Chapter 1

INTRODUCTION to PHYSICAL HAZARDS

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Physical hazards are hazards that result from energy and matter and the interrelationships between the two. Conceptually, physical hazards in the workplace can be subdivided into worker–material interfaces, the physical work environment, and energy and electromagnetic radiation. The consequences of exposure to these hazards can be modified by worker protection and a variety of human factors. This chapter will review the general principles of basic physics and worker protection.

Physics is the science of energy and matter and of the interrelationships between the two, grouped in traditional fields such as acoustics, optics, mechanics, thermodynamics, and electromagnetism. Quantum physics deals with very small energy forces; relativity deals with objects traveling at very high speeds (which causes time effects). Thus, physical hazards can be thought of as primarily hazards of energy, temperature, pressure, or time. This broad definition allows for the investigation of many hazards that are otherwise hard to classify but nevertheless represent important issues in the workplace. An understanding of these physical hazards requires familiarity with the two basic concepts of physics: classical mechanics, with its derivatives of thermodynamics and fluid dynamics, and electromagnetic radiation. For measurements, we have used Standard International (SI) units throughout this book, but we have included conversions to other units where they are in common usage. Table 1.1 reviews the standard unit prefixes for mathematics that are used in the physical hazards section. The mathematical equations for principles discussed in this section are included in tables that accompany the text. Although they are not necessary to understand the material, they are presented for those readers who wish to review them.

MECHANICS

Mechanics deals with the effects of forces on bodies or fluids at rest or in motion (Table 1.2). From mechanics, we can get to the study of sound, which is a result of the mechanical vibration of air molecules. The behavior of heat arises from the vibration of molecules. Temperature is proportional to the average random vibrational (in solids) or translational (in liquids and gases) kinetic energy. The physics of pressure arises from the laws of motion and temperature. The laws that govern electricity can be derived from special cases of mechanics (see below), and electromagnetic energy and waves are a direct result of the laws that govern electricity.

Classical mechanics is the foundation of all physics. Galileo (1564–1642) first described the study of kinematics. Kinematics is primarily concerned with uniform straight-line motion and motion where there is uniform acceleration. As a practical example, Galileo used these insights to predict the flight of projectiles. In uniform straight-line motion, velocity (v) is equal to the change in displacement (Δs) divided by the change in time (Δt). Acceleration (a) is the instantaneous change of velocity with respect to time, which is calculated by taking the derivative of velocity with respect to time. Where there is uniform acceleration, the new velocity is equal to the original velocity (v_0) plus acceleration times time. The distance traveled under acceleration is described by a combination of the component traveled at the original velocity plus the component traveled under acceleration. The mathematical equations for these forces are summarized in Table 1.3.

Sir Isaac Newton (1642–1727) originally described the study of mechanics in his 1687 *Philosophiæ Naturalis*

Physical and Biological Hazards of the Workplace, Third Edition. Edited by Gregg M. Stave and Peter H. Wald.

TABLE 1.1 Mathematical unit prefixes.

Prefix	Symbol	Multiplier
Tetra-	T	10^{12}
Giga-	G	10^{9}
Mega-	M	10^{6}
Kilo-	k	10^{3}
Deci-	d	10^{-1}
Centi-	c	10^{-2}
Milli-	m	10^{-3}
Micro-	μ	10^{-6}
Nano-	n	10^{-9}
Pico-	p	10^{-12}

TABLE 1.2 The disciplines of mechanics.

Solid mechanics	
Statics	The study of bodies at rest or equilibrium
Dynamics or kinetics	The study of forces or the change of motion that forces cause
Kinematics	The study of pure motion without reference to forces
Fluid dynamics	
Hydrostatics	The study of still liquids
Hydraulics	The study of the mechanics of moving liquids
Aerodynamics	A special subset of hydraulics that deals with the movement of air around objects

TABLE 1.3 Mathematical expressions of Galileo's description of kinematics.

$v=\Delta s/\Delta t$	Average straight-line velocity
$s=vt$	Distance traveled at constant velocity
$a=dv/dt$	Acceleration (derivative of velocity with respect to time)
$v=v_0+at$	Velocity at straight-line acceleration
$s=v_0t+\frac{1}{2}at^2$	Distance traveled at uniform acceleration

Variables: Δs = change in distance placement, Δt = change in time, v_0 = original velocity, v = velocity, a = acceleration, s = distance, t = time.

Principia Mathematica. He formulated three laws that serve as the foundation of classical mechanics (Table 1.4).

The first law is known as the law of inertia. It states that all matter resists being accelerated and will continue to resist until it is acted upon by an outside force. The second law states that the acceleration of this outside force will be related to the size of that net force (F) but inversely related to the mass (m) of the object. This relationship is described mathematically by the following expression:

$$a \propto \frac{F\text{net}}{m}$$

The third law states that when two bodies exert a force on each other, they do so with an action and reaction pair. The force between two bodies is always an interaction.

TABLE 1.4 Newton's laws of motion.

Newton's first law of motion: A body remains at rest, or if in motion it remains in uniform motion with a constant speed in a straight line, unless it is acted on by an unbalanced external force

Newton's second law of motion: The acceleration produced by an unbalanced force acting on a body is proportional to the magnitude of the net force, in the same direction as the force, and inversely proportional to the mass of the body

Newton's third law of motion: Whenever one body exerts a force upon a second body, the second body exerts a force upon the first body; these forces are equal in magnitude and oppositely directed

A good example of how all three laws operate can be seen at the bowling alley. When a bowling ball is sitting on the rack, the force of the ball pressing down on the rack (gravity) is equal and opposite to the force of the rack pressing up on the ball to resist gravity (the third law). The speed of the bowling ball at the end of the alley is dependent on the amount of acceleration imparted to it. An adult can apply more force to the ball than a child, so the adult's ball will go faster. However, if smaller balls (i.e., of less mass) are used, less force is required; therefore, a child can accelerate the ball to the same speed (the second law). Once the ball leaves your hand, no more net force is applied to the ball (if we ignore friction), and it travels down the alley at a constant speed (the first law).

Mechanics has been central to the advancement of physics. Two mechanical concepts are central to understanding what strategies to adopt in order to prevent injury and illness from physical hazards: kinetic energy and potential energy. In order for physical hazards to affect humans, they must possess energy to impart to the biological system. Energy is commonly described in terms of either force (F) or work (W). Force equals mass times the acceleration, and the result is a vector. $F=ma$ is the mathematical representation of Newton's second law. The work done on an object equals the amount of displacement times the force component acting along that displacement. In the special case of the force acting parallel to the displacement, work equals force times displacement. These two relationships are described mathematically in Table 1.5, equations 1 and 2.

Kinetic energy (KE) is the energy of a mass that is in motion relative to some fixed (inertial) frame. KE is related to the mass of the object, and the speed at which it is traveling (Table 1.5, equation 3). Potential energy (PE) is stored energy that can do work when it is released as kinetic energy.

Since mass and energy are conserved in all interactions, the sums of potential and kinetic energy from before and after an encounter are equal. The equation for kinetic energy is also important for electromagnetic radiation. An electric system can store electric energy in a magnetic field in an induction coil. The kinetic energy of the electric charges equals the amount of work done to set up the field in the coil, which is stored as potential energy.

TABLE 1.5 Mathematical expressions of force, work, and energy.

1. $F = kma$ $= ma$ (if units $=$ kg m/s^2 $=$ newtons)	Force
2. $W = (F \cos\theta)s = F \cdot s$ $= Fs$ (if F and s are parallel)	Work
3. KE $= \frac{1}{2}mv^2$	Kinetic energy—mechanical system
4. PE $= \frac{1}{2}LI^2$	Potential energy—electrical system

Variables: v = velocity, a = acceleration, I = the current (in amperes), k = a constant, L = the inductance of the coil (in henries), m = mass, s = displacement.

Work, kinetic energy and potential energy in this system are related to the inductance of the coil and the current (Table 1.5, equation 4). Potential energy is the potential to do work, and theoretically all this work can be turned into kinetic energy. The expressions for kinetic energy in the mechanical system and potential energy in the electric system have an identical form. This form shows the similarity between kinetic and potential energy in mechanics and electromagnetic radiation and lays the groundwork for examining the electromagnetic wave.

ELECTROMAGNETIC RADIATION

By far the most complicated concept related to the understanding of physical hazards is that of electromagnetic radiation (EMR). Energy can be transmitted directly by collision between two objects, or it can be transmitted by EMR. We see direct examples of energy transfer by EMR when we are warmed by the infrared rays of the sun or burned by its ultraviolet rays. EMR is a continuum of energies with different wavelengths and frequencies. Two similarities of all types of EMR are that they all move at the same speed and they are all produced by the acceleration or deceleration of electric charge. EMR has a dual, particle–wave nature: its energy transfer is best described by a particle, but the behavior of the radiation is best described as a wave. All EMR travels at a constant speed, $c = 3 \times 10^8$ m/s (the speed of light). Each particle of energy, called a photon, is accompanied by an electric field (E-field) and a magnetic field (H-field); these fields are perpendicular to each other and perpendicular to the direction of travel of the wave (Figure 1.1).

It is important to remember that EMR is only produced when an electric charge is moving. Coulomb forces are forces between stationary charges, whereas magnetic forces are due to the motion of charges relative to each other. A moving electric charge (or electric field) induces a magnetic field, and a moving or changing magnetic field induces an electric field. In 1873, James Maxwell linked together these electric and magnetic phenomena into a unified field theory of EMR. As an electric charge moves, it induces a magnetic field, which in turn induces an electric field. The mutual interaction of these two fields is what allows the electromagnetic wave to propagate and what dictates its physical form in Figure 1.1.

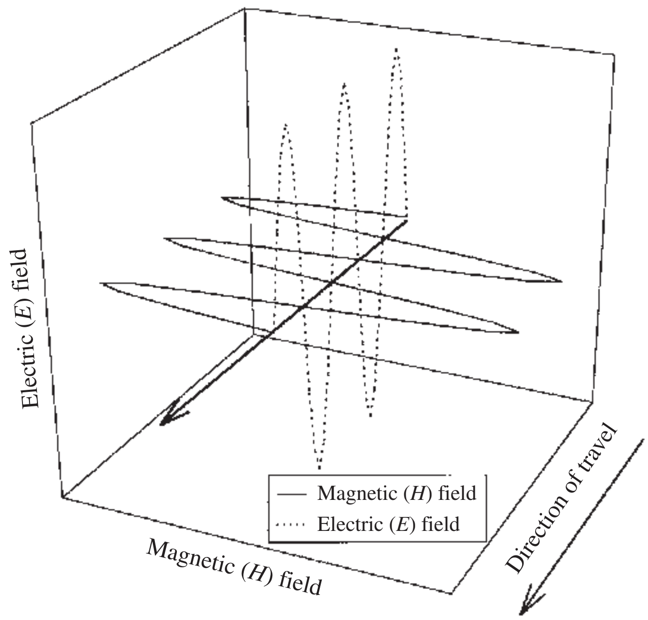

FIGURE 1.1 Stylized representation of an electromagnetic wave.

TABLE 1.6 Mathematical equations for electromagnetic radiation.

1. $E = hv$	Energy in joules
2. $c = v\lambda$	Wavelength and frequency related to the speed of light
3. $\lambda = c/v$, $v = c/\lambda$	Rearrangements of equation 2
4. $E = hc/\lambda$	Energy in joules, by substituting equation 3 into equation 1
5. $E = 12\,400/\lambda$	Energy in electron volts, where λ is in angstroms ($1\,\text{Å} = 10^{-10}$ m)
6. $E = 1:24 \times 10^{-6}/\lambda$	Energy in electron volts, where λ is in meters

Variables: λ = wavelength, v = frequency, c = speed of light (3×10^8 m/s), h = Planck's constant (6.626×10^{-34} Js).

The energy (E) in each photon in the wave can be calculated in joules (J) and is related to the frequency of the radiation in hertz (Hz). Energy is calculated by multiplying the frequency by Planck's constant (6.626×10^{-34} Js). The mathematical representation of this is shown in Table 1.6, equation 1.

Since the velocity at which the wave travels equals the frequency times the wavelength (Table 1.6, equation 2), we can discover the wavelength (λ) for each frequency by dividing 3×10^8 m/s (the speed of light or c) by the frequency (Table 1.6, equation 3). The energy of the wave can also be calculated in terms of the wavelength by substituting the speed of light divided by the wavelength for frequency (Table 1.6, equation 4). In biological systems, it is useful to determine photon energy in electron volts from the wavelength.

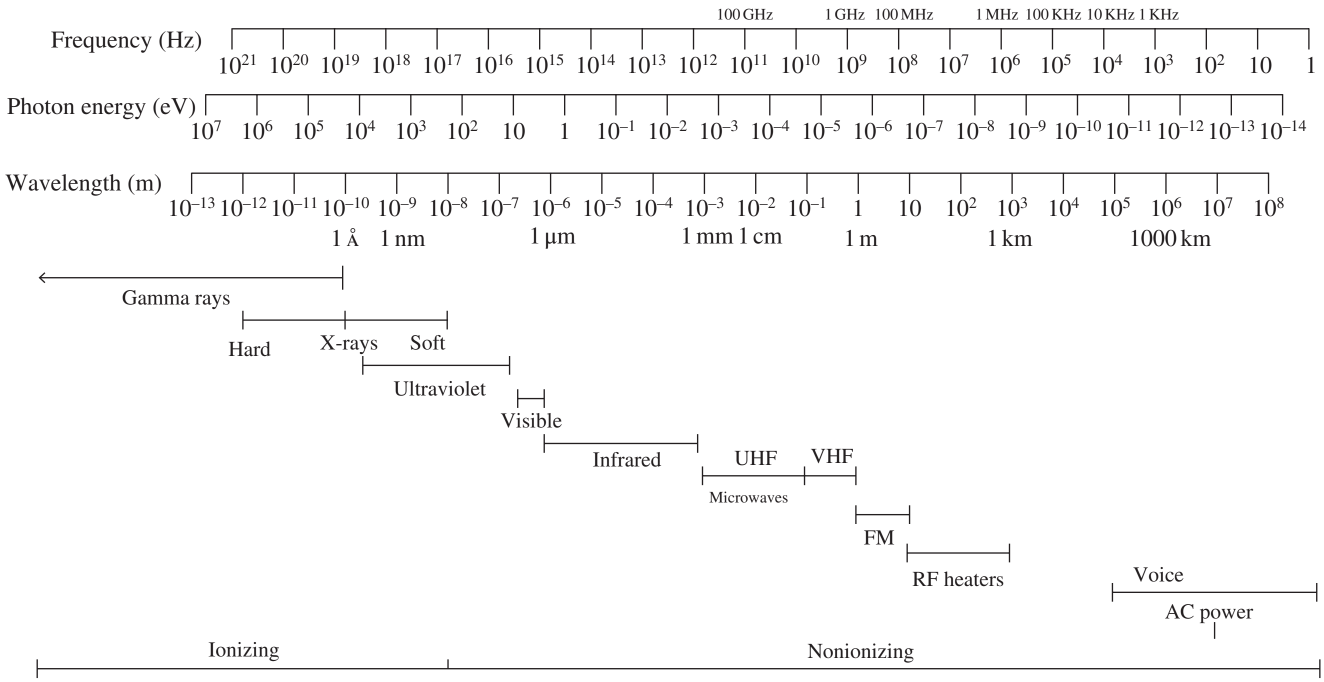

FIGURE 1.2 The electromagnetic spectrum.

This can be calculated from the wavelength in angstroms (Å) according to Table 1.6, equation 5. The electron volt is a convenient unit to use with biological systems, because it takes greater than roughly 10 electron volts (eV) to cause ionization in tissue.

We can also see from equations 1 and 2 in Table 1.6 that the energy of a given type of EMR varies directly with its frequency and inversely with its wavelength. Figure 1.2 shows a representative cross section of the electromagnetic spectrum, with the major classes noted. Notice that there are not strict divisions between the different classes of EMR. An important division in the EMR spectrum relates to the ability to ionize chemical bonds in biological tissue. As frequency increases from the radio bands, so does energy, until ionization potential is reached in the "hard" ultraviolet or "soft" X-ray bands.

A final important point about EMR involves the ways in which it can interact with objects. EMR interacts with biological tissues in one of the following three ways: (i) transmission, where the radiation passes through the tissue without any interaction; (ii) reflection, where the radiation is unable to pass through the air–tissue interface (also called the boundary layer) and is reflected back into space; and (iii) absorption, where the radiation is able to pass through the boundary layer and deposit its energy in the tissue. The frequency of the EMR determines what energy is released in the tissues (heat, electric potential, bond breaking, etc.). These interactions are summarized in Figure 1.3.

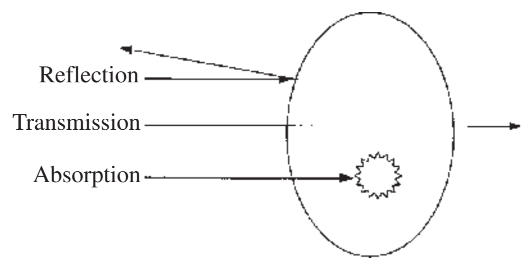

FIGURE 1.3 Interactions of electromagnetic radiation and biological tissue.

WORKER PROTECTION

Potential energy can also be called a potential hazard. The key to avoiding injuries and illnesses is to prevent the individuals in the workplace from being overexposed to the kinetic energy in the hazards. The major characteristics of the physical hazards covered in this text are reviewed in Table 1.7. Each of the following chapters will deal with the most appropriate method to prevent overexposure. However, there are certain recurring themes.

Since we are trying to prevent exposure, the first step is to educate the workforce. A good training program includes education about the potential hazards, the safest procedures to follow for each manufacturing or maintenance operation, correct tool selection and use for each job, use and care of personal protective equipment, and procedures to follow

TABLE 1.7 Major characteristics of the physical hazards.

Hazards	Occupational Settings	Measurement	Exposure Guidelines	Effects of Exposure	Surveillance
Worker–material interfaces					
Repetitive ergonomic hazards—extremities	Service and industrial operations	Repetition, force, posture	OSHA (pending)	Musculoskeletal strain, tunnel syndromes	Survey workers, observe tasks, measure physical parameters of the job
Manual materials handling—backs	Service and industrial operations	Repetition, force, posture	The National Institute for Occupational Safety and Health (NIOSH) lifting guide	Musculoskeletal strain, disk herniation	Survey workers, observe tasks, measure physical parameters of the job
Vibration	Whole body—vehicle/heavy equipment/industrial equipment operator, hand–arm-powered hand tool users	Frequency, motion	ISO 2631, ANSI S3 NIOSH criteria document, ACGIH	Whole body—low back pain. Hand–arm—hand–arm vibration syndrome (HAVS)	Survey workers, observe tasks, measure physical parameters of the job
Mechanical energy—direct injuries	Service and industrial operations	Velocity, distance, acceleration, force, weight, pressure, friction	None	Direct injury	Epidemiology of workplace injuries
The physical work environment					
Hot environments	Hot indoor or outdoor environments	Wet globe bulb temperature, core temperature	ISO 7243, NIOSH criteria document	Heat strain, heat stroke	Heart rate, core temperature, worker selection
Cold environments	Cold indoor or outdoor environments	Wind chill, core temperature	ACGIH-TLV®	Frostbite, trench/immersion foot, hypothermia	Worker selection
High-pressure environments	Divers, caisson workers	Pressure in atmosphere absolute (ATA), changes in pressure	OSHA, marine occupational health safety standards	Barotrauma, decompression sickness, indirect effects secondary to pressure acting on other gases (O_2, N_2)	Worker selection
Low-pressure environments	Aircraft crews, private pilots, astronauts	Pressure in atmosphere absolute (ATA), changes in pressure	None	Barotrauma, decompression sickness, hypoxia	Worker selection
Shift work	Service and industrial operations	Rotation, duration and hour changes of shift schedule	None	Sleep disturbance, gastrointestinal upset	Worker selection

(*Continued*)

TABLE 1.7 (Continued)

Hazards	Occupational Settings	Measurement	Exposure Guidelines	Effects of Exposure	Surveillance
Energy and electromagnetic radiation					
Ionizing radiation	Pilots, underground miners, radiographers, medical and dental X-ray personnel, operators of high-voltage equipment, nuclear power and fuel cycle workers, medical and scientific researchers, some commercial products manufacturing	Personal dosimetry of radiation exposures	NCRP, ICRP, NRC, UNSCEAR	Acute radiation injury, carcinogenesis	Personal dosimetry. Lung and whole-body scanning, biological monitoring as appropriate
Ultraviolet radiation	Outdoor workers, welders, printers	Wavelength, intensity	ACGIH-TLV®	Corneal photokeratitis, skin erythema, cataracts	None
Visible light and infrared radiation	Outdoor workers, welders, printers, glass blowers	Visible duration, wavelength, intensity. Infrared wavelength, intensity	ACGIH-TLV®	Visible scotoma, thermal burn, photosensitivity, urticaria. Infrared-thermal burns, cataracts	None
Laser radiation	Service and industrial operations, researchers, medical personnel, maintenance personnel	Wavelength, power, energy, duration	ACGIH-TLV®, (ANSI Z136.1)	Retinal and skin burns	None
Microwave and radiofrequency (MW/RF) and extremely low-frequency (ELF) radiation	MW/RF—communication workers, industrial heating and RF welding operations. ELF—electricians and electrical workers, telephone and cable workers, electric arc welders, movie projectionists	Frequency, electric field, magnetic field, power density, operating mode	ACGIH-TLV®, OSH	MW/RF—thermal effects. ELF—no proven effects	None
Noise	Service and industrial operations	Time-weighted dBA	NIOSH, OSHA	Noise-induced hearing loss	Hearing conservation program for all exposed workers
Electric power and electrocution injuries	Service and industrial operations	Current, voltage	OSHA	Electrical burns, electrocution	None

TABLE 1.8 Engineering and administrative controls for physical hazards.

Hazards	Engineering Controls	Administrative Controls
Worker–material interfaces		
Repetitive ergonomic hazards—extremities	Repetition—mechanical aids, automation, distribution of tasks across the shift and the workforce	More frequent or longer rest breaks, limit overtime, varying work tasks, rotation of workers between less and more ergonomically stressful jobs
	Force—decrease weight of tools/containers, optimize handles, torque control devices	
	Postures—locate work for mechanical advantage	
Manual materials handling—backs	Same as above	Same as above
Vibration	Whole body—relocate worker away from vibration, mechanically isolate vibration, use vibration-isolating seats in vehicles	Hand–arm—removal from work for significantly affected workers
	Hand–arm—use antivibration tools	
Mechanical energy—direct injuries	Guards, interlocks, proper lighting, nonskid floors	None
The physical work environment		
Hot environments	Air conditioning, increase air movement, insulate and shield hot surfaces, decrease air humidity, shade work area, mechanize heavy work	Use recommended work/rest cycles, work during cool hours of the day, provide cool rest areas, use more workers for a given job, rotate workers between less and more physically stressful jobs, provide fluids for cooling and hydration
Cold environments	Enclose and heat work area	Use recommended work/rest cycles, provide appropriate clothing, provide shelter for break, provide fluids for warming and hydration
High-pressure environments	Engineer a “shirtsleeve” environment which avoids high-pressure work	Work under no decompression guidelines/tables. Adhere to recommended decompression guidelines
Low-pressure environments	Work remotely at low altitude	Wait 12–48 hours after diving to fly, schedule time for acclimation when working at altitude
Shift work	Automate processes to reduce the number of workers/shift	Rotate shifts forward, get worker input for desires of time off and shift design
Energy and electromagnetic radiation		
Ionizing radiation	Shielding, interlocks, increase worker distance to source, warning signs, enclose radionuclides	Worker removal if dose limit reached, minimize exposure times, use radionuclides only in designated areas using safe handling techniques, limited personnel access
Ultraviolet radiation	Enclosure, opaque shielding and/or tinted viewing windows, interlocks, increase worker distance to source, nonreflective surfaces, warning signs	Minimize exposure times, limited personnel access
Visible light and infrared radiation	Enclosure, shielding, interlocks, increase worker distance to source, nonreflective surfaces, warning signs	Limited personnel access
Laser radiation	Enclosure, interlocks, nonreflective surfaces, warning signs	Limited personnel access
Microwave and radiofrequency (MW/RF) and extremely low-frequency (ELF) radiation	MW/RF—wire mesh enclosure, interlocks, increase worker distance to source, warning signs	MW/RF—limited personnel access
	ELF—increase worker distance to source	
Noise	Enclose sources, warning signs	Limited personnel access
Electric power and electrocution injuries	Interlocks, warning signs	Limited personnel access

TABLE 1.9 Commonly used personal protective equipment for physical hazards.

Equipment Type	Hazard Category	Specific Hazard
Helmet	Direct injuries	1. Falling objects 2. Low clearances/"bump hazards"
Safety glasses	1. Direct injuries	1. Flying objects 2. Sparks
	2. Lasers	Retinal burns
Face shield	Direct injury	1. Flying objects 2. Molten metal, sparks
Welding helmet/goggles	1. Direct injury	1. Flying objects 2. Molten metal, sparks
	2. Ultraviolet radiation	Skin/conjunctival burns
Earplugs/earmuffs	Noise	Noise
Fall protection systems—safety belt, body harness, lines, and/or other hardware	Direct injury	Falls
Respirators	Ionizing radiation	α-Emitters: internal contamination
Clothing		
Leather	Heat	Burns
Aluminized	Heat	Heat stroke, burns
Lead	Ionizing radiation	γ-Emitter, X-rays
Fire resistant	Direct injury	Burns
Insulating	Cold	Hypothermia
Disposable	Ionizing radiation	α-Emitter: external contamination
Gloves		
Leather	Direct injury	Abrasions, lacerations
Rubber	Electric injury	Electrocution
Metal mesh	Direct injury	Lacerations
Antivibration	Vibration	Vibration
Footwear		
Steel toe	Direct injury	Falling objects
"Traction sole"	Direct injury	Slips, trips, falls
Rubber	Electric energy	Electrocution

in emergency situations, including fire and loss control, shutdown, rescue, and evacuation.

Substitution of less dangerous equipment or agents is the best protection from hazards, because it totally removes any chance of exposure. However, substitution is often not possible; therefore, worker protection from physical hazards generally focuses on engineering controls. Engineering and administrative controls for physical hazards are summarized in Table 1.8. Often, these controls involve isolation or shielding from the hazard. The most effective isolation involves physically restricting an individual from a hazard area by fencing off the area whenever the hazard is present. Interlocks that inactivate the equipment when the exclusion area is entered are often used to further enhance physical barriers. Alternatively, the hazard can be "locked out" when a worker is present in an area that would become hazardous if the equipment were energized (Chapter 5). This process of excluding maintenance workers from hazardous areas has been institutionalized in the Occupational Safety and Health Administration (OSHA) lockout/tagout (LOTO) standard (Code of Federal Regulations [CFR] 1910.147).

Another way to protect workers is to specifically shield them from the hazard. In some cases, an individual piece of equipment can be shielded to prevent exposure. With some higher-energy hazards, such as ionizing radiation, shielding may be needed in addition to isolation of the equipment. In special cases where it is not practical to shield the hazard (e.g., cold, low pressure), individual workers can be shielded with personal protective equipment, such as jackets or environment suits. In addition, it is sometimes possible to alter the process so as to decrease exposure. This is often the case with hazards affecting the worker–material interface, where engineering design is often inadequate. Personal protective equipment can also be used as an adjunct to engineering controls. Table 1.9 contains a summary of the most common personal protective equipment used for physical hazards.

The final strategy for hazard control is the use of administrative controls. These controls are implemented when exposures cannot be controlled to acceptable levels with substitution, engineering controls, or personal protective equipment. Administrative measures can be instituted to either rotate workers through different jobs to prevent repetitive motion injuries or to remove workers from ionizing radiation exposure once a predetermined exposure level is reached. Although this is not the preferred method of hazard control, it can be effective in some circumstances. Administrative controls are also reviewed in Table 1.8.

The best way to determine what hazards are present in a specific workplace is to go to the site and walk through the manufacturing or service process. There are a number of excellent texts available on evaluating workplaces from both an industrial hygiene and a safety perspective; they are included in the list of further reading at the end of this chapter. An additional point that will become obvious as you read through the text is that there are some significant measurement issues that need to be addressed by an appropriate health professional. Although larger employers will undoubtedly have such a person on staff, at the majority of smaller work sites, no such person will be available.

If you are unfamiliar with the measurement technology, make sure that you (or the employer) retain someone who knows how to perform an exposure assessment. Inaccurate measurements will invalidate the entire process of a prevention program. There are, of course, a number of physical hazards that do not require special measurements and can be handled quite nicely with relatively low-cost safety programs. Several excellent texts describing how to set up general safety programs are included in the further reading list at the end of this chapter.

Finally, remember that the human being is a biological system. For a given exposure, different people will respond differently because of interindividual variation. Most workplace standards are designed with a safety factor to protect against overexposure related to this variation (and to account for any knowledge gaps). In addition, a worker's perception of the hazard must also be taken into account. Some workers may have an exaggerated response to a nonexistent or low-threat hazard, whereas others may not respond appropriately to a series hazard with which they have "grown comfortable." The challenge in assessing and communicating the relative danger entailed by the hazard is to strike the right balance between these two competing tendencies.

The goal of the first section of this volume is to acquaint the reader with the types of physical hazards that may be present in the workplace. Once these hazards are identified at the site, he or she can refer to the specific chapter that addresses the salient measurement issues or offers general strategies to control exposures and monitor effects.

Further Reading

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