubble-free covered with water without air bubbles which raise the impact sensitivity considerably. The nitroglycerine produced is ideally processed immediately to the products (e.g. explosives; double-base powders).

Nitroglycerine is prepared by running highly concentrated, almost anhydrous, and nearly chemically pure glycerin (dynamite glycerin) into a highly concentrated mixture of nitric and sulfuric acids, with constantly efficient cooling and stirring. At the end of the reaction the nitroglycerine acid mixture is given to a separator, where the nitroglycerine separates by gravity. Following washing processes with water and an alkaline soda solution remove the diluted residual acid.

Since nitroglycerine is dangerous to handle, its industrial production by continuous method has always been of the highest interest, since it is always desirable to have the smallest possible quantity of the product in any particular manufacturing stage. Accordingly, several competing methods (*Schmidt, Meissner, Biazzi*, *KONTINITRO*), have been developed, each method being characterized by a different approach to the problem of safety. The most recent procedures involve the reaction of glycerin and acid in injectors (Nitroglycerine AB).

Nitroglycerine is one of the most important and most frequently used components of explosive materials; together with nitroglycol, it is the major component of gelatinous industrial explosives. In combination with nitrocellulose and stabilizers, it is the principal component of powders, gun propellants and smokeless solid rocket propellants (→ *double-base propellants*).

Care has to be taken for complete removal of acid residues from nitroglycerine, because they may enhance the exothermic autocata-lytic decomposition process, from which severe explosions have occurred in the path.

Specifications

1. Nitroglycerine as a component of explosives

Nitrogen content:	not less than 18.35%
Abel test at 82.2 °C (180 °F):	not less than 10 min

2. *Nitroglycerine* as a component of propellants

nitrogen content:	not less than 18.40%
moisture:	not more than 0.5%
alkalinity, as Na_2CO_3:	not more than 0.002%
acidity, as HNO_3:	not more than 0.002%

3. *Glycerol* as a raw material

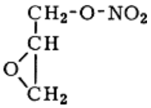
smell:	not offensively pungent
color:	clear, as pale as possible
reaction to litmus:	neutral
inorganic impurities:	none
reducing matter (ammoniacal $AgNO_3$ test):	traces only
fatty acids:	traces only
ash content:	max. 0.03%
water content:	max. 0.50%
net content (oxidation value):	min. 98.8%
density, d_4^{20}:	1.259–1.261 g/cm^3
refractive index n_D^{20}:	1.4707–1.4735
acidity:	not more than 0.3 ml 0.1 N NaOH/100 ml
alkalinity:	not more than 0.3 ml 0.1 N HCl/100 ml

Nitroglycerine Propellants

→ *Double-Base Propellants* and → *Gunpowder*.

Nitroglycide

glycide nitrate; *Nitroglycid*; *nitrate de glycide*



water-white liquid
empirical formula: $C_3H_5NO_4$
molecular weight: 119.1 g/mol
oxygen balance: −60.5%
nitrogen content: 11.76%
density: 1.332 g/cm^3
lead block test: 310 cm^3/10 g
deflagration point: 195–200 °C = 383–390 °F
impact sensitivity: 0.2 kp m = 2 N m

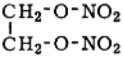
Nitroglycide is soluble in alcohol, ether, acetone, and water; it is highly volatile.

This nitrate ester of glycide is prepared from dinitroglycerine by splitting off one HNO_3 molecule with concentrated alkali. It is the anhydride of glycerin mononitrate.

Nitroglyceride is precursor for → *PolyGlyn*.

Nitroglycol

ethyleneglycol dinitrate; *Nitroglykol*; *dinitrate de glycol*; *EGDN*



$$\begin{array}{l} CH_2\text{-}O\text{-}NO_2 \\ | \\ CH_2\text{-}O\text{-}NO_2 \end{array}$$

colorless, oily liquid
empirical formula: $C_2H_4N_2O_6$
molecular weight: 152.1 g/mol
energy of formation: −358.2 kcal/kg = −1498.7 kJ/kg
enthalpy of formation: −381.6 kcal/kg = −1596.4 kJ/kg
oxygen balance: ±0%
nitrogen content: 18.42%
volume of explosion gases: 737 l/kg
heat of explosion
  (H_2O liq.): 1742 kcal/kg = 7289 kJ/kg
  (H_2O gas): 1612 kcal/kg = 6743 kJ/kg
specific energy: 121 mt/kg = 1190 kJ/kg
density: 1.48 g/cm^3
solidification point: −20 °C = −4 °F
vapor pressure:

Pressure	Temperature	
(mbar)	(°C)	(°F)
0.006	0	32
0.05	20	68
0.35	40	104
1.7	60	140
7.8	80	176
29	100	212

lead block test: 620 cm^3/10 g
detonation velocity, confined: 7300 m/s = 24 000 ft/s
  at $\rho = 1.48$ g/cm^3
deflagration point: 217 °C = 423 °F
impact sensitivity: 0.02 kp m = 0.2 N m

friction sensitivity: at 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 24 mm

Nitroglycol is not hygroscopic, is sparingly soluble in water and readily soluble in common organic solvents; its properties and performance characteristics are practically the same as those of nitroglycerine; it is 150 times more volatile and about four times more soluble in water; it is less viscous and gelatinizes nitrocellulose more rapidly than nitroglycerine.

Glycol can be nitrated in the same vessels as glycerin – in batches or continuously. The same applies to its separation and washing, which are in fact easier since nitroglycol is less viscous.

Nitroglycol is utilized in mixtures with nitroglycerine, since it markedly depresses the freezing temperature of the latter compound. Ammongelits contain only nitroglycol alone as the main explosive component, and therefore only freeze in winter below −20 °C.

The vapor pressure of nitroglycol is markedly higher than that of nitroglycerine; for this reason nitroglycol cannot be used in propellant formulations.

Like all nitrate esters, nitroglycol strongly affects blood circulation; its maximum permitted concentration at the workplace is 1.5 mg/m^3.

Specifications

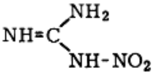
nitrogen content:	not below 18.30%
Abel test:	not under 15 min
alkali (Na_2CO_3):	for use in industrial explosives no limit

Specifications for glycol (raw material)

net content (determination by oxidation with dichromate):	at least 98%
density (20/4):	1.1130–1.1134 g/cm^3
content of diglycol and triglycol (residue of vacuum distillation):	not more than 2.5%
moisture:	not more than 0.5%
glow residue:	not more than 0.02%
chlorides:	none
reaction:	neutral
reducing components (test with NH_3-$AgNO_3$):	none
test nitration:	no red fumes
yield:	at least 23.0%

Nitroguanidine; Picrite

Nitroguanidin; *nitroguanidine*; *Nigu; NQ*



$NH=C(NH_2)(NH-NO_2)$

white, fiber-like crystals
empirical formula: $CH_4N_4O_2$
molecular weight: 104.1 g/mol
energy of formation: −184.9 kcal/kg = −773.4 kJ/kg
enthalpy of formation: −213.3 kcal/kg = −893.0 kJ/kg
oxygen balance: −30.7%
nitrogen content: 53.83%
volume of explosion gases: 1042 l/kg
heat of explosion
  (H_2O liq.): 734 kcal/kg = 3071 kJ/kg
  (H_2O gas): 653 kcal/kg = 2730 kJ/kg
specific energy: 95 mt/kg = 932 kJ/kg
density: 1.71 g/cm^3
melting point: 245–250 °C
specific heat: 0.078 kcal/kg = 0.33 kJ/kg
lead block test: 305 cm^3/10 g
detonation velocity, confined at max. density:
  8200 m/s = 26 900 ft/s
deflagration point: at melting point decomposition;
  no deflagration
impact sensitivity: $>$ 50 N m
friction sensitivity: $>$ 360 N
critical diameter of steel sleeve test: at 1 mm ∅ no reaction

Nitroguanidine is soluble in hot water, practically insoluble in cold water, very sparingly soluble in alcohol, insoluble in ether, and readily soluble in alkali. It is not very sensitive to shock or impact. It has excellent chemical stability.

Guanidine nitrate, which has been prepared from dicyanodiamide and ammonium nitrate, is dehydrated under formation of nitroguanidine, when treated with concentrated sulfuric acid. Nitroguanidine can be incorporated into nitrocellulose powder, nitroglycerine powder, or diglycol dinitrate powder; it is not dissolved in the powder gel, but is embedded in it as a fine dispersion. These "cold" (calorie-poor) powders erode gunbarrels to a much lesser extent than do the conventional "hot" powders.

Nitroguanidine has the advantage of quenching muzzle flash, but smoke formation is somewhat more intensive.

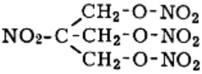
Nitroguanidine is also of interest as an insensitive high explosive (→ *LOVA*); its energy is low, but density and detonation velocity are high.

*Specifications*white, free flowing, crystalline powder

Type 1	
net content:	not less than 98%
acidity as H_2SO_4:	not more than 0.60%
Type 2	
net content:	not less than 99%
acidity as H_2SO_4:	not more than 0.06%
Both types	
ash content:	not more than 0.30%
acid content, as H_2SO_4:	not more than 0.06%
volatile matter:	not more than 0.25%
sulfates:	not more than 0.20%
water insolubles:	not more than 0.20%
pH:	4.5–7.0

Nitroisobutylglycerol Trinitrate

nib-glycerin trinitrate; *Nitroisobutylglycerintrinitrat*; *trimethylolnitromethane trinitrate; trinitrate de nitroisobintylglycérine*; *NIBTN*



$$NO_2\text{-}C\begin{array}{l}\diagup CH_2\text{-}O\text{-}NO_2\\ \text{-}CH_2\text{-}O\text{-}NO_2\\ \diagdown CH_2\text{-}O\text{-}NO_2\end{array}$$

yellow viscous oil
empirical formula: $C_4N_6N_4O_{11}$
molecular weight: 286.1 g/mol
energy of formation: −169.1 kcal/kg = −707.5 kJ/kg
enthalpy of formation: −190.8 kcal/kg = −797.5 kJ/kg
oxygen balance: ±0%
nitrogen content: 19.58%
volume of explosion gases: 705 l/kg
heat of explosion
  (H_2O liq.): 1831 kcal/kg = 7661 kJ/kg
  (H_2O gas): 1727 kcal/kg = 7226 kJ/kg
specific energy: 125 mt/kg = 1225 kJ/kg
density: 1.68 g/cm^3
solidification point: −35 °C = −31 °F
lead block test: 540 cm^3/10 g
detonation velocity, confined: 7600 m/s = 24 900 ft/s
  at $\rho = 1.68$ g/cm^3
deflagration point: 185 °C = 365 °F
impact sensitivity: 0.2 kp m = 2 N m

The compound is less volatile than nitroglycerine, practically insoluble in water and petroleum ether, soluble in alcohol, acetone, ether, benzene, and chloroform, and is a good gelatinizer of guncotton. Its explosive strength is close to that of nitroglycerine.

It is prepared by condensation of formaldehyde with nitromethane and by nitration of the nitroisobutylglycerine product under the same conditions as nitroglycerine. The nitration and stabilization procedures are very difficult because of decomposition reactions.

While being of interest to the explosives industry, since it has an ideal oxygen balance, its stabilization in practice has proven to be impossible.

Nitromethane

Nitromethan; *nitrométhane*; *NM*

CH_3NO_2
colorless liquid
molecular weight: 61.0 g/mol
energy of formation: −413.7 kcal/kg = −1731 kJ/kg
enthalpy of formation: −442.8 kcal/kg = −1852.8 kJ/kg
oxygen balance: −39.3%
nitrogen content: 22.96%
volume of explosion gases: 1059 l/kg
heat of explosion
  (H_2O liq.): 1152 kcal/kg = 4821 kJ/kg
  (H_2O gas): 1028 kcal/kg = 4299 kJ/kg
specific energy: 127 mt/kg = 1245 kJ/kg
density: 1.1385 g/cm^3
solidification point: −29 °C = −20 °F
boiling point: 101.2 °C = 214.2 °F
heat of vaporization: 151 kcal/kg = 631 kJ/kg
vapor pressure:

Pressure (mbar)	Temperature (°C)	(°F)
1.3	−29	−20 (solidification point)
10	0	32
32	20	68
140	50	122
283	80	176
1010	101.2	214.2 (boiling point)

lead block test: 400 cm^3/10 g
detonation velocity, confined: 6290 m/s = 20 700 ft/s
at $\rho = 1.138$ g/cm^3

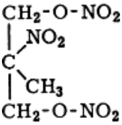
Nitromethane is sparingly soluble in water. The compound is of industrial interest as a solvent rather than as an explosive. Its technical synthesis involves nitration of methane with nitric acid above 400 °C in the vapor phase.

It was used in the USA for underground model explosions (e.g. Pre-Gondola), in preparation for the Nuclear Charge technique. Nitromethane was also employed in stimulation blasting in oil and gas wells. PLX (Picatinny Liquid Explosive) is a mixture of nitromethane with 5% ethylenediamine and is used to clean up mine fields.

Nitromethane is of interest as a monopropellant or as a fuel in liquid or gelled form for rockets → Gel Propellants.

Nitromethylpropanediol Dinitrate

methylnitropropanediol dinitrate; *Nitromethylpropandioldinitrat*; *dinitrate de nitromethylpropanediol*



empirical formula: $C_4H_7N_3O_8$
molecular weight: 225.1 g/mol
oxygen balance: −24.9%
nitrogen content: 18.67%
volume of explosion gases: 890 l/kg
heat of explosion
(H_2O liq.): 1266 kcal/kg = 5295 kJ/kg
(H_2O gas): 1163 kcal/kg = 4866 kJ/kg
specific energy: 126.5 mt/kg = 1240 kJ/kg
density: 1.5 g/cm^3

The product is prepared by condensation of → *Nitroethane* with formaldehyde and subsequent nitration of nitromethylpropanediol.

Nitroparaffins

Aliphatic hydrocarbons with NO_2-groups attached directly to carbon atoms. They are mainly obtained by nitration in a gaseous state; → *Nitromethane*; → *Nitroethane*; → *Trinitromethane*; → *Tetranitromethane*.

Nitroparaffins can be reacted with formaldehyde to obtain nitroalcohols, which can be further esterified with nitric acid (e.g. → *Nitroisobutylglycerol Trinitrate*).

Nitrostarch

Nitrostärke; *nitrate d'amidon*

$[C_6H_7O_2(ONO_2)_3]_n$
pale yellow powder
empirical formula of the structural unit: $C_6H_7N_3O_9$
oxygen balance at 12.2% N: −35%
density: 1.6 g/cm^3
maximum value attainable by pressing: 1.1 g/cm^3
lead block test: 356 cm^3/10 g
deflagration point: 183 °C = 361 °F
impact sensitivity: 1.1 kp m = 11 N m

Nitrostarch is insoluble in water and ether, but is soluble in ether alcohol mixtures and in acetone.

Nitrostarch, with various nitrogen contents (12–13.3%), is prepared by nitration of starch with nitric acid or nitrating mixtures. The resulting crude product is washed in cold water and is then dried at 35–40 °C.

Nitrostarch resembles nitrocellulose in several respects, but, owing to its poor stability, difficulty in preparation and hygroscopicity, it is not used anywhere outside the USA. Headache-free industrial explosives are based on nitrostarch.

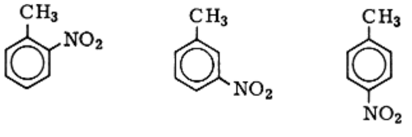
Nitrosugar

Nitrozucker, Zuckernitrat; *nitrate de sucre*

Nitrosugar in its pure form is too unstable to be utilized in practice; however, during the First World War, a liquid explosive named Nitrohydren was prepared by nitration of solutions of cane sugar in glycerol and was then further processed into explosives and gunpowders. However, these mixtures are much more difficult to stabilize than nitroglycerine alone and are no longer of interest, since glycerin is freely available.

Nitrotoluene

Nitrotoluol; *nitrotoluène*



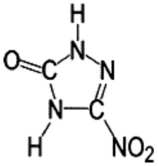
pale yellow liquid
empirical formula: $C_7H_7O_2N$
molecular weight: 137.1 g/mol
oxygen balance: −180.9%
nitrogen content: 10.22%

Nitrotoluene is of importance as an intermediate or precursor for in the manufacture of TNT. There are three isomers, of which only the ortho- and para-isomers can yield pure 2,4,6-trinitrotoluene. Mononitration of toluene yields mostly the orthocompound, as well as 4% of the meta-, and about 33% of the para-compound.

It is often advantageous to separate the isomers from each other (by distillation or by freezing out) in the mononitro stage.

3-Nitro-1,2,4-triazole-5-one

Oxynitrotriazole, NTO, ONTA



colorless crystals
empirical formula: $C_2H_2N_4O_3$
molecular weight: 130,1 g/mol
energy of formation: −164.69 kcal/kg = −689.10 kJ/kg
enthalpy of formation: −185.14 kcal/kg = −774.60 kJ/kg
oxygen balance: −24.6%
nitrogen content: 43.07%
volume of detonation gases: 855 l/kg
heat of explosion
(H_2O liq.): 752.4 kcal/kg = 3148 kJ/kg
(H_2O gas): 715.4 kcal/kg = 2993 kJ/kg
specific energy: 96.4 mt/kg = 945.4 kJ/kg
density: 1.91 g/cm³
detonation velocity: unconfined 7860 m/s at $\rho = 1.80$ g/cm³
confined 7940 m/s at $\rho = 1.77$ g/cm³
deflagration point: > 270 °C => 540 °F
impact sensitivity: ≥ 120 N m
friction sensitivity: at 36 kp = 353 N pistil load no reaction
melting point: 270 °C

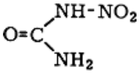
NTO is synthesized in a two-step process by reacting semicarbazide HCl with formic acid to obtain 1,2,4 triazole-5-one and followed by nitration to NTO.

NTO is used as a component in insensitive high explosives (IHE).

It forms easily salts with organic bases like melamine guanidine and ethylene diamine.

Nitrourea

Nitroharnstoff; *nitro-urée*



colorless crystals
empirical formula: $CH_3N_3O_3$
molecular weight: 105.1 g/mol
energy of formation: −617.2 kcal/kg = −2582.4 kJ/kg
enthalpy of formation: −642.5 kcal/kg = −2688.4 kJ/kg
oxygen balance: −7.6%
nitrogen content: 39.98%
volume of explosion gases: 853 l/kg
heat of explosion (H_2O liq.): 895 kcal/kg = 3745 kJ/kg
specific energy: 93.0 mt/kg = 912 kJ/kg
density: 1.69 g/cm^3
melting point: 159 °C = 318 °F (decomposition)
beginning of decomposition: 80 °C = 176 °F

Nitrourea is soluble in benzene, ether, and chloroform; it is decomposed by water.

It is synthesized by dehydration of urea nitrate with sulfuric acid.

No-Fire Current

Grenz-Stromstärke; *intensite de courant de non-allumage*

Maximum current that can be continuously applied to bridgewire circuit without igniting prime material (Note: Continued applications of this current may degrade prime and dud the unit).

Nonel

Trade name of a new nonelectric device for the firing of explosive charges. The basic unit consists, of detonating cords of a plastic hose (3 mm in diameter), the inner wall of which is coated with a thin layer of explosive instead of electrical wires. A shock wave initiated by a special initiator passes through the tube with a speed of ≈ 2000 m/s. The spectator observes this shockwave process as a flash in the hose. The plastic tube is not destroyed by the shock.

In order to initiate a charge, the Nonel line must be combined with a conventional detonator. Branching is possible.

Nonelectric Delay Device

Detonationsverzögerer; *detonateur avec retard*

A detonator with an integral delay element used in conjunction with, and capable of being initiated by, a detonating impulse.

Nozzle

Düse; *tuyère*

Mechanical device designed to control the characteristics of a fluid flow from a chamber into an outer medium.

In rocket technology it is intended to increase the kinetic energy of exhaust fumes by reduction of pressure energy or internal energy. A Laval nozzle, as often used, has a convergent section followed by a divergent section. Convergent nozzles accelerate fluids even up to the sonic velocity at the smallest cross-section if the nozzle pressure ratio enough. Divergent nozzles decelerate subsonic flowing fluids and accelerate sonic or supersonic fluids.

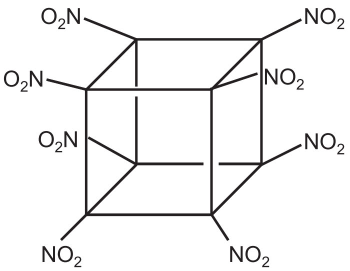
Obturate

Verschluss; *dispositif de clôture*

To stop or close an opening to prevent escape of gas or vapor, to seal as in delay elements.

Octanitrocubane

Octanitrocuban; *octanitrocubane*; *ONC*



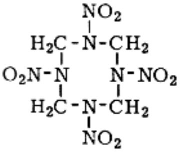
colorless crystals
empirical formula: $C_8N_8O_{16}$
molecular weight: 464.132 g/mol
oxygen balance: 0%

energy of formation: 443.50 kJ/mol = 955.55 kJ/kg
enthalpy of formation: 413.8 kJ/mol = 891.55 kJ/kg
density: 1.979 g/cm^3
melting point: −275 °C

ONC was synthesized for the first time in 1999. It is a derivate of cubane, where each of the eight hydrogen atoms is replaced by a nitro group. It is however less powerful than predicted, as the high theoretical density above 2.1 g/cm^3 has not been achieved.

Octogen

cyclotetramethylene tetranitramine; *Homocyclonit*; *cyclotétraméthyléne tétranitramine; Octogéne*; *HMX*



colorless crystals
empirical formula: $C_4H_8N_8O_8$
molecular weight: 296.2 g/mol
energy of formation: +84.5 kcal/kg = +353.6 kJ/kg
enthalpy of formation: +60.5 kcal/kg = +253.3 kJ/kg
oxygen balance: −21.6%
nitrogen content: 37.83%
volume of explosion gases: 902 l/kg
heat of explosion
 (H_2O gas): 1255 kcal/kg = 5249 kJ/kg (calculated)29)
 (H_2O liq.): 1338 kcal/kg = 5599 kJ/kg (calculated)30)
heat of detonation
 (H_2O liq.): 1480 kcal/kg = 6197 kJ/kg (experimental)31)
specific energy: 139 mt/kg = 1367 kJ/kg
density
 α-modification: 1.84 g/cm^3
 β-modification: 1.90 g/cm^3
 γ-modification: 1.82 g/cm^3
 δ-modification: 1.58 g/cm^3

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29) Computed by the ICT-Thermodynamic-Code.

30) Computed by the ICT-Thermodynamic-Code.

31) Value quoted from Debratz, B.M. (1981) *Properties of Chemical Explosives and Explosive Simulants*, University of California, Livermore.

melting point: 275 °C = 527 °F
modification transition temperatures
$\alpha \rightarrow \delta$: 193–201 °C = 379–394 °F
$\beta \rightarrow \delta$: 167–183 °C = 333–361 °F
$\gamma \rightarrow \delta$: 167–182 °C = 333–359 °F
$\alpha \rightarrow \beta$: 116 °C = 241 °F
$\beta \rightarrow \gamma$: 154 °C = 309 °F
transition enthalpies
$\alpha \rightarrow \delta$: 5.98 kcal/kg = 25.0 kJ/kg
$\beta \rightarrow \delta$: 7.90 kcal/kg = 33.1 kJ/kg
$\gamma \rightarrow \delta$: 2.26 kcal/kg = 9.46 kJ/kg
$\beta \rightarrow \gamma$: 5.64 kcal/kg = 23.6 kJ/kg
$\alpha \rightarrow \gamma$: 3.71 kcal/kg = 15.5 kJ/kg
$\alpha \rightarrow \beta$: 1.92 kcal/kg = 8.04 kJ/kg
specific heat, β-modification: 0.3 kcal/kg at 80 °C = 176 °F
lead block test: 480 cm^3/10 g
detonation velocity, confined, β-mod.: 9100 m/s = 29 800 ft/s at $\rho = 1.9\ g/cm^3$
deflagration point: 287 °C = 549 °F
impact sensitivity: 0.75 kp m = 7.4 N m
friction sensitivity: at 12 kp = 120 N
pistil load: reaction
critical diameter of steel sleeve test: 8 mm

Octogen appears in four modifications, of which only the β-modification displays a particularly high density and hence also a particularly fast detonation rate.

It is practically insoluble in water. Its solubilities in other solvents resemble those of → *Hexogen*.

The compound is formed as a byproduct from the manufacture of hexogen by the Bachmann process (from hexamethylenetetramine, ammonium nitrate, nitric acid, and acetic anhydride). It is obtained as the sole product, when 1,5-methylene-3,7-dinitro-1,3,5,7-tetrazacyclooctane is treated with acetic anhydride, ammonium nitrate, and nitric acid.

The above starting material is formed when acetic anhydride is made to react on hexamethylenetetramine dinitrate.

In high-power charges, especially in shaped charges, octogen performs better than Hexogen.

The δ-phase, which may occur after heating is much more sensitive against impact. friction and dectrostatic impulse.

Specifications

net content of β-modification:	grade A, not less than 93% grade B, not less than 98%
melting point:	not less than 270 °C = 518 °F
acetone-insolubles:	not more than 0.05%
ashes:	not more than 0.03%
acidity, as CH_3COOH:	not more than 0.02%

Octol

A mixture of octogen (HMX) and TNT 70/30 and 75/25. Performance values:

	70/30	**75/25**	
detonation velocity, confined	8377	8643	m/s
at $\rho =$	1.80	1.81	g/cm^3
volume of explosion gases	827	825	l/kg
heat of explosion (H_2O liq.)	1112	1147	kcal/kg
	4651	4789	kJ/kg

Oxidizer

Sauerstoffträger; *comburant*

All explosive materials contain oxygen, which is needed for the explosive reaction to take place. The oxygen can be introduced by chemical reactions (nitration) or by mechanical incorporation of materials containing bound oxygen. The most important solid-state oxidizers are nitrates, especially → *Ammonium Nitrate* and → *Sodium Nitrate* for explosives; → *Potassium Nitrate* for → *Black Powder* and ion exchanged → *Permitted Explosives*; potassium chlorate for → *Chlorate Explosives* and for pyrotechnical compositions; → *Ammonium Perchlorate* (APC) for → *Composite Propellants*.

Important liquid oxidizers for liquid fuel rocket motors include liquid oxygen (LOX), highly concentrated nitric acid, liquid N_2O_4, liquid fluorine, and halogen fluorides. See also → *Oxygen Balance*.

Oxygen Balance

Sauerstoffwert; *bilan d'oxygène*

The amount of oxygen, expressed in weight percent, liberated as a result of complete conversion of the explosive material to CO_2, H_2O, SO_2, Al_2O_3, etc. (positive oxygen balance). If the amount of oxygen bound in the explosive is insufficient for the complete oxidation reaction (negative oxygen balance), the deficient amount of the oxygen needed to complete the reaction is reported with a negative sign. This negative oxygen balance can be calculated in exactly the same manner for nonexplosive fuels.

Examples:

TNT ($C_7H_5N_3O_6$)	−74%
nitroglycerine ($C_3H_5N_3O_9$)	+3.5%
ammonium nitrate (NH_4NO_3)	+20%

Table 21 Oxygen balance of explosives and explosive components.

Material	Available O_2, (%)	Material	Available O_2, (%)
Aluminum	−89.0	Ammonium chloride	−44.9
Ammonium nitrate	+20.0	Ammonium perchlorate	+34.0
Ammonium picrate	−52.0	Barium nitrate	+30.6
Dinitrobenzene	−95.3	Dinitrotoluene	−114.4
Wood meal, purified	−137.0	Potassium chlorate	+39.2
Potassium nitrate	+39.6	Carbon	−266.7
Sodium chlorate	+45.0	Sodium nitrate	+47.0
Nitroglycerine	+3.5	Nitroguanidine	−30.8
Nitrocellulose (guncotton)	−28.6	Nitrocellulose (soluble guncotton)	−38.7
Picric acid	−45.4	Sulfur	−100.0
Tetryl	−47.4	Trinitroresorcinol	−35.9
TNT	−74.0		

The most favorable composition for an explosive can be easily calculated from the oxygen values of its components. Commercial explosives must have an oxygen balance close to zero in order to minimize the amount of toxic gases, particularly carbon monoxide, and nitrous gases, which are evolved in the fumes.

Further data are found under the respective compounds described in this book; see also, → *Thermodynamic Calculation of Decomposition Reactions*.

Paraffin

$CH_3-(CH_2)_x-CH_3$

Paraffin serves to impregnate explosive cartridges against moisture. The technical product may contain ceresin, wax, or fat.

Specifications

solidification point:	not below 50–55 °C (122–131 °F)
inflammation point:	not below 200 °C (392 °F)
volatile matter:	not more than 1%
glow residue:	none
insolubles in toluene:	not more than 0.03%
solution in ether, CS_2, ligroin:	clear, without residue
acidity, as CH_3COOH:	not more than 0.005%
alkalinity; test with concentrated	none
sulfuric acid:	no alteration, no darkening of the acid
saponification index:	zero
iodine index:	low to zero
adhesion test:	negative

Parallel Connection

Parallelschaltung; *branchement en parallèle*

In multiple blastings with electric priming, → *Bridgewire Detonators* are usually connected in series to the priming line. If the boreholes are very wet, and there is a real danger of voltage loss, the charges are connected in parallel. Since only a very small fraction of the electric energy employed is then actuated in the primer bridges (the bulk of the energy is dissipated in the lead wires), parallel connections require special high-energy-supplying blasting machines.

Paste

Pulverrohmasse; *galette*

A nitrocellulose-nitroglycerine mixture for the solvent-free manufacture of → *Double-Base Propellants*. It is obtained by introducing nitroglycerine (or diglycol dinitrate or similar nitrate esters) into a stirred nitrocellulose suspension in water. The mixture is then centrifuged or filtered off; it contains about 35% water; its appearance resembles that of moist nitrocellulose. The paste, containing materials such as stabilizers and gelatinizers, is manufactured to the double-base powder by hot rolling and pressing without application of solvents.

PAX (Picatinny Arsenal Explosive)

Explosive formulations developed at Picatinny Arsenal, NJ, USA; e.g. PAX-21, PAX-41 and PAX-48, which contain → DNAN, → RDX, and → APC, DNAN, and RDX, DNAN, → HMX, and → NTO, respectively. The formulations are used in mortars, spider grenades, and high explosive cartridges.

PBX

Abbreviation for plastic-bonded explosives: see also → *LX*.

Pressed explosives:

PBX-9010: 90% RDX, 10% Kel F[32]
PBX-9011: 90% HMX, 10% Estane
PBX-9404-03: 94% HMX, 3% NC, 3% chloroethylphosphate
PBX-9205: 92% RDX, 6% polystyrene, 2% ethylhexylphthalate
PBX-9501: 95% HMX, 2.5% dinitropropyl, acrylate-furmarate, 2.5% estane
PBXN-1: 68% RDX, 20% Al, 12% nylon
PBXN-2: 95% HMX, 5% nylon
PBXN-3: 86% HMX, 14% nylon
PBXN-4: 94% DATNB, 6% nylon
PBXN-5: 95% HMX, 5% Viton A
PBXN-6: 95% RDX, 5% Viton A
PBX P31: 95% HMX 4% Silicone
PBX P63: 94% HNS 6% PU

Extruded explosive:

PBXN-201: 83% RDX, 12% Viton A, 5% Teflon
PBX KS 22: 67% RDX 18% Al 15% HTPB
PBX KS 32: 85% HMX 15% HTPB
PBX KS 33: 90% HMX 10% HTPB
PBX RH 26: 90% RDX 10% HTPB

Cast explosives:

PBXN-101: 82% HMX, 18% Laminac
PBXN-102: 59% HMX, 23% Al, 18% Laminac

---

[32] Kel F: chlorotrifluoropolyethylene.

Injection molded explosive:

PBXC-303 80% PETN, 20% Sylgard 183[33)]

PE

Abbreviation for plastic explosives. They consist of high brisance explosives such as RDX or PETN, plasticized with Vaseline or other plasticizers. Depending on the additives they contain, the plastic explosives are denoted as PE-1, PE-2 or PE-3 (see also → *Plastic Explosives* and *PBX*).

Pellet Powder

Black powder pressed into cylindrical pellets 2 in in length and 1 1/4 to 2 in in diameter.

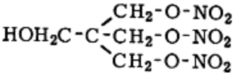
In the United Kingdom pellet powder is the term used for rounded black powder for hunting ammunition.

Pellets

Explosives in the form of round-shaped granules, e.g. of TNT, used for filling the residual vacant spaces in boreholes.

Pentaerythritol Trinitrate

Pentaerythrittrinitrat; *trinitrate de pentaérythrite*; *PETRIN*



$$\mathrm{HOH_2C{-}C}\begin{array}{l}\diagup \mathrm{CH_2{-}O{-}NO_2}\\ {-}\mathrm{CH_2{-}O{-}NO_2}\\ \diagdown \mathrm{CH_2{-}O{-}NO_2}\end{array}$$

empirical formula: $C_5H_9N_3O_{10}$
molecular weight: 271.1 g/mol
energy of formation: −470.2 kcal/kg = −1967 kJ/kg
enthalpy of formation: −494.2 kcal/kg = −2069 kJ/kg
oxygen balance: −26.5%
nitrogen content: 15.5%
density: 1.54 g/cm^3
volume of explosion gases: 902 l/kg
heat of explosion
  (H_2O liq.): 1250 kcal/kg = 5230 kJ/kg
  (H_2O gas): 1142 kcal/kg = 4777 kJ/kg
specific energy: 125 mt/kg = 1227 kJ/kg

---

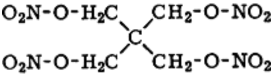
33) Sylgard: silicone resin.

The compound is prepared by cautious partial nitration of pentaerythritol.

The free hydroxyl group can react with an acid, e.g. acrylic acid; the polymer PETRIN acrylate serves as a binder.

Pentaerythritol tetranitrate, PETN

Nitropenta; *tétranitrate de pentaerythrite; Pertitrit; corpent*



colorless crystals
empirical formula: $C_5H_8N_4O_{12}$
molecular weight: 316.1 g/mol
energy of formation: −385.0 kcal/kg = −1610.7 kJ/kg
enthalpy of formation: −407.4 kcal/kg = −1704.7 kJ/kg
oxygen balance: −10.1%
nitrogen content: 17.72%
volume of explosion gases: 780 l/kg
heat of explosion
  (H_2O gas): 1398 kcal/kg = 5850 kJ/kg (calculated)[34]
  (H_2O liq.): 1507 kcal/kg = 6306 kJ/kg (calculated)[35]
heat of detonation (H_2O liq.):
  1510 kcal/kg = 6322 kJ/kg (experimental)[36]
specific energy: 123 mt/kg = 1205 kJ/kg
density: 1.76 g/cm^3
melting point: 141.3 °C = 286.3 °F
heat of fusion: 36.4 kcal/kg = 152 kJ/kg
specific heat: 0.26 kcal/kg = 1.09 kJ/kg
vapor pressure:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
0.0011	97.0	207
0.0042	110.6	231
0.015	121.0	250
0.050	131.6	267
0.094	138.8	282 (near melting point)

---

[34] Computed by the ICT-Thermodynamic-Code.

[35] Computed by the ICT-Thermodynamic-Code.

[36] Value quoted from Dobratz, B.M. (1981) *Properties of Chemical Explosives and Explosive Simulants*, University of California, Livermore.

lead block test: 523 cm^3/10 g
detonation velocity, confined: 8400 m/s = 27 600 ft/s
at $\rho = 1.7$ g/cm^3 deflagration point: 202 °C = 396 °F
impact sensitivity: 0.3 kp m = 3 N m
friction sensitivity: 6 kp = 60 N pistil load
critical diameter of steel sleeve test: 6 mm

PETN is very stable, insoluble in water, sparingly soluble in alcohol, ether, and benzene, and soluble in acetone and methyl acetate.

It is prepared by introducing pentaerythrol into concentrated nitric acid with efficient stirring and cooling.

The bulk of the tetranitrate thus formed crystallizes out of the acid. The solution is diluted to about 70% HNO_3 in order to precipitate the remainder of the product. The washed crude product is purified by reprecipitation from acetone.

PETN is one of the most powerful and most brisant explosives, its → *Stability* is satisfactory, and its → *Sensitivity* is moderate. It is used in high-efficiency blasting-cap fillings and detonation cords. If phlegmatized with a small amount of wax and pressed, it may be used to produce boosters and fillings for smaller-caliber projectiles. PETN can also be incorporated into gelatinous, industrial explosives (e.g. for seismic prospecting).

Specifications

melting point:	not below 140 °C (284 °F)
nitrogen content:	not below 17.5%
Bergmann–Junk test at 132 °C (267 °F):	not above 2 ml NO/g
deflagration point:	not below 190 °C (374 °F)
acetone-insoluble matter:	not more than 0.1%
acidity, as HNO_3:	not more than 0.003%
alkalinity, as Na_2CO_3:	not more than 0.003%
→ *Vacuum Test* at 120 °C (248 °F):	not more than 5 cm^3
Pentaerythrol (raw material):	$C(CH_2OH)_4$
molecular weight:	136.15 g/mol
melting point:	260.5 °C (501 °F)

Specifications

melting point:	beginning not below 230 °C (446 °F)
moisture:	not more than 0.5%
chlorides:	none; not more than 0.5%
reaction:	neutral
reducing matter ($AgNO_3$-NH_3-test):	not more than traces

Pentastit

Name for → *PETN* phlegmatized with 7% wax. detonation velocity, confined: 7720 m/s = 23 700 ft/s
at $\rho = 1.59$ g/cm^3
deflagration point: 192–194 °C = 378–390 °F
impact sensitivity: 3 kp m = 29 N m
friction sensitivity: crackling at 24 kp = 240 N pistil load
critical diameter of steel sleeve test:
begins to explode at 4 mm ∅

Pentolite

Pourable mixtures of → *TNT* and *PETN*, used for shaped charges and for cast boosters (for initiation of insensitive explosives, such as ANFO). A 50 : 50 mixture has a density of 1.65 g/cm^3; the detonation velocity is 7400 m/s.

Perchlorate Explosives

Perchlorat-Sprengstoffe; *explosifs perchlorates*

In these explosives, the main oxidizer is sodium, potassium, or ammonium perchlorate; the combustible components consist of organic nitro compounds, hydrocarbons, waxes, and other carbon carriers. Nowadays, these explosives are uneconomical and are no longer industrially produced.

A mixture of 75% $KClO_4$ and 25% asphalt pitch, melted together under the name of Galcit, was used as a rocket propellant and was thus a precursor of the modern → *Composite Propellants*.

Percussion Cap

Anzündhütchen; *amorce*

Percussion caps serve as primers for propellant charges. In mechanical percussion caps, a friction-sensitive or impact-sensitive priming charge (containing, e.g. mercury fulminate with chlorates or lead trinitroresorcinate with Tetrazene) is ignited by the mechanical action of a firing pin.

Percussion Primer = Percussion-actuated initiator.

Perforation of Oil Wells

Perforation von Erdölbohrlöchern; *perforation des trous de sondage*

In petroleum technology, shaped charges fired from special firing mechanisms (jet perforators) are lowered into the borehole down to the level of the oil horizon. Their purpose is to perforate the pipework and the cement work at the bottom of the borehole, so as to enable the oil to enter it.

Permissibles; Permitted Explosives

Wettersprengstoffe; *explosifs antigrisouteux*

1. Definition

Shotfiring in coal mines constitutes a risk in the presence of firedamp and coal dust. Permitted explosives are special compositions which produce short-lived detonation flames and do not ignite methane-air or coal-dust-air mixtures.

The methane oxidation

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

needs an induction period[37] before the reaction proceeds. If the time required for ignition by the detonation flames is shorter than the induction period, then ignition of firedamp will not occur. Thus, the composition of permitted explosives must ensure that any secondary reactions with a rather long duration, which follow the primary reaction in the detonation front, are suppressed and that slow → *Deflagration* reactions are avoided (→ *Audibert Tube*).

Such explosives are known as permissibles in the USA, as permitted explosives in the United Kingdom, as Wettersprengstoffe in Germany, as explosifs antigrisouteux in France, and as explosifs S.G.P. (sécurité grisou poussières) in Belgium.

Safety measures to avoid ignition of firedamp uses salt (NaCl), which is included in the usual compositions of commercial explosives. It lowers the → *Explosion Temperature* and shortens the detonation flame.

Higher safety grades are achieved in ion exchange explosives in which the ammonium and sodium (or potassium) ions are exchanged; instead of

$$NH_4NO_3 + (\text{inert})NaCl \rightarrow N_2 + 2H_2O + 1/2O_2 + (\text{inert})NaCl$$

---

[37] Contrary to the delayed ignition, the oxidation of hydrogen with the salt-pair aid of an ignition source, $2H_2 + O_2 \rightarrow 2H_2O$, is instantaneous.

the reaction is:

$$NH_4Cl + NaNO_3 \text{ (or } KNO_3) \rightarrow N_2 + 2H_2O + 1/2O_2 + NaCl \text{ (or KCl)}$$

Thus, a flame-extinguishing smoke of very fine salt particles is produced by the decomposition reaction itself. Combinations of salt-pair reactions and classic detonation reactions quenched by adding salt are possible.

Permitted explosives with a higher grade of safety are powder explosives. They contain a minimum percentage of nitroglycerine-nitroglycol to ensure reliable initiation and transmission of detonation and to exclude slow deflagration reactions. The mechanism of salt-pair detonation in confined and unconfined conditions is explained in → *Detonation, Selective Detonation*.

2. *Testing galleries*

Versuchsstrecken, Sprengstoffprüfstrecken; *galeries d’essai*

All coal-mining countries have issued detailed regulations for the testing, approval, and use of explosives which are safe in firedamp. The main instrument for these tests is the testing gallery.

A test gallery consists of a steel cylinder which initiates an underground roadway; the cross-sectional area is about 2 m^2; one end is closed by a shield of about 30-cm diameter, against which the cannon is placed. The other end of the chamber which has a volume of ca. 10 m^3 is closed by means of a paper screen. The remaining part of the tube length (10 m) behind the paper screen is left open to the atmosphere. (The gallery tube can be constructed in closed form if the noise of the test shots can be diminished.) After charging and positioning the cannon, the closed chamber is filled with a methane-air mixture (containing, e.g. 9.5% CH_4 to give the most dangerous composition), and the charge is fired. Whether or not ignition of the gas occurs is observed from a safe position.

Amongst the known types of mortars is the borehole cannon, as shown in Figure 19. A steel cylinder about 1.5-m long and about 35 cm in diameter has in it a borehole of 55-mm diameter and 1.20-m length. The explosive to be tested is placed in the borehole, unstemmed or stemmed by a clay plug, and the detonator is introduced last in the hole (direct initiation). If the detonator is inserted first, followed by the train of cartridges, initiation is inverse. The required test conditions can be severe; ignition of the gas mixture is more probable to occur using unstemmed charges and inverse initiation than with stemmed charges and direct initiation. The different mortars are designed to simulate different underground conditions. The borehole cannon in the testing gallery illustrates the action of a single shot in the roadway of gassy mines. The British break test and the slotted mortar in Poland imitate the exposure of a charge and, consequently, the more extended contact between the fir-

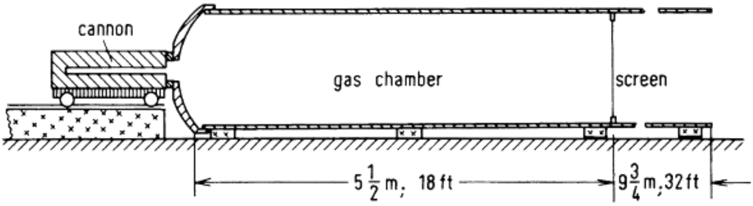


Figure 19 Testing gallery with borehole cannon.

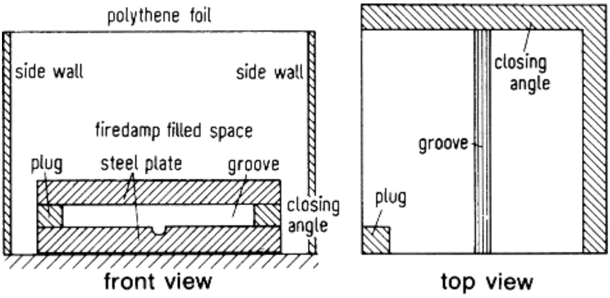


Figure 20 Break test.

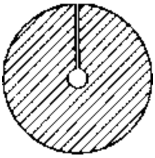


Figure 21 Slotted mortar.

ing charge and the firedamp atmosphere where breaks in the strata intersect a shothole.

Two steel plates are held at a given distance by means of a closing angle and a plug. The lower plate has a groove for the cartridge train. The plate arrangement is covered with a polyethylene sheet laid upon two steel side walls; the gas-tight room is filled with the methane-air mixture after charging. The break test conditions are varied; permitted explosives which meet the most stringent test conditions belong to the British safety class P4.

The slotted mortar allows similar test procedures.

The slot does not extend over the whole length of the borehole and does not begin at the mouth of the hole.

An especially dangerous condition can arise when several shots are fired in one round by means of electric delay detonators. A preceding shot may then break the coal of another hole or even cut off the whole burden

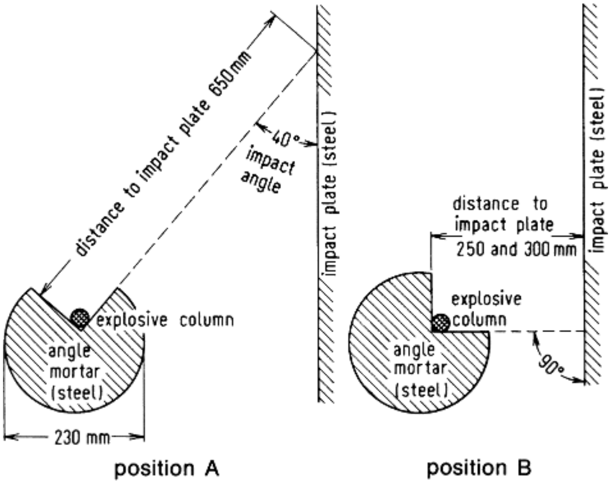


Figure 22 Angle shot mortar.

of the charge in question so that it is partly or completely exposed. This condition is simulated in the angle-mortar test.

A steel cylinder of 230-mm (9-in) diameter and 2-m in length with a right-angled groove is positioned in the gas chamber of a testing gallery against an impact steel plate at given distances and different impact angles, as shown in Figure 22. Trains of several cartridges or of the full length of 2 m are placed in the groove of the angle and fired into the methane-air mixture.

3. Safety classes

The different mortar set-ups and other test arrangements can be varied to give a higher or lower probability of ignition; consequently, different safety grades for the explosives have been defined.

In France, there are three categories: explosifs roche, couche, and couche améliorés. They satisfy different requirements according to the borehole cannon test: short or long cannon, direct or inverse initiation, different thicknesses of stemming by means of steel plates.

In the United Kingdom, 5 groups are listed: group P1, the classic permitted explosives diluted with rock salt which must pass the least severe cannon test, direct initiation and stemmed; group P2, the now abandoned → *Sheathed Explosives*; group P3, the successor of Eq. S. (equivalent to sheathed) explosives; group P4, the class of highest safety, which meets the most severe break test conditions; and group P5, safe in cut-off conditions.

Table 22 Areas of use and associated authorized application of German permitted explosives.

Working areas	CH_4 in the mine air (%)	Type of explosive	Safety class
Working in stone without coal	0–0.5	non permitted explosives for rock blasting	–
(except upcasts)	0.5–1.0	permitted explosives	Class I
Working in stone with coal seams up to 0.2-m thickness (except upcasts)	0–0.5 0.5–1.0	permitted explosives permitted explosives	Class I Class II
Working in stone with coal bands of more than 0.2-m thickness	0–0.3 0.3–0.5	permitted explosives permitted explosives	Class I Class II
gate-end roads (except upcasts)	0.5–1.0	permitted explosives	Class III
Rises and dips, gate roads, coal faces and adjacent rock in areas near coal faces, upcasts	less than 1.0	permitted explosives	Class III

In Germany there are three classes: class I, the classic permissibles; class II, which are safe in the angle mortar test in position A, with charges of 40 cm in length in the groove; class III, the class of highest safety, which must give no ignition in the angle-mortar test in position B and with the groove filled over its full length with the explosive charge (2 m, 6-1/2 ft).

As an example for possible authorized applications a diagram of the use of the German permitted explosives is given in Table 22.

Peroxides

Organic peroxides may act as explosive. They are usually not manufactured for blasting purposes, but rather as catalysts for polymerization reactions. They are utilized in a safely phlegmatized condition. → *Tricycloacetone Peroxide*, → *Hexamethylenetriperoxide-Diamine* and → Methyl ethyl ketone peroxide display properties of primary explosives.

Petroleum Jelly

Vaseline

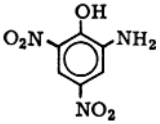
This substance is used as a gunpowder stabilizer. It is believed that the stabilizing effect is due to the presence of unsaturated hydrocarbons, which are capable of binding any decomposition products formed.

Phlegmatization

The impact sensitivity and friction sensitivity of highly sensitive crystalline explosives (e.g. → *Hexogen* and → *PETN*) can be reduced to a considerable extent by the addition of small amounts of a phlegmatizer. This can be an organic polymer or plasticizer, which may act as a lubricant or elastifying agent. For pressed charges it was wax that serves as a desirable lubricant and as a binder → RDX, → PETN, and → *Octogen* cannot be compacted by pressing, unless they contain phlegmatization additives. Wax can also be added to pourable mixtures if they contain aluminum powder (→ *Torpex*).

Picramic Acid

Dinitroaminophenol; *acide picramique*



empirical formula: $C_6H_5N_3O_5$
molecular weight: 199.1 g/mol
energy of formation: −279 kcal/kg = −1167 kJ/kg
enthalpy of formation: −298 kcal/kg = −1248 kJ/kg
oxygen balance: −76.3%
nitrogen content: 21.11%
volume of explosion gases: 847 l/kg
heat of explosion (H_2O liq.): 639 kcal/kg = 2674 kJ/kg
specific energy: 68.2 mt/kg = 669 kJ/kg
melting point: 169.9 °C = 337.8 °F
lead block test: 166 cm^3/10 g
deflagration point: 240 °C = 464 °F
impact sensitivity: 34 N m
friction sensitivity: up to 36 kp = 353 N pistil load no reaction
critical diameter of steel sleeve test: 2.5 mm

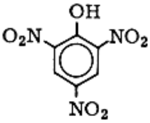
Diazotization of picramic acid yields → *Diazodinitrophenol* (DDNP). Lead picramate and DDNP are → *Initiating Explosives*.

Picratol

A 52 : 48 mixture of ammonium picrate and TNT was used as a bomb filling in the Second World War. casting density: 1.62 g/cm^3
detonation velocity, at casting density, confined: 22 600 ft/s = 6900 m/s

Picric Acid

2,4,6-trinitrophenol; *Pikrinsäure*; *acide picrique*



yellow crystals; (colorant)
empirical formula: $C_6H_3N_3O_7$
molecular weight: 229.1 g/mol
energy of formation: −242.5 kcal/kg = −1014.5 kJ/kg
enthalpy of formation: −259.3 kcal/kg = −1084.8 kJ/kg
oxygen balance: −45.4%
nitrogen content: 18.34%
volume of explosion gases: 826 l/kg
heat of explosion
(H_2O liq.): 822 kcal/kg = 3437 kJ/kg
(H_2O gas): 801 kcal/kg = 3350 kJ/kg
specific energy: 101 mt/kg = 995 kJ/kg
density: 1.767 g/cm^3
solidification point: 122.5 °C = 252.5 °F
heat of fusion: 18.2 kcal/kg = 76.2 kJ/kg
specific heat: 0.254 kcal/kg = 1.065 kJ/kg
vapor pressure:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
0.01	122	252 (melting point)
2.7	195	383
67	255	491

lead block test: 315 cm^3/10 g
detonation velocity, confined: 7350 m/s at $\rho = 1.7$ g/cm^3
deflagration point: 300 °C = 570 °F
impact sensitivity: 0.75 kp m = 7.4 N m
friction sensitivity: up to 353 N pistil load no reaction
critical diameter of steel sleeve test: 4 mm

Picric acid is toxic, soluble in hot water, and readily soluble in alcohol, ether, benzene, and acetone.

The explosive power of picric acid is somewhat superior to that of → *TNT*, both as regards the strength and the detonation velocity. Picric acid is prepared by dissolving phenol in sulfuric acid and subsequent nitration of the resulting phenoldisulfonic acid with nitric acid or by further nitration of dinitrophenol (prepared from dinitrochlorobenzene). The crude product is purified by washing in water.

Picric acid was used as a grenade and mine filling. It needs a high pouring temperature, which is undesirable. However, the solidification point can be depressed by the addition of nitronaphthalene, dini-trobenzene or trinitrocresol.

A drawback of picric acid is its tendency to form impact-sensitive metal salts (picrates) when in direct contact with shell walls, etc.; → *TNT*.

Plastic Explosives, PE

kunststoffgebundene Sprengstoff-Mischungen; *explosive composite*

High-brisance crystalline explosives, such as → RDX or → HMX, can be embedded in curable or polyadditive plastics such as polysulfides, polybutadienes, which forms together with diisocyanates or polyurethane, acrylic acid, polyurethane, etc. The mixture is then cured into the desired shape. Other components such as aluminum powder can also be incorporated. The products obtained can be of any desired size, and specified mechanical properties can be imparted to them, including rubber-like elasticity (→ *LX* and → *PBX*). They can also be shaped into foils.

Plastic also means mixtures of → RDX and → PETN with silicon rubber or silicon oil, Vaseline or gelatinized liquid nitro compounds of plastiline-like consistency.

Propellant charges for rockets and guns have also been developed by compounding solid explosives such as nitramines (e.g. → *Hexogen*) with plastics. Plastic explosives and plastic propellants are of interest, if low thermal and impact sensitivity is needed (→ *LOVA*; Insensitive High Explosives (IHE)).

Plate Dent Test

A brisance comparison test used in the USA for military explosives. There are two methods:

Method A – The charge is contained in a copper tube, having an internal diameter of 3/4-in and a 1/16-in wall. This loaded tube is placed vertically on a square piece of cold-rolled steel plate, 5/8-in thick; 4-in and 3-1/4-in square plate gave the same results. The steel plate is in a horizontal position and rests in turn on a short length of heavy steel tubing 1-1/2 in ID and 3 in OD. The charge rests on the center of the plate, and the centers of the charge, plate, and supporting tube are in the same line. A 20 g charge of the explosive under test is boostered by a 5-g pellet of tetryl, in turn initiated by a No. 8 detonator.

Method 13 – A 1-5/8-in diameter, 5-in long uncased charge is fired on a 1-3/4-in thick, 5-in^2 cold-rolled steel plate, with one or more similar plates as backing. The charge is initiated with a No. 8 detonator and two 1-5/8-in diameter, 30-g tetryl boosters.

Plate dent test value, or relative brisance

$$\text{Relative brisance} = \frac{\text{Sample Dent Depth}}{\text{Dent Depth for TNT at } 1.61\ \text{g/cm}^3} \times 100$$

Plateau Combustion

Plateau-Abbrand

→ Burning Rate.

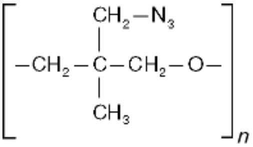
Pneumatic Placing

Druckluft-Ladeverfahren; *chargement pneumatique*

The loading of explosives or blasting agents into a borehole using compressed air as the loading force.

Poly-3-azidomethyl-3-methyl-oxetane

Poly-AMMO



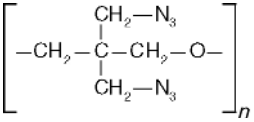
$$\left[-CH_2-\underset{\displaystyle CH_3}{\underset{|}{\overset{\displaystyle CH_2-N_3}{\overset{|}{C}}}}-CH_2-O- \right]_n$$

colorless oil to wax
empirical formula of the structural unit: $C_5H_9N_3O$
molecular weight of the structural unit: 127.15 g/mol
mean molecular weight: 1000–3000 g/mol
energy of formation: 471.88 kJ/kg
enthalpy of formation: 345.19 kJ/kg
oxygen balance: −169.88%
nitrogen content: 33.05%
density: 1.17 g/cm^3
specific energy: 568.3 kJ/kg

Poly-AMMO is synthesized via cationic polymerization from the monomer 3-azidomethyl-methyl-oxetane (AMMO). The polymerization reaction is quenched with water to get polymer chains with hydroxyl endgroups, which enable these pre-polymers to later react with isocyanate for curing reaction. Poly-AMMO is suggested as → *Energetic binder* component in → *Composite propellants* and is in the scope of current research. The disadvantage of this polymer is a glass transition point of −25 °C.

Poly-3,3-bis-(azidomethyl)-oxetane

Poly-BAMO

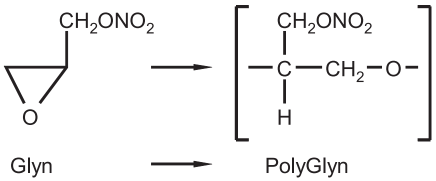


$$\left[-CH_2-\overset{\displaystyle CH_2-N_3}{\underset{\displaystyle CH_2-N_3}{C}}-CH_2-O-\right]_n$$

colorless solid
empirical formula of the structural unit: $C_5H_8N_6O$
molecular weight of the structural unit: 168.16 g/mol
mean molecular weight: 1000–10 000 g/mol
energy of formation: 2517.7 kJ/kg
enthalpy of formation: 2460.8 kJ/kg
oxygen balance: −123.69%
nitrogen content: 49.98%
density: 1.25 g/cm^3
mech. sensitivity: 5.0 N m (impact); 288 N (friction)

Poly-BAMO is synthesized via cationic polymerization from the monomer 3,3-bis(azidomethyl)l-oxetane (BAMO). The polymerization reaction is quenched with water to get polymer chains with hydroxyl endgroups which enable these pre-polymers to later react with isocyanate for curing reaction. Poly-BAMO has one of the highest nitrogen content of the → *Energetic binder* components and is suggested for → *Composite propellants*. It is in the scope of current research.

PolyGLYN

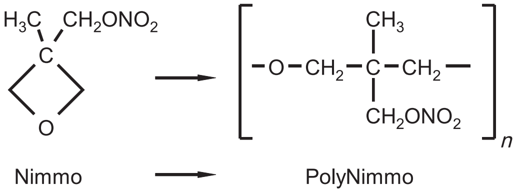


liquid
empirical formula: $C_3H_5NO_4$

molecular weight: 119.077 g/mol
oxygen balance: −60.46%
energy of formation: −295.56 kJ/mol
enthalpy of formation: −307.94 kJ/mol = −2586.08 kJ/kg
density: 1.47 g/cm³
boiling point: 180 °C

Due to the nitrate ester functionality of the pendant groups PolyGLYN exhibits a very good oxygen balance and can act as → *Energetic binder* in propellant and explosive formulations.

PolyNIMMO



liquid
empirical formula: $C_5H_9NO_4$
molecular weight: 147.131 g/mol
oxygen balance: −114.18%
energy of formation: −291.88 kJ/mol
enthalpy of formation: −309.2 kJ/mol = −2101.51 kJ/kg
density: 1.26 g/cm³
boiling point: 187 °C

Due to the nitrate ester functionality of the pendant groups PolyNIMMO exhibits a very good oxygen balance and can act as energetic binder in propellant and explosive formulations.

Polynitrogen Compounds

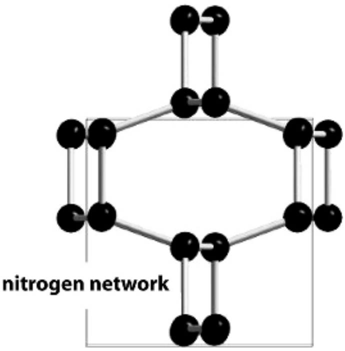
Polystickstoff-Verbindungen

Polynitrogen compounds contain 100% N. However, no further modification of nitrogen which is metastable under normal conditions (1 atm, 298 K) in the condensed phase is known except N_2, despite some very nitrogen-rich compounds being known. No all-nitrogen/polynitrogen compound is currently in use or even under investigation for practical uses. However calculations have suggested the following advantages for this class of compounds:

- only gaseous reaction products (N_2)
- large positive standard enthalpies of formation ($\Delta_f H°$)

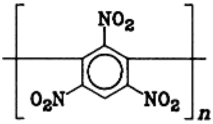
- large propulsive or explosive power
- very high specific impulse (200% > value for hydrazine)
- very high (adiabatically calculated) reaction temperature (up to 7500 K)
- smoke-free combustion
- minimal signature of a rocket engine
- low erosion of gun barrels (no formation of iron carbide).

McMahan and LeSar predicted that the triple bond in N_2 should be breakable under very high pressures, resulting in a solid containing trivalent (*i.e*. three-coordinate) nitrogen atoms (pressure-coordination rule). The transformation pressure for nitrogen should lie in the range between 500 and 940 kbar with estimated N–N bond energies of 38 kcal/mol which is 188 kcal/mol lower than the value for a N≡N triple bond. A 3-D structure containing trivalent nitrogen atoms (*d*(N–N) at 1.1 Mbar = 1.346 Å; < (NNN) = 108.8 °) was achieved in 2004 by Eremets *et al.* at high pressures (1.15 Mbar at 2000 K) in a diamond cell. Unfortunately, cubic polynitrogen is unstable under normal conditions and decomposes at ca. 42 GPa to molecular dinitrogen. The crystallographic data for the trivalent nitrogen is: cubic, lattice parameters $a = 3.4542(9)$ Å.



Polynitropolyphenylene

Polynitropolyphenylen; *Polynitropolyphénylène*; *PNP*



greenish, yellow-brown amorphous powder
empirical formula of structural unit: $C_6HN_3O_6$

molecular weight of structural unit: 211.1 g/mol
mean molecular weight: 2350 g/mol
oxygen value: −49.3%
nitrogen content: 19.91%
explosion heat (H_2O liq.): 3200 kJ/kg = 764 kcal/kg
density: 1.8−2.2 g/cm^3
bulk density: 520 g/l
deflagration temperature: 280–304 °C
impact sensitivity: 0.2−0.5 kp m = 3−5 N m
sensitivity to friction: at 360 N = 37 kp pin load, reaction
marginal diameter, steel case test: 6 mm

Polynitropolyphenylene is obtained from the reaction of a solution of 1,3-dichloro-2,4,6-trinitrobenzene in nitrobenzene at 150–180 °C with copper powder (Ullmann reaction).

The raw product obtained in this manner is first separated from copper chloride and then cleaned in several stages from solvent residues and low molecular weight elements. The resulting compound is a non-crystalline explosive of extremely high thermal resistance. In the field of → *LOVA* technology, it is used as an → *Energetic Binder* in high ignition temperature propellants.

Polypropylene Glycol

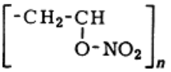
Polypropylenglykol; *polypropylene glycol*; *PPG*

$HO{-}[(CH_2)_3{-}O{-}]_{34}H$
viscous liquid
empirical formula: $C_{10}H_{20.2}O_{3.4}$
molecular weight: 1992 g/mol
energy of formation: −853 kcal/kg = −3571 kJ/kg
enthalpy of formation: −888 kcal/kg = −3718 kJ/kg
oxygen balance: −218.4%
density (20/4): 1.003 g/cm^3

PPG serves as a prepolymer, which reacts with diisocyanates as curing agents to form polyurethanes used as a binder in → *Composite Propellants*

Polyvinyl Nitrate

Polyvinylnitrat; *nitrate de polyvinyle*; *PVN*



$$\left[-CH_2-\underset{\substack{|\\ O-NO_2}}{CH}\right]_n$$

yellowish-white powder
empirical formula of the structure unit: $C_2H_3NO_3$
molecular weight of the structure unit: 89.05 g/mol
average molecular weight: 200 000 g/mol
energy of formation: −252.1 kcal/kg = −1054.8 kJ/kg
enthalpy of formation: −275.4 kcal/kg = −1152.1 kJ/kg
oxygen balance: −44.9%
nitrogen content: depends on nitration grade
volume of explosion gases: 958 l/kg
heat of explosion
  (H_2O liq.): 1143 kcal/kg = 4781 kJ/kg
  (H_2O gas): 1073 kcal/kg = 4490 kJ/kg
specific energy: 129 mt/kg = 1269 kJ/kg
density: 1.6 g/cm^3
softening point: 30–40 °C = 86–104 °F
detonation velocity: 7000 m/s = 23 000 ft/s
  at $\rho = 1.5$ g/cm^3
deflagration point: 175 °C = 350 °F
impact sensitivity: 1.0 kp m = 10 N m
friction sensitivity: at 20 kp = 196 N pistil load reaction
critical diameter of steel sleeve test: 8 mm

Polyvinyl nitrate is prepared by esterification of polyvinyl alcohol (PVA) using nitric acid or a nitrating mixture. Depending on the degree of saponification of polyvinyl alcohol, which is prepared from polyvinyl acetate, the products have varying nitrogen contents and rheological properties, depending on the manufacturing conditions and the degree of polymerization. PVN is a thermoplastic, macromolecular substance, with a softening zone which varies between 30 and 45 °C, depending on the molecular weight of the starting polyvinyl alcohol. Polyvinyl Nitrate is used in a plasticizer for TNT charges called X28M, which is a solution of 22% PVN in 78% mononitrotoluene MNT.

Porous Powder

Poröses Pulver; *poudre poreux*

Special powders for exercise ammunition with a large internal surface area and thus, a fast burning rate. The porosity is produced by adding a soluble salt to the powder being manufactured; the salt is then leached out again at a later stage.

Post Combustion

Nachflammen

Combustion of flammable fumes of a deflagrated or detonated explosive with a negative oxygen balance (see also → *Muzzle Flash*).

Potassium Chlorate

Kaliumchlorat; *chlorate de potassium*

$KClO_3$
colorless crystals
molecular weight: 122.6 g/mol
oxygen balance: +39.2%
density: 2.34 g/cm^3
melting point: 370 °C = 700 °F

Potassium chlorate is sparingly soluble in cold water, readily soluble in hot water, and insoluble in alcohol. It is the principal component of → *Chlorate Explosives* and is an important component of primer formulations and pyrotechnical compositions, in particular matchheads.

Potassium Nitrate

saltpetre; *Kaliumnitrat*; *nitrate de potasse*

KNO_3
colorless crystals
molecular weight: 101.1 g/mol
energy of formation: −1157 kcal/kg = −4841 kJ/kg
enthalpy of formation: −1169 kcal/kg = −4891 kJ/kg
oxygen balance: +39.6%
nitrogen content: 13.86%
density: 2.10 g/cm^3
melting point: 314 °C = 597 °F

Potassium nitrate is readily soluble in water, sparingly soluble in alcohol, and insoluble in ether.

It is used as a component in pyrotechnical compositions, in industrial explosives, and in black powder.

Potassium Perchlorate

Kaliumperchlorat; *perchlorate de potassium*

$KClO_4$
colorless crystals
molecular weight: 138.6 g/mol
oxygen balance: +46.2%
density: 2.52 g/cm^3
melting point: 610 °C = 1130 °F
(decomposition begins at 400 °C = 750 °F)

Table 23 Specifications.

	Class 1 (%)	**Class 2 (%)**	**Class 3 (%)**
Net content (e.g. by N-determination): at least	99.5	99.5	99.5
Moisture: not more than	0.2	0.2	0.2
Water-insoluble: not more than	0.1	0.1	0.1
Grit:	none	none	none
Acidity:	0	0	0
Alkalinity:	0	0	0
Chlorides as KCl: not more than	0.07	0.07	0.07
Chlorates and perchlorates, as K-salt: not more than	0.5	0.5	0.5
$Al_2O_3 + Fe_2O_3$: not more than	0.5	0.5	–
CaO + MgO: not more than	0.5	0.5	0.5
Na as Na_2O: not more than	0.25	0.25	–
Nitrogen content: at least	13.77	13.77	13.77

Potassium perchlorate is insoluble in alcohol but soluble in water. It is prepared by reacting a soluble potassium salt with sodium perchlorate or perchloric acid. It is employed in pyrotechnics.

Specifications

colorless odorless crystals	
net content (KCl determination after reduction):	not below 99%
moisture:	not more than 0.5%
insolubles in water:	not more than 0.1%
solution in hot water:	clear
chlorides as KCl:	not more than 0.1%
bromate as $KBrO_3$:	not more than 0.1%
chlorate as $KClO_3$:	not more than 0.1%
NH_4-, Na-, Mg- and Ca-salts:	none
heavy metals	none
pH	6.5 ± 0.5

Poudre B

French gunpowder. A single-base nitrocellulose propellant stabilized by 1.5–2% diphenylamine. The suffix (e.g. Poudre B Ba) denotes:

Suffix	Shape of Powder Grain
Ba	short rods (bâtonnet)
Bd	bands
Cd	long rods (corde)
Di	disks
FP	flakes (paillette; obsolete denomination)
Pa	flakes (paillette)
Se	flattened balls (sphere écrasée)
SP	balls (sphère)
7T	tubes with 7 holes
19T	tubes with 19 holes
Tf	slotted tubes (tube fendu)
Tu	tubes (tubulaire)

Powder Form Explosives

Pulverförmige Sprengstoffe; *explosifs pulverulents*

Industrial explosives must be easy to shape, i.e. must have a gelatinous or powdery consistency in order to introduce the detonator or electric cap. Powder-form explosives are mostly based on ammonium nitrate and fuel components (e.g. aluminum).

The powders can be sensitized by the addition of nitroglycerine in small percentages. Non-cap sensitive powders (→ *Blasting Agents*) need a booster charge for safe initiation.

Certain types of powder-form explosives contain moisture repelling additives such as stearates; in paraffinated cartridges they can be applied even under wet conditions. Noncartridged powder form explosives must be free-flowing (→ *ANFO*).

Ion exchanged → *Permitted Explosives* are based on so-called salt pairs (sodium nitrate ammonium chloride or potassium nitrate – ammonium chloride) and are thus also in powder form.

Pre-ignition

Vorzeitige Selbstentzündung; *allumage spontané*

Spontaneous and premature ignition.

Premature Firing

Frühzündung; *départ prématuré*

The detonation of an explosive charge or the ignition of an electric blasting cap before the planned time. This can be a hazardous occurrence and is usually accidental.

Prequalification Test

Vorprüfung; *tést préliminaire*

Brief test program conducted on an item or system to determine if it will meet only the most rigorous specified requirements.

Pre-splitting (Pre-shearing)

Vorspalten; *tendage préliminaire*

A → *Contour Blasting* method in which cracks for the final contour are created by firing a single row of holes prior to the blasting of the rest of the holes for the blast pattern.

Press Molding of Explosives

Pressen von Sprengstoffen; *moinlage d'explosifs pa pression*

The purpose of compression by hydraulic presses is similar to that of casting, i.e. to attain a high loading density (→ *Brisance*) while at the same time imparting the desired shape to the charge.

Certain explosives (TNT, tetryl, etc.) can be compacted by compression in the absence of any additives; sensitive explosives such as PETN (Nitropenta), RDX (Hexogen), or HMX (Octogen) have to be phlegmatized by the incorporation of wax. The wax reduces the impact sensitivity and, at the same time, acts as a binder.

Plastic binder materials: → *LX* and → *PBX*.

Pressing of Rocket Propellant Charges

Pressen von Treibsätzen; *moulage des propellants de roquette par pression*

Rocket compositions of both double-base and composite type are shaped into the desired form (e.g. star-shaped configurations) on extrusion or screw-type presses through a die or by casting and curing.

Pressure Cartridge

Druckgas-Patrone; *cartouche génératrice de gaz*

Pyrotechnic device in which propellant combination is used to produce pressurized gas for short duration.

Prills

Denote the ammonium nitrate pellets obtained by cooling free-falling droplets of the molten salt in so-called prill towers. By special processing, they can be porous and are capable of absorbing a certain percentage of liquid hydrocarbons (→ *ANFO*). The ready made ANFO-explosive is also marketed under the name Prills.

Prills is also a description for spherical particles produced from molten energetic materials like → *Ammonium dinitramide (ADN)*. In this case the molten phase is dispersed by atomization (in a gas phase) or emulsification (in an antisolvent). The spherical particles occur by recrystallization of the molten droplets in a following cooling step. This refined product is named ADN-prills.

Primary Blast

Hauptsprengung; *tir primaire*

A blast that loosens rock ore from its original or natural location in the ground. A secondary blast may be used to reduce the rocks from the primary blast to smaller size for ease of handling.

Primary Explosive

Initialsprengstoff; *explosif d'amorcage*

A sensitive explosive which nearly always detonates by simple ignition from such means as spark, flame, impact and other primary heat sources of appropriate magnitude (→ *Initiating Explosives*).

Primer

A primary initiating device to produce a hot flame. A primary stimulus sensitive component generally is used to generate a brisant output for initiating detonating compositions. Infrequently used to initiate deflagrating compositions (→ *Squib*; → Detonator; → Initiator).

Primer Charge

Zündladung; *charge d'amorçage*

Secondary component in an → *Ignition Train*, which is ignited by an initiator, starts pressurization of a generator, and ignites the booster charge.

For the firing of industrial explosives, primers are prepared by inserting a blasting cap or an electric detonator in hole of a cartridge of a cap-sensitive explosive.

In military ammunition primers are charges used to initiate the main explosive charge of a weapon containing built in detonators.

Progressive Burning Powder

Progressive-Pulver; *poudre progressive*

Gunpowder which burns at a progressively increasing rate, owing to the appropriate choice of the geometry of the powder grain and sometimes owing to a suitable grain surface coating. Examples are perforated powders (7-hole powder, 19-hole powder, etc.).

Projectile Impact Sensitivity

Beschußempfindlichkeit; *sensibilité à l'impact de projectiles*

See also → *Armor Plate Impact Test* and → *Impact Sensitivity*.

The projectile impact sensitivity is the reaction of an explosive charge if hit by infantry projectiles. Impact safety is given if the charge does not fully explode at impact. The projectile impact sensitivity does not only depend on the type of explosive itself, but also on the nature of its confinement (metallic, plastic, thin-walled, or thick-walled). A single bullet impact by an ordinary or a hard steel cored projectile, or a machine-gun burst, will create different reactions.

A test has been developed in Sweden: cylinders made of copper, brass, and aluminum (15-mm diameter) are brought to accurately adjusted and measured impact velocities (→ *Impact Sensitivity*).

Propellant (Rocket Propellants, Gun Propellants)

Treibstoff; produit propulsif

→ Gunpowder.

Explosive material with low rate of combustion. May be either solid, gelled, or liquid. Will burn smoothly at uniform rate after ignition without depending on interaction with atmosphere. Single-base propellant consists primarily of matrix of nitrocellulose. Double-base propellant contains nitrocellulose and nitroglycerine. Composite propellant contains oxidizing agent in matrix of binder.

Propellant Types:

a) *Composite* Finely divided oxidizers dispersed in fuel matrix.
   1) Ammonium nitrate oxidizer
   2) Ammonium perchlorate oxidizer
   3) Nitramine (RDX or HMX) oxidizer
b) *Double-Base* Homogeneous colloidal propellant consisting of nitrocellulose dissolved in plasticizer comprised of nitroglycerine and inert materials
c) *Plastisol* PVC-composite or double-base propellant in which polymer is dissolved in plasticizer
d) *Composite Double-Base* Double-base propellant containing dispersed phase of finely ground oxidizer and (usually) powdered fuel additive
e) *Single-Base* Colloid of nitrocellulose and inert plasticizers
f) *Triple-Base* Heterogeneous propellant consisting of nitrocellulose, plasticizer (NGL or/and DEGDN) and nitroguanidine

Propellant Area Ratio

Klemmung; *resserrement*

In rocket technology, the ratio between the burning surface of the propellant and the smallest cross-section of the nozzle. It determines the resultant pressure in the combustion chamber of the rocket (other relevant keywords: → *Burning Rate*, → Gas Jet Velocity, → *Rocket*, → *Solid Propellant Rockets*, → Specific Impulse, → Thrust).

Propellant-Actuated Power Devices

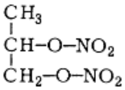
Any tool or special mechanized device or gas generator system which is actuated by a propellant or which releases and directs work through a propellant charge.

Propergol

In rocket technology, a collective term for all chemical propellants.

Propyleneglycol Dinitrate

methylnitroglycol; *Propylenglykoldinitrat*; *dinitrate de propylèneglycol propanediol dinitrate*



$$\begin{array}{l} CH_3 \\ | \\ CH{-}O{-}NO_2 \\ | \\ CH_2{-}O{-}NO_2 \end{array}$$

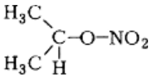
colorless liquid
empirical formula: $C_3H_6N_2O_6$
molecular weight: 166.1 g/mol
oxygen balance: −28.9%
nitrogen content: 16.87%
density (20 °C): 1.368 g/cm^3
lead block test: 540 cm^3/10 g

Propyleneglycol dinitrate is readily soluble in organic solvents, but is practically insoluble in water. It is obtained by nitration of propyleneglycol with mixed acid.

Propyl Nitrate

Propylnitrat; *nitrate de propyle*

$CH_3{-}CH_2{-}CH_2ONO_2$ and



n-propyl nitrate, NPN isopropyl nitrate, IPN

colorless liquid
empirical formula: $C_3H_7NO_3$
molecular weight: 105.1 g/mol
energy of formation
  n: −1911 kJ/kg
  iso: −2057 kJ/kg
enthalpy of formation
  n: −2041 kJ/kg
  iso: −2184 kJ/kg
oxygen balance: −99.0%
nitrogen content: 13.33%
heat of explosion (H_2O liq.)
  n: 3272 kJ/kg
  iso: 3126 kJ/kg
density
  n: 1.058 g/cm^3 (20 °C)
  iso: 1.036 g/cm^3 (20 °C)
impact sensitivity: up to 5 kp m = 49 N m no reaction

n-Propyl nitrate serves as a → *Monergol* in liquid propellant rockets.

Isopropylnitrate is used in → thermobaric explosives together with Magnesium.

Pulsed Infusion Shotfiring

Stoßtränkungssprengen, Drucktränksprengen; *tir d'imprégnation*

This blasting technique combines the effect of an explosive charge in coal mine blasting with the effect of water pressure. The borehole is loaded with the explosive charge, after which water is pressed into the borehole with the aid of the so-called water infusion pipe, and the charge is ignited while maintaining the water pressure. The pressure shock in the water causes the coal to disintegrate into large lumps.

In addition, the water fog, which is produced at the same time, causes the dust to settle to the ground.

Pyrophoric

Materials that will ignite spontaneously. Examples of pyrophoric substances in air: white phosphorus, alcyl derivatives of aluminum or zinc or finely dispersed metals, which are readily oxidizers.

Pyrotechnical Compositions

Feuerwerksätze; *compositions pyrotechniques*

Oxidizer – fuel mixtures, which give off bright or colored light (Bengal fireworks), evolve heat (thermites), produce fogs (also colored fogs), or give acoustic effects (howling, whistling, and banging).

Special black powder granules for pyrotechnics → *Black Powder*. The additives employed for colored light are:

- barium salts or boric acid for green
- strontium salts for red
- cupric oxide for blue
- sodium salts for yellow.

Pyrotechnical Fuses

Feuerwerkszündschnüre; *fusées pyrotechniques*

Pyrotechnical fuses are → *Safety Fuses*, which are specially adapted for pyrotechnical purposes by their diameter and their rigidity. They are cut into small (4–6 cm) segments.

Quantity – Distance Table

Sicherheitsabstands-Tabelle; *tableau des distances des sécurité*

A table listing recommended minimum distances between explosive materials stores of various weights and some predetermined location.

Quick-Match

match cord; cambric; Stoppine

Quick-match serves to transfer ignition to pyrotechnic sets. It consists of between 2 and 16 spun cotton threads, which have been impregnated with black powder and dried. This impregnation is carried out by using an alcohol-water saturated black powder sludge, and the threads are drawn through this mixture and gauged by drawing them through an extruder die. The impregnation mass contains resin and gum Arabic as binders. After the match cords have dried, they are cut into size; if they are to be used for larger fireworks, they receive an additional cover of paraffin-treated paper, and both ends are then tied. For additional safety, two quickmatches are inserted into the paper sleeve.

Burning time is preset at between 30 and 100 s/m. A quickmatch contained in paper tubes, is preset to a maximum of 40 m/s to avoid ignition failure.

RDX (Research Department Explosive)

→ Hexogen

REACH

REACH stands for Registration, Evaluation and Authorization of Chemicals. This new legislation is intended to standardize and simplify chemical law throughout Europe. See: http://echa.europa.eu/.

Recommended Firing Current

Soll-Zündimpulse; *ampèrage recommande our le mise á feu*

Current that must be applied to bridgewire circuit to cause operation of device within specified time.

Recommended Test Current

Maximum current that can be applied to bridgewire circuit for extended period of time without degrading prime material.

Reduced Sensitivity, RS

This term describes improved properties of energetic materials. In the 1990s it was shown that with careful recrystallization techniques the sensitivity of RDX can be reduced on a crystalline level. Nowadays, reduced sensitivity variants of RDX, assigned as RS-RDX or I-RDX (for insensitive), are provided by different manufacturer and tested, particularly in plastic bonded explosives PBX for → *Insensitive Munitions*. Besides, RS-variants of HMX and other high explosives, and characterization and quality assessment techniques for Reduced Sensitivity are in the scope of current research.

Regressive Burning

Degressiver Abbrand; *brûlage regressive*

Condition in which mass flow produced by the propellant grain decreases as web is consumed, due to a decreasing area, decreasing burn rate, or both (→ *Progressive Burning Powder*).

Relay

An explosive train component that requires explosive energy to reliably initiate the next element in the train. Specifically applied to small charges that are initiated by a delay element, and in turn, cause the functioning of a detonator.

Reliability

Zuverlässigkeit

Statistical evaluation of probability of device performing its design function.

Resonance

→ Erosive Burning.

RID

Abbreviation for Règlement Concernant le Transport International Ferroviaires des Marchandises Dangereuses. It contains the official regulations governing the haulage, admission, and packing for international railway traffic. → *ADR* are the corresponding regulations governing international motor traffic.

Table 24 shows the examination procedure as exemplified for the powder-form ammonium nitrate explosive Donarit 1 manufactured in Germany.

Rifle Bullet Impact Test

Beschussprobe

A US standard test procedure for explosives of military interest.

Approximately 0.5 pd of explosive is loaded in the same manner as for actual use: cast, pressed or liquid in a 3-in pipe nipple (2-in inside diameter, 1/16-in wall) closed on each end by a cap. The loaded item, in the standard test, contains a small air space that can, if desired, be filled by inserting a wax plug. The loaded item is subjected to the impact of a caliber 30 bullet fired perpendicularly to the long axis of the pipe nipple from a distance of 90 ft.

Rocket

Rakete; *roquette*

Pressure vessel containing a propellant that, on being ignited, produces hot gases that, in turn, are expelled through a nozzle or nozzles to produce thrust.

Rocket Motor

Raketentriebwerk; *moteur fusée; propulseur*

The propulsion assembly of a rocket or → *Missile*. The driving force can be produced by burning liquid fuels in liquid oxidizers (liquid oxygen, nitric acid, or other oxidants such as liquid fluorine), by burning of solid propellants (→ *Solid Propellant Rockets*), by burning solid fuels in liquid oxidizers (→ *Hybrids*), or by catalytic decomposition of endothermal compounds (→ *Hydrazine*; → *Aerozin*; → *Aurol*).

Rocket Test Stand

Raketen-Prüfstand; *banc d’essai*

The test stand serves to determinate the thrusts and pressures that develop during the combustion process (→ *Thrust Determination*). Since we are interested in the combustion behavior at different temperatures, the test stands are mostly equipped with warm and cold chambers for conditioning prior to testing.

The design of some stands makes it possible to determine other thrust components (e.g. the side component in inclined nozzles) and torques.

Table 24 RID Test results of Donarit 1.

Composition Components in (%)	Declared	Found	External appearance and texture	Storage at 75 °C (167 °F) (closed weighting bottles)	Behavior on being heated in Wood's metal bath	Behavior when lit by a match	Behavior when lit with a 10 mm high, 5 mm wide gas flame	Behavior when thrown into a red-hot steel bowl	Behavior when heated inside a steel sheet box in a wood fire	Behavior when heated confined in a steel sleeve with escape diameter of	Sensitivity under drop-hammer	Sensitivity under drop-hammer (a 5-kp weight falling from a height of cm: 15 20 30 40 50)	Sensitivity in the friction tester
Ammonium nitrate	80	79.8	light-yellow fine-grained powder	weight loss after 2 days 0.2%; no nitrous gases	at 180 °C (365 °F) evolution of brown vapors; at 212 °C (414 °F) and 320 °C (608 °F) decomposition not accompanied by burning	ignition failed 5 times	ignition failed 5 times	catches fire and burns with a steady flame for 12/14/10 s	catches fire after 64–78 s; end of burning after 390–500 s; strongly hissing flame; the box bulges on all sides	2.0 mm ∅: explosion; $t_1 = 16$ s $t_2 = 20$ s 2.5 mm ∅: no explosion	no reaction decomposition explosion	6 4 3 1 0 0 0 0 0 0 0 2 3 5 6	at 36 kp pistil load no reaction
TNT	12	12.1											
Nitroglycerine	6	5.9											
Wood meal	2	2.2											

Test stands may be designed for the engine to be tested in a vertical or horizontal position.

Modern test stands are also equipped for environmental testing (e.g. temperature, vibration, impact and drop tests).

Rotational Firing

Delay blasting system used so that the detonating explosives will successfully displace the burden into the void created by previously detonated explosives in holes, which fired at an earlier delay period.

Round Robin Test

Ringversuch

Round Robin tests are testing procedures developed through the joint effort of several institutes in different countries, with the purpose of obtaining comparable results. Such international tests are particularly useful if they are recognized as binding in the sales of munition from one country to another.

SAFE & ARM

Device for interrupting (safing) or aligning (arming) an initiation train of an explosive device, i.e. bomb or warhead.

Safety Diaphragm

Berstscheibe; *diaphragme de securité*

Diaphragm, usually metal, that will rupture in the event of excessive gas-generator chamber pressure.

Safety Fuses

Schwarzpulverzündschnüre; *mêches de sureté*

Safety fuses are black powder cords with an external yarn winding adjusted to a definite burning time – usually 120 s/m. The purpose is to initiate the explosive charge by igniting the blasting cap of the primer. The fuse must be freshly cut in the plane perpendicular to its axis, and the plane of the cut must reach the ignition level of the cap. The length of the fuse depends on the safety period required. The structure of the fuse comprises a black powder core with one or two marking threads (the color of which indicates the identity of the manufacturer), two or three layers of yarn wound around it (jute, cotton, or some other yarn), a bitumen impregnation and a plastic coating.

The black powder contains 65–74% potassium nitrate and its grain size is 0.25–0.75 mm. A 1-m length of fuse contains about 4–5 g of powder.

A special type of safety fuse is employed in Switzerland. The core is a pyrotechnical composition in meal form, which is sheathed in paper strips and has a large number of textile threads around it.

SAFEX International

SAFEX International, a nonprofit organization established in 1954, is a voluntary, global association of manufacturers of civil and military explosives as well as technical grade → *Ammonium Nitrate (TGAN)*. It strives to eliminate the harmful effects of explosives on people, property and the environment by encouraging its members to learn from each other's experiences. In pursuance of this purpose, SAFEX operates exclusively in the explosives health, safety, security and environmental domain with activities that encompass the whole explosives life-cycle – from design to development, manufacture, storage, distribution, use and disposal/recycling of explosives products.

SAFEX International has more than 250 members in 50 countries from all over the world. The organization is strictly nonpolitical; all information is for SAFEX members only. Every member is obliged to notify the secretary of any accident or incident within a plant. The secretary then sends out this information to all members; any further clarification can be requested from the secretary, who will in turn contact the member concerned.

Every third year a congress is organized for the presentation of papers on common themes by the members. Admission is for SAFEX members only.

Sand Test

A performance test of an explosive, used in the USA. A known amount of the explosive is exploded in sand consisting of a single grain size (sieve) fraction; the magnitude determined is the amount of sand that passes a finer-meshed sieve following the fragmentation. The test descriptions follow:

1. *Sand test for solids.*
   A 0.4-g sample of explosive, pressed at 3000 psi into a No. 6 cap, is initiated by lead azide or mercury fulminate (or, if necessary, by lead azide and tetryl) in a sand test bomb containing 200 g of "on 30 mesh" Ottawa sand. The amount of azide on tetryl that must be used to ensure that the sample crushes the maximum net weight of sand is designated as its sensitivity to initiation, and the net weight of sand crushed, finer than 30 mesh, is termed the sand test value.

The net weight of sand crushed is obtained by subtracting from the total amount crushed by the initiator when shot alone.

2. *Sand test for liquids.*
   The sand test for liquids is made in accordance with the procedure given for solids except that the following procedure for loading the test samples is substituted:
   Cut the closed end of a number 6 blasting cap and load one end of the cylinder with 0.20 g of lead azide and 0.25 g of tetryl, using a pressure of 3000 psi to consolidate each charge. With a pin, prick the powder train at one end of a piece of miner's black powder fuse, 8 or 9 in long. Crimp a loaded cylinder to the pricked end, taking care that the end of the fuse is held firmly against the charge in the cap. Crimp near the mouth of the cap to avoid squeezing the charge. Transfer of 0.400 g of the test explosive to an aluminum cap, taking precautions with liquid explosives to insert the sample so that as little as possible adheres to the side walls of the cap; when a solid material is being tested, use material fine enough to pass through a number 100 US standard sieve. The caps used should have the following dimensions: length 2.00 in, internal diameter 0.248 in, wall thickness 0.025 in. Press solid explosives, after insertion into the aluminum cap, by means of hand pressure to an apparent density of approximately 1.2 g/cm^3. This is done by exerting hand pressure on a wooden plunger until the plunger has entered the cap to a depth of 3.93 cm. The dimensions of the interior of the cap are: height 5.00 cm, area of cross-section 0.312 cm^2. Insert the cylinder containing the fuse and explosive charge to tetryl and lead azide into the aluminum cap containing the test explosive for the determination of sand crushed.

Scaled Distance

Abstandsberechnung

A factor relating similar blast effects from various size charges of the same explosive at various distances. Scaled distance referring to blasting effects is obtained by dividing the distance of concern by an exponential root of the mass of the explosive materials.

Screw Extruder

Schneckenpresse; *extrudeuse à vis*

These shaping machines, which are commonly employed in the plastics industry, were introduced at an early stage in the manufacture of explosives and gunpowders.

Many cartridging machines for gelatinous explosives utilize double screws as conveyors, but pressures are not allowed to build up to significant values.

Screw extruders were also used for filling ammunition with powder for explosives, since these can be compacted by the application of pressure.

Continuously charged, continuous-operation horizontal screw extruders are employed, in particular, to impart the desired profile to → *Double-Base Propellants* (e.g. shaping of tubes or special profiles for rocket propellants).

Secondary Blasting

Knäppern; *pétardage de blocs*

Blasting to reduce the size of boulders resulting from a primary blast. See also → *Mud Cap*

Secondary Explosives

Sekundär-Sprengstoffe; *explosifs secondaires*

Explosives in which the detonation is initiated by the detonation impact of an initial (primary) explosive. Accordingly, this definition includes all explosives used to obtain blasting effects.

Materials such as → *Ammonium Nitrate* or → *Ammonium Perchlorate* are classified as tertiary explosives, which are less sensitive to detonation impact.

Seismic Explosives

Seismische Sprengstoffe; *explosifs sismiques*

Seismic explosives produce the pressure impact during seismic measurements, which are carried out in prospecting for geological deposits, particularly oil horizons. Such explosives must detonate even under high hydrostatic pressures.

For practical reasons, the shape of the cartridges must differ from the conventional. These shapes allow for cartridges that can be coupled, canisters that can effect explosions in coastal areas, and canned blasting agents (sleeper charges) that can resist water pressure in boreholes for several days.

Seismograph

An instrument, useful in blasting operations, that records ground vibration. Particle velocity, displacement or acceleration are generally measured and recorded in three mutually perpendicular directions.

Seismometer, Falling Pin

An instrument used to indicate relative intensity of ground vibration. It consists of a level glass plate on which a series of 1 1/4″ diameter steel pins (6″ to 15″ lengths) stand upright inside metal tubes. The use of the falling pin seismometer is based on the theory that the length of the pin toppled depends upon the amount of ground vibration present.

Semiconductor Bridge (SCB) Igniter

A solid-state device that, when driven with a low-energy current pulse, produces a plasma discharge that ignites energetic materials pressed against the SCB. A microconvective process transfers the plasma’s energy into the explosive, causing ignition in a few tens of microseconds. The SCB consists of a small polysilicon volume formed on a silicon substrate; typical bridge dimensions are 100 µm long by 360 µm wide by 2 µm thick. While components using the SCB igniter function at one tenth the energy of conventional bridgewire devices, they have been shown to be explosively safe meeting both no-fire and electrostatic discharge (ESD) requirements. SCB chips are processed using standard semiconductor fabrication techniques; consequently, circuitry on the same die can be incorporated to provide a smart igniter that can be used in architectures to sense environments, provide precise delays or respond to coded signals, to name a few possibilities. SCB devices can be used for commercial, military, and government applications that range from sophisticated intelligent devices to rock blasting. R.W. Bickes, Jr. and A.C. Schwarz at Sandia National Laboratories patented the SCB in 1987. Sandia patents for other semiconductor bridges and devices have also been issued.

Semigelatin Dynamites

Semigelatin dynamites are so named because of their consistency. These so-called semigelatins contain ammonium nitrate and wood meal as their main components, and also 10–14% of a weakly gelatinized nitroglycerine.

Sensitivity

Empfindlichkeit; *sensibilité*

The sensitivity of an explosive to heat, mechanical stress, shock, impact, friction impact and detonation impact (initiability) determine its handling safety and its application potential.

All explosives are intrinsically sensitive to impact and shock. The introduction of additives – such as oil or paraffin – may diminish the sensitivity to mechanical stress.

Testing methods ensuring uniform evaluation were developed accordingly. Some of them are included in the Railroad Traffic Regulations (→ *RID*), since certain sensitivity limits are clearly specified by law for the transportation of explosives within individual countries, as well as for international traffic.

(For details, see also: → *Friction Sensitivity*; → *Impact Sensitivity*; → *Heat Sensitivity*.)

(For the behavior of explosives at elevated temperatures, see also → *Stability*.)

Series in Parallel Electric Blasting Cap Circuit

Zündkreis in Serien-Parallel-Schaltung; *circuit combiné paralléle et en série*

A combination of series and parallel where several series of caps are placed in parallel.

(See also → *Parallel Connection*.)

Set Forward

Relative forward movement of component parts that occurs in a projectile, missile or bomb in flight when impact occurs. The effect is caused by inertia and is opposite in direction to setback.

Setback

Rückstoß; *recul*

The relative rearward movement of component parts in a projectile, missile, or fuze undergoing forward acceleration during launching.

Shaped Charges

Hollow Charges; *Hohlladung*; *charge creuse*

See also → *Munroe Effect*

A shaped charge is an explosive charge with a hollow space facing the target.

A rotationally symmetric shaped charge is an explosive charge with an axis of symmetry that acts preferentially in the direction of the rotational axis. Shaped charges lined in a rotationally symmetric manner can pierce steel sheets eight times as thick as the diameter of the charge.

Liners for shaped charges are made of inert material, usually a metal. The lining acts as an energy carrier, since the energy of the explosive charge is concentrated on a small cross-section of the target.

The detonation of the explosive charge causes the lining material to collapse and to converge in the axis of symmetry of the charge. During this process the colliding metal mass separates into a large mass portion moving slowly and a smaller mass portion moving forward at very high speed. Only the fast moving portion with its high kinetic energy produces the perforation effect in the target: it forms a jet of very small diameter and correspondingly high density of energy. The slow moving portion is left as a conglomerated molten slug after detonation.

The main parameters to characterize a lined shaped charge are the detonation velocity, the density of the explosive, the geometry of the detonation wave, the shape of the lining, the lining material and its wall thickness.

Cutting charge

A plane-symmetrical shaped charge, or cutting charge, is an explosive charge with a hollow space, which acts longitudinally in the plane of symmetry (roof-shaped charges).

Plane charge

In a plane charge the opening angle of the conical liner is larger than 100°. When the explosive is detonated, the lining no longer converges into a jet in the axis of symmetry, so that no jet or slug can be formed out of the collapse point; rather, the lining is turned inside out. The resulting sting is much thicker and much shorter with a weaker perforating power, but a larger perforation diameter than that made by a shaped charge.

Projectile-forming charge; self-forging fragment; EFP (explosively formed projectile)

In a projectile-forming charge, the geometry of the lining is such that all its elements have approximately the same velocity. The strength of the material is chosen so that it can easily absorb the residual differences in the velocities. In this way a projectile with a greater kinetic energy is obtained, which consists, roughly speaking, of the entire mass of the lining, and which can also be employed against distant targets.

The shaped-charge effect was first described in 1883. Shortly before the Second World War, Thomanek found that the piercing power of the shaped charge could be significantly increased by lining the hollow space.

The first theoretical treatment of the subject was by Trinks in 1943/44 in a report submitted by the Research Department of the German Army Weapons Command.

The first nonclassified study on the subject was that by Birkhoff Mac Dougall, Pugh and Taylor: Explosives with Lined Cavities, J. Appl. Phys., Vol. 19, p. 563 (1948).

For the first nonclassified study concerning an interpretation of jet extension and the attendant increase in the duration of the effect, see Pugh, Eichelberger and Rostoker: Theory of Jet Formation by Charges with Lined Conical Cavities. J. Appl. Phys., Vol. 23, pp. 532–536 (1952).

Sheathed Explosives

ummantelte Sprengstoffe; *explosifs gainés*

Permitted high-safety explosives that are enveloped in a special cooling sheath; they are now obsolete.

Other high-safety explosives that are homogeneous (i.e. without a sheath) are known as explosives equivalent to sheathed (Eq. S.).

See also → *Permissibles*

Shelf Life

Lebensdauer; *durée de vie*

The length of time of storage during which an explosive material, generator, rocket motor or component retains adequate performance characteristics under specified environmental conditions.

Shock Wave

Stoßwelle; *onde de choc*

Intense compression wave produced by detonation of explosive.

See also → *Detonation*, *2. Shock Wave Theory*

Shot Anchor

A device that anchors explosive charges in the borehole so that the charge will not be blown out by the detonation of other charges.

Shot Firer

Sprengmeister; *boutefeu*

The qualified person in charge of and responsible for the loading and firing of a blast (same as a → *Blaster*).

Shunt

A short-circuiting device provided on the free ends of the leg wires of electric blasting caps to protect them from accidental initiation by extraneous electricity.

Silver Acetylide

silver carbide; *Silberkarbid, Acetylensilber*; *acétylure dargent*

Ag_2C_2
molecular weight: 239.8 g/mol
oxygen balance: −26.7%
deflagration point: 200 °C = 392 °F

Silver carbide is very sensitive to impact. It is prepared by bubbling acetylene through a slightly acidic or neutral silver nitrate solution.

Silver Azide

Silberazid; *azoture dargent*

AgN_3
molecular weight: 149.9 g/mol
oxygen balance: 0%
nitrogen content: 28.03%
volume of detonation gases: 224 l/kg
density: 5.1 g/cm^3
melting point: 251 °C = 484 °F
lead block test: 115 cm^3/10 g
deflagration point: 273 °C = 523 °F

Silver azide is sensitive to light, insoluble in water, and soluble in ammonia, from which it can be recrystallized. It is prepared from sodium azide and solutions of silver salts (depending on the working conditions) as a cheesy, amorphous precipitate.

It gives a very satisfactory initiating effect which is superior to that of lead azide. Nevertheless, its practical use is limited because of its high sensitivity to friction, and because its particular texture makes the dosing difficult.

Silver Fulminate

Knallsilber; *fulminate d'argent*

$AgCNO$

white, crystalline powder
molecular weight: 149.9 g/mol
oxygen balance: −10.7%
nitrogen content: 9.34%

Silver fulminate is prepared by the reaction employed in the preparation of → *Mercury Fulminate*, i.e. by reacting a solution of silver in nitric acid with alcohol. Like mercury fulminate, it is also toxic.

Silver fulminate is much more sensitive than mercury fulminate. Since its detonation development distance is very short, its initiation effect is superior to that of mercury fulminate, but the compound is too sensitive to be used commercially.

An altogether different product, called Berthollet's detonating silver (which is not a fulminate), is obtained when a solution of freshly precipitated silver oxide in ammonia is allowed to evaporate. Its probable formula is Ag_3N. It is highly sensitive and explodes even during the evaporation of the ammoniacal solution.

Silvered Vessel Test

In this testing procedure the propellant sample (about 50 g) is heated in an insulating Dewar vessel, and the rise in temperature produced by the heat of decomposition of the powder is determined. The powder sample is heated to 80 °C (176 °F); the time is determined in which the powder reaches 82 °C (180 °F) by its own heat development on decomposition.

Frey's variant of the silvered vessel test is used in Germany. In this variant, different amounts of heat are supplied to the electric heating elements mounted inside the Dewar flask, and the temperature differences between the interior of the Dewar vessel and the furnace are measured by thermocouples. A calibration curve is plotted from the values thus obtained, and the heat of decomposition of the propellant is read off the curve. In this way, the decomposition temperature at a constant storage temperature can be determined as a function of the storage time, and the heat of decomposition of the propellants can thus be compared with each other. If the measurements are performed at different storage temperatures, the temperature coefficient of the decomposition rate can be calculated. See also → *Differential Thermal Analysis*

SINCO® Ignition Booster and Gas Mixture for Motor Vehicle Safety

SINCO was developed by the Dynamit Nobel AG as an environmentally compatible and particularly stable class of substances for rapid gas evolution. It involves a pyrotechnic gas mixture based on nitrogen-rich fuels and oxygen carriers as reactants. A solid combustion residue (consisting essentially of alkali carbonates), nontoxic gas products (nitrogen, water vapor, carbon dioxide and oxygen) and heat are liberated during the reaction between fuels and the oxygen carriers.

The gas mixtures themselves are free from heavy metals and have high toxicological compatibility. In the acute oral toxicity test carried out according to the EU directive, the LD_{50} value was greater than 2500 mg/kg.

In addition the pyrotechnic mixtures are characterized by high thermal stability. This is also necessary in order to guarantee a constant reaction characteristic over a long period of time and even after thermal stressing.

Stable reaction of the mixtures is possible only with tamping. This property reduces the potential risk that may occur in the event of improper handling or possible misuse.

Because of its properties, SINCO is suitable for personal protection in passive safety systems in motor vehicles. In addition to the use of SINCO in pressure elements for seat-belt or lock tensioners, the gas mixture is also suitable for driver and passenger gas generators. In this case the mixture also performs the function of a booster charge in the igniter elements of the gas generators in addition to the main task of gas evolution.

The proportion of solids formed, which can be controlled via the composition of the mixture, promotes the process of tablet ignition in the gas generator combustion chamber.

Single-Base Powders

Nitrocellulose-Pulver; *poudre à simple base*

Such powders mainly consist of nitrocellulose and stabilizers as well as other additives such as dinitrotoluene in some formulations. Nitrocellulose is gelatinized with the aid of solvents, mostly ether-alcohol mixtures, and additives are incorporated and gelatinized by prolonged kneading. The mixture is shaped into tubes, perforated tubes, flakes, etc., by extrusion and cutting, and the solvents are removed by evaporation, displacement by warm water, vacuum drying, etc., and the material is surface-treated. The purpose of the surface treatment is to let phlegmatization agents diffuse into the material, thus retarding the combustion rate in the surface layers and attaining a progressive burning rate (see also → *Progressive Burning Powders*).

SINOXID Primer Composition

SINOXID is the trademark used for the traditional primer compositions of Dynamit Nobel AG. The formulation was developed by Rathsburg and Herz and patented as tetrazene-tricinate primer composition in 1928.

The term SINOXID derives from sine and oxide, meaning without rust. This underlines the fact that this composition is not susceptible to corrosion, in contrast to mercury fulminante or potassium chlorate mixtures. SINOXID compositions consist of the following components: lead tricinate, → *Tetrazene*, → *Barium Nitrate*, lead dioxide, antimony trisulfide and calcium silicide. These components meet all requirements currently applied in ammunition technology. SINOXID compositions feature very good chemical stability and storage life, they are abrasion-, erosion- and corrosion-free, and ignite propellants with precision.

SINTOX Primer Composition

SINTOX is the international registered trademark for newly developed primer compositions of Dynamit Nobel AG. They are useful if the ambient air in closed firing ranges must not be polluted with combustion products containing lead, antimony or barium. → *Diazodinitrophenol* or the newly developed strontium diazodinitroresorcinate (diazinate) are used as initial explosives. Special types of → *Zinc Peroxide* are used as oxidizers. Additionally, the primer compositions may contain substances like titanium. → *Tetrazene* may also be required as a sensitizer.

For the primer composition, the residual content of lead, barium or antimony compounds is less than 0.01%. Zinc is emitted as nontoxic zinc oxide.

In terms of corrosion and erosion, SINTOX primer compositions behave like → *SINOXID Primer Compositions*. There is no adverse effect on hit accuracy.

Skid Test

This test is intended to simulate a bare explosive charge accidently hitting a rigid surface at an oblique angle during handling. An uncased hemispherical charge, 254 mm in diameter, is dropped in free fall onto a rigid target. In a second version, the charge swings down in a harness on the end of a cable and strikes the target at a pre-determined angle.38)

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38) Gibbs, T.R. and Popolato, A. (1980) *LASL Explosive property Data*, University of California Press.

Slurries

Sprengschlamm; *bouillies*

Slurries consist of saturated aqueous solutions of ammonium nitrate (saturated ammonium nitrate solution at 20 °C = 68 °F contains about 65% NH_4NO_3) and other nitrates, which also contain additional amounts of undissolved nitrates in suspension and fuels that take up the excess oxygen of the nitrate. The structure of the nitrate solution can be significantly affected by added thickeners (e.g. → *Guar Gum*) and cross-linking agents (e.g. borax). The most important fuel is aluminum powder. Water soluble fuels such as glycol can also be employed. The nitrates may also include nitrates of organic amines, e.g. → *Methylamine Nitrate* (MAN).

Slurries may contain sensitizing additives (e.g. *TNT*; *PETN*, etc.). Sensitization can also be achieved by introducing finely dispersed air bubbles, e.g. by introducing air-filled → *Microballoons* (in this form the bubbles will not be compressed by static pressure). Sensitized slurries can be cap-sensitive and may detonate even when the diameter of the borehole is small (see also → *Emulsion Slurries*). Sensitized explosive slurries in the form of cartridges can be utilized in boreholes of conventional and large diameters. In addition, explosive slurries may be pumped into large boreholes.

Addition of rock salt, which reduces the detonation temperature (see also → *Permissibles*), may impart a certain degree of safety against firedamp to the slurry explosives.

Small Arms Ammunition Primers

Anzündhütchen; *amorces*

Small percussion-sensitive explosive charges, encased in a cap and used to ignite propellant powder (see also → *Percussion Cap*).

Snakehole

Sohlenbohrloch; *trou de fond*

A borehole drilled in a slightly downward direction from the horizontal into the floor of a quarry. Also, a hole driven under a boulder.

Sodatol

A pourable 50/50 mixture of sodium nitrate with → *TNT*.

Sodium Chlorate

Natriumchlorat; *chlorate de sodium*

$NaClO_3$
molecular weight: 106.4 g/mol
oxygen balance: + 45.1%
density: 2.48 g/cm^3
melting point: 248 °C = 478 °F

Sodium chlorate, though containing more oxygen than potassium chlorate, has the disadvantage of being more hygroscopic. Like all other chlorates, it must not be used in contact with ammonium salts and ammonium nitrate explosives.

Its practical significance in explosives is very limited.

Sodium Nitrate

Natronsalpeter, Natriumnitrat; *nitrate de sodium*; *SN*

$NaNO_3$
colorless crystals
molecular weight: 85.0 g/mol
energy of formation: −1301 kcal/kg = −5443 kJ/kg
enthalpy of formation: −1315 kcal/kg = −5503 kJ/kg
oxygen balance: + 47.1%
nitrogen content: 16.48%
density: 2.265 g/cm^3
melting point: 317 °C = 603 °F

This salt is hygroscopic and readily soluble in water; less so in ethanol, methanol, and glycerin. It is used in industrial explosives and in 8-black blasting powder as an oxidizer.

Specifications

net content (by nitrogen determination in Lunges nitrometer):	not below 98.5%
moisture:	not more than 0.2%
insolubles in water:	not more than 0.05%
NH_4-, Fe-, Al-, Ca-, Mg- and K-salts:	none
NaCl:	not more than 0.02%
Na_2SO_4:	not more than 0.2%
reaction:	neutral
Abel test 80 °C (176 °F):	not under 30 min

Sodium Perchlorate

Natriumperchlorat; *perchlorate de sodium*

$NaClO_4$
colorless crystals
molecular weight: 122.4 g/mol
oxygen balance: +52.3%
density: 2.54 g/cm^3
melting point: 482 °C = 900 °F (anhydrous product)
energy of formation: −377 kJ/mol
enthalpy of formation: −383 kJ/mol = −3130 kJ/kg

Sodium perchlorate is hygroscopic and is readily soluble in water and alcohol. Standard product contains 1 mol of crystal water.

Soil Grain Powder

Weichkornpulver; *poudre à grain souple*

Type of → *Black Powder* for firework manufacture. Soft grain powder is not compacted in hydraulic presses.

Solid Propellant Rockets

Feststoff-Raketen; *roquettes à propergol solide*

These rockets operate on homogeneous solid propellants. Following ignition, the propellant charge burns, and it is not possible to interrupt or to control the combustion process (for certain possibilities in this respect see → *Hybrids*). The course and the rate of the combustion process may be modified by suitable shaping of the charge (front of cigarette burner, internal burner, all-side burner, and charges with special configurations), by varying its composition and grain size, and by incorporating special accelerating or retarding additives. The propellant charge must be carefully examined for cracks, since in their presence the combustion will not proceed uniformly. If case-bonded charges are employed, adequate cohesion between the wall of the combustion chamber and the propellant charge (see → *Case Bonding*) must be ensured.

The advantages of solid rockets are the short time needed for the actuation, long storage life, and a simple design.

The burning process in the rocket motor is influenced by: the thermodynamic performance values of the propellant (→ *Thermodynamic Calculation of Decomposition Reactions*); the burning characteristics of the propellant grain (→ *Burning Rate*), depending on its shape; and by the pressure influence on the burning rate. The pressure exponent can be zero in the case of modern propellants (Plateau, Mesa, see → *Burning*

Rate). The pressure function of the burning rate cannot be described by a universal equation, but within smaller pressure ranges the equation of Saint-Robert or Vieille equation is applicable:

$$r = ap^{\alpha} \tag{14}$$

r: rate of burning normal to the burning surface, p: pressure, α: pressure exponent a: constant.

(See also → *Burning Rate, Charbonnier equation*.)

At any time during the reaction, equilibrium must exist between the gas produced

$$r \cdot f_T \cdot \rho \tag{15}$$

(f_T: burning surface, ρ: density of propellant)
and the gas discharged through the nozzle

$$p \cdot f_m \cdot C_D \tag{16}$$

(f_m: nozzle cross-section, C_D: mass flow coefficient)

The ratio f_m/f_T = nozzle cross-section to the burning surface at any time is called the → *Propellant Area Ratio* (Klemmung; K); the Eqs. (15) and (16) are considered to be equal; Eq. (14) can be rearranged to

$$p = \frac{a}{C_D} \varrho K^{\frac{1}{1-\alpha}} \tag{17}$$

Equation (17) allows plotting of the gas pressure–time diagram, if a, C_D and α are known and the course of the propellant area ratio K with the burning time can be assumed. Modification of the pressure–time diagram may be caused by the pressure falling off along the propellant grain (Bernoulli's equation), by → *Erosive Burning*, by the igniter system, and by irregular combustion of the remaining propellant. The thrust–time diagram (see → *Thrust*; → *Thrust Determination*) can be derived from the pressure–time diagram obtained from Eq. (17).

Solventless Propellants

POL-Pulver; *poudre propulsive sans solvant*

These propellants use an effective plasticizer, which is worked into the nitrocellulose fibers under the mechanical effect of a shear roll mill and the use of heat to produce a gel. Following this mixing and shear roll processing the gel is then pressed to small cavities to form propellant granules.

Spacing

Bohrlochabstand; *distance entre trous*

The distance between boreholes measured parallel to the free face toward which rock is expected to move.

Spark Detonators

Spaltzünder; *amorce électrique à l'étincelle*

Spark detonators, like bridgewire detonators, were employed in the past to produce electric initiation of explosive charges. The priming charge itself, containing current conducting additives, served as a current conductor through the priming pill itself. Relatively high voltages were required to produce the ignition, so that such devices were safe from stray currents.

Spark detonators have now been substituted by → *Bridgewire Detonators*. If there is danger of stray currents, low-sensitivity primer types are employed, which can be actuated only by a strong current pulse.

Special Effects

These are special arrangements for the simulation of dangerous events in military, western, and science fiction scenes in motion pictures and television programs.

Frequently, specially designed fireworks are used for creating these effects, e.g. tiny detonators (→ *Bullet Hit Squib*) for the simulation of bullet impacts.[39)]

Specific Energy

spezifische Energie; *force*

The specific energy of an explosive is defined as its working performance per kg, calculated theoretically from the equation of state for ideal gases:

$$f = pV = nRT$$

where p is the pressure, V is the volume, n is the number of moles of the explosion gases per kg (see also → *Volume of Explosive Gases*), R is the ideal gas constant, and T is the absolute temperature of the explosion. If we put the volume equal to unity, i.e. if the loading density is unity, the specific energy becomes

$$f = p$$

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39) Clark, F.F. (1979) *Special Effects in Motion Pictures*, Society of Motion Picture and Television Engineers, Inc., 862 Scarsdale Avenue, Scarsdale, N.Y. 10583, Second Printing.

i.e. is equal to the pressure which would be exerted by the compressed explosion gases in their container, if the latter were indestructible. This is why the term specific pressure is also frequently used, and why the magnitude f is often quoted in atmospheres.

Nevertheless, strictly speaking, f is an energy per unit mass and for this reason is reported in mt/kg. The value of T will have this dimension if R is taken as $0.8479 \cdot 10^{-3}$ m t K mol.

In accordance with recent standardization regulations, the energy data are also reported in joules.

(For more details on the calculation see → *Thermodynamic Calculation of Decomposition Reactions*; also → *Strength*)

Specific Impulse

spezifischer Impuls; *impulse spécifique*

The mass specific impulse of a propellant in rocket motors is the most important characteristics of its performance. It is the → *Thrust* multiplied by the time (i.e. the impulse) per unit mass of propellant:

$$I_s = \frac{F \cdot t}{m}$$

I_s: specific impulse, F: thrust, t: time, m: mass of propellant.

It is measured in kilopond-seconds (or Newton-seconds) per kilogram of propellant[40]. It can be evaluated by the equation

$$I_s = \sqrt{2J(H_c - H_e)} \quad (\mathrm{N\,s/kg})$$

J: mechanical heat equivalent, H_c: enthalpy of the reaction products in the rocket chamber (at chamber pressure and chamber temperature) (unit: kcal/kg), H_e: enthalpy of the reaction products at the nozzle exit (unit: kcal/kg).

The equation can be solved with the aid of computers, considering various equilibrium reactions (see → *Thermodynamic Calculation of Decomposition Reactions*).

The relation of the specific impulse to the temperature of the reaction gas in the rocket chamber is

$$I_s = k_1 \sqrt{T_c \cdot N} = k_2 \sqrt{\frac{T_c}{M}}$$

---

40) Since the numerical values of kp and kg are the same, the apparent dimension of the specific impulse is simply the second. For this reason, all impulse data can be directly compared with each other, even if other unit systems are employed.

T_c: flame temperature in the chamber, N: number of moles per weight unit, M: average molecular weight of the flame gases, k_1, k_2: constants.

The value for the specific impulse is high if the reaction heat is high and produces a high flame temperature, and if the average molecular weight of the reaction products is low. Data concerning specific impulses are only comparable if they refer to the same working pressure in the combustion chamber; a frequently employed standard value is 1000 lb s/in^2 approx. 70 bar in test chambers.

For more details on this subject, see: *Barrére, Jaumotte, Fraeijs de Veubeke Vandenkerckhove:* Raketenantriebe. Elsevier, Amsterdam, 1961. Also: *Dadieu, Damm, Schmidt:* Raketentreibstoffe Springer, Wien 1968

(See also → *Gas Jet Velocity*;→ *Thermodynamic Calculation of Decomposition Reactions*)

Springing

Vorkesseln; *agrandissement par explosion*

The practice of enlarging the bottom of a blast hole by the use of a relatively small charge of explosive material. Typically used so that a larger charge of explosive material can be loaded in a subsequent blast in the same borehole.

Squib

Anzünder; *allumeur (électrique)*

Used in a general sense to mean any of the various small size pyrotechnic or explosive devices. Specifically, a small explosive device, similar in appearance to a detonator, but loaded with low explosive, so that its output is primarily heat (flash). Usually electrically initiated and provided to initiate the action of pyrotechnic devices and rocket propellants. An electric squib is a tube containing a flammable material and a small charge of powder compressed around a fine resistance wire connected to electrical leads or terminal (see also → *Initiator*; → *Bullet Hit Squib*).

Stability

Stabilität; *stabilité*

A distinction must be made between chemical and physical stability. While physical stability is important, particularly in the evaluation of solid propellants, the chemical stability is of prime importance in the estimation of the course of decomposition of nitrate esters. The nitrate esters that are processed for use as propellants – unlike nitro compounds, which are relatively stable under these conditions – undergo a steady decomposition, which is due to imperfect purification of the starting materials and to the effect of other parameters such as temperature and air humidity. The rate of this decomposition is auto-catalyzed by the acidic decomposition products and may in certain cases produce spontaneous ignition. In order to reduce the decomposition rate as much as possible, suitable stabilizers are added to the powders, which are capable of accepting the acid cleavage products with formation of the corresponding nitro compounds (see also → *Stabilizers*). The stability is controlled by means of several tests (see also → *Hot Storage Tests*).

A distinction must be made between tests of short duration, in which the possible decomposition reactions are accelerated by a considerable rise in temperature, and so-called service-life tests or surveillance tests, which take place over several months and may sometimes take more than a year. Short-duration tests alone do not suffice for a reliable estimate of stability, at least where imperfectly known products are concerned.

An estimation of the probable → *Shelf Life* of aged propellants can be made by chromatography41). If e.g. diphenylamine is used as a stabilizer, the transformation into the nitro derivatives up to hexanitrodiphenylamine can be analyzed; if this stage is reached, decomposition of the powder occurs.

Stabilizers

Stabilisatoren; *stabilisateurs*

Stabilizers are generally defined as compounds that, when added in small amounts to other chemical compounds or mixtures, impart stability to the latter.

In propellant chemistry, especially so in the case of nitrocellulose-containing powders, the stabilizers employed are compounds that, owing to their chemical structure, prevent the acid-catalyzed decomposition of nitrocellulose, nitroglycerine, and similar nitrate esters.

They exert their stabilizing effect by binding the decomposition products, such as the free acid and nitrous gases. The stabilizers themselves are converted into relatively stable compounds at the same time. Neither stabilizers nor their secondary products should undergo a chemical reaction (saponification) with nitroglycerine or nitrocellulose. Compounds used as stabilizers are mostly substitution products of urea and diphenylamine. Readily oxidizable compounds – such as higher alcohols, cam-

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41) Volk, F. (1976) Determination of the shelf life of solid propellants. *Propellants and Explosives*, **1**, 59–65.
Volk, F. (1976) Determination of the lifetime of gun-propellants using thin layer chromatography. *Propellants and Explosives*, **1**, 90–97.

phor, unsaturated hydrocarbons (Vaselines) – may also be employed. For such compounds to be effective, their homogeneous incorporation into the powder must be easy, they must not be too volatile, and they must not be leached out by water. Many stabilizers also display plasticizing (gelatinizing) properties; accordingly, they have both a stabilizing effect and – in the manufacture of powders – a gelatinizing (softening) effect.

Pure stabilizers include:
- Diphenylamine
- Akardite I (*asym*-diphenylurea)

Stabilizers with a gelatinizing effect include:
- Centralite I (*sym*-diethyldiphenylurea)
- Centralite II (*sym*-dimethyldiphenylurea)
- Centralite III (methylethyldiphenylurea)
- Akardite II (methyldiphenylurea)
- Akardite III (ethyldiphenylurea)

Substituted urethanes:
- Ethyl-, methyl- and diphenylurethane
- Pure gelatinizers, without a stabilizing effect, include: dibutyl phthalate
- Diamyl phthalate
- Camphor

For formulas and properties see appropriate keywords.

STANAG

Standardization Agreement of the NATO, which defines processes, procedures, terms and conditions for common military or technical procedures or equipment. Examples relevant to energetic materials are STANAG 4022 – Specification For RDX (Hexogene) For Deliveries From One NATO Nation To Another, STANAG 4178 – Test Procedures For Assessing The Quality Of Deliveries Of Nitrocellulose, STANAG 4439 – Policy For Introduction And Assessment Of Insensitive Munitions, and STANAG 4489 – Explosive Impact Sensitivity Tests. Supporting guidance may be documented in Allied Ordnance Publications (→ AOP).

Stemming

Besatz; *bourrage*

In mining, stemming refers to the inert material used to plug up a borehole into which the explosive charge has been loaded. The classic stemming materials are mud or clay noodles. Stemming brings about more economical utilization of the explosive charge, provided the explosive columns employed are short and the detonation is at the mouth of the borehole. Stemming is mandatory if there is any danger of firedamp.

The strongest stemming is not necessarily the best; if the stemming is too strong, deflagration may take place. In coal mining water, stemming cartridges have proved to be the best; these are plastic tubes filled with water or water gel and closed at both ends, which are easily inserted into the borehole, do not stem too strongly, and make a significant contribution to the settling of dust and fumes.

See also → *Confinement*

Storage

Lagerung; *magasinage*

The safekeeping of explosive materials, usually in specially designed structures called → *Magazines*.

Stray Current Protection

Streustromsicherheit; *protection contre les courants vagabonds*

The increasingly large consumption of electric current has resulted in intensified stray currents. The stray current safety of an electric primer is the maximum current intensity at which the glowing wire just fails to attain the ignition temperature of the charge in the primer. To improve protection against stray currents, the "A" bridgewire detonators, which were formerly used in Germany, have now been replaced by the less sensitive "U" detonators (see also → *Bridgewire Detonators*).

Strength

Arbeitsvermögen; *force*

See also → *Bulk Strength*; → *Weight Strength*

The performance potential of an explosive cannot be described by a single parameter. It is determined by the amount of gas liberated per unit weight, the energy evolved in the process (→ *Heat of Explosion*), and by the propagation rate of the explosive (detonation velocity; see → *Detonation*). If an explosive is to be detonated in a borehole, the relevant parameter is its strength; here the criterion of the performance is not so much a high detonation rate as a high gas yield and a high heat of explosion. If, on the other hand, a strong disintegration effect in the vicinity of the detonation is required, the most important parameters are the detonation rate and the density (see → *Brisance*).

A number of conventional tests and calculation methods exist for determining the comparative performance of different explosives. The determinations of the detonation rate and density require no conventions, since they are both specific physical parameter.

Lead block test and ballistic mortar test

Practical tests for comparative strength determination are the lead block test and the declination of a ballistic mortar. In both cases relatively small amounts of the explosive (of the order of 10 g) are initiated by a blasting cap. In the lead block test, the value measured is the volume of the pear-shaped bulge made in the block borehole by the sample introduced into it; in the ballistic mortar test the value measured is the deflection angle, which is a measure of the recoil force of a heavy steel weight suspended as a pendulum bob, after the exploding cartridge has fired a steel projectile out of a hole made in the bob. The performance of the explosive being tested is reported as the percentage of that of → *Blasting Gelatin*, which is conventionally taken as 100% (For further details see also → *Ballistic Mortar*). In both cases the explosive is enclosed in a confined space so that, for all practical purposes, the parameter measured is the work of decomposition of an explosive in a borehole. The disadvantage of both methods is that the quantity of the sample used in the test (exactly or approximately 10 g) is quite small, and for this reason accurate comparative data can be obtained only with more sensitive explosives; less sensitive materials require a longer detonation development distance (see → *Detonation*), within which a considerable proportion of the 10 g sample does not fully react. Practical methods for determining the performance of explosives requiring much larger samples (up to 500 g) include the following.

Jumping mortar test

Two halves with finely ground surfaces fitting exactly onto one another form a mortar with a borehole. One of the halves is embedded in the ground at a 45° angle, while the other half is projected like a shot, when the explosive charge is detonated in the hole. The distance it is thrown is then determined. A disadvantage of this method is that when high-brisance explosives are tested, the surfaces must be reground after each shot. This method gives excellent results with weaker → *Permitted Explosives*.

Vessel mortar test

This test is also based on the determination of the range distance of a heavy projectile. The explosive is suspended in a thick-walled vessel, and an accurately fitting cap of the vessels is projected. This apparatus is stronger, and the weight of the charge may be made as large as 500 g.

Large lead block test

The device consists of a lead block with linear dimensions three times as large as normal. This technique has been used to obtain information

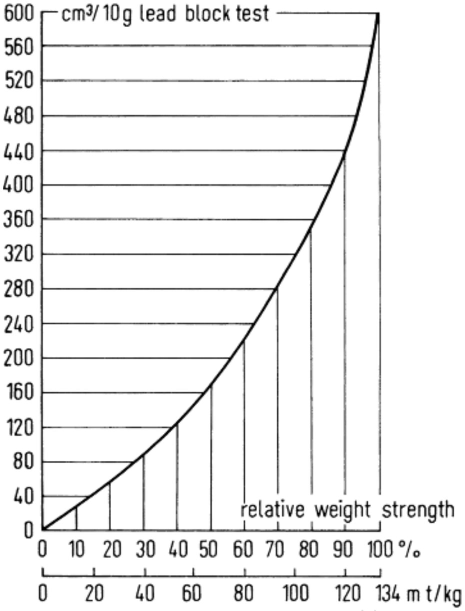


Figure 23 Specific energy and relative weight strength in relation to lead block test values.

about slurries. The method is too expensive for practical work, since more than one ton of lead must be cast for each shot.

The crater method

This method is based on the comparison of the sizes (volumes) of the funnels produced in the ground by underground explosions. It is used for explosives with a large critical diameter only if no other method is available, since it is inaccurate and the scatter is large. → *Aquarium Test*

The sample is exploded underwater (in a natural water reservoir or in a man-made pool), and the pressure of the resulting impact wave is measured with the aid of lead or copper membranes. → *Specific Energy*

For calculations of performance parameters of explosives (see → *Thermodynamic Calculation* of *Decomposition Reactions*). As far as the strength of propellants and explosives is concerned, the most relevant thermodynamically calculable parameter is the → *Specific Energy*. This is the amount of energy released when the gases in the body of the explosive (assumed to be compressed in their initial state) are allowed to expand at the explosion temperature while performing useful work. In order to illustrate the working performance obtainable from explosive materials, this magnitude is conventionally reported in meter-tons per kilogram; in this book, it is also given in joules.

The calculated values of the specific energy agree well with the performance data obtained by conventional tests. This is particularly true of the tests in which larger samples are employed, but the apparatus required for such tests is not always available, and the tests themselves are relatively expensive.

The following empirical formula relating the specific energy to the relative weight strength is valid in most cases:

$$\text{weight strength (\%)} = 0.0746 \times \text{spec. energy (in mt/kg)}$$

The relationship between the size of the lead block excavation and the specific energy is not linear. The true relationship may be seen in Figure 23 (representation of experimental results).

The relationship between weight strength and the coefficient d'utilisation pratique (c.u.p.) used in France (see → *Lead Block Test*) is shown in the empirical formulas:

$$\text{weight strength (\%)} = 0.645 \times \text{(\%) c.u.p.}$$

$$\text{(\%) c.u.p.} = 1.55 \times \text{(\%) weight strength}$$

Strontium Nitrate

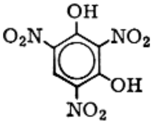
Strontiumnitrat; *nitrate de strontium*

$Sr(NO_3)_2$
colorless crystals
molecular weight: 211.7 g/mol
energy of formation: −968.3 kJ/mol
enthalpy of formation: −4622 kJ/kg
oxygen balance: +37.8%
nitrogen content: 13.23%
density: 2.99 g/cm^3
melting point: 570 °C

Strontium nitrate is used in pyrotechnics as a flame-coloring oxidizer for red-colored fireworks. Recently, strontium nitrate has also been used as an oxidizer in gas-generating propellants, e.g. for airbags.

Styphnic Acid

trinitroresorcinol; 2,4,6-trinitro-1,3-dihydroxybenzene; trinitroresorcin; trinitroresorcinol; acide styphnique; *Trizin*; *TNR*



yellow-brown to red-brown crystals
empirical formula: $C_6H_3N_3O_8$
molecular weight: 245.1 g/mol
energy of formation: −493.1 kcal/kg = −2063.1 kJ/kg
enthalpy of formation: −510.0 kcal/kg = −2133.8 kJ/kg
oxygen balance: −35.9%
nitrogen content: 17.15%
volume of explosion gases: 814 l/kg
heat of explosion
  (H_2O liq.): 706 kcal/kg = 2952 kJ/kg
  (H_2O gas): 679 kcal/kg = 2843 kJ/kg
specific energy: 89 mt/kg = 874 kJ/kg
density: 1.83 g/cm^3
melting point: 176 °C = 349 °F
lead block test: 284 cm^3/10 g
deflagration point: 223 °C = 433 °F
impact sensitivity: 0.75 kp m = 7.4 N m
friction sensitivity: at 36 kg = 353 N
  pistil load: no reaction
critical diameter of steel sleeve test: 14 mm

Styphnic acid is prepared by dissolving resorcinol in concentrated sulfuric acid and nitrating the resulting solution with concentrated nitric acid. It is a relatively weak explosive. Its lead salt (→ *Lead Styphnate*) is used as an initiating explosive.

Sulfur

Schwefel; *soufre*

S
atomic weight: 32.07
melting point: 113 °C = 235 °F
boiling point: 445 °C = 833 °F
density: 2.07 g/cm^3

Sulfur is used with charcoal as a fuel component in → *Black Powder*. Sublimated sulfur is not completely soluble in carbon sulfide and contains traces of sulfuric acid; the use of sublimated sulfur for black powder production is therefore not permitted.

Surface Treatment

Oberflächenbehandlung; *traitement de surface*

When gunpowder burns in the chamber of a weapon, the internal ballistic energy of the powder charge is best exploited if the gas pressure is kept constant almost up to the emergence of the projectile from the barrel, despite the fact that the gas volume keeps growing larger during that period owing to the movement of the projectile. It follows that gas evolution from the powder charge should be slow at first, while towards the end of the combustion process it must be quicker (progressive burning). This is achieved mainly by imparting a suitable shape to the powder granule (in a seven-hole powder, the surface area increases during combustion, and the combustion is therefore progressive). Progressive combustion is also enhanced to a considerable extent by surface treatment, i.e. by allowing phlegmatizing, combustion retarding substances (such as centralit, dibutyl phthalate, camphor, dinitrotoluene, etc.) to soak into the powder. A careful surface treatment is an excellent way of keeping the maximum pressure peak of the combustion curve low.

Susan Test

The Susan Sensitivity Test[42] is a projectile impact test. The explosive to be tested is loaded into a projectile (shown in Figure 24) and thrown against a steel target. The reaction on impact is recorded by measuring the shock wave pressure by a gauge 10 ft (3.1 m) away. The percentage of the reaction (0 = no reaction; 40 = fast burning reactions; 70 = fully reacted TNT; 100 = detonation) is plotted against the projectile velocity (0–1600 ft/s = 488 m/s). → *Plastic Explosives* with rubber-like binders give better results than cast RDX/TNT mixtures.

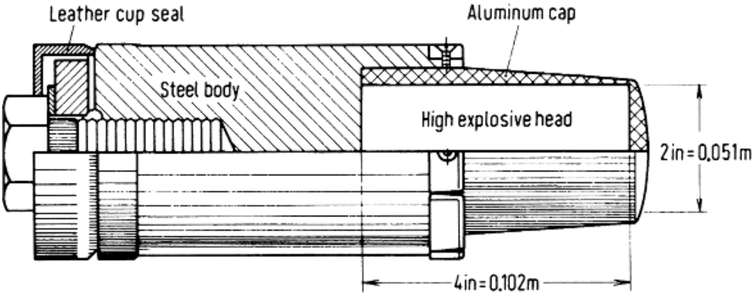


Figure 24 The Susan projectile.

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[42] Information, results, and figure obtained from Brigitta M. Dobratz, Properties of Chemical Explosives and Explosive Simulants, publication UCEL-51319, University of California, Livermore.

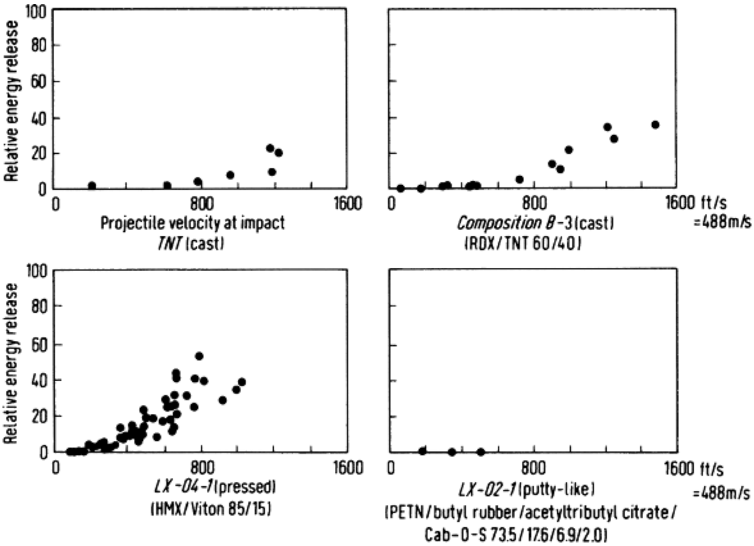


Figure 25 Test results.

Sustainer Charge

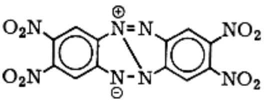
Component (optional) of ignition system (train) that maintains operating pressure until thermal equilibrium is obtained.

Sympathetic Propagation

See → *Detonation, Sympathetic Detonation*

Tacot

Tetranitrodibenzo-1,3a,4,6a-tetrazapentalene; *tetranitrodibenzo-tétrazapentaléne*



orange red crystals
empirical formula: $C_{12}H_4N_8O_8$
molecular weight: 388.1 g/mol
oxygen balance: −74.2%
nitrogen content: 28.87%
melting point: 378 °C = 712 °F (decomposition)
density: 1.85 g/cm^3

heat of detonation, experimental (H_2O liq.)[43]:
980 kcal/kg = 4103 kJ/kg
detonation velocity, confined:
7250 m/s = 23 800 ft/s at $\rho = 1.64$ g/cm^3
impact sensitivity: 69 N m[44]

The compound is prepared by direct nitration of dibenzotetrazapentalene in sulfuric acid solution.

Tacot is insoluble in water and in most organic solvents; its solubility in acetone is only 0.01%. It is soluble in 95% nitric acid, and is sparingly soluble in nitrobenzene and dimethylformamide. It does not react with steel or with nonferrous metals.

This explosive is of interest because of its exceptionally high stability to high temperatures; it remains serviceable:

after	10 min	at 660 °F = 350 °C
after	4 h	at 620 °F = 325 °C
after	10 h	at 600 °F = 315 °C
after	2 weeks	at 540 °F = 280 °C
after	4 weeks	at 530 °F = 275 °C

Taliani Test

An improved version of the manometric test developed by Obermüller in 1904. The method was considerably modified, first by Goujan and, very recently, by Brissaud. In all modifications of the method, the test tube containing the sample preheated to the desired temperature is evacuated, and the increase in pressure produced by the gaseous decomposition products is measured with a mercury manometer. The test is usually terminated when the pressure has attained 100 mm Hg. The test temperature are:

for nitrocellulose	135 °C = 275 °F
for propellants	110°C = 230 °F.

The sample must be thoroughly dried before the test; the result would otherwise also include all other components which increase the pressure on being heated, such as water and organic solvents. Since the result is also affected by the nitroglycerine content of the propellant sample, the test can only be used in order to compare propellants of the same kind with one another. This, in addition to the high testing temperature, makes the applicability of the Taliani test for propellants question-

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[43] Value quoted from Dobratz, B.M. *Properties of Chemical Explosives and Explosive Simulants*, University of California, Livermore.

[44] Quoted from the psospectus leaflet of DU PONT.

able. Another disadvantage is the necessity for thorough drying, since in the course of the drying operation the test sample is altered in an undesirable manner, and the experimental stability data may show better values than its true stability. The latter disadvantage does not apply to nitrocellulose testing.

Tamping

Verdämmen; *bourrage*

Synonymous with → *Stemming*

Tamping Pole

Ladestock; *bourroir*

A wooden or plastic pole used to compact explosive charges for → *Stemming*.

TBX – IAT

An insensitive thermobaric mixture of IPN (Isopropylnitrate), Magnesium and additives for industrial applications developed by *A. Kappl* at Austin Powder Austria in 2003. Nonconfined detonation velocity is 2920 m/s. Duration of positive blast pressure is 0.2 s. Heat of combustion is > 16 kJ/g.

Test Cap No. 8

Prüfkapsel (Zündkapsel); *detonateur d'epreuve*

Defined by the Institute of Makers of Explosives (USA):

A No. 8 test blasting cap is one containing 2 g of a mixture of 80% mercury fulminate and 20% potassium chlorate, or a cap of equivalent strength.

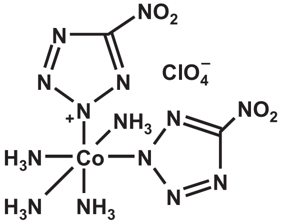
In comparison, the European test cap contains 0.6 g PETN; the commercial No. 8 cap contains 0.75 g tetryl (German).

Test Galleries

Versuchsstrecken; Sprengstoffprüfstrecken; *galeries d'essai*

See → *Permissibles*.

Tetraamine-*cis*-bis(5-nitro-2H-tetrazolato) Cobalt(III) Perchlorate, BNCP



solid
empirical formula: $C_2ClCoH_{12}N_{14}O_8$
molecular weight: 454.592 g/mol
oxygen balance: −8.8%
density: 2.03 g/cm^3
melting point: 269 °C

BNCP is a primary explosive material with a rapid DDT (deflagration to detonation transition) sensitive to laser pulses, and thus may be used in optical detonators.

Tetramethylammonium Nitrate

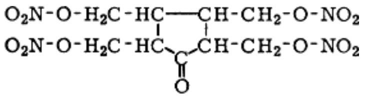
Tetramethylammoniumnitrat; *nitrate de tétraméthylammonium*

$(CH_3)_4NNO_3$
colorless crystals
empirical formula: $C_4H_{12}N_2O_3$
molecular weight: 136.2 g/mol
energy of formation: −562.3 kcal/kg = −2352.7 kJ/kg
enthalpy of formation: −599.3 kcal/kg = −2507.3 kJ/kg
oxygen balance: −129.2%
nitrogen content: 20.57%
density: 1.25 g/cm^3

During the Second World War, this compound was utilized as a fuel component in fusible ammonium nitrate mixtures. It can be homogeneously incorporated into the melt.

Tetramethylolcyclopentanone Tetranitrate

Nitropentanon; *tétranitrate de tétraméthylolcyclopentanone*; *Fivonite*



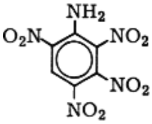
colorless crystals
empirical formula: $C_9H_{12}N_4O_{13}$
molecular weight: 384.2 g/mol
energy of formation: −398.2 kcal/kg = −1666 kJ/kg
enthalpy of formation: −420.6 kcal/kg = −1760 kJ/kg
oxygen balance: −45.8%
nitrogen content: 14.59%
density: 1.59 g/cm^3
melting point: 74 °C = 165 °F
lead block test: 387 cm^3/10 g
detonation velocity, confined: 7040 m/s = 23 100 ft/s
at $\rho = 1.55$ g/cm^3

Condensation of formaldehyde with cyclopentanone yields a compound with four $-CH_2OH$ groups, which can be nitrated to the tetranitrate. Analogous derivatives of hexanone, hexanol, and pentanol can be prepared in the same manner, but in the case of pentanol and hexanone the fifth hydroxyl group also becomes esterified:

- tetramethylolcyclohexanol pentanitrate Sixolite;
- tetramethylolcyclohexanone tetranitrate Sixonite;
- tetramethylolcyclopentanol pentanitrate Fivolite.

2,3,4,6-Tetranitroaniline

Tetranitroanilin; *tétranitroaniline*; *TNA*



pale yellow crystals
empirical formula: $C_6H_3N_5O_8$
molecular weight: 273.1 g/mol
energy of formation: −25.5 kcal/kg = −107 kJ/kg

Table 25 Thermochemical data.

Compound	Empirical formula	Molecular weight (g/mol)	Oxygen balance (%)	Energy of formation (kcal/kg)	(kJ/kg)	Enthalpy of formation (kcal/kg)	(kJ/kg)
Sixolite	$C_{10}H_{15}N_5O_{15}$	445.3	−44.9	−334	−1397	−357	−1494
Sixonite	$C_{10}H_{14}N_4O_{13}$	398.2	−56.3	−402	−1682	−425	−1778
Fivolite	$C_9H_{13}N_5O_{15}$	431.2	−35.3	−325	−1360	−348	−1456

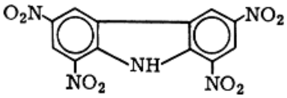
enthalpy of formation: −42.8 kcal/kg = −179 kJ/kg
oxygen balance: −32.2%
nitrogen content: 25.65%
volume of explosion gases: 813 l/kg
heat of explosion
  (H_2O liq.): 1046 kcal/kg = 4378 kJ/kg
  (H_2O gas): 1023 kcal/kg = 4280 kJ/kg
specific energy: 123 mt/kg = 1204 kJ/kg
density: 1.867 g/cm^3
melting point: 216 °C = 421 °F (decomposition)
deflagration point: 220–230 °C = 428–446 °F
impact sensitivity: 0.6 kp m = 6 N m

Tetranitroaniline is soluble in water, hot glacial acetic acid and hot acetone, and is sparingly soluble in alcohol, benzene, ligroin and chloroform.

It is prepared by nitration of 3-nitroaniline or aniline with a H_2SO_4/HNO_3 mixture. The yield is moderate.

Tetranitrocarbazole

Tetranitrocarbazol; *tétranitrocarbazol*; *TNC*



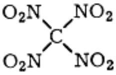
yellow crystals
empirical formula: $C_{12}H_5N_5O_8$
molecular weight: 347.2 g/mol
energy of formation: +28.3 kcal/kg = +118.5 kJ/kg
enthalpy of formation: +13.0 kcal/kg = +54.4 kJ/kg
oxygen balance: −85.2%
nitrogen content: 20.17%
melting point: 296 °C = 565 °F
heat of explosion (H_2O liq.): 821 kcal/kg = 3433 kJ/kg

Tetranitrocarbazole is insoluble in water, ether, alcohol, and carbon tetrachloride, and is readily soluble in benzene. It is not hygroscopic.

It is prepared by the nitration of carbazole. Preparation begins with sulfuric acid treatment until the compound becomes fully soluble in water, after which the sulfonic acid derivative is directly converted to the nitro compound by adding mixed acid without previous isolation.

Tetranitromethane

Tetranitromethan; *tétranitrométhane*; *TNM*



colorless liquid with a pungent smell
empirical formula: CN_4O_8
molecular weight: 196.0 g/mol
energy of formation: +65.0 kcal/kg = +272.1 kJ/kg
enthalpy of formation: +46.9 kcal/kg = +196.4 kJ/kg
oxygen balance: +49.0%
nitrogen content: 28.59%
volume of explosion gases: 685 l/kg
heat of explosion[45]: 526 kcal/kg = 2200 kJ/kg
specific energy: 69.1 mt/kg = 677 kJ/kg
density: 1.6377 g/cm^3
solidification point: 13.75 °C = 56.75 °F
boiling point: 126 °C = 259 °F
vapor pressure:

Pressure (mbar)	Temperature (°C)	(°F)
12	20	68
57	50	122
420	100	212
1010	126	259 (boiling point)

detonation velocity, confined: 6360 m/s = 20 900 ft/s
at $\rho = 1.637$ g/cm^3

Tetranitromethane is insoluble in water, but soluble in alcohol and ether. The volatile compound strongly attacks the lungs. The oxygen-rich derivative is not explosive by itself, but forms highly brisant mixtures with hydrocarbons such as toluene.

Tetranitromethane is formed as a byproduct during nitration of aromatic hydrocarbons with concentrated acids at high temperatures, following opening of the ring. It can also be prepared by reacting acetylene with nitric acid in the presence of mercury nitrate as a catalyst. According to a more recent method, tetranitromethane is prepared by introducing a

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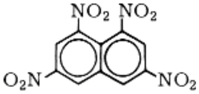
45) The presence of small amounts of impurities may easily increase the experimental value to above 1000 kcal/kg.

slow stream of ketene into cooled 100% nitric acid. When the reaction mixture is poured into ice water, tetranitromethane separates out.

Mixtures of tetranitromethane with organic fuels are very sensitive to impact and friction and may react spontaneously by detonation or fast deflagration.

Tetranitronaphthalene

Tetranitronaphthalin; *tétranitronaphthaléne*; *TNN*



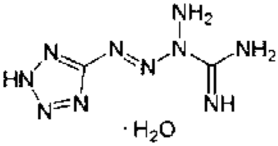
yellow crystals
empirical formula: $C_{10}H_4N_4O_8$
molecular weight: 308.2 g/mol
energy of formation: +23.7 kcal/kg = +99.2 kJ/kg
enthalpy of formation: +8.4 kcal/kg = +35.3 kJ/kg
oxygen balance: −72.7%
nitrogen balance: 18.18%
density: 1.8 g/cm^3
melting point: softening of the isomer mixture begins at 190 °C = 374 °F

Tetranitronaphthalene is a mixture of isomers, which is obtained by continued nitration of dinitronaphthalenes.

The tetrasubstituted compound can only be attained with difficulty. The crude product is impure and has an irregular appearance. It can be purified with glacial acetic acid.

Tetrazene[46)]

tetrazolyl guanyltetrazene hydrate; *Tetrazen*; *tétrazéne*



feathery, colorless to pale yellow crystals
empirical formula: $C_2H_8N_{10}O$

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46) The structural formula found in the earlier literature: HN−C(=NH)−NH−NH−N=N−C(=NH)−NH−NH−NO was corrected in 1954 by Patinkin, S.H. (Chem. Zentr. 1955, p. 8377).

molecular weight: 188.2 g/mol
energy of formation: +270.2 kcal/kg = +1130 kJ/kg
enthalpy of formation: +240.2 kcal/kg = +1005 kJ/kg
oxygen balance: −59.5%
nitrogen content: 74.43%
density: 1.7 g/cm^3
lead block test: 155 cm^3/10 g
deflagration point: ca. 140 °C = 294 °F
impact sensitivity: 0.1 kp m = 1 N m

Tetrazene is classified as an initiating explosive, but its own initiation effect is weak.

It is practically insoluble in water, alcohol, ether, benzene, and carbon tetrachloride. It is prepared by the reaction between aminoguanidine salts and sodium nitrite.

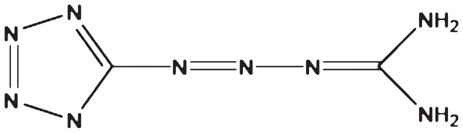
Tetrazene is an effective primer that decomposes without leaving any residue behind. It is introduced as an additive to erosion-free primers based on lead trinitroresorcinate in order to enhance the response. Its sensitivity to impact and to friction are about equal to those of mercury fulminate.

Specifications

moisture:	not more than 0.3%
reaction, water extract to universal indicator paper:	no acid indication
mechanical impurities:	none
pouring density:	about 0.3 g/cm^3
deflagration point:	not below 138 °C = 280 °F

1-[(2*E*)-3-(1*H*-Tetrazol-5-yl)triaz-2-en-1-ylidene]methanediamine

MTX-1



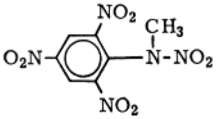
MTX-1

white crystals
empirical formula: $C_2H_5N_9$
molecular weight: 155.1 g/mol
enthalpy of formation: +383 kJ/mol = 2469 kJ/kg
deflagration point: 209 °C
impact sensitivity: 0.02 N m
electrostatic sensitivity: 3–4 mJ

MTX-1 has been suggested as a possible replacement for → *Tetrazene* (1-amino-1(1*H*-tetrazol-5-yl)-azo-guanidine hydrate) which is widely used in ordnance systems as a sensitizer of primer mixes for use in both percussion and stab applications. Tetrazene has the disadvantages of having a low thermal and hydrolytic stability compared with other components of primer mixes. Currently a need exists for a replacement for tetrazene with enhanced stability characteristics.

Tetryl

trinitro-2,4,6-phenylmethylnitramine; *Tetryl*; *tétryl*; *Tetranitromethylanilin; pyronite; tetralita*



pale yellow crystals
empirical formula: $C_7H_5N_5O_8$
molecular weight: 287.1 g/mol
energy of formation: +35.3 kcal/kg = +147.6 kJ/kg
enthalpy of formation: +16.7 kcal/kg = +69.7 kJ/kg
oxygen balance: −47.4%
nitrogen content: 24.39%
volume of explosion gases: 861 l/kg
heat of explosion
(H_2O gas): 996 kcal/kg = 4166 kJ/kg
1021 kcal/kg = 4271 kJ/kg (calculated)[47]
(H_2O liq.): 1140 kcal/kg = 4773 kJ/kg (experimental)[48]
specific energy: 123 mt/kg = 1208 kJ/kg
density: 1.73 g/cm^3
melting point: 129.5 °C = 265 °F
heat of fusion: 19.1 kcal/kg = 80 kJ/kg
lead block test: 410 cm^3/10 g
detonation velocity, confined: 7570 m/s = 24 800 ft/s
at $\rho = 1.71$ g/cm^3
deflagration point: 185 °C = 365 °F
impact sensitivity: 0.3 kp m = 3 N m
friction sensitivity: 36 kp = 353 N
pistil load: reaction
critical diameter of steel sleeve test: 6 mm

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[47] Computed by the ICT-Thermodynamic-Code.

[48] value quoted from *Brigitta M. Dobratz*, Properties of Chemical Explosives and Explosive Simulants, University of California, Livermore.

Tetryl is poisonous. It is practically insoluble in water, sparingly soluble in alcohol, ether and benzene, and is more readily soluble in acetone.

It is obtained by dissolving mono- and dimethylaniline in sulfuric acid and pouring the solution into nitric acid, with cooling.

Tetryl is a highly brisant, very powerful explosive, with a satisfactory initiating power which is used in the manufacture of primary and secondary charges for blasting caps. Owing to its relatively high melting point, it is employed pressed rather than cast.

Specifications

melting point:	not less than 128.5 °C = 270 °F
volatiles, incl. moisture:	not more than 0.10%
benzene insolubles:	not more than 0.07%
ash content:	not more than 0.03%
acidity, as HNO_3:	not more than 0.005%
alkalinity:	none

Tetrytol

A pourable mixture of 70% tetryl and 30% TNT.

Thermal Explosion

Thermische Explosion

The theory of thermal explosion describes with mathematical and physical tools the macroscopic behavior of a chemical reaction. This procedure is summarized in the technical term chemical macro kinetic. The theoretical basis is found in the theories of heat transfer and diffusion, and in the formulations of formal reaction kinetics. The theory of thermal explosion forms the basis of combustion, deflagration and detonation.

The reason why a chemical reaction runs away may be found in

- thermal explosion
- autocatalytic thermal explosion
- chain reaction.

Thermal explosion deals also with the evaluation of experiments. This leads to the determination of kinetic and thermophysical parameters of the chemical substance. The heat source may be identified according to Arrhenius, van't Hoff or others. The accurate determination of these parameters serves to make safe predictions concerning the thermal and chemical behavior of nearly any chemical substance.

The steady state theory of thermal explosion predicts critical ambient (boundary) temperatures. These temperatures are termed as auto (self)-

ignition temperatures. All temperature states below that temperature level are unconditionally stable, i.e. no runaway will occur. This state means that internal exothermic heat production is less than or equal to external heat loss. The consumption of the reactant is usually not considered because a reaction of zero order is assumed. The critical ignition temperature depends on the kinetic parameters and the thermal diffusivity of the substance and on the specific geometry of the package. This means that the critical ignition temperature is volume dependent.

The transient theory of thermal explosion adopts that the critical ignition temperature is surpassed. This leads unavoidably to a runaway chemical reaction. Consumption should be taken into account. The time-dependent theory combines the differential equations of heat transfer and of diffusion. The source term is adopted to be of Arrhenius type. But this is not compulsory. The time from the beginning of the runaway process up to the final end of explosion is called the induction time or induction period. The induction period may be thought of as consisting of two parts. The first one is the so-called extinguishing or quenching time. The second one is the pure ignition time. During this period, upset conditions govern the temperature behavior. Emergency actions have to be initiated in order to avoid explosion.

The time dependent theory also concerns the decomposition of a substance. Decomposition may happen at a temperature level that is far below the critical ignition temperature. The concentration of the reactant is decreased and the concentrations of reaction products are increased. This phenomenon of chemical stability is reliably solved with knowledge of the kinetic and thermophysical parameters of the specific substance and with the aid of the theories of Fourier and Fick.

Finally, the theory of thermal explosion is applied to problems of chemical safety in production processes. Process safety, transport and storage of dangerous goods and fire and explosion protection are considered with the aid of this theory. Transport and storage may be influenced by solar radiation.

Thermite

Originally the word Thermit was the trade name for a pyrotechnic welding process basing on the highly exothermic reaction of aluminum with iron oxide to iron and alumina. Meanwhile the expression thermite compositions has come to be used for all exothermic reactions between metal particles with granular metal oxides. Most important metal fuels are aluminum, boron, magnesium and titanium.

Typical oxidizers are barium(IV) oxide, bismuth(III) oxide, copper(II) oxide, chromium(III) oxide, iron(III) oxide, manganese(IV) oxide and tungsten(VI) oxide. Some thermites react with temperatures close to 4000 K and more. The main pyrotechnic applications are incendiaries, igniters and delay compositions.

Recently the investigation of thermite reactions was pushed on the application of nanoparticles.

Thermobaric Explosives

TBX; single-event FAE; solid fuel SAE; *explosifs thermobarique*; *Thermobare Sprengstoffe*

Type of → *FAE* with solid fuel, mainly using aluminum or magnesium. Because their reaction with atmospheric oxygen only produces solid oxides the blast wave is primarily generated by heat of combustion (thermobaric) instead of expanding explosion gases.

The advantage to classical FAE is the shorter delay between distribution of the fuel cloud and ignition of the fuel/air mixture. In this third and fourth generation of fuel air explosives there is no need for an atomization charge, which makes them a true single-event FAE.

The peak pressure of TBX is obviously lower than in typical high explosives, but with an explosion of up to 200 ms it lasts over 200 times longer. In the 1990s Russia brought a thermobaric warhead into service: the Anti-Tank Rocket RPG-7 (RPO-A) (Satan's pipe) against snipers in urban areas. A thermobaric mixture developed at NSWC Indian Head in 2001 contains high-insensitive explosive on → HMX-Aluminum- HTPB -basis called PBXIH-135 (a Type of SFAE solid fuel air explosive). PBXIH-135 is used in the laser-guided bomb BLU 118/B.

Thermodynamic Calculation of Decomposition Reactions

Important characteristics of explosives and propellants may be calculated from the chemical formula and the → *Energy of Formation* (enthalpy in the case of rocket propellants) of the explosive propellant components under consideration. The chemical formula of mixtures may be obtained by the percentage addition of the atomic numbers of the components given below, for example

composition:	8% nitroglycerine
	30% nitroglycol
	1.5% nitrocellulose
	53.5% ammonium nitrate
	2% DNT
	5% wood dust

The number of atoms of C, H, O and N per kilogram are calculated from table:

	C	H	O	N
Nitroglycerine 13.21 C; 22.02 H; 39.62 O; 13.21 N; 8% thereof:	1.057	1.762	3.170	1.057
Nitroglycol 13.15 C; 26.30 H; 39.45 O; 13.15 N; 30% thereof:	3.945	7.890	11.835	3.945
Nitrocellulose (12.5% N) 22.15 C; 27.98 H; 36.30 O; 8.92 N; 1.5% thereof:	0.332	0.420	0.545	0.134
ammonium nitrate 49.97 H, 37.48 O; 24.99 N; 53.5% thereof:	–	26.73	20.052	13.37
Dinitrotoluene 38.43 C; 32.94 H; 21.96 O; 10.98 N; 2% thereof:	0.769	0.659	0.439	0.220
Wood meal 41.7 C; 60.4 H; 27.0 O; 53.5% thereof:	2.085	3.02	1.35	–
$\sum$	8.19	40.48	37.39	18.73

As a result, the formula for one kilogram of the explosive can be written:

$$C_{8.19}H_{40.48}O_{37.39}N_{18.73}$$

The same calculation has to be made for gun and rocket propellants as the first step.

In decomposition processes (detonation in the case of high explosives or burning processes in the case of gunpowders and rocket propellants), the kilogram $C_aH_bO_cN_d$ is converted into one kilogram

$$n_1CO_2 + n_2H_2O + n_3N_2 + n_4CO + n_5H_2 + n_6NO$$

In the case of industrial explosive with a positive → *Oxygen Balance*, the occurrence of free oxygen O_2, and in the case of explosive with a very negative oxygen balance, e.g. TNT, the occurrence of elementary carbon C, have to be considered. If alkali metal salts such as $NaNO_3$ are included, the carbonates of these are taken as reaction products, e.g. Na_2CO_3. The alkaline earth components, e.g. $Ca(NO_3)_2$ are assumed to form the oxides, e.g. CaO. Chlorine will be converted into HCl; sulfur into SO_2.

Exact calculations on burning processes in rocket motors must include dissociation phenomena. This is done by computer facilities (at leading national institutes[49]), and the relevant industrial laboratories in this field are today equipped with suitable computers and programs. The following explanations are based on simplifying assumptions.

1. Conventional Performance Data of Industrial Explosives

The explosion of an industrial explosive is considered as an isochoric process, i.e. theoretically it is assumed that the explosion occurs confined in undestroyable adiabatic environment. Most formulations have a positive oxygen balance. Conventionally it is assumed that only CO_2, H_2O, N_2 and surplus O_2 are formed. The reaction equation of the example above is then

$$\begin{aligned} C_{8.19}H_{40.48}O_{37.39}N_{18.73} &= 8.19CO_2 + \frac{40.48}{2}H_2O + \frac{18.73}{2}N_2 \\ &\quad + \frac{1}{2}\left(37.39 - 2 \times 8.19 - \frac{40.48}{2}\right) O_2 \\ &= 8.19CO_2 + 20.24H_2O + 9.37N_2 + 0.39O_2 \end{aligned}$$

The real composition of the explosion gases is slightly different; CO and traces of NO are also formed.

1.1 Heat of explosion

Table 29 also lists the enthalpies and energies of formation of the explosives and their components.

In the case of isochoric explosion, the value for the energy of formation referring to constant volume has to be employed. The heat of explosion is the difference of the energies between formation of the explosive components and the reaction products, given in Tables 26 and 27.

The heat of explosion is obtained by the difference

$$-767.91 - (-1934.1) = +1934.1 - 767.91 = 1167$$

In this example, 1,167 kcal/kg or 4,886 kJ/kg (H_2O gas).

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[49] The data for the heat of explosion, the volume of explosion gases and specific energy given in this book for the individual explosives have been calculated with the aid of the ICT-Code in the Fraunhofer Institut für Chemische Technologie, 76327 Pfinztal, including consideration of the dissociation phenomena. Therefore, the values have been changed in comparison to the figures listed in the first edition of this book (computed without dissociation).

1.2 Volume of explosion gases

The number of moles of the gaseous reaction products are multiplied by 22.4 l, the volume of 1 mole ideal gas at 0 °C (32 °F) and 1 atmosphere. The number of moles in the example composition:

CO_2:	8.19
H_2O:	20.24
N_2:	9.37
O_2:	0.39
sum:	$38.19 \times 22.4 = 855$ l/kg volume of explosion gases.

Table 26 Energy of formation of the example composition.

Component	**Energy of formation (kcal/kg)**	**Thereof in (%)**	**in (kcal/kg)**
Nitroglycerine	−368, 0	8	−29.44
Nitroglycol	−358.2	30	−107.46
Nitrocellulose (12,5% N)	−605.6	1.5	−9.08
Ammonium nitrate	−1058	53.5	−566.03
DNT	−70	2	−1.40
Wood dust	−1090	5	−54.5
			−767.91

Table 27 Energy of formation of the reaction products.

Component	**Energy of formation (kcal/mol)**	**Mole number**	**Portion of component (kcal/kg)**
CO_2	−94.05	8.19	−770.27
H_2O (vapor)[a)]	−57.50	20.24	−1163.80
			−1934.1

a) Conventionally, the computed figure for the heat of explosion for industrial explosives is given based on H_2O vapor as the reaction product. The values for the individual explosive chemicals (now calculated by the ICT-Code are based on H_2O liquid). They are directly comparable with results obtained by calorimetric measurements.

1.3 Explosion temperature

The heat of explosion raises the reaction products to the explosion temperature. Table 28 gives the internal energies of the reaction products in relation to the temperature. The best way to calculate the explosion temperature is to assume two temperature values and to sum up the internal energies for the reaction product multiplied by their corresponding mole number. Two calorific values are obtained, of which one may be slightly higher than the calculated heat of explosion and the other slightly lower. The explosion temperature is found by interpolation between these two values.

Table 28 For the example composition at: 3600 and 3700 K.

	3600 K	**Mole number**	**Product (kcal)**	**3700 K**	**Product (kcal)**
CO_2	38.76	8.19	317.4	40.10	328.4
H_2O	30.50	20.24	617.3	31.63	640.2
N_2	20.74	9.37	194.3	21.45	201.0
O_2	22.37	0.39	8.7	23.15	9.0
		38.19	1138		1178

The interpolated temperature value for 1167 kcal/kg is 3670 K.

For industrial nitroglycerine-ammonium nitrate explosives, the following estimated temperature values can be recommended:

Heat of explosion found (kcal/kg)	**Lower value (K)**	**Upper value (K)**
900	2900	3000
950	3000	3100
1000	3100	3200
1050	3300	3400
1100	3400	3500
1150	3500	3600
1200	3700	3800

1.4 Specific energy

The concept of specific energy can be explained as follows. When we imagine the reaction of an explosion to proceed without volume expansion and without heat evolution, it is possible to calculate a theoretical thermodynamic value of the pressure, which is different from the shock-wave pressure (see → *Detonation*); if this pressure is now multiplied by the volume of the explosive, we obtain an energy value, the specific energy, which is the best theoretically calculable parameter for the comparison of the → *Strengths* of explosives. This value for explosives is conventionally given in meter-tons per kilogram.

The specific energy results from the equation

$$f = nRT_{\text{ex}}$$

f: specific energy, n: number of gaseous moles, T_{ex}: detonation temperature (in K), R: universal gas constant (for ideal gases).

If f is wanted in meter-ton units, R[50] has the value 8.478×10^{-4}.

The values for the considered example composition are $n = 38.19$, $T_{\text{ex}} = 3670\,\text{K}$, $f = 38.19 \times 8.478 \times 10^{-4} \cdot 3670 = 118.8\,\text{mt/kg}$.

For the significance of specific energy as a performance value see → *Strength*.

1.5 Energy level

Because higher loading densities involve higher energy concentration, the concept of energy level was created; it means the specific energy per unit volume instead of per unit weight. The energy level is

$$l = \rho \cdot f$$

l: energy level in mt/l, ρ: density in g/cm^3, f: specific energy in mt/kg.

Since the example composition will have a gelatinous consistency, p may be assumed as $1.5\,\text{g/cm}^3$. The energy level is then $l = 1.5 \times 118.8 = 178.2\,\text{mt/l}$.

1.6 Oxygen balance

See → *Oxygen Balance*

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[50] For the values of *R* in different dimensions, see the conversion tables on the back fly leaf.

2. Explosive and Propellant Composition with a Negative Oxygen Balance

Calculation of gunpowders

The decomposition reactions of both detonation and powder combustion are assumed to be isochoric, i.e. the volume is considered to be constant, as above for the explosion of industrial explosives.

The first step is also the sum formula

$$C_aH_bO_cN_d$$

as described above, but now

$$c < 2a + \frac{1}{2}b$$

The mol numbers n_1, n_2, etc. cannot be directly assumed as in the case of positive balanced compositions. More different reaction products must be considered, e.g.

$$C_aH_bO_cN_d = n_1CO_2 + n_2H_2O + n_3N_2 + n_4CO + n_5H_2 + n_6NO$$

CH_4 and elementary carbon may also be formed. If the initial composition contains Cl, Na, Ca, K, and S atoms (e.g. in black powder), the formation of HCl, Na_2O, Na_2CO_3, K_2O, K_2CO_3, CaO and SO_2 must be included. Further, the occurrence of dissociated atoms and radicals must be assumed.

The mole numbers n_1, n_2, etc., must meet a set of conditions: first, the stoichiometric relations

$$a = n_1 + 2n_5 \qquad (18)$$

(carbon-containing moles)

$$h = 2n_2 + 2n_5 \qquad (19)$$

(hydrogen-containing moles)

$$c = 2n_1 + n_2 + n_4 + n_6 \qquad (20)$$

(oxygen-containing moles)

$$d = 2n_3 + n_6 \qquad (21)$$

(nitrogen-containing moles); second, the mutual equilibrium reactions of the decomposition products: the water gas reaction

$$H_2O + CO \rightarrow CO_2 + H_2$$

The equilibrium is influenced by temperature and is described by the equation

$$K_1 = \frac{[CO][H_2O]}{[H_2][CO_2]} \tag{22}$$

K_1: equilibrium constant.

$[CO_2]$, $[H_2]$, $[H_2O]$ and $[CO]$ represent the partial pressures of the four gases. The total mole number n is not altered by the water gas reaction. K_1, is therefore independent of the total pressure p, but depends on the temperature (→ *Table* 32). Equation (22) can be written as

$$K_1 = \frac{n_2 \cdot n_4}{n_1 \cdot n_5} \tag{23}$$

The reaction for NO formation must also be considered

$$\frac{1}{2}N_2 + CO_2 \rightarrow CO + NO$$

with the equilibrium equation

$$K_2 = \frac{[CO] \cdot [NO]}{[N_2]^{1/2} \cdot [CO_2]} = \frac{\frac{p}{n}n_4 \cdot \frac{p}{n}n_6}{\left(\frac{p}{n}\right)^{1/2} \cdot n_3^{1/2} \cdot \frac{p}{n}n_1} \quad \text{or}$$

$$K_2 = \sqrt{\frac{p}{n}}\frac{n_4 \cdot n_6}{\sqrt{n_3 \cdot n_1}} \tag{24}$$

K_2: equilibrium constant, p: total pressure; $p/n - n_1$, etc. the partial pressures, n: total number of moles.

Because NO formation involves an alteration of n, the equilibrium constant K_2 depends not only on the temperature, but also on the total pressure p.

For the calculation of the six unknown mole numbers $n_1, \ldots, n_6$, there are six equations. Alteration of the mole numbers cause alteration of the values for the reaction heat, the reaction temperature, the reaction pressure, and hence the constants K_1 and K_2. Calculations without the aid of a computer must assume various reaction temperatures to solve the equation system, until the values for the reaction heat as a difference of the energies of formation and the internal energy of the reaction products are the same (as shown above for the detonation of industrial explosives). This is a long trial and error calculation; therefore the use of computer programs is much more convenient.

For low caloric propellants and for highly negative balanced explosives, such as TNT, the formation of elementary carbon must be assumed (Boudouard equilibrium):

$$CO_2 + C \rightleftharpoons 2CO$$

with the equilibrium equation

$$K_3 = \frac{[CO]^2}{[CO_2]} \qquad (25)$$

Explosion fumes with a dark color indicate the formation of carbon. The calculation becomes more complicated if dissociation processes are taken into consideration (high-caloric gunpowders; rocket propellants).

In the computer operation, the unknown mole numbers are varied by stepwise iteration calculations, until all equation conditions are satisfied. The following results are obtained:

- heat of explosion
- temperature of explosion
- average molecular weight of the gaseous explosion products
- total mole number
- specific energy (force)
- composition of the explosion gases
- specific heat ratio c_p/c_v
- covolume
- etc.

The basis data for internal ballistic calculations are thus obtained (see also → *Ballistic Bomb*; → *Burning Rate*). For example, for the calculation of a double-base gunpowder(51):

composition
nitrocellulose (13.25% N): 57.23%
nitroglycerine: 40.04%
potassium nitrate: 1.49%
Centralite I: 0.74%
ethanol (solvent rest): 0.50%

Enthalpy of formation of the composition:
−2149.6 kJ/kg = −513.8 kcal/kg.

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(51) Calculated by the ICT-Fortran program.

The results (loading density assumed: 210 kg/m^3)

sum formula for 1 kg powder: $C_{18.14}H_{24.88}O_{37.41}N_{10.91}K_{0.015}$

temperature of explosion:	3841 K
pressure:	305.9 MPa = 3059 bar
average molecular weight of gases:	27.28 g/mol
total mole number:	36.66 mol/kg
specific energy (force):	1.17×10^6 N m/kg = 1170 kJ/kg
kappa ($\kappa = c_p/c_v$):	1.210
covolume:	9.37×10^{-4} m^3/kg

The composition of the reaction products (mol %):

28.63%	H_2O	
28.39%	CO	
21.07%	CO_2	
4.13%	H_2	
14.63%	N_2	
0.21%	O_2	
0.48%	NO	
0.37%	KOH	
1.50%	OH	dissociated atoms and radicals
0.42%	H	
0.09%	O	
0.02%	K	

3. *Rocket Propellants*

Raketentreibstoffe; propellants de roquette

The calculation of the performance data of rocket propellants is carried out in the same manner as shown above for gunpowders, but the burning process in the rocket chamber proceeds at constant pressure instead of constant volume. For the evaluation of the heat of reaction, the difference of the enthalpies of formation instead of the energies must now be used. For the internal heat capacities, the corresponding enthalpy values are listed in Table 34 below (instead of the energy values in Table 28); they are based on the average specific heats c_p at constant pressure instead of the c_v values. The first step is to calculate the reaction temperature T_c and the composition of the reaction gases (mole numbers n_1, etc.). The second step is to evaluate the same for the gas state at the nozzle exit (transition from the chamber pressure p_c to the nozzle exit pressure p_e e.g. the atmospheric pressure). The basic assumption is that this transition is isentropic, i.e. that the entropy values of the state under chamber pressure and at the exit are the same. This means that the thermodynamic transition gives the maximum possible output of kinetic energy (acceleration of the rocket mass).

The calculation method begins with the assumption of the temperature of the exit gases, e.g. $T_e = 500$ K. The transition from the thermodynamical state in the chamber into the state at the nozzle exit is assumed to be instantaneous, i.e. the composition of the gases remains unchanged (frozen equilibria). The entropy of the exit gases at the assumed temperature T_e is assumed to be the same as the entropy of the gases in the chamber (known by calculation). The assumed value T_a is raised until both entropy values are equal. Since both states are known, the corresponding enthalpy values can be calculated. Their difference is the source of the kinetic energy of the rocket (half the mass × square root of the velocity). The → *Specific Impulse* (mass × velocity) can be calculated according to the following equation (the same as shown at → *Specific Impulse*):

$$I_s = \sqrt{2J(H_c - H_e)} \quad \text{N s/kg}$$

or

$$I_{\text{sfroz}} = 92.507\sqrt{H_c - H_e}$$

J: mechanical heat equivalent, I_{sfroz}: specific impulse for frozen equilibrium (N s/kg), H_c: enthalpy of the burnt gases in the chamber (kcal/kg), H_e: enthalpy of the gases at the nozzle exit (kcal/kg), T_c: gas temperature in the chamber (K), T_e: gas temperature at the nozzle exit with frozen equilibrium (K).

The computer program also allows calculation of shifting (not frozen) equilibria by stepwise iteration operations.

The following parameters can also be calculated with computer facilities:

- chamber temperature (adiabatic flame temperature);
- temperature of exit gas with frozen equilibrium;
- composition of exit gas with shifting equilibrium;
- temperature of the burnt gases in the chamber and at the nozzle exit;
- average molecular weight of the burnt gases in the chamber and at the nozzle exit;
- total mole number of the burnt gases in the chamber and at the nozzle exit;
- specific impulse at frozen and with shifting equilibrium;
- ratio of specific heats c_p/c_v.

An example for the calculation of a double-base rocket propellant:

Composition:
nitrocellulose 52.15% (13.25% N)
nitroglycerine 43.54%
diethylphthalate 3.29%
Centralit I 1.02%
sum formula for 1 kg propellant: $C_{19.25}H_{25.96}O_{36.99}N_{10.76}$
chamber pressure: 7.0 MPa (1015 p.s.i.)

Results of the computer calculation[52]:

temperature in the rocket chamber: 3075 K
temperature at the nozzle exit: 1392 K (frozen equilibrium)
temperature at the nozzle exit: 1491 K (equilibrium flow)
average molecular weight: 26.33 g/mol
total mole number: 37.98 mol/kg
kappa ($\kappa = c_p/c_v$): 1.216
specific impulse for frozen equilibrium: 2397 N s/kg
specific impulse for shifting equilibrium: 2436 N s/kg

For more detailed calculations (e.g. if the presence of free carbon must be assumed), the reader is referred to *M.A. Cook:* The Science of High Explosives, Chapman & Hall, London 1958 and, by the same author: The Science of Industrial Explosives, copyright 1974 by IR-Eco Chemicals, Salt Lake City, USA. They contain basic data on heat capacities and equilibria constants concerned, as well as computing programs for hand and machine calculations.

The data for the following Tables have been taken from this book. The data for enthalpies and energies of formation are taken from H. Bathelt, F. Volk, M. Weindel, ICT-Database of Thermochemical Values, Sixth update (2001), Fraunhofer-Institut für Chemische Technologie, D-76327 Pfinztal-Berghausen.

Thrust

Schub; *poussée*

In rocket technology, the recoil force produced by rearward gas discharge. It is expressed in tons, kiloponds or newtons, and is one of the most important characteristic rocket parameters. The initial weight of a rocket must remain within a certain limit in relation to the thrust. The launching thrust is usually higher than the cruising thrust; this can be achieved with the use of → *Booster*.

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[52] Calculated by the ICT-Thermodynamic-Code.

Table 29 Enthalpy and energy of formation of explosive and propellant components and their number of atoms per kg. Reference temperature: 298.15 K = 25 °C = 77 °F; reference state of carbon: as graphite. (1) primary explosive, (2) secondary explosive, (3) tertiary explosive, (4) propellant component, (5) oxidizer, (6) fuel, (7) stabilizer, (8) gelatinizer, (9) burning moderator, (10) polymer binder, (11) prepolymer, (12) hardener, (13) thickener, (14) anticaking agent, (15) anti acid, (16) component of permitted explosives, (17) slurry component.

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram					Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N		
Arkadit I	$C_{13}H_{12}ON_2$	−138.2	−578	−117.3	−490	61.25	56.54	4.71	9.42		(7)
Arkadit II	$C_{14}H_{14}ON_2$	−112.7	−472	−90.5	−379	61.86	61.86	4.42	8.84		(7); (8)
Arkadit III	$C_{15}H_{16}ON_2$	−151.9	−636	−128.5	−538	62.42	66.58	4.16	8.32		(7); (8)
Aluminum	Al	–	–	–	–	–	–	–	–	Al: 37.08	(6); (17)
Ammonium chloride	H_4NCl	−1405	−5878	−1372	−5739	–	74.77	–	18.69	Cl: 18.69	(16)
Ammoniumdinitramide	$H_4N_4O_4$	−288.58	−1207.4	−259.96	−1086.6	–	32.24	32.24	32.24		(4); (5)
Ammonium nitrate	$H_4O_3N_2$	−1092	−4567	−1058	−4428	–	49.97	37.48	24.99		(3); (5); (16); (17)
Ammonium oxalate · H_2O	$C_2H_{10}O_5N_2$	−2397	−10031	−2362	−9883	14.07	70.36	35.18	14.07		(6); (16)
Ammonium perchlorate	H_4O_4NCl	−602	−2517	−577	−2412	–	34.04	34.04	8.51	Cl: 8.51	(3); (5)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram					Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N		
Barium nitrate	O_6N_2Ba	−907.3	−3796	−898.2	−3758	–	–	22.96	7.65	Ba: 3.83	(5)
Calcium carbonate	CO_3Ca	−2882	−12059	−2873	−12022	10.00	–	30.00	–	Ca: 10.00	(15)
Calcium nitrate	O_6N_2Ca	−1367	−5718	−1352	−5657	–	–	36.56	12.19	Ca: 6.09	(5); (17)
Calcium stearate	$C_{36}H_{70}O_4Ca$	−1092	−4567	−1055	−4416	59.30	115.31	6.59	–	Ca: 1.65	(6); (14)
Camphor	$C_{10}H_{16}O$	−513	−2146	−480	−2008	65.69	105.10	6.57	–		(8)
Centralite I	$C_{17}H_{20}ON_2$	−93.5	−391.5	−68.2	−285.6	63.34	74.52	3.73	7.45		(7); (8)
Centralite II	$C_{15}H_{16}ON_2$	−60.8	−254	−37.3	−156	62.42	66.58	4.16	8.32		(7); (8)
Centralite III	$C_{16}H_{18}ON_2$	−119.1	−499	−94.7	−396	62.90	70.76	3.93	7.86		(7); (8)
Coal (pit coal dust)		−16	−67	0	0	72.08	49.90	5.24	–		(6)
Diamyl phthalate	$C_{18}H_{26}O_4$	−721	−3017	−692	−2895	58.75	84.85	13.06	–		(8)
Dibutyl phthalate	$C_{18}H_{22}O_4$	−723	−3027	−696	−1913	57.47	79.02	14.37	–		(8)
Diethyleneglycol dinitrate	$C_4H_8O_7N_2$	−532	−2227	−507	−2120	20.40	40.79	35.69	10.20		(4)
Dimethylhydrazine	$C_2H_8N_2$	+198	+828	+247	+1035	33.28	133.11	–	33.28		(4)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram					Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N		
2.4-Dinitrotoluene	$C_7H_8O_4N_2$	−89.5	−374.5	−70.0	−292.8	38.43	32.94	21.96	10.98		(4); (6)
2.6-Dinitrotoluene		−57.7	−241.2	−38.1	−159.5						(4); (6)
Diphenylamine	$C_{12}H_{11}N$	+183.6	+768.2	+204.6	+856.0	70.92	65.01	–	5.91		(7)
Diphenylurethane	$C_{15}H_{15}O_2N$	−278.1	−1164	−256.0	−1071	62.16	62.16	8.29	4.14		(7); (8)
Ethriol trinitrate	$C_5H_{11}O_9N_3$	−426	−1783	−401	−1678	22.30	40.88	33.44	11.15		(4)
Ethylenediamine dinitrate	$C_2H_{10}O_6N_4$	−839.2	−3511	−807.4	−3378	10.75	53.73	32.24	21.49		(2)
Ferrocene	$C_{10}H_{10}Fe$	+199	+833	+215	+899	53.76	53.76	–	–	Fe:	
Glycidyl azide polymer	$C_3H_5ON_3$	+340.1	+1423	+366.9	+1535	30.28	50.46	10.09	30.28		(4); (10)
										5.38	(9)
Glycol	$C_2H_6O_2$	−1752	−7336	−1714	−7177	32.22	96.66	32.22	–		(6)
Guanidine nitrate	$CH_6O_3N_4$	−758	−3170	−726.1	−3038	8.19	49.14	24.57	32.76		(4)
Guar gum		−1671	−7000	−1648	−6900	37.26	55.89	31.05	–		(13)
Hexanitrodiphenylamine	$C_{12}H_5O_{12}N_7$	+22.5	+94.3	+38.7	+162	27.32	11.38	27.32	15.94		(2)
Hexanitrohexaaza-isowurtzitane (CL-20)	$C_6H_6N_{12}O_{12}$	+299.0	+920.5	+240.3	+1005.3	13.69	13.69	27.39	27.39		(2); (4)
Hexogen (RDX)	$C_3H_6O_6N_6$	+72	+301.4	+96.0	+401.8	13.50	27.01	27.01	17.01		(2)
Hydrazine	H_4N_2	+377.5	+1580	+433.1	+1812	–	124.80	–	62.40		(6)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram					Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N		
Hydrazine nitrate	$H_5O_3N_3$	−620.7	−2597	−586.4	−2453	–	52.60	31.56	31.56		(2); (4)
Iron acetylacetonate	$C_{15}H_{21}O_6Fe$	−859	−3593	−836	−3498	42.47	59.46	16.99	–		(9)
Kerosene		−540	−2260	−500	−2100	71.90	135.42	–	–		(6)
Lead acetylsalicylate · H_2O	$C_{18}H_{16}O_9Pb$	−823	−3444	−810	−3391	30.85	27.42	15.42	–	Fb: 1.71	(9)
Lead azide	N_6Pb	+391.4	+1638	+397.5	+1663	–	–	–	20.60	Pb: 3.43	(1)
Lead ethylhexanoate	$C_{16}H_{30}O_4Pb$	−724	−3027	−703	−2940	32.41	60.78	8.10	–	Pb: 2.03	(9)
Lead nitrate	O_6N_2Pb	−326.1	−1364	−318.9	−1334	–	–	18.11	6.04	Fb: 3.02	(5)
Lead styphnate	$C_6H_3O_9N_3Pb$	−427.1	−1787	−417.6	−1747	12.81	6.41	19.22	6.41	Pb: 2.13	(1)
Magnesium carbonate	CO_3Mg	−3106	−12994	−3095	−12950	11.86	–	35.60	–	Mg: 11.86	(14); (15)
Mannitol hexanitrate	$C_6H_8O_{18}N_6$	−357.2	−1494	−336.2	−1407	13.27	17.70	39.82	13.27		(2)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram				Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N	
Methylamine nitrate (MAN)	$CH_6O_3N_2$	−896	−3748	−862	−3604	10.63	63.78	31.89	21.26	(17)
Metriol trinitrate	$C_5H_9O_9N_3$	−398.2	−1666	−373.8	−1564	19.60	35.27	35.27	11.76	(4)
Nitroaminoguanidine	$CH_5N_5O_2$	+44.3	+185.5	+74.2	+310.2	8.40	41.99	16.79	41.99	(4)
Nitrocellulose, 13.3% N		−577.4	−2416	−556.1	−2327	21.10	25.83	36.66	9.50	(4)
Nitrocellulose, 13.0% N		−596.1	−2494	−574.6	−2404	21.55	26.64	36.52	9.28	(4)
Nitrocellulose, 12.5% N		−627.2	−2624	−605.6	−2534	22.15	27.98	36.30	8.92	(4)
Nitrocellulose, 12.0% N		−658.4	−2755	−636.5	−2663	22.74	29.33	36.08	8.57	(4)
Nitrocellulose, 11.5% N		−689.6	−2885	−667.4	−2793	23.33	30.68	35.86	8.21	(4)
Nitrocellulose, 11.0% N		−720.7	−3015	−698.4	−2922	23.94	32.17	35.65	7.84	(4)
Nitrodiphenylamine	$C_{12}H_{10}O_2N_2$	+88.13	+369	+107.5	+450	56.01	46.68	9.34	9.34	(4)
Nitroglycerine	$C_3H_5O_9N_3$	−392.0	−1633	−369.7	−1540	13.21	22.02	39.62	13.21	(2); (4)
Nitroglycol	$C_2H_4O_6N_2$	−381.6	−1596	−358.2	−1499	13.15	26.30	39.45	13.15	(2)
Nitroguanidine (picrite)	$CH_4O_2N_4$	−213.3	−893.0	−184.9	−773	9.61	38.42	19.21	38.42	(4)
Nitromethane	CH_3O_2N	−442.8	−1853	−413.7	−1731	16.39	49.17	32.70	16.39	
Nitrotriazolone (NTO)	$C_2H_2N_4O_3$	−185.14	−774.60	−164.69	−689.10	15.37	15.37	23.06	30.75	(2)
Nitrourea	$CH_3O_3N_3$	−642.5	−2688	−617.2	−2582	9.52	28.55	28.55	28.55	
Octogen (HMX)	$C_4H_8O_8N_8$	+60.5	+253.3	+84.5	+353.6	13.50	27.01	27.01	27.01	(2)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram					Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N		
Paraffin (solid)		−540	−2261	−500	−2094	71.0	148	–	–		(6)
PETN (Nitropenta)	$C_5H_8O_{12}N_4$	−407.4	−1705	−385.0	−1611	15.81	25.30	37.95	12.65		(2)
Petroleum		−40	−1842	−400	−1675	70.5	140	–	–		(6)
Picric acid	$C_6H_3O_7N_3$	−259.3	−1085	−242.4	−1015	26.20	13.10	30.55	13.10		(2)
Polybutadiene, carboxy terminated	$(C_4H_6)_{100}C_2H_2O_4$	−140	−586	−107	−448	73.10	109.65	0.73	–		(6); (10)
Polyisobutylene	$(CH_2)_n$	−374	−1570	−331	−1386	71.29	142.58	–	–		(10)
Polypropyleneglycol	$(C_3H_5O)_nH_2O$	−888.1	−3718	−852.9	−3571	51.19	103.37	17.56	–		(11)
Polyvinyl nitrate	$(C_2H_3O_3N)_n$	−275.4	−1152	−252.1	−1055	22.46	33.68	33.68	11.23		(4) (values for % N = 15.73)
Potassium nitrate	O_3NK	−1169	−4891	−1157	−4841	–	−29.67	9.89		K: 9.89	(5); (16)
n-Propyl nitrate	$C_3H_7O_3N$	−487.8	−2041	−436.8	−1911	28.55	66.63	28.55	9.52		(4)
Sodium hydrogen carbonate	CHO_3Na	−2705	−11318	−2691	−11259	11.90	11.90	35.71	–	Na: 11.90	(15)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram					Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N		
Sodium nitrate	O_3NNa	−1315	−5506	−1301	−5447	–	−35.29	11.76	Na. 11.76		(5); (16)
Tetranitromethane	CN_4O_8	+46.9	+196.4	+65.0	+272.1	5.10	–	40.81	20.40		
Tetryl	$C_7H_5O_8N_5$	+16.7	+67.9	+35.3	+147.6	24.40	17.40	27.86	17.40		(2)
TNT (trinitrotoluene)	$C_7H_5O_6N_3$	−70.6	−295.3	−52.4	−219.0	30.82	22.01	26.40	13.20		(2)
Toluene diisocyanate (TDI)	$C_9H_6O_2N_2$	−179.7	−752	−162.7	−681	51.71	34.47	11.49	11.49		(12)
Triaminoguanidine nitrate	$CH_9O_3N_7$	−68.8	−287.9	−35.2	−147.2	5.98	53.86	17.95	41.89		(4)
Triaminotrinitrobenzene	$C_6H_6O_6N_6$	−129.4	−541.3	−108.7	−455.0	23.25	23.25	23.25	23.25		(2); (4)
Trimethylamine nitrate	$C_3H_{10}O_3N_2$	−673.1	−2816	−636.7	−2664	24.57	81.90	24.57	16.38		(17)
1,3,3-Trinitroazetidine (TNAZ)	$C_3H_4O_6N_4$	+45.29	+189.50	+66.84	+279.77	15.62	20.82	31.23	20.82		(2)
Trinitrobenzene	$C_6H_3O_6N_3$	−48.8	−204	−32.1	−135	28.15	14.08	28.15	14.08		(2)
Trinitrochlorobenzene	$C_6H_2O_6N_3Cl$	+25.9	+108	+40.4	+169	24.24	8.08	24.24	12.12	Cl: 4.04	(2)
Trinitropyridine	$C_5H_2O_6N_4$	+88.0	+368.5	+104.6	+437.9	23.35	9.34	28.03	18.68		(2)
Trinitropyridine-1-oxide	$C_5H_2O_7N_4$	+102.5	+428.9	+119.2	+499.1	21.73	8.69	30.42	17.38		(2)

Table 29 (Continued).

Component	Empirical formula	Enthalpy of formation		Energy of formation		Number of atoms per kilogram				Uses
		(kcal/kg)	(kJ/kg)	(kcal/kg)	(kJ/kg)	C	H	O	N	
Trinitroresorcinol (styphnic acid)	$C_6H_3O_8N_3$	−510.0	−2134	−493.1	−2063	24.48	12.24	32.64	12.24	lead salt
Urea	CH_4ON_2	−1326	−5548	−1291	−5403	16.65	66.60	16.65	33.30	(5); (17)
Urea nitrate	$CH_5O_4N_3$	−1093	−4573	−1064	−4452	8.12	40.62	32.49	24.37	
Water	H_2O	−3792	−15880	−3743	−15670	–	111.01	55.51	–	(17)
Wood dust		−1116	−4672	−1090	−4564	41.7	60.4	27.4	–	(6)

Table 30 Enthalpy and energy of formation of gaseous reaction products.

Product	Formula	Molecular weight	Enthalpy of formation (kcal/mol)	Enthalpy of formation (kJ/mol)	Energy of formation (kcal/mol)	Energy of formation (kJ/mol)
Carbon monoxide	CO	28.01	−26.42	−110.6	−26.72	−111.9
Carbon dioxide	CO_2	44.01	−94.05	−393.8	−94.05	−393.8
Water (vapor)	H_2O	18.02	−57.80	−242.0	−57.50	−240.8
Water (liquid)			−68.32	−286.1	−67.43	−282.3
Nitrogen monoxide	NO	30.01	+21.57	+90.3	+21.57	+90.3
Nitrogen dioxide (gas)	NO_2	46.01	+7.93	+33.2	+8.23	+34.5
Nitrogen	N_2	28.02	±0	±0	±0	±0
Oxygen	O_2	32.00	±0	±0	±0	±0
Hydrogen chloride	HCl	36.47	−22.06	−92.4	−22.06	−92.4

Table 31 Moles per kilogram of inert components.

Component	Formula	(mol/kg)
Aluminum oxide	Al_2O_3	9.808
Barium sulfate	$BaSO_4$	4.284
Calcium carbonate	$CaCO_3$	9.991
Guhr (silicic acid)	SiO_2	16.65
Iron(II) oxide	FeO_3	6.262
Magnesium sulfate	$MgSO_4$	11.858
Potassium chloride	KCl	13.413
Sodium chloride	$NaCl$	17.11
Talc	$Mg_3(Si_4O_{10})(OH)_2$	2.636 (21 atoms)
Water (slurry component)[a]	H_2O	55.509

[a] Heat of evaporation of H_2O: 555.5 kcal/kg = 2325.9 kJ/kg = 10.01 kcal/mol = 41.91 kJ/mol.

Table 32 Data of solid explosion reaction products.

Product	Formula	Molecular weight (g/mol)	Energy of formation (kcal/mol)	Molar heat of fusion (kcal/mol)	Number of atoms in molecules	Molar heat of sublimation (kcal/mol)
Sodium chloride	NaCl	58.44	−97.98	2	6.73	50.3
Potassium chloride	KCl	74.56	−104.03	2	6.28	48.1
Magnesium chloride	$MgCl_2$	95.23	−152.68	3	10.3	
Sodium carbonate	Na_2CO_3	105.99	−269.4	6	8.0	
Potassium carbonate	K_2CO_3	138.21	−274.0	6	7.8	
Calcium carbonate	$CaCO_3$	100.09	−287.6	5		
Magnesium carbonate	$MgCO_3$	84.33	−261.0	5		
Barium carbonate	$BaCO_3$	197.37	−289.8	5		
Lead carbonate	$PbCO_3$	267.22	−166.2	5		
Aluminum oxide	Al_2O_3	101.96	−399.6	5	28.3	115.7 (at 2480 K)
Iron(III) oxide	Fe_2O_3	159.70	−196.1	5	–	
Lead	Pb	207.21	±0	1	1.21	46.34
Mercury	Hg	200.61	±0	1	–	14.0

Table 33 Molar internal energies of reaction products $\bar{c}_v (T - T_0)$; $T_0 = 25\,°\mathrm{C} \approx 300\,\mathrm{K}$.

Temper-ature (K)	CO		CO_2		H_2O		H_2		O_2		N_2		NO		C[a]	
	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)
1000	3.65	15.28	6.34	26.55	4.64	19.43	3.41	14.28	4.33	18.13	3.59	15.03	3.77	15.78	3.31	13.86
1200	4.86	20.35	8.59	35.97	6.26	26.21	4.47	18.72	5.62	23.53	4.78	24.01	5.02	21.02	4.33	18.13
1400	6.11	25.35	10.91	45.68	7.99	33.45	5.58	23.36	6.93	29.02	6.01	25.16	6.30	26.38	5.32	22.27
1500	6.75	28.26	12.10	50.66	8.89	37.22	6.14	25.71	7.58	31.74	6.64	27.80	6.95	29.10	5.88	24.62
1600	7.39	30.94	13.31	55.73	9.81	41.07	6.72	28.14	8.22	34.42	7.28	30.48	7.61	31.86	6.38	28.71
1700	8.05	33.71	14.51	60.75	10.75	45.01	7.31	30.61	8.67	36.30	7.92	33.16	8.28	34.67	6.92	28.97
1800	8.69	36.39	15.77	66.03	11.52	48.23	8.13	34.04	9.61	40.24	8.57	35.88	9.02	37.77	7.48	31.32
1900	9.34	39.11	16.94	70.92	12.43	52.04	8.64	36.17	10.17	42.58	9.20	38.52	9.66	40.44	7.95	33.27
2000	19.99	41.83	18.13	75.91	13.38	56.02	9.17	38.39	10.77	45.09	9.84	41.20	10.31	43.16	8.46	35.42
2100	10.64	44.55	19.33	80.93	14.35	60.08	9.74	40.78	11.39	47.68	10.49	43.92	10.97	45.93	8.94	37.43
2200	11.31	47.35	20.56	86.08	15.34	64.22	10.32	43.20	12.04	50.41	11.15	46.68	11.64	48.73	9.53	39.90
2300	11.98	50.16	21.81	91.31	16.36	68.49	10.92	45.72	12.71	53.21	11.81	49.44	12.31	51.54	10.10	42.28
2400	12.65	52.97	23.07	96.59	17.39	72.81	11.54	48.31	13.39	56.06	12.48	52.25	12.99	54.38	10.68	44.71
2500	13.33	55.81	24.34	101.91	18.43	77.16	12.17	50.95	14.09	58.99	13.15	55.05	13.67	57.23	11.28	47.22
2600	14.02	58.70	25.61	107.22	19.49	81.60	12.81	53.63	14.80	61.96	13.83	57.90	14.36	60.12	11.88	49.74
2700	14.70	61.55	26.90	112.63	20.56	86.08	13.47	56.39	15.52	64.98	14.51	60.75	15.06	63.05	12.50	52.32
2800	15.39	64.44	28.20	118.07	21.63	90.56	14.13	49.16	16.25	68.03	15.20	63.64	15.75	65.94	13.12	54.93
2900	16.08	67.33	29.50	123.51	22.72	95.12	14.80	61.96	17.00	71.17	15.88	66.48	16.45	68.87	13.75	57.57
3000	16.78	70.26	30.81	129.00	23.81	99.69	15.47	64.77	17.75	74.31	16.57	69.37	17.15	71.80	14.30	59.87
3100	17.47	73.15	32.12	134.48	24.91	104.29	16.16	67.66	18.50	77.45	17.26	72.26	17.85	74.73	15.04	62.97
3200	18.17	76.08	33.44	140.01	26.02	108.94	16.84	70.50	19.26	80.64	17.96	75.19	18.56	77.71	15.69	65.69

a) If carbon separation occurs.

Table 33 (Continued).

Temper-ature (K)	CO		CO_2		H_2O		H_2		O_2		N_2		NO		C[a]	
	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)
3300	18.87	79.01	34.77	145.58	27.13	113.59	17.54	73.43	20.03	83.86	18.65	78.08	19.26	80.64	16.35	68.45
3400	19.57	81.94	36.10	151.15	28.25	118.28	18.23	76.32	20.80	87.08	19.35	81.01	19.97	83.61	17.01	71.22
3500	20.27	84.87	37.43	156.71	29.37	122.97	18.93	79.25	21.58	90.35	20.05	83.94	20.68	86.58	17.67	73.98
3600	20.97	87.86	38.76	162.28	30.50	127.70	19.64	82.23	22.37	93.66	20.74	86.83	21.39	89.55	18.34	76.78
3700	21.67	90.73	40.10	167.89	31.63	132.43	20.35	85.20	23.15	96.92	21.45	89.81	22.11	92.51	19.01	79.59
3800	22.38	93.71	41.44	173.50	32.76	137.16	21.06	88.17	23.94	100.23	22.15	92.74	22.82	95.54	19.69	82.44
3900	23.08	96.64	42.78	179.11	33.89	141.89	21.78	91.19	24.73	103.54	22.85	95.67	23.53	98.52	20.36	85.24
4000	23.79	99.61	44.13	184.77	35.03	146.67	22.49	94.16	25.53	106.89	23.55	98.60	24.25	101.53	21.04	88.09
4100	24.50	102.58	45.47	190.38	36.17	151.44	23.21	97.18	26.33	110.24	24.26	101.57	24.97	104.54	21.73	90.98
4200	25.20	105.51	46.82	196.03	37.32	156.25	23.94	100.23	27.13	113.59	24.96	104.50	25.68	107.52	22.41	93.83
4300	25.91	108.49	48.17	201.68	38.46	161.03	24.66	103.25	27.93	116.94	25.67	107.48	26.40	110.53	23.10	96.71
4400	26.62	111.46	49.52	207.34	39.61	165.84	25.39	106.30	28.74	120.33	26.37	110.41	27.12	113.55	23.79	99.60
4500	27.33	114.43	50.88	213.03	40.76	170.66	26.12	109.36	29.54	123.68	27.08	113.38	27.84	116.56	24.49	102.53
4600	28.04	117.40	52.23	218.68	41.91	175.47	26.85	112.42	30.35	127.07	27.79	116.35	28.56	119.58	25.17	105.38
4700	28.75	120.38	53.59	224.38	43.07	180.33	27.58	115.47	31.16	130.46	28.50	119.32	29.28	122.59	25.86	108.27
4800	29.46	123.35	54.95	230.07	44.22	185.14	28.31	118.53	31.98	133.90	29.21	122.30	30.00	125.61	26.56	111.20
4900	30.17	126.32	56.31	235.76	45.38	190.00	29.04	121.59	32.79	137.29	29.91	125.23	30.72	128.62	27.26	114.13
5000	30.88	129.29	57.67	241.46	46.54	194.86	29.78	124.68	33.60	140.68	30.62	128.20	31.44	131.63	27.95	117.02
5100	31.60	132.31	59.03	247.15	47.70	199.71	30.52	127.78	34.42	144.11	31.33	131.17	32.16	134.65	28.65	119.95
5200	32.31	135.28	60.39	252.85	48.86	204.57	31.25	130.84	35.24	147.54	32.04	134.15	32.89	137.71	29.35	122.88
5300	33.02	138.25	61.76	258.59	50.02	209.43	31.99	133.94	36.06	150.98	32.76	137.12	33.61	140.72	30.05	125.81

a) If carbon separation occurs.

Table 34 Molar internal enthalpies of reaction products $\bar{c}_v\,(T - T_0)$; $T_0 = 25\,°\mathrm{C} \approx 300\,\mathrm{K}$. (Values for carbon C can be taken from Table 33)

Temper-ature (K)	CO		CO_2		H_2O		H_2		O_2		N_2		NO	
	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)
700	4.99	20.89	7.68	32.16	5.98	25.04	4.75	19.89	5.22	21.85	4.93	20.64	5.11	21.39
900	6.60	27.63	10.33	43.25	8.00	33.49	6.21	26.00	6.91	28.93	6.52	27.29	6.75	28.30
1100	8.24	34.50	13.04	54.59	10.12	42.37	7.71	32.28	8.62	36.09	8.14	34.00	8.43	35.29
1200	9.08	38.01	14.43	60.41	11.22	46.98	8.47	35.46	9.49	39.73	8.97	37.55	9.28	38.86
1300	9.92	41.53	15.84	66.32	12.34	51.67	9.25	38.73	10.36	43.38	9.81	41.07	10.14	42.46
1400	10.78	45.14	17.25	72.23	13.48	56.44	10.04	42.03	11.25	47.10	10.65	44.59	11.01	46.10
1500	11.62	48.66	18.70	78.30	14.45	60.50	11.06	46.31	12.54	52.50	11.50	48.15	11.95	50.03
1600	12.47	52.21	20.07	84.03	15.56	65.15	11.77	49.28	13.30	55.69	12.33	51.63	12.79	53.55
1700	13.32	55.77	21.46	89.86	16.71	69.96	12.50	52.33	14.10	59.04	13.17	55.14	13.64	57.11
1800	14.16	59.29	22.85	95.67	17.87	74.82	13.26	55.52	14.91	62.43	14.00	58.62	14.49	60.67
1900	15.03	62.93	24.28	101.66	19.06	79.80	14.04	58.79	15.76	65.99	14.87	62.26	15.36	64.31
2000	15.81	66.20	25.73	107.73	20.29	84.91	14.84	62.14	16.63	69.63	15.73	65.86	16.23	67.96
2100	16.77	70.22	27.19	113.84	21.51	90.06	15.66	65.57	17.51	73.31	16.60	69.50	17.11	71.64
2200	17.65	73.90	28.66	120.00	22.79	95.42	16.49	69.04	18.41	77.08	17.47	73.15	17.99	75.32
2300	18.54	77.63	30.16	126.28	24.01	100.53	17.33	72.56	19.32	80.89	18.35	76.83	18.88	79.05
2400	19.42	81.31	31.62	132.39	25.28	105.85	18.19	76.16	20.24	84.74	19.23	80.52	19.78	82.82
2500	20.30	85.00	33.11	138.63	26.54	111.12	19.04	79.72	21.16	88.60	20.11	84.20	20.66	86.50
2600	21.19	88.72	34.61	144.91	27.83	116.52	19.91	83.36	22.11	92.60	20.99	87.90	21.56	90.27
2700	22.09	92.49	36.12	151.23	29.12	121.93	20.78	87.01	23.06	96.55	21.88	91.61	22.46	94.04
2800	22.98	96.22	37.63	157.56	30.42	127.37	21.67	90.73	24.01	100.53	22.77	96.34	23.36	97.81
2900	23.88	99.99	39.15	163.92	31.73	132.85	22.55	94.42	24.97	104.55	23.67	99.11	24.27	101.62

Table 34 (Continued).

Temperature (K)	CO		CO_2		H_2O		H_2		O_2		N_2		NO	
	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)	(kcal /mol)	(kJ /mol)
3000	24.78	103.75	40.68	170.33	33.04	138.34	23.48	98.31	25.94	108.61	24.56	102.83	25.17	105.39
3100	25.68	107.52	42.21	176.73	34.36	143.87	24.34	101.91	26.91	112.67	25.46	106.60	26.08	109.20
3200	26.57	111.25	43.73	183.10	35.67	149.35	25.21	105.64	27.88	116.73	26.35	110.33	26.98	112.97
3300	27.47	115.02	45.26	189.50	37.00	154.92	26.14	109.45	28.87	120.88	27.24	114.05	27.89	116.78
3400	28.37	118.79	46.80	195.95	38.33	160.49	27.05	113.26	29.85	124.98	28.15	117.86	28.81	120.63
3500	29.28	122.60	48.34	202.40	39.66	166.06	27.96	117.07	30.84	129.13	29.05	121.63	29.72	124.44
3600	30.18	126.36	49.88	208.85	40.99	171.63	28.88	120.02	31.83	133.27	29.95	125.40	30.63	128.25
3700	31.09	130.17	51.43	215.34	42.33	177.24	29.79	124.73	32.83	137.46	30.85	129.17	31.55	132.10
3800	32.00	133.98	52.97	221.79	43.67	182.85	30.71	128.58	33.83	141.65	31.76	132.98	32.47	135.95
3900	32.89	137.71	54.51	228.23	45.01	188.46	31.69	132.69	34.82	145.79	32.65	136.71	33.37	139.72
4000	33.80	141.52	56.06	234.72	46.35	194.07	32.55	136.29	35.82	149.98	33.56	140.52	34.29	143.57
4100	34.71	145.33	57.61	241.21	47.70	199.72	33.48	140.18	36.83	154.21	34.46	144.28	35.21	147.42
4200	35.62	149.14	59.17	247.74	49.05	205.37	34.41	144.07	37.83	158.39	35.37	148.09	36.13	151.28
4300	36.53	152.95	60.72	254.23	50.40	211.02	35.34	147.97	38.85	162.66	36.28	151.90	37.05	155.13
4400	37.44	156.76	62.28	260.77	51.76	216.72	36.27	151.86	39.85	166.85	37.19	155.71	37.97	158.98
4500	38.35	160.57	63.84	267.30	53.11	222.37	37.20	155.76	40.78	170.75	38.10	159.52	38.89	162.83
4600	39.26	164.38	65.40	273.83	54.47	228.07	38.13	159.65	41.88	175.35	39.00	163.29	39.81	166.58
4700	40.17	168.19	66.96	280.36	55.84	233.80	39.07	163.59	42.89	179.58	39.91	167.10	40.73	170.54
4800	41.08	172.00	68.51	286.85	57.18	239.41	40.00	167.48	43.90	183.81	40.81	170.87	41.64	174.35
4900	41.99	175.81	70.07	293.38	58.54	245.11	40.93	171.37	44.92	188.08	41.72	174.68	42.57	178.24
5000	42.90	179.62	71.64	299.96	59.90	250.80	41.87	175.31	45.94	192.35	42.63	178.49	43.49	182.09

Table 35 Equilibrium constants.

Temperature (K)	$K_1 = \frac{[CO]\cdot[H_2O]}{[CO_2][H_2]}$ a)	$K_2 = \frac{[CO]\cdot[NO]}{[N_2]^{1/2}[CO_2]}$	$K_3 = \frac{[CO]^2}{[CO_2]}$ b)
1000	0.6929	1.791×10^{-16}	2.216×10^{-3}
1200	1.3632	2.784×10^{-13}	5.513×10^{-2}
1400	2.1548	5.238×10^{-11}	5.346×10^{-1}
1500	2.5667	4.240×10^{-10}	1.317
1600	2.9802	2.638×10^{-9}	2.885
1700	3.3835	1.321×10^{-8}	5.744
1800	3.7803	5.520×10^{-8}	10.56
1900	4.1615	1.982×10^{-7}	18.15
2000	4.5270	6.254×10^{-7}	29.48
2100	4.8760	1.767×10^{-6}	45.61
2200	5.2046	4.536×10^{-6}	67.67
2300	5.5154	1.072×10^{-5}	96.83
2400	5.8070	2.356×10^{-5}	134.2
2500	6.0851	4.858×10^{-5}	181.0
2600	6.3413	9.467×10^{-5}	238.1
2700	6.5819	1.755×10^{-4}	306.5
2800	6.8075	3.110×10^{-4}	387.0
2900	7.0147	5.295×10^{-4}	480.2
3000	7.2127	8.696×10^{-4}	586.8
3100	7.3932	1.383×10^{-4}	706.9
3200	7.5607	2.134×10^{-3}	841.0
3300	7.7143	3.207×10^{-3}	989.1
3400	7.8607	4.704×10^{-3}	1151
3500	7.9910	6.746×10^{-3}	1327
3600	8.1144	9.480×10^{-3}	1517
3700	8.2266	1.307×10^{-2}	1720
3800	8.3310	1.772×10^{-2}	1936
3900	8.4258	2.364×10^{-2}	2164
4000	8.5124	3.108×10^{-2}	2406
4100	8.5926	4.030×10^{-2}	2656
4200	8.6634	5.160×10^{-2}	2919
4300	8.7296	6.530×10^{-2}	3191
4400	8.7900	8.173×10^{-2}	3474
4500	8.8442	1.013×10^{-1}	3765
4600	8.8888	1.243×10^{-1}	4064
4700	8.9304	1.511×10^{-1}	4370
4800	8.9698	1.823×10^{-1}	4684
4900	9.0001	2.181×10^{-1}	5003
5000	9.0312	2.591×10^{-1}	5329
5100	9.0524	3.056×10^{-1}	5659
5200	9.0736	3.581×10^{-1}	5993
5300	9.0872	4.171×10^{-1}	6331

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a) Revised values published in JANAF Thermochemical Tables, The Dow Chemical Company, Midland, Michigan, 1965. The values for K_2 and K_3 are taken from Cook, M.A. The Science of High Explosives, Chapman & Hall, London 1958.

b) Applies only in the presence of elementary carbon.

Thrust Determination

Schubmessung; *mesurage de la poussée*

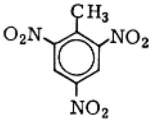
The determination of the thrust of a rocket motor involves recording the time diagram of the force (t, kp or N) during combustion. The force is allowed to act on a support, with a pick-up element thrust cell interposed between them. The measurement is carried out with the aid of a strain gauge element (variation of resistance with pressure) or a piezo-quartz element, and the results are recorded on an oscillograph connected in a compensation circuit. Modern measuring and computation techniques yield the total thrust time (impulse) immediately.

The same technique is applied for the determination of the pressure in the combustion chamber. The pressure cell must be attached to the previously prepared measuring points on the combustion chamber.

See also → *Solid Propellant Rockets*; → *Specific Impulse*

TNT

2,4,6-trinitrotoluene; *Trinitrotoluol*; *trinitrotoluene*; *Trotyl; tolite*



pale yellow crystals; if granulated; flakes
empirical formula: $C_7H_5N_3O_6$
molecular weight: 227.1 g/mol
energy of formation: −52.4 kcal/kg = −219.0 kJ/kg
enthalpy of formation: −70.6 kcal/kg = −295.3 kJ/kg
oxygen balance: −73.9%
nitrogen content: 18.50%
volume of explosion gases: 825 l/kg
heat of explosion
  (H_2O gas): 871 kcal/kg = 3646 kJ/kg
  (H_2O liq.): 1090 kcal/kg = 4564 kJ/kg (experimental)[53)]
900 kcal/kg = 3766 kJ/kg (calculated)[54)]
heat of detonation
specific energy: 92.6 mt/kg = 908 kJ/kg
density, crystals: 1.654 g/cm^3
density, molten: 1.47 g/cm^3
solidification point: 80.8 °C = 177.4 °F
heat of fusion: 23.1 kcal/kg = 96.6 kJ/kg

[53)] Value quoted from *Brigitta M. Dobratz*, Properties of Chemical Explosives and Explosive Simulants, University of California, Livermore.

[54)] Computed by the ICT-Thermodynamic-Code.

specific heat at 20 °C = 68 °F: 0.331 kcal/kg = 1.38 kJ/kg
vapor pressure:

Pressure (mbar)	Temperature (°C)	(°F)
0.057	81	178 (melting point)
0.14	100	212
4	150	302
14	200	392
86.5	250	482 (beginning decomposition)

lead block test: 300 cm^3/10 g
detonation velocity, confined: 6900 m/s = 22 600 ft/s at $\rho = 1.60$ g/cm^3
deflagration point: 300 °C = 570 °F
impact sensitivity: 1.5 kp m = 15 N m
friction sensitivity: up to 353 N no reaction
critical diameter of steel sleeve test: 5 mm

TNT is almost insoluble in water, sparingly soluble in alcohol, and soluble in benzene, toluene and acetone.

It is produced by nitration of toluene with mixed nitric and sulfuric acid in several steps. The trinitration step needs highly concentrated mixed acids with free SO_3. There are batchwise and continuous nitration methods. TNT for military use must be free from any isomer other than the 2,4,6-isomers. This can be done by recrystallization in organic solvents (alcohol; benzene) or in 62% nitric acid. The nonsymmetrical isomers can be destroyed by washing with an aqueous sodium sulfite solution; this processing, however, produces large quantities of red colored waste waters.

The purity grade of the product is determined by its solidification point. The minimum value for military purposes is 80.2 °C; the value for the pure 2,4,6-isomer is 80.8 °C. Owing to the nitric acid recrystallization procedure, products with solidification points of 80.6 and 80.7 °C are currently available.

TNT was one of the most important explosive for blasting charges of all weapons. It is very stable, neutral, and does not attack metals. It can be charged by casting as well by pressing. It is insensitive and needs no phlegmatizers. It can be applied pure and mixed with ammonium nitrate (→ *Amatols*), aluminum powder (→ *Tritonal*), with RDX (→ *Composition B*) and combinations (→ *Torpex*, → *HBX*, → *Trialenes*).

TNT is no longer important for the weapons industry. Molten TNT is as sensitive to → *Impact* as → *Nitroglycerine*. Bigger charges are not easy to

Table 36 Data of the nonsymmetrical TNT isomers.

TNT isomer	Melting point (°C)	(°F)	Heat of fusion (kcal/kg)	(kJ/kg)	Beginning of decomposition (°C)	(°F)
2,3,4-	112	234	25.8	108	282	540
2,3,5-	97	207	20.3	85	283	542
2,3,6-	108	226	24.9	104	280	536
2,4,5-	104	219	26.3	110	262	504
3,4,5-	132	270	21.2	89	288	550

TNT isomer	Energy of formation (kcal/kg)	(kJ/kg)	Enthalpy of formation (kcal/kg)	(kJ/kg)
2,3,4-	+34.2	+143	+15.9	+67
2,3,5-	−5.9	−25	−24.2	−101
2,3,6-	+0.7	+3	−17.6	−74
2,4,5-	+2.0	+8	−16.3	−68
3,4,5-	+13.0	+54	−5.3	−22

cast, because there is a volume shrinking of 11%. There is no TNT production anymore in Europe.

Cast charges of TNT are insensitive to blasting caps and need a booster for safe initiation. Pressed TNT is cap-sensitive.

Specifications

Appearance:	pale yellow, flakes or crystals
solidification point, depending on quality requirement:	not less than 80.6 °C (177.1 °F); the point for TNT as a component in industrial explosives can be lower: 80.4 and 80.2 °C (176.7 and 176.4 °F)
volatiles:	not more than 0.1%
tetranitromethane:	none
acidity as H_2SO_4:	not more than 0.005%
alkalinity as Na_2CO_3:	not more than 0.001%
benzene – insolubles:	not more than 0.05%
ash content:	not more than 0.01%

Other specification characteristics may also be included in the list, e.g. referring to the behavior of pressed specimens at 70 °C = 158 °F (see → *Exudation*).

TPE

thermoplastic elastomers

TPE are a type of copolymers or mixtures of polymers that combine both thermoplastic and elastomeric properties. A thermoplastic elastomer contains hard (crystalline) and soft (amorphous) segments. The hard segments are responsible for the thermoplastic behavior, the soft segments for the elastomeric properties of the binder. There are mainly five chemical types of copolymers that build thermoplastic elastomers:

TPO	thermoplastic elastomers based on olefins
TPS	thermoplastic styrene-block copolymers
TPC/TPE	thermoplastic copolyesters
TPA	thermoplastic copolyamides
TPU	thermoplastic elastomers based on urethanes

Some TPEs are suitable binders for propellants or explosives.

Toe

Fuß-Vorgabe; *distance entre le trou et la surface libre din massit*

The perpendicular distance from blast hole to the free face measured at the floor elevation of a quarry pit.

Torpex

Castable mixtures of RDX (hexogen), TNT and aluminum powder, e.g. a 41 : 41 : 18 mixture. It contains 1% added wax. Other phlegmatized mixtures of similar compositions are → *DBX* and → *HBX*.

density: 1.81 g/cm^3
detonation velocity, confined: 7600 m/s = 24 900 ft/s at ρ = 1.81 g/cm^3

Tracers

Leuchtspur; *compositions lumineuses*

Tracers are slow-burning pyrotechnical compositions, used in tracer bullets, signal cartridges, tracer rockets and light-track shells. The colored flame is due to the presence of added salts such as sodium, barium, strontium and copper salts. Signal formulations are used in smoke generators, including colored smoke generators, and staining formulations that mark ground and water surfaces with organic dyes.

Transmission of Detonation

→ *Detonation, Sympathetic Detonation*

Transport Regulations

Transportvorschriften; *règlement de transport*

→ *ADR* (Road); → *RID* (Rail); → *IATA DGR, ICAO TI* (Air); → *IMDG Code* (Maritime).

Trauzl Test

(→ *Lead Block Test*)

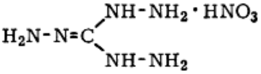
Trauzl, an officer in the pioneer corps of the Austrian army, proposed the lead block method for the determination of the strength of explosive materials. The first international standardization of his method was enacted in 1904.

Trialenes

Mixtures of TNT, hexogen, and aluminum powder in the following proportions: 80 : 10 : 10; 70 : 15 : 15; 60 : 20 : 20; 50 : 10 : 40 and 50 : 25 : 25. They were used as fillings for bombs and torpedo warheads in the Second World War.

Triaminoguanidine Nitrate

Triaminoguanidinnitrat; *nitrate de triaminoguanidine; TAGN*



$H_2N-N=C(NH-NH_2 \cdot HNO_3)(NH-NH_2)$

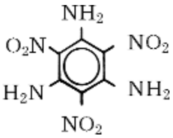
colorless crystals
empirical formula: $CH_9N_7O_3$
molecular weight: 167.1 g/mol
energy of formation: −35.2 kcal/kg = −147.2 kJ/kg
enthalpy of formation: −68.8 kcal/kg = −287.9 kJ/kg
oxygen balance: −33.5%
nitrogen content: 58.68%
volume of explosion gases: 1163 l/kg
heat of explosion
  (H_2O liq.): 950 kcal/kg = 3974 kJ/kg
  (H_2O gas): 835 kcal/kg = 3492 kJ/kg
density: 1.5 g/cm^3
melting point: 216 °C = 420 °F (decomposition)
lead block test: 350 cm^3/10 g
detonation velocity, confined: 5300 m/s at $\rho = 0.95$ g/cm^3
deflagration point: 227 °C = 440 °F
impact sensitivity: 0.4 kp m = 4 N m
friction sensitivity: over 12 kp = 120 N
pistil load: crackling

This compound is prepared by reacting 1 mol of guanidine dinitrate with 3 mol of hydrazine hydrate at 100 °C for 4 h. The reaction is accompanied by the liberation of ammonia.

The product is distinguished by high contents of hydrogen and nitrogen. TAGN serves as an ingredient for LOVA gun propellants with high force but comparable low combustion temperature. It is chemically not stable in connection to nitrate esters and some transition metal compounds, e.g. copper.

1,3,5-Triamino-2,4,6-trinitrobenzene

Triaminotrinitrobenzol; *triaminotrinitrobenzène*; *TATB*



bright yellow crystals
empirical formula: $C_6H_6N_6O_6$
molecular weight: 258.1 g/mol
energy of formation: −108.7 kcal/kg = −455.0 kJ/kg
enthalpy of formation: −129.4 kcal/kg = −541.3 kJ/kg
oxygen balance: −55.8%
nitrogen content: 32.6%
heat of explosion (H_2O liq.): 732 kcal/kg = 3062 kJ/kg
density: 1.93 g/cm^3
melting point: 360 °C = 600 °F (decomposition)
lead block test: 175 cm^3/10 g
detonation velocity, confined: 7350 m/s at $\rho = 1.80$ g/cm^3
deflagration point: 384 °C
impact sensitivity: 50 N m
friction sensitivity: 36.7 kp = 360 N

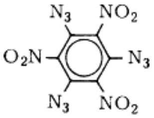
TATB is obtained by nitration of trichlorobenzene and conversion of the trinitrotrichlorobenzene to TATB.

It resists heat up to 300 °C (570 °F) and is very insensitive to friction and impact; the → *Critical Diameter* is high. Therefore the lead block test value listed above may be too low in comparison with its other performance data. TATB is only used as a booster in nuclear weapons, replacing → HMX based charges for safety reasons.

Direct contact with some transition metals (e.g. copper) must be avoided.

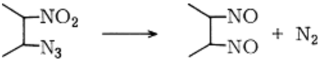
1,3,5-Triazido-2,4,6-trinitrobenzene

Triazidotrinitrobenzol; *triazidotrinitrobenzene*; *TATNB*



green-yellow crystals
empirical formula: $C_6N_{12}O_6$
molecular weight: 336.2 g/mol
oxygen balance: −28.6%
nitrogen content: 50.0%
volume of explosion gases: 755 l/kg
specific energy: 170 mt/kg = 1666 kJ/kg
density: 1.805 g/cm^3
melting point: 131 °C = 268 °F (decomp.)
lead block test: 470 cm^3/10 g
impact sensitivity: 0.5 kp m = 5 N m

The product can be obtained by treating 2,4,6-trichloro-1,3,5-trinitrobenzene with an alkali metal azide in alcoholic solution. It is a powerful, lead-free → *Initiating Explosive* and does not produce toxic fumes (see → *Lead-free Priming Compositions*). The product undergoes a slow conversion into hexanitrosobenzene,



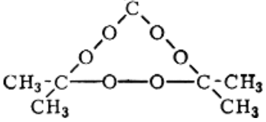
thus losing its initiating power. This reaction is reached

- at 20 °C = 68 °F after 3 years: 2.7%
- at 35 °C = 95 °F after 1 year: 9.5%
- at 50 °C = 122 °F after 10 days: 2.6%
- at 50 °C = 122 °F after 6 years: 50%

TATNB can be dead pressed, like mercury fulminate.

Tricycloacetone Peroxide

Acetonperoxid; *peroxyde de tricycloacétone*; *TATP*

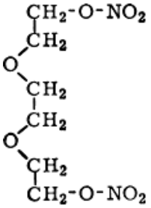


colorless crystals
empirical formula: $C_9H_{18}O_6$
molecular weight: 222.2 g/mol
oxygen balance: −151.18%
energy of formation: −86.19 kJ/mol = −387.83 kJ/kg
enthalpy of formation: −115.9 kJ/mol = −521.50 kJ/kg
density: 1.22 g/cm^3
melting point: 98.5 °C
detonation velocity: 5300 m/s at 1.18 g/cm^3
impact sensitivity: 0.3 N m
friction sensitivity: 0.1 N

This compound is formed from acetone in sulfuric acid solution when acted upon by 45% hydrogen peroxide. It displays the properties of primary explosives. It is not used in practice because of its tendency to sublimation and the relatively high friction sensitivity.

Triethyleneglycol Dinitrate

triglycol dinitrate; *Triglykoldinitrat*; *dinitrate de triéthyleneglycol*; *TEGN*



pale yellow liquid
empirical formula: $C_6H_{12}N_2O_8$
molecular weight: 240.1 g/mol
energy of formation: −598.9 kcal/kg = −2505.8 kJ/kg
enthalpy of formation: −626.0 kcal/kg = −2619.2 kJ/kg
oxygen balance: −66.7%
nitrogen content: 11.67%
volume of explosion gases: 1065 l/kg
heat of explosion: (H_2O liq.): 793 kcal/kg = 3317 kJ/kg
specific energy: 91.7 mt/kg = 899 kJ/kg
density: 1.335 g/cm^3
lead block test: 320 cm^3/10 g
deflagration point: 195 °C = 383 °F
impact sensitivity: 1.3 kp m = 12.7 N m

Triglycol dinitrate is less volatile than → *Diethylenglycol Dinitrate*. It gelatinizes nitrocellulose just as well as diglycol dinitrate, i.e. better than nitroglycerine.

Its chemical stability is better than that of nitroglycerine or nitrocellulose, and at least as good as that of diglycol dinitrate.

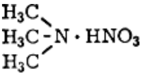
Triglycol dinitrate is prepared by nitration of triglycol with mixed acid. The solubility of triglycol dinitrate in the waste acid is very high (about 9%). It is particularly suited for the production of low caloric → *Double-Base Propellants*.

Specifications

density 20/4:	1.1230–1.1234 g/cm^3
boiling analysis, start:	not below 280 °C = 536 °F
90% distilled:	not over 295 °C = 563 °F
moisture:	not more than 0.5%
chlorides:	not more than traces
acid, as H_2SO_4:	not more than 0.02%
saponification value, as Na_2O:	not more than 0.05%
reducing matter ($AgNO_3$-NH_3-test):	none

Trimethylamine Nitrate

Trimethylaminnitrat; *nitrate de trimèthylamine*

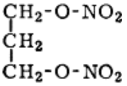


colorless crystals
empirical formula: $C_3H_{10}N_2O_3$
molecular weight: 122.1 g/mol
energy of formation: −636.7 kcal/kg = −2664.1 kJ/kg
enthalpy of formation: −637.1 kcal/kg = −2816.2 kJ/kg
oxygen balance: −104.8%
nitrogen content: 22.95%
volume of explosion gases: 1244 l/kg
explosion heat: (H_2O liq.): 511 kcal/kg = 2140 kJ/kg
specific energy: 70.5 mt/kg = 691 J/kg
density: 1.5 g/cm^3

This salt, as well as other methylamine nitrates, has been proposed as a component of castable charges and of → *Slurries*.

Trimethyleneglycol Dinitrate

Trimethylenglykoldinitrat; *dinitrate de trimethléneglycol*



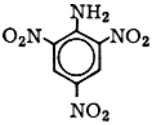
$$\begin{array}{l} CH_2\text{-}O\text{-}NO_2 \\ | \\ CH_2 \\ | \\ CH_2\text{-}O\text{-}NO_2 \end{array}$$

colorless oil
empirical formula: $C_3H_6N_2O_6$
molecular weight: 166.1 g/mol
oxygen balance: −28.9%
nitrogen content: 16.87%
density: 1.393 g/cm^3
lead block test: 540 $cm^3/10\ g$
deflagration point: 225 °C = 437 °F (decomposition begins at 185 °C = 365 °F)
impact sensitivity: up to 2 kp m = 20 N m no reaction

Trimethyleneglycol dinitrate is less volatile than nitroglycol, but more volatile than nitroglycerine. Its solubilities in various solvents are similar to those of nitroglycerin. Like nitroglycerine, it forms satisfactory gels with nitrocelluloses. It causes headaches. Trimethyleneglycol dinitrate is prepared by nitration of trimethylene glycol with nitric acid or mixed acid at 0–10 °C. It is less impact-sensitive than nitroglycerine and is much more stable to store. It is no longer used.

Trinitroaniline

Picramid; *TNA*



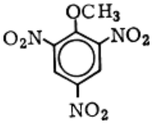
orange red crystals
empirical formula: $C_6H_4N_4O_6$
molecular weight: 228.1 g/mol
energy of formation: −69.8 kcal/kg = −292.2 kJ/kg
enthalpy of formation: −88.0 kcal/kg = −368.1 kJ/kg
oxygen balance: −56.1%
nitrogen content: 24.56%
volume of explosion gases: 838 l/kg
heat of explosion
  (H_2O liq.): 858 kcal/kg = 3589 kJ/kg
  (H_2O gas): 834 kcal/kg = 3488 kJ/kg
density: 1.762 g/cm^3
melting point: 188 °C = 370 °F
lead block test: 310 $cm^3/10\ g$
detonation velocity, confined: 7300 m/s at $\rho = 1.72\ g/cm^3$
deflagration point: 346 °C = 654 °F

impact sensitivity: 1.5 kp m = 15 N m
friction sensitivity: at 36 kp = 353 N
pistil load: no reaction
critical diameter of steel sleeve test: 3.5 mm

Trinitroaniline is prepared by reacting trinitrochlorobenzene with ammonia or by nitration of 4-nitroaniline.

Trinitroanisole

methylpicrate: 2,4,6-trinitrophenylmethylether; Pikrinsäuremethylether Methoxytrinitrobenzol



pale yellow crystals
empirical formula: $C_7H_5N_3O_7$
molecular weight: 243.1 g/mol
energy of formation: −131.0 kcal/kg = −548.2 kJ/kg
enthalpy of formation: −150.6 kcal/kg = −630.1 kJ/kg
oxygen balance: −62.5%
nitrogen content: 17.29%
volume of explosion gases: 844 l/kg
heat of explosion
  (H_2O liq.): 903 kcal/kg = 3777 kJ/kg
  (H_2O gas): 874 kcal/kg = 3656 kJ/kg
specific energy: 99.1 mt/kg = 972 kJ/kg
density, crystals: 1.61 g/cm^3
density, molten: 1.408 g/cm^3
heat of fusion: 19.3 kcal/kg = 80.8 kJ/kg
melting point: 68 °C = 155 °F
lead block test: 295 g/cm^3
detonation velocity, confined: 6800 m/s = 22 300 ft/s
  at $\rho = 1.57$ g/cm^3
deflagration point: 285 °C = 545 °F
impact sensitivity: 2.0 kp m = 20 N m
friction sensitivity: at 36 kp = 353 N
pistil load: no reaction
critical diameter of steel sleeve test: 12 mm

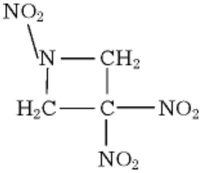
Trinitroanisole is insoluble in water, but soluble in hot alcohol and ether. It is toxic.

It is prepared by treating dinitrochlorobenzene with methyl alcohol and alkali and nitration of the dinitroanisole thus obtained. Recrystallization from methanol yields the pure, pale yellow product.

It is a very low sensitive explosive. Its performance is intermediate between that of TNT and picric acid. It has found use as a bomb filling component. It produces skin eczemas and is not safe physiologically. Owing to this and its very low melting point, the compound is only of limited practical importance.

1,3,3-Trinitroazetidine

Trinitroazetidin; *TNAZ*



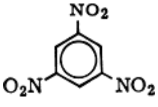
empirical formula: $C_3H_4N_4O_6$
molecular weight: 192.09 g/mol
energy of formation: +66.84 kcal/kg = +279.77 kJ/kg
enthalpy of formation: +45.29 kcal/kg = +189.50 kJ/kg
oxygen balance: −16.66%
nitrogen content: 29.2%
heat of explosion
 (H_2O liq.): 1516 kcal/kg = 6343 kJ/kg
 (H_2O gas): 1440 kcal/kg = 6024 kJ/kg
specific energy: 138.5 mt/kg = 1358 kJ/kg
density: 1.84 g/cm^3
melting point: 101 °C

Several synthetic routes for trinitroazetidine have been described, e.g. from epichlorhydrin and *tert*-butylamine to give 1-*tert*-butylazetidine and subsequent stepwise nitration to yield TNAZ.

Trinitroazetidine's performance data as an explosive lies between → *Hexogen* and → *Octogen*, but it is considerably less sensitive and therefore attractive for → *LOVA* (Low Vulnerability Ammunition) applications.

1,3,5-Trinitrobenzene

Trinitrobenzol; *trinitrobenzène*; *TNB*



pale green-yellow crystals
empirical formula: $C_6H_3N_3O_6$
molecular weight: 213.1 g/mol
energy of formation: −32.1 kcal/kg = −134.5 kJ/kg
enthalpy of formation: −48.8 kcal/kg = −204.2 kJ/kg
oxygen balance: −56.3%
nitrogen content: 19.72%
volume of explosion gases: 805 l/kg
heat of explosion
  (H_2O liq.): 947 kcal/kg = 3964 kJ/kg
  (H_2O gas): 926 kcal/kg = 3876 kJ/kg
specific energy: 107 mt/kg = 1050 kJ/kg
density: 1.76 g/cm^3
solidification point: 123.2 °C = 253.7 °F
heat of fusion: 16.0 kcal/kg = 67.2 kJ/kg
vapor pressure:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
0.5	122	252 (melting point)
2	150	302
14	200	392
133	270	518

lead block test: 325 cm^3/10 g
detonation velocity, confined: 7300 m/s = 23 900 ft/s
  at $\rho = 1.71$ g/cm^3
impact sensitivity: 0.75 kp m = 7.4 N m
friction sensitivity: up to 36 kp = 353 N
pistil load: no reaction

Trinitrobenzene is insoluble in water, sparingly soluble in hot alcohol, and is readily soluble in acetone, ether, and benzene.

Trinitrobenzene is formed by of decarboxylation of trinitrobenzoic acid. It can also be prepared from trinitrochlorobenzene by reduction with copper in alcohol. Further nitration of dinitrobenzene also yields trinitrobenzene, but the reaction must be carried out under very severe conditions (high SO_3-concentration in the mixed acid; high nitration temperature) and the yields are low.

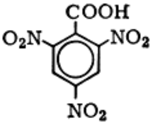
All the above syntheses are difficult and uneconomical. For this reason, no practical application has been found, despite the fact that its strength and detonation velocity are superior to those of TNT and it is very stable.

Specifications

solidification point:	not below 121 °C = 250 °F
moisture, volatile matter:	not more than 0.1%
glow residue:	not more than 0.2%
insoluble in benzene:	not more than 0.2%
HNO_3:	not more than traces
sulfate, as N_2SO_4:	not more than 0.02%
acid, as H_2SO_4:	not more than 0.005%
alkali:	none
Abel test 80 °C = 176 °F:	not under 30 min

Trinitrobenzoic Acid

Trinitrobenzosäure; *acide trinitrobenzoique*



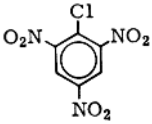
yellow needles
empirical formula: $C_7H_3N_3O_8$
molecular weight: 257.1 g/mol
energy of formation: −358.4 kcal/kg = −1500 kJ/kg
enthalpy of formation: −374.6 kcal/kg = −1567 kJ/kg
oxygen balance: −46.7%
nitrogen content: 16.35%
volume of explosion gases: 809 l/kg
heat of explosion
(H_2O liq.): 719 kcal/kg = 3008 kJ/kg
(H_2O gas): 700 kcal/kg = 2929 kJ/kg
specific energy: 88.8 mt/kg = 871 kJ/kg
lead block test: 283 cm^3/10 g
impact sensitivity: 1 kp m = 10 N m
friction sensitivity: at 36 kp = 353 N
pistil load: no reaction
critical diameter of steel sleeve test: 2 mm

Trinitrobenzoic acid is sparingly soluble in water, and soluble in alcohol and ether. It is prepared by oxidation of TNT with nitric acid, or with a solution of $KClO_3$ in nitric acid, or with a chromic acid mixture.

The crude product is purified by dissolving it in a dilute sodium carbonate solution and reprecipitating with sulfuric acid. If trinitrobenzoic acid is exposed to water vapor for a long period of time, → *Trinitrobenzene* is formed as a result of the liberation of CO_2.

Trinitrochlorobenzene

picryl chloride; *Trinitrochlorbenzol*; *trinitrochlorobenzene; chlorure de picryle*



pale yellow needles
empirical formula: $C_6H_2N_3O_6Cl$
molecular weight: 247.6 g/mol
energy of formation: +40.4 kcal/kg = +169 kJ/kg
enthalpy of formation: +25.9 kcal/kg = +108.2 kJ/kg
oxygen balance: −45.3%
nitrogen content: 16.98%
density: 1.797 g/cm^3
solidification point: 83 °C = 181 °F
heat of fusion: 17.5 kcal/kg = 73.3 kJ/kg
vapor pressure:

Pressure (mbar)	**Temperature (°C)**	**(°F)**
0.05	83	181 (melting point)
0.2	100	212
2.0	150	302
12.5	200	392
100	270	518

lead block test: 315 cm^3/10 g
detonation velocity, confined: 7200 m/s = 23 600 ft/s at $\rho = 1.74$ g/cm^3
deflagration point: 395–400 °C
impact sensitivity: 1.6 kp m = 16 N m
friction sensitivity: up to 36 kp = 353 N pistil load: no reaction

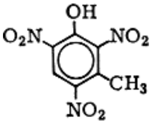
Trinitrochlorobenzene is sparingly soluble in alcohol and benzene, somewhat more soluble in ether, and insoluble in water.

It is prepared by nitration of dinitrochlorobenzene. Manufacture is difficult, and highly concentrated acid must be employed.

Trinitrochlorobenzene is just as insensitive as TNT, its brisance is somewhat higher, and its density and heat stability are excellent.

2,4,6-Trinitrocresol

Trinitrometakresol; trinitrométacrésol



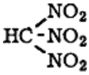
yellow needles
empirical formula: $C_7H_5N_3O_7$
molecular weight: 243.1 g/mol
energy of formation: −229.7 kcal/kg = −961.2 kJ/kg
enthalpy of formation: −248.0 kcal/kg = −1038 kJ/kg
oxygen balance: −62.5%
nitrogen content: 17.95%
volume of explosion gases: 844 l/kg
heat of explosion
  (H_2O liq.): 805 kcal/kg = 3370 kJ/kg
  (H_2O gas): 776 kcal/kg = 3248 kJ/kg
specific energy: 87.8 mt/kg = 861 kJ/kg
density: 1.68 g/cm^3
melting point: 107 °C = 225 °F
heat of fusion: 25.5 kcal/kg = 107 kJ/kg
lead block test: 285 cm^3/10 g
detonation velocity, confined: 6850 m/s = 22 500 ft/s
  at $\rho = 1.62$ g/cm^3
deflagration point: 210 °C = 410 °F
impact sensitivity: 1.2 kp m = 12 N m
friction sensitivity: up to 36 kp = 353 N
pistil load: no reaction

Trinitrocresol is readily soluble in alcohol, ether, and acetone, and is sparingly soluble in water.

It is prepared by nitration of *m*-cresoldisulfonic acid. During the First World War, 60 : 40 mixtures of trinitrocresol and picric acid were used (under the name of Kresylith) as grenade fillings, since they melt at a temperature as low as 85 °C (185 °F).

Trinitromethane

Nitroform



$HC(NO_2)_3$

oil with a pungent smell
empirical formula: CHN_3O_6
molecular weight: 151.0 g/mol
oxygen balance: +37.1%
nitrogen content: 27.83%
density: 1.59 g/cm^3
melting point: 22 °C = 72 °F
boiling point at 23 mbar pressure: 48 °C = 118 °F

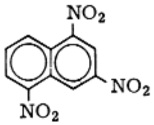
Nitroform is obtained when acetylene is introduced into nitric acid; it may also be prepared from tetranitromethane.

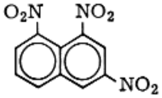
Nitroform cannot be used on its own either as an oxidant or as an explosive. It is possible, however, to add nitroform to formaldehyde and to prepare explosives from the resulting trinitroethanol product (→ *Bi-trinitroethylamine* and *Bi-trinitroethylurea*).

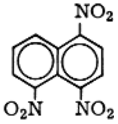
Its hydrazine salt HNF has been proposed as a halogen-free oxidizer for propellant formulations.

Trinitronaphthalene

Trinitronaphthalin; *trinitronaphthalène*; *Naphtit; Trinal*







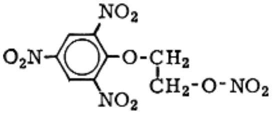
brownish crystals
empirical formula: $C_{10}H_5N_3O_6$
molecular weight: 263.2 g/mol
oxygen balance: −100.3%
nitrogen content: 15.97%
volume of explosion gases: 723 l/kg
heat of explosion
  (H_2O liq.): 842 kcal/kg = 3521 kJ/kg
  (H_2O gas): 819 kcal/kg = 3425 kJ/kg
specific energy: 76 mt/kg = 746 kJ/kg
melting point: 115 °C = 239 °F (beginning softening of the isomer mixture)
detonation velocity: 6000 m/s = 19 700 ft/s
deflagration point: 350 °C = 660 °F
impact sensitivity: 2 kp m = 19 N m

Trinitronaphthalene is soluble in glacial acetic acid, and is sparingly soluble in alcohol and ether. It is prepared by dissolving mononitronaphthalene in concentrated sulfuric acid and adding mixed acid. The product thus obtained – a mixture of *α*-(1,3,5)-, *β*-(1,3,8)-, and *γ*-(1,4,5)-isomers – melts above 115 °C (239 °F).

Trinitronaphthalene is difficult to detonate. It was used, in mixture with other compounds, as grenade filling, especially in France and Belgium. It is of no technological interest at present.

Trinitrophenoxethyl Nitrate

Trinitrophenylglykolethernitrat; *nitrate de trinitrophénoxethyle*



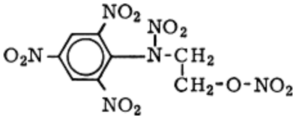
yellowish-white crystals
empirical formula: $C_8H_6N_4O_{10}$
molecular weight: 318.2 g/mol
energy of formation: −189.8 kcal/kg = −794.0 kJ/kg
enthalpy of formation: −208.4 kcal/kg = −871.9 kJ/kg
oxygen balance: −45.3%
nitrogen content: 17.61%
volume of explosion gases: 878 l/kg
heat of explosion
  (H_2O liq.): 935 kcal/kg = 3911 kJ/kg
  (H_2O gas): 906 kcal/kg = 3792 kJ/kg
specific energy: 115 mt/kg = 1131 kJ/kg
density: 1.68 g/cm^3
melting point: 104.5 °C = 219.6 °F
lead block test: 350 cm^3/10 g
detonation velocity, confined: 7600 m/s = 25 000 ft/s
  at $\rho = 1.65$ g/cm^3
deflagration point: > 300 °C => 570 °F
impact sensitivity: 0.8 kp m = 7.9 N m

The compound is insoluble in water, but soluble in acetone and toluene. It is very stable and gelatinizes nitrocellulose on heating.

It is prepared by nitration of the corresponding dinitro compound.

2,4,6-Trinitrophenylnitraminoethyl Nitrate

Trinitrophenylethanolnitraminnitrat; *nitrate de trinitrophenylnitramine-éthyl*; *Pentryl*



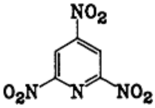
yellowish crystals
empirical formula: $C_8H_6N_6O_{11}$
molecular weight: 362.2 g/mol
oxygen balance: −35.4%
nitrogen content: 23.19%
density: 1.75 g/cm^3
melting point: 128 °C = 262 °F
lead block test: 450 cm^3/10 g
deflagration point: 235 °C = 455 °F
impact sensitivity: 0.4 kp m = 4 N m

The compound is soluble in water, sparingly soluble in common organic solvents, but soluble in nitroglycerine. Its stability is satisfactory, but one of the five NO_2-groups in the molecule is a nitrate rather than a nitro group, so that the compound cannot be as stable as e.g. TNT.

It is prepared by nitration of dinitrophenylaminoethanol, which is in turn formed by condensation of dinitrochlorobenzene with monoethanolamine.

Trinitropyridine

Trinitropyridin; *Trinitropyridine, 2,4,6-Trinitropyridine*; *TNPy*



yellow needles
empirical formula: $C_5H_2N_4O_6$
molecular weight: 214.1 g/mol
energy of formation: +437.9 kJ/kg = +104.6 kcal/kg
enthalpy of formation: +368.5 kJ/kg = +88.0 kcal/kg
oxygen value: −37.4%
nitrogen content: 26.17%
specific energy: 129 mt/kg = 1260 kJ/kg
explosion heat (H_2O liq.): 4418 kJ/kg = 1056 kcal/kg
normal volume of gases: 818 l/kg
fusion point: 162 °C (sublimation)
density: 1.77 g/cm^3

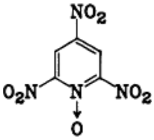
detonation rate: 7470 m/s at $\rho = 1.66$ g/cm^3
impact sensitivity: 4.5–6.5 N m = 0.46–0.66 kp m
sensitivity of friction: at 353 N = 36 kp pin load, no reaction

Trinitropyridine is obtained by means of reduction of → *Trinitropyridine-N*-oxide with sodium nitrite in a solution of sulfuric acid.

Although this compound is a potent explosive, it has yet to gain widespread use.

Trinitropyridine-*N*-oxide

Trinitropyridin-N-oxid; Trinitropyridine-N-oxide, 2,4,6-Trinitropyridin-1-oxide; *TNPyOX*



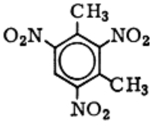
yellow crystals
empirical formula: $C_5H_2N_4O_7$
molecular weight: 230.1 g/mol
energy of formation: +499.1 kJ/kg = +119.2 kcal/kg
enthalpy of formation: +428.9 kJ/kg = +102.5 kcal/kg
oxygen value: −27.8%
nitrogen content: 24.34%
specific energy: 134 mt/kg = 1315 kJ/kg
explosion heat: (H_2O liq.): 5320 kJ/kg = 1271 kcal/kg
normal volume of gases: 777 l/kg
fusion point: 170 °C (decomposition)
density: 1.86 g/cm^3
detonation rate: 7770 m/s at $r = 1.72$ g/cm^3
impact sensitivity: 1.5–3.0 N m = 0.15–0.31 kp m
sensitivity to friction: 157 N = 16 kp

Trinitropyridine-*N*-oxide is produced through a cyclical reaction of potassium salt of 2,2-dinitroethanol in diluted phosphoric acid.

The product serves as the basis material for the production of → *Trinitropyridine*, which is not obtainable by means of direct nitration.

2,4,6-Trinitroxylene

Trinitroxylol; *trinitrométaxylène*; *TNX*



pale yellowish needles
empirical formula: $C_8H_7N_3O_6$
molecular weight: 241.2 g/mol
energy of formation: −82.1 kcal/kg = −343.4 kJ/kg
enthalpy of formation: −101.7 kcal/kg = −425.6 kJ/kg
oxygen balance: −89.57%
nitrogen content: 17.42%
volume of explosion gases: 843 l/kg
heat of explosion
  (H_2O liq.): 845 kcal/kg = 3533 kJ/kg
  (H_2O gas): 810 kcal/kg = 3391 kJ/kg
specific energy: 83.5 mt/kg = 819 kJ/kg
density: 1.69 g/cm^3
melting point: 182 °C = 360 °F

Separation of the xylene isomers is not easy, and nitration to the trinitrate stage is technically difficult.

Tritonal

A castable mixture of 20–40% aluminum and 80–20% TNT.

Trixogen

A pourable mixture of RDX with TNT.

Ullage

Empty volume provided for thermal expansion of propellant in a liquid propellant tank.

Unbarricaded

The absence of a natural or artificial barricade around explosive storage areas or facilities.

Unconfined Detonation Velocity

Detonationsgeschwindigkeit ohne Einschluss; *velocite de detonation sans enserrernent*

The detonation velocity of an explosive material without confinement; for example, a charge fired in the open.

Underwater Detonations[55]

Unterwasserdetonationen; *détonations sous l'eau*

Destructive effects of underwater detonations differ in their distant and close-proximity effects. The first effect is caused by the action of the pressure shock wave; the latter mainly by the thrust produced by the expanding gas bubble.

Basically the process can be subdivided into three distinct stages:

1. *Detonation*
   The detonation of an explosive charge is triggered by the fuse. The explosive matter undergoes an extremely rapid deterioration, and the heat developed during this process creates a large amount of gas. This first enters into the cavity previously occupied by the solid explosive and is therefore under high pressure. This hot compressed gas constitutes the whole of the performance potential.
2. *Shock wave*
   The adjacent layer of water is compressed under the influence of this high pressure, which in turn transfers that pressure onto the next layer, and this transfers the pressure onto the next one, and so forth in a chain reaction.
   The velocity of propagation increases with pressure, thus creating a steeply ascending pressure front, which imparts the nature of a shock wave to the pressure wave. At the onset, the velocity of propagation exceeds that of the speed of sound, but deteriorates with increasing distance to approximately 1450 m/s.
   The maximum pressure achieved is directly proportional to the cube root of the charge weight, and inversely proportional to the distance, resulting in the following approximate formula:

   $$p_{\max} = C\frac{L^{1/3}}{e}$$

   p: pressure in bar, L: loading weight in kg, e: distance in m, c: empirical factor; $\approx$ 500.
3. *Gas bubble*
   As stated previously, the gas formed by the underwater explosion first enters the small cavity previously occupied by the explosive, thus creating a gas bubble under high pressure. The water surrounding the bubble gives away, and the gas bubble expands. This causes

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[55] Extract of a lecture held by W.E. Nolle at the annual meeting of the Fraunhofer Institut at Karlsruhe, 1978.

> the water mass to move radially at great velocity away from the point of explosion. This movement is known as the thrust.

The maximum amount of kinetic energy imparted to the water during an explosion is called the thrust energy.

The increase of expansion of the gas bubble causes a decrease in pressure on the enclosed gases, which slows down expansion to the point where all of the kinetic energy is expended. This causes lowering of pressure in the gas bubble contents, influenced by the static water pressure, and the water mass engulfs it again. The gases are compressed again up to a second minimum, at which point another pressure wave (secondary pressure wave) is formed. Oscillation of the gas bubble can be repeated several times, causing a third, and, under favorable conditions, further minima. The gas bubble is propelled upwards towards the surface of the water. The difference in pressure between the top and the bottom layer of the bubble causes the bottom layer to move at greater speed, thus forcing it upwards into the bubble. It is possible for both surfaces to meet. Within a limited area the water receives an upward thrust, creating the so-called water hammer (water jet).

From observations it is clear that the most effective underwater explosives are those that can produce a high-pressure gas bubble for the formation of the thrust.

Mixtures containing a high percentage of aluminum powder have proven to be most effective (see also→ *Aluminum Powder*; → *Torpex*; → *Trialenes*; → *Tritonal*).

References:

- *G. Bjarnholt* and *P. Holmberg*, Explosive Expansion Work in Underwater Detonations, Reprints of the Sixth Symposium on Detonation, San Diego, 1976 (from: Office of Naval Research, San Diego, USA).
- *S. Paterson* and *A.H. Begg*, Underwater Explosion, Propellants and Explosives 3, 63–89 (1978).

Upsetting Tests

Stauchung; *écrasement du crusher*

Upsetting tests are used to determine the → *Brisance* of the explosives. An unconfined cartridge (enveloped in paper or in metal sheet) acts upon a copper or lead crusher; the loss of height of the crusher is a measure for the brisant performance of the tested explosive (see → *Brisance*).

The test according to Kast is shown in Figure 26; the cartridge shock acts by means of a guided pestle onto a copper crusher of 7 mm diameter and 10.5 mm height.

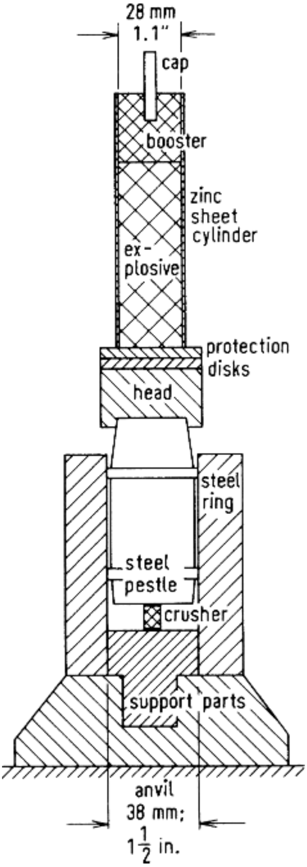


Figure 26 Upsetting test according to Kast.

The simplified test according to Hess is shown in Figure 27.

A lead cylinder, 60 mm (2.36 in) high, 40 mm (1.57 in) diameter, protected by two 6 mm-thick steel disks, is upset by a 100-g (3.53 oz) cartridge of the same diameter, 40 mm. The cylinder is pressed down into a mushroom shape; in the case of sensitized special gelatins for seismic use, the cylinder can be destroyed completely.

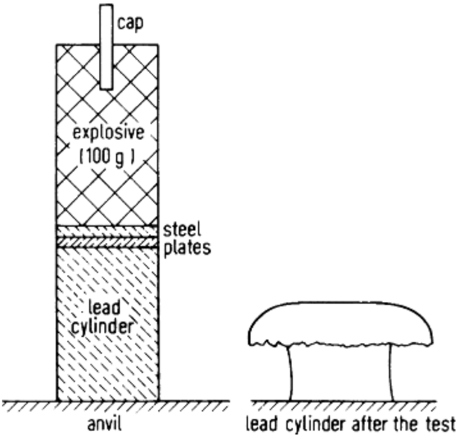
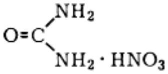


Figure 27 Upsetting test according to Hess.

Urea Nitrate

Harnstoffnitrat; *nitrate d'urée*



colorless crystals
empirical formula: $CH_5N_3O_4$
molecular weight: 123.1 g/mol
energy of formation: −1064 kcal/kg = −4452 kJ/kg
enthalpy of formation: −1093 kcal/kg = −4573 kJ/kg
oxygen balance: −6.5%
nitrogen content: 34.14%
volume of explosion gases: 910 l/kg
heat of explosion
  (H_2O liq.): 767 kcal/kg = 3211 kJ/kg
  (H_2O gas): 587 kcal/kg = 2455 kJ/kg
specific energy: 77 mt/kg = 755 kJ/kg
density: 1.59 g/cm^3
melting point: 140 °C = 284 °F (decomposition)
lead block test: 270 cm^3/10 g
deflagration point: 186 °C = 367 °F
impact sensitivity: up to 49 N m no reaction
friction sensitivity: up to 353 N no reaction
critical diameter of steel sleeve test: at 1 mm diameter no destruction of steel sleeve

Urea nitrate is readily soluble in hot water and sparingly soluble in ethanol. Its thermal stability is satisfactory. The compound is prepared from urea and nitric acid. The salt is strongly acidic. Chemical stability is poor.

Vacuum Test

This test, which was developed in the USA and has been adopted by several countries, is a modification of the → *Taliani Test*, in which the gaseous products of the reaction are determined volumetrically rather than by manometry. The test, which is carried out at 100 °C (212 °F) for single-base propellants and at 90 °C (194 °F) for multi-base propellants, is terminated after 40 h, unlike the → *Taliani Test*, which is interrupted after a given pressure or a given volume has been attained.

The vacuum test is used for compatibility testing and applied as a so-called reactivity test. The compatibility between the explosive and the contact material (adhesive, varnish, etc.) is tested by determining the gases liberated by the explosive alone, by the contact material alone, and by the two together. The measure of compatibility (reactivity) is the difference between the sum of the gas volume liberated by each component separately and the gas volume obtained after storing the explosive and the contact material together. If this difference is below 3 ml, the compatibility is considered to be stable; between 3 and 5 ml the compatibility is considered uncertain; and above 5 ml the two materials are incompatible.

Vibrometer

Erschütterungsmessgerät

Vibrometers are instruments to measure the intensity of shock waves caused by blasting operations. The magnitude of the shock depends on the kind of rocks, underground conditions and distance to the people and buildings to be protected. The regular control of ground shocks caused by blasting is therefore in the interest of companies active in this field to safeguard friendly relations with the neighborhood. Vibrometer records can also be important in forensic defense against claims in densely populated areas.

Vieille Test

This method for the stability testing of propellants was proposed by Vieille in 1896. The sample is heated at 110 °C (230 °F) in the presence of a strip of litmus paper, and is then exposed to air at room temperature overnight, after which the cycle is repeated. This treatment is continued until the litmus paper turns red within 1 h. The overall duration of the heating operations thus performed is a measure of the stability.

The advantage of the method is that when the propellant is periodically exposed to the atmosphere it can reabsorb moisture, which means that the decomposition takes place under realistic conditions. The test is now much less frequently applied ever since a powder manufactured with pentanol as a solvent, which had been tested by this method, decomposed onboard two warships that sank from the resulting explosion (1911). The Vieille test is now used only in France and in Belgium.

Volume of Explosion Gases

fume volume; *Normalgasvolumen*; *volume des produits d'explosion*

The volume of the gases (fumes) formed by the explosive reaction, in liters per kilogram of explosive material, as calculated from the chemical composition of the explosive. The calculation of the number of gas moles of the decomposition products takes the equilibria (e.g. water gas equilibrium and Boudourd equilibrium) at the explosion temperature and during cooling to 1500 K into account. Below 1500 K the equilibria are considered as frozen.

Conventionally, the volume of explosion gases refers to 0 °C and 1.013 bar. Water is considered to be gaseous.

The volume can be determined experimentally by test explosion in the → *Bichel Bomb*.

Volume Strength

Same as *Cartridge Strength* or → *Bulk Strength*.

(See also → *Weight Strength*; → *Strength*)

Water-Driven Injector Transport

Emulsionsförderung; *transport par injection d'eau*

The liquid nitrate esters – nitroglycerine and nitroglycol – are highly sensitive to impact; handling of these substances in the factory in free, unbound condition is dangerous. They are conveyed in the form of emulsions: the explosive oil is sucked up by means of a compressed-water-driven injector, and the emulsion is sent through conduit pipes for processing (mixing houses). It is then separated from the carrier water and, if required, is dried by passing through a salt filter.

Water-Gel Explosives

Slurries; *Sprengschlamm*; *bouillies*

See → *Slurries* and → *Emulsion Slurries*.

Water Resistance

Wasserfestigkeit; *résistance a l'eau*

In the USA the following method is employed for testing the water resistance of commercial explosives:

Sixteen regularly spaced holes (about 6 mm in diameter) are cut in the cartridge paper (30 mm in diameter, 200-mm long) of the explosive to be tested, and the flaps on the front faces are sealed with tallow. The cartridges thus prepared are placed in a flat, porcelain-coated dish covered with a thin layer of sand, and water at 17–25 °C (63–77 °F) is poured over the sand layer up to a height of about 25 mm. The cartridges are left underwater for a certain period of time, are then taken out. The seal is cut off at one end, and the cartridge is tested for detonation and transmission with the aid of a No. 6 blasting cap. The water resistance of the explosive is described by the time of exposure to water after which it still retains its capacity to detonate the cartridge in three trials without leaving any nondetonated residual explosive behind.

There is no generally accepted quality classification. Nevertheless, water resistance of an explosive is considered to be satisfactory, acceptable, or poor if the cartridge can still be detonated after 24, 8, or 2 h, respectively.

In Germany, the following method for testing the water resistance of powder-form permissibles has been laid down at the Test Station at Dortmund-Derne:

A train of four cartridges is fixed in a file on a wooden board; the first of the four cartridges is equipped with a detonator No. 8. Five longitudinal; 2 cm long notches, uniformly distributed over the circumference, are cut into each cartridge. The train is immersed for 5 h in water, in a horizontal position, 20 cm under the water surface, after which they are detonated. The train must detonate in its entirety.

This method, including some additions regarding the preparation of the test sample, is standardized as EN 13631-5 as a so-called Harmonized European Standard. The water resistance of partly water- soluble, powder-form explosives (e.g. ammonium nitrate explosives or blasting agents) can be improved by the addition of hydrophobic or gelling agents. If, e.g. → *Guar Gum* is added, the water entering immediately forms a gel which blocks the penetration of more water.

Water-Resistant Detonator

Unterwasserzünder; *détonateur pour tir sous l'eau*

Such detonators differ from conventional detonators in being watertight; water cannot penetrate into the detonator even under increased water pressure (see → *Bridgewire Detonator*).

Water Stemming

Wasserbesatz; *bourrage à l'eau*

Water stemming of explosive-blasted boreholes consists of water-filled cartridges made of plastic material, which give some protection against firedamp and coal dust explosions.

Web

In a solid propellant grain, the minimum distance that can burn through as measured perpendicular to the burning surface (see → *Burning Rate*).

Weight Strength

The strength of an explosive material per unit of weight expressed as a percentage of the weight of a recognized explosive standard.

See also → *Strength*

Wetter

Prefix given to all permitted explosives in Austria and Germany. The powder-form explosives are cartridged and inserted in plastic hoses as a loading device.

All class II and class III explosives belong to the group of ion-exchanged explosives. For test conditions and applicability restrictions see → *Permitted Explosives*.

X-Ray Flash

By using special X-ray tubes and very fast high-voltage circuitry, it is possible to generate and trigger ultrashort X-ray flashes down to the nano/microsecond range.

These X-ray flashes are an important type of short-time photography because they enable fast-occurring phenomena to be recorded by means of X-ray photographs.

In practice, short-time radioscopy of test specimens is used for → *Shaped Charges*. In this way it is possible, during a desired time of detonation, to make a photographic record, in the form of single X-ray photographs, of the penetration and streaming behavior of a sting into a target.

Zinc Peroxide

Zinkperoxid; *peroxyde de zinc*

$n\mathrm{ZnO_2} \cdot \mathrm{Zn(OH)_2}$, $n \geq 3$
light yellow amorphous powder
formula: ZnO_2
molecular weight: 97.38 g/mol
energy of formation: −344.8 kJ/mol
enthalpy of formation: −347.3 kJ/mol
oxygen balance: 16.43%
density: 1.57 g/cm^3
melting point: > 150 °C; (decomposition upwards of 200 °C)

Zinc peroxide is not hygroscopic, and is insoluble in water and organic solvents. The compound results from reaction of an ammoniacal zinc sulfate solution with 30% H_2O_2 at 80–95 °C. The bulk density and oxygen value can be varied over a relatively wide range if certain temperature and concentration conditions are maintained.

Zinc peroxide is used in pyrotechnic mixtures and primer compositions whose reaction products should not contain any corrosive and hazardous components (see → *SINTOX Primer Compositions*).