

1 Atomic Structure, Periodic Table, Electronic Structure

There is a *smallest* unit of substance. This smallest unit may be only a single atom or a group of atoms chemically joined together.

This chapter deals with the structure of the atom, which is the very backbone of chemistry. In this chapter we introduce the three basic subatomic particles in an atom, their arrangement in the atom, and the similarities of this arrangement revealed by the position of the elements in the periodic table. A clear understanding of this chapter will give you a sound basis for learning chemistry.

OBJECTIVES

After completing this chapter, you will be able to

- define, describe, or illustrate: proton, neutron, electron, atom, nucleus, atomic number, shell, orbital, subshell, alkali metal, noble gas, halogen, alkaline earth, period, group, family, oxide, ductile, malleable, metal, nonmetal, metalloid, and Bohr model of an atom;
- determine the numbers of protons, neutrons, and electrons in a neutral atom when given its mass number and atomic number;
- compare and contrast the three fundamental particles in an atom according to mass and charge;
- determine the maximum number of electrons any given shell can hold;
- determine the maximum number of orbitals in any given shell;
- write the electron configuration for any element;
- determine what element is represented when given its electron configuration;
- use the periodic table to locate different families of elements and determine whether an element is a metal, nonmetal, or metalloid.

- 1** An **atom**, the smallest unit of an element, is composed primarily of three fundamental particles: **electrons**, **protons**, and **neutrons**. The combination of these particles in an atom is distinct for each element. An atom of the element radon is composed primarily of a specific combination of what three basic particles? _____

Answer: electrons, protons, neutrons (any order)

- 2** Let's forget about neutrons for the moment and consider just electrons and protons. Each atom of the same element has the same combination of protons and electrons. An atom of the element hydrogen in outer space has (the same, a different) _____ combination of electrons and protons as that of an atom of hydrogen on earth.

Answer: the same

- 3** Each element has a unique combination of protons and electrons in its atoms. The combination of electrons and protons in an atom of one element is different from that in an atom of any other element. Since each element has a known unique number of protons and electrons in its atoms, would it be possible to identify an element if you know the number of protons and electrons in its atoms? _____

Answer: yes (if you could compare the number of electrons and protons in your unknown atom with a list of the electrons and protons in atoms of each known element)

- 4** Protons are particles with a positive (plus) charge. Electrons are particles with a negative (minus) charge. Unless otherwise stated, an atom is assumed to be **neutral**, with the positive and negative charges being equal. In any neutral atom, the number of electrons (having a negative charge) is always equal to the number of protons (having a positive charge).

An oxygen atom contains eight protons. We assume the atom to be neutral. How many electrons must it have? _____

Answer: eight

- 5** An atom contains 10 electrons. How many protons does it contain? _____

Answer: 10

- 6** Each element has a unique number of electrons and protons in its atoms. Since the number of electrons in a neutral atom is equal to the number of protons, do

you think we can identify an element if we know just the number of protons in its atoms? _____

Answer: yes (if we could compare the number of protons in an atom of the unknown element with a list or table of the number of protons in atoms of every known element)

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The **periodic table** is a very useful table describing the atoms of every known element. A complete periodic table is included in Appendix (see page 399) of this book. Each box in the periodic table represents an element. The one- or two-letter symbol in each box is a shorthand notation used to represent a neutral atom of an element. The symbol “C” represents a neutral atom of the element carbon. The symbol “He” represents a neutral atom of the element helium.

The number of protons in an atom is listed above each symbol. (Ignore the number underneath the symbol, called the “atomic weight,” for the time being as you will get this information from the periodic table. More on that to come.)

6	2
C	He
12.011	4.00260

An atom of carbon has six protons. How many protons does an atom of helium have? _____

Answer: two

Note: The table of atomic weights, located in the Appendix along with the periodic table, lists all the elements alphabetically and gives the symbol for each. (Ignore the atomic weights for now.) You’ll be using the periodic table and the table of atomic weights throughout this book.

8

The number of protons in an atom of an element is called its **atomic number**. What is the atomic number of the element helium (He)? _____

Answer: 2

9

The element iron (Fe) has an atomic number of 26. How many protons does an atom of iron contain? _____

Answer: 26

10

A neutral atom of iron contains how many electrons? _____

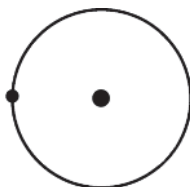
Answer: 26 (the same as the number of protons)

- 11** Using the periodic table, determine the number of electrons in a neutral atom of zinc (Zn). _____

Answer: 30 (the same as the number of protons)

BOHR ATOMIC MODEL

- 12** A Danish physicist, Niels Bohr, came up with a model that pictured the atom with a **nucleus** of protons in the center and electrons spinning in an orbit around it (similar to the movement of the planets around the sun). The following Bohr model contains one orbiting electron and a nucleus of one proton.



What is the atomic number of the element represented? _____

What element is represented? _____

Answer: 1 (The atomic number equals the number of protons.); hydrogen (H)

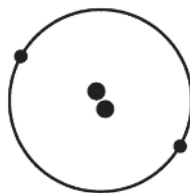
- 13** An electron always carries a negative charge. A proton carries a charge exactly opposite that of the electron. A proton must therefore have a (negative, positive, neutral) _____ charge.

Answer: positive

- 14** An electron has very little mass when compared to a proton. It takes about 1836 electrons to equal the weight of just one proton. In a hydrogen atom consisting of just one proton and one electron, the greatest proportion by weight is accounted for by the (electron, proton) _____.

Answer: proton (The proton accounts for about 99.95% of the weight of a hydrogen atom and the electron 0.05%.)

- 15** The element helium (He), represented by the Bohr model below, has an atomic number of _____.



Answer: 2

16

The neutral atom of He contains how many protons? _____

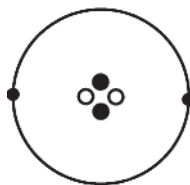
How many electrons? _____

Answer: two; two

17

The weight of an atom of helium is not totally accounted for by the protons and electrons. A third subatomic particle, the **neutron**, is responsible for the additional weight. The neutral atoms of all elements except the most common form of the element hydrogen have one or more neutrons in the nucleus of their atoms. The diagram below shows the neutrons in the corrected Bohr model of helium.

Since a neutral atom contains equal numbers of negatively charged electrons and positively charged protons, what type of electrical charge do you think is possessed by a neutron? _____ (negative, positive, no charge)



*Answer: no charge (The name **neutron** means a neutral particle.)*

18

A neutron is slightly heavier than a proton. Of the primary fundamental particles in an atom:

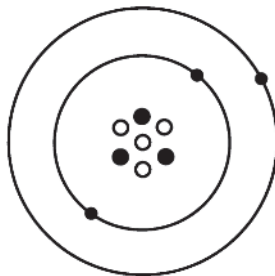
(a) which is the lightest in weight? _____

(b) which is the heaviest? _____

(c) which is between the other two in weight? _____

Answer: (a) the electron; (b) the neutron; (c) the proton

- 19** In the Bohr model of a lithium atom shown below, which subatomic particle(s) is (are) represented by the circular orbits shown by the larger circles? _____
Which particle(s) make(s) up the nucleus or center of the atom? _____



Answer: electrons; protons and neutrons

- 20** If the negative charge of an electron is represented by -1 , the charge on the proton would be $(-1, +1, \text{neutral})$ _____ and the charge on the neutron would be $(-1, +1, \text{neutral})$ _____.

Answer: $+1$; neutral

- 21** Neutrons can be found in all atoms of all elements except the most common form of the simplest element. Identify that element. _____ (Hint: If you don't remember, reread frame 17.)

Answer: hydrogen

You have just learned the names, charges, and relative sizes of the fundamental particles that constitute an atom. You have also been shown one model representing the arrangement of these particles in an atom.

We have referred you to the periodic table and hinted that atoms with certain numbers of protons and electrons are located in a specific place in that table. You learned from your introduction to the periodic table that each atom is identified by a symbol.

We continue this chapter by looking more closely at the periodic table. You will be introduced to specific groups of elements and their physical and chemical properties as they relate to their location on the periodic table. We expand upon the use of symbols and the numbers of each particle in an atom as we prepare to study a second model of an atom.

PERIODIC TABLE

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Look at the periodic table. An atom of each element is represented by a one- or two-letter symbol, such as “C” for carbon and “Al” for aluminum. These symbols serve as shorthand notation for the elements. The shorthand symbol in each case indicates a neutral atom. The symbol “Ca” represents a neutral atom of the element calcium. Remembering the definition of a neutral atom, you know that Ca contains 20 protons and how many electrons? _____

Answer: 20 (A neutral atom contains an equal number of protons and electrons.)

23

The periodic table of the elements is made up of several rows and some columns. The rows are called **periods** and the columns are called **groups**. The groups are labeled IA, IIA, IIIB, and so on. The elements Be, Mg, Ca, Sr, Ba, and Ra are included in which group? _____

Answer: Group IIA

24

The elements Li, Be, B, C, N, O, F, and Ne are all members of a (group, period) _____.

Answer: period

25

Groups are often called **families** because the elements that make up the groups or families have similar chemical properties. Argon (Ar) is part of Group VIIIA. It is a rather unreactive gas. Since families or groups of elements have similar properties, would you expect krypton (Kr) to be a highly reactive gas? _____

Answer: no (All of the elements in Group VIIIA are rather unreactive.)

26

Because all Group VIIIA elements are rather unreactive and are gaseous at room temperature, they have been named the **noble gas** family. An element in Group VIIIA may be generalized by its family name as a(n) (noble gas, alkaline earth, alkali metal) _____.

Answer: noble gas

- 27** Group IA on the left side of the chart is often called by the family name of **alkali metals** (with the exception of hydrogen). These elements can react vigorously with water to form strong alkaline solutions. If a friend told you that aluminum (Al) was an alkali metal, would he be right or wrong? _____

Answer: wrong (Aluminum is located in Group IIIA and the alkali metals are all located in Group IA.)

- 28** Group IIA elements are known as the **alkaline earth** metals because the oxides of these metals (chemical compounds of the metals and oxygen) form alkaline solutions in water. The element potassium (K) can be classified as a(n) (noble gas, alkaline earth, alkali metal) _____.

Answer: alkali metal (Group IA)

- 29** The element Ba (barium) can be classified as a(n) (alkali metal, alkaline earth, or noble gas) _____.

Answer: alkaline earth (Group IIA)

- 30** An unknown element is placed in water. A vigorous reaction takes place, and the result is an alkaline solution. Of which family is the element probably a member: alkaline earth, alkali metal, or noble gas? _____

Answer: alkali metal (Alkali metals react *directly* with water to form alkaline solutions. The *oxides* of alkaline earth elements react with water to form alkaline solutions.)

- 31** The elements in Group VIIA are known as the **halogens**, which means “salt formers.” Elements from the halogen family combine with metals to form compounds known as salts. Common table salt (NaCl) is made up of sodium (Na) and chlorine (Cl). These two elements (Na and Cl) are members of what families or groups?

Na: _____

Cl: _____

Answer: Group IA, the alkali metals (either answer is acceptable); Group VIIA, the halogens (either answer is acceptable).

- 32** Strontium (Sr) is an element in the _____ family. Iodine (I) is an element in the _____ family.

Answer: alkaline earth; halogen

METALS, NONMETALS, AND METALLOIDS

- 33** The periodic table can also be divided into just three classes of elements: the metals, the nonmetals, and the metalloids. In the periodic table, you may have noticed a steplike line. Elements to the left of this line can be classified as **metals** (with the exception of hydrogen). A friend informed you that the element Cu (copper) is a metal. Is your friend correct? _____

Answer: Yes, copper can be classified as a metal.

- 34** Certain properties are characteristic of metals. Metals are usually **malleable** (can be beaten into fine sheets) and **ductile** (can be drawn into wires). Gold leaf is a very thin sheet of gold. In making gold leaf, we are using what common property of metals? _____

Answer: the property of malleability

- 35** Besides being malleable and ductile, metals are also good conductors of heat and electricity. Copper is useful in making electrical wiring. What two metallic properties would be useful in electrical wiring? _____

Answer: The metal is a conductor of electricity and it is ductile (can be drawn into fine wires).

- 36** Metals have a lustrous or shiny surface and are solid at ordinary room temperature (with the exception of mercury, which is liquid at room temperature). Metal cooking utensils take advantage of what two properties of metal? _____ (conducts electricity, conducts heat, ductile, solid)

Answer: Metal conducts heat and is solid.

- 37** **Nonmetals** are located on the right side of the steplike line in the periodic table. Which of the following families of elements are classified as nonmetals? _____ (halogens, alkaline earths, noble gases)

Answer: halogens and noble gases

- 38** Nonmetals have properties almost opposite those of metals. Nonmetals are usually very brittle and do not conduct electricity or heat well. Most nonmetals are gases at ordinary temperatures, although some are liquids or solids. An unknown element exists as a gas at room temperature. How would you classify the unknown element, as a metal or as a nonmetal? _____

Answer: nonmetal (With the exception of mercury, which is liquid at room temperature, all metals are solid at ordinary room temperature.)

- 39** An unknown element is a solid but does not conduct electricity. The element is probably a (metal, nonmetal) _____.

Answer: nonmetal (Some nonmetals are solids, although most are gases at room temperature. Nonmetals do not conduct electricity well, but metals usually do.)

- 40** A third category of elements is classified as **metalloids** because they don't clearly fall into either the metal or nonmetal categories. Metalloids border the steplike line on the periodic table and include elements such as silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), boron (B), tellurium (Te), polonium (Po), and astatine (At). Metalloids could be expected to have some of the properties of metals and some of the properties of _____.

Answer: nonmetals

- 41** Which of the following elements is (are) classified as metalloid: silicon (Si), phosphorus (P), and sulfur (S)? _____

Answer: silicon

MASS AND MASS NUMBER

- 42** The following box represents the element sulfur (S) on the periodic table.

16
S
32.06

The number 16 represents the atomic number of the element sulfur and also represents the number of protons in an atom of sulfur.

Locate the element phosphorus (P) on the periodic table. The number of protons in an atom of phosphorus is _____.

Answer: 15 (same as the atomic number)

- 43** By convention, the atomic number is often written as a subscript preceding an element's symbol. The symbol and number ${}_7\text{N}$ indicates nitrogen with atomic

number of 7. Thus, $_{30}\text{Zn}$ indicates the element zinc with an atomic number of _____.

Answer: 30

44

Almost all of the mass of an atom (more than 99.9%) is attributed to the nucleus. The nucleus is made up largely of which two fundamental particles? _____ (protons, electrons, neutrons)

Answer: protons and neutrons

This is the first time we have referred to mass in this book. **Mass** is a measure of the amount of matter. The mass of an object determines its **weight**. Weight is the effect of gravity on mass. An astronaut may weigh 180 pounds on earth and 30 pounds on the moon and be weightless in space. That person's mass, however, does not change. In the remaining chapters, we will follow the common practice of most chemistry texts and refer to the masses of objects as their weights to prevent confusion between the two terms. In this chapter and Chapter 2 we will use the term **mass**.

45

Adding together the number of protons and neutrons in the nucleus of an atom results in what is known as the mass number of the atom. The **mass number** is simply the number of protons added to the number of neutrons in an atom. Suppose an atom has a mass number of 15. The atom contains eight protons. How many neutrons does it have? _____

Answer: seven (The total number of neutrons and protons is 15, the mass number. If eight protons are present, there must be seven neutrons, since $15 - 8 = 7$.)

46

The element $_{18}\text{Ar}$ has a mass number of 40. How many neutrons does its atom contain? _____

Answer: 22 ($_{18}\text{Ar}$ indicates an atomic number of 18 for element Ar. An atomic number of 18 indicates 18 protons. Mass number is equal to protons plus neutrons, $40 = 18 + 22$.)

47

By convention, the mass number is often written as a superscript in front of the element symbol. $^{40}_{18}\text{Ar}$ indicates the element argon with a mass number of 40 and atomic number of 18.

$^{200}_{80}\text{Hg}$ indicates the element mercury with a mass number of _____ and an atomic number of _____.

Answer: 200; 80

- 48** $^{52}_{24}\text{Cr}$ indicates chromium with _____ protons and _____ neutrons.

Answer: 24; 28

- 49** The element scandium (Sc) contains 21 protons and 24 neutrons in its atom. Write the atomic number and mass number to complete the following symbolic expression.
_____Sc

Answer: $^{45}_{21}\text{Sc}$

- 50** The letter A represents an unknown element. Use the periodic table to identify the element.



Answer: sodium, Na (The subscript 11 represents the atomic number. Sodium is the element with an atomic number of 11.)

- 51** Unknown element X has a mass number of 55 and contains 30 neutrons in its atoms. Identify element X. _____

Answer: Mn (manganese) (A mass number of 55 indicates 55 protons and neutrons. Subtract 30 neutrons from 55; this leaves 25 protons. The number of protons is equal to the atomic number, 25. Manganese has an atomic number of 25.)

- 52** Be (beryllium) contains five neutrons in its atom. Complete the following symbolic expression.
_____Be

Answer: ^9_4Be (Find the atomic number of Be on the periodic table. The atomic number indicates the number of protons. Add the neutrons, five, to the protons, four, to find the mass number.)

- 53** Fill in the required information for the following element: F

- (a) Atomic number: _____
- (b) Mass number: _____
- (c) Number of protons: _____
- (d) Number of neutrons: _____

Answer: (a) 9; (b) 19; (c) 9; (d) 10

You have just learned some properties of metals and nonmetals, the common names of a few families of elements, and how to determine the numbers of protons, neutrons, and electrons in an atom.

Now we are going to look at a model of the atom that helps chemists explain many properties and reactions. Essentially, we will try to develop in your mind a picture of the arrangement of the electrons in an atom and how this arrangement relates to the location of the atom in the periodic table. Later, we will use this arrangement in discussing chemical bonding, chemical reactions, and chemical properties.

QUANTUM ATOMIC MODEL

The model we discuss has evolved from the study of quantum mechanics (a theoretical mathematical approach to the study of atomic and molecular structure). We do not attempt an in-depth presentation here. Instead, we present some of the basic concepts so you may use them later in this book or build upon them in other chemistry courses.

Keep in mind that we are studying the basic model of a *very complex* theory. A good way to help you remember the model is to compare it to an apartment building. An apartment building has different floors, different apartments on each floor, and different rooms within each apartment.

We can look upon the electrons of an atom as rather peculiar apartment dwellers. Electrons prefer the floor closest to the ground and the smallest apartments. Electrons also prefer to live one to a room until each room in an apartment has one occupant. The electrons will then pair up until each room has two. Each room in the apartment can hold only two electrons.

Apartment buildings may have several floors. The model we discuss has several floors, but only the first seven floors will be occupied. All the electrons of the elements known today will fit within seven floors of the building. Additional floors are available but will be occupied only in special cases.

54

The floors in the apartment building are called **shells** in the electron model and are numbered 1 through 7. According to what you have just read, what shell will be occupied first by electrons? _____

Answer: shell 1 (the first floor)

55

Each shell (or floor) in the model has one or more apartments, which are called **subshells**. These subshells are apartments of four sizes: **s**, **p**, **d**, and **f**. An **s** subshell (apartment) has only a single room. A **p** subshell has three rooms. A **d**

subshell has five rooms, while an f subshell has seven rooms. An s subshell then will hold a maximum of two electrons according to the model.

- (a) A p subshell will hold a maximum of how many electrons? _____
- (b) How many will a d subshell hold? _____
- (c) How many will an f subshell hold? _____

Answer: (a) six (three rooms $\times$ two electrons/room); (b) 10 (five rooms $\times$ two electrons/room); (c) 14 (seven rooms $\times$ two electrons/room).

56

Each room in a subshell is called an **orbital**. From frame 55 we know, then, that an s subshell will consist of one orbital with a capacity (occupancy) of two electrons.

- (a) A p subshell will consist of three orbitals with a total subshell capacity of _____ electrons.
- (b) A d subshell will consist of _____ orbitals with a total subshell capacity of _____ electrons.
- (c) An f subshell will consist of _____ orbitals and hold _____ electrons.

Answer: (a) six (three orbitals $\times$ two electrons, or two electrons/orbital); (b) five, 10; (c) seven, 14.

57

The first shell (floor) has only one subshell (apartment), which is an s subshell. Because of its location on the first shell, it is called a $1s$ subshell.

- (a) How many orbitals (rooms) are there in this $1s$ subshell? _____
- (b) How many electrons will the subshell hold? _____

Answer: (a) one (s subshells have only one orbital.); (b) two (Each orbital holds only two electrons.)

58

The second shell (floor) only has an s subshell (apartment) and a p subshell.

- (a) If the s subshell is called $2s$, what do you suppose the p subshell is called? _____
- (b) How many orbitals (rooms) are in that p subshell? _____
- (c) How many subshells are in the second shell? _____
- (d) How many orbitals are there in the second shell? _____
- (e) How many electrons can occupy the second shell? _____

Answer: (a) $2p$; (b) three (p subshells have three orbitals.); (c) two (s and p); (d) four (one s orbital and three p orbitals); (e) eight ($4 \text{ orbitals} \times 2 \text{ electrons/orbital}$).

59

The third shell has three subshells: s , p , and d .

- (a) What are they called? _____
- (b) How many subshells are in the third shell? _____
- (c) How many orbitals are in the third shell? _____
- (d) How many electrons can be in the third shell? _____

Answer: (a) $3s$, $3p$, $3d$; (b) three; (c) nine (one s orbital, three p orbitals, and five d orbitals); (d) 18 ($9 \text{ orbitals} \times 2 \text{ electrons/orbital}$).

60

Shells 4 through 7 each have four subshells: s , p , d , and f .

- (a) What would you call the subshells in the fourth shell? _____
- (b) What would you call the subshells in the sixth shell? _____

Answer: (a) $4s$, $4p$, $4d$, $4f$; (b) $6s$, $6p$, $6d$, $6f$

61

How many subshells are there in the fifth shell? _____

How many subshells are there in the seventh shell? _____

Answer: four; four

62

How many orbitals are there in the fourth shell? _____

How many electrons will that shell hold? _____

Answer: 16 (one s orbital, three p orbitals, five d orbitals, and seven f orbitals); 32 ($16 \text{ orbitals} \times 2 \text{ electrons/orbital}$).

63

Let's review what we have just learned. Assume that we have only seven floors in our "building."

- (a) A shell may have as many as _____ subshells or as few as _____ subshell(s).
- (b) A subshell may have as many as _____ orbitals or as few as _____ orbital(s).
- (c) A subshell may hold as many as _____ electrons or as few as _____ electron(s), assuming full occupancy.

- (d) A shell may hold as many as _____ electrons or as few as _____ electron(s), assuming full occupancy.

Answer: (a) four, one; (b) seven, one; (c) 14, two; (d) 32, two

As we have mentioned previously, electrons prefer the lower shells (floors) and the smaller subshells (apartments). Electrons prefer the smaller subshells to such a degree that they will sometimes occupy a smaller subshell on the next higher shell rather than the larger subshell on the lower shell.

By experimentation, it has been determined that electrons will fill the $1s$ subshell (apartment) first. They will then fill the $2s$ subshell and then the $2p$ subshell. Next, they will fill the $3s$ subshell and then the $3p$ subshell. However, before going into the large five-orbital $3d$ subshell, electrons will first fill the $4s$ subshell. After filling the $4s$ subshell, electrons will then proceed to fill the $3d$ subshell. The $4p$ subshell is filled next. The electrons prefer to fill the small $5s$ subshell before filling the larger $4d$ subshell. The $4d$ is filled after $5s$. Next, the electrons fill the $5p$ subshell. Then the small $6s$ subshell is filled. The very large $4f$ subshell is occupied only after $6s$ is filled. After $4f$ comes $5d$. Next is $6p$, then $7s$, and then $5f$.

A diagram to help you remember the order of filling the subshells appears on page 17.

Note that as we fill consecutive subshells, the energy of the electrons increases. Electrons in the $2s$ subshell have a higher energy than electrons in the $1s$ subshell; $2p$ electrons have a higher energy than $2s$ electrons, and so on.

64

Using the diagram, which subshell is filled first? _____

Answer: $1s$

65

Is the $4s$ subshell filled before or after the $3d$ subshell? _____

Answer: before

66

Neon has 10 electrons. The order of filling its subshells is first $1s$, then $2s$, and finally $2p$. What is the order of filling the subshells in an atom of magnesium (Mg)? (Use the periodic table to determine the number of electrons in an atom of magnesium.) _____

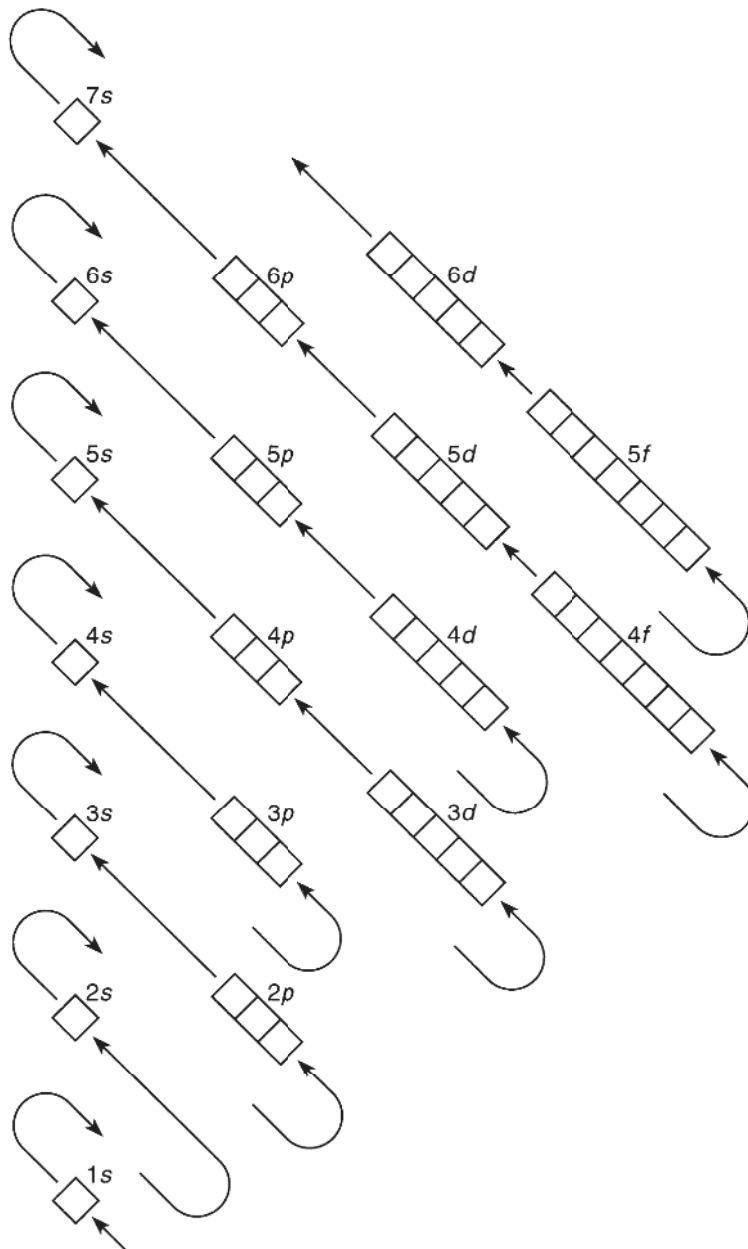
Answer: Since there are 12 electrons in an atom of magnesium, the order of filling of the subshells is $1s\ 2s\ 2p\ 3s$.

67

The notation shown on page 17 is used to indicate the number of electrons in each subshell of an atom. For example, neon has 10 electrons; therefore its subshells are written as $1s^2\ 2s^2\ 2p^6$. The numbers to the upper right of each subshell indicate the number of electrons in each subshell. If we add these numbers ($2 + 2 + 6 = 10$), we get the number of electrons in a neon atom.

How would you use this notation for the magnesium (Mg) atom?

Answer: $1s^2 2s^2 2p^6 3s^2$ ($2 + 2 + 6 + 2 = 12$)



Order of filling of subshells and approximate energy ranking

ELECTRON CONFIGURATION

68

You have just learned the notation a chemist uses to indicate the arrangement of electrons in an atom. This arrangement is called its **electron configuration**. Use the diagram on page 17 to determine the electron configuration of argon, $_{18}\text{Ar}$. _____

Answer: $1s^2 2s^2 2p^6 3s^2 3p^6$

69

Chlorine ($_{17}\text{Cl}$) is an example of an atom in which the last subshell is not completely filled. Its electron configuration is $1s^2 2s^2 2p^6 3s^2 3p^5$. Note that the $3p$ subshell has only five electrons and all other subshells are filled.

Oxygen is another example of an atom in which the last subshell is unfilled. What is its electron configuration? _____

Answer: $1s^2 2s^2 2p^4$ ($2 + 2 + 4 = 8$ electrons)

70

What are the electron configurations of the following elements?

(a) Potassium (K) _____

(b) Arsenic (As) _____

Answer: (a) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$; (b) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$

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We can also identify an atom if we are given its electron configuration. For example, the configuration $1s^2 2s^2 2p^6 3s^2 3p^1$ has 13 electrons. Only the aluminum atom has 13 electrons; therefore this configuration must be that of an aluminum atom.

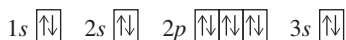
What atom has the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^4$? _____

Answer: sulfur, S ($2 + 2 + 6 + 2 + 4 = 16$)

Another way to represent the arrangement of electrons around an atom is to use arrows as electrons and boxes to represent orbitals (see frame 72). The boxes become occupied by electrons as we “build up” the atoms of each element in the periodic table. Remember, only one electron will occupy an orbital in a given subshell until all the orbitals in that subshell have one electron in them. Then and only then will a second electron occupy each orbital.

72

Using this method, the electron arrangement for $_{12}\text{Mg}$ follows.



The arrow notation for $_7\text{N}$ is



Note the unpaired or single electrons in the partially filled $2p$ subshell. The electrons occupy as many orbitals as possible in the same subshell before pairing with another electron. This is known as the **Principle of Maximum Multiplicity**.

Using the Principle of Maximum Multiplicity and the arrow notation, indicate the arrangement of electrons for the following:

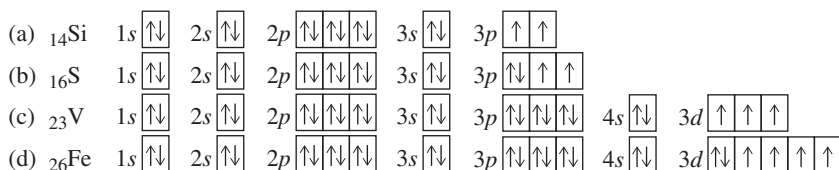
(a) $_{14}\text{Si}$ _____

(b) $_{16}\text{S}$ _____

(c) $_{23}\text{V}$ _____

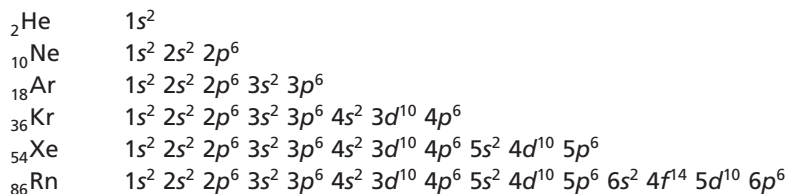
(d) $_{26}\text{Fe}$ _____

Answer:



73

The electron configurations of the naturally occurring noble gases are given below.



With the exception of $_2\text{He}$, the subshell of greatest energy (last subshell) in each noble gas consists of six electrons occupying a(n) (s , p , d , f) subshell.

Answer: p

74

With the exception of $_2\text{He}$, the similar properties of the noble gases are due to their similar electron configuration.

Noble gas	Subshells of the outermost shell
$_{10}\text{Ne}$	$2s^2 2p^6$
$_{18}\text{Ar}$	$3s^2 3p^6$
$_{36}\text{Kr}$	$4s^2 4p^6$
$_{84}\text{Xe}$	$5s^2 5p^6$
$_{86}\text{Rn}$	$6s^2 6p^6$

The subshell of greatest energy of each noble gas (mark the correct answer):

- _____ (a) is completely filled with electrons.
 _____ (b) is half-filled with electrons.
 _____ (c) can take one more electron each.

Answer: (a) (Only six electrons can occupy the orbitals in a p subshell.)

75

The electron configurations of the naturally occurring halogens are as follows.

$_{9}\text{F}$	$1s^2 2s^2 2p^5$
$_{17}\text{Cl}$	$1s^2 2s^2 2p^6 3s^2 3p^5$
$_{35}\text{Br}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$
$_{53}\text{I}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^5$
$_{85}\text{At}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^5$

The incomplete subshell in each halogen is made up of how many electrons?

_____ In what subshell? _____

Answer: five; p

76

The electron configurations of the alkaline earth metals are as follows.

$_{4}\text{Be}$	$1s^2 2s^2$
$_{12}\text{Mg}$	$1s^2 2s^2 2p^6 3s^2$
$_{20}\text{Ca}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
$_{38}\text{Sr}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$
$_{56}\text{Ba}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2$
$_{88}\text{Ra}$	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^2$

The subshell of the outermost shell in each alkaline earth is made up of _____ electrons in a(n) _____ subshell.

Answer: two; s

77

Each group of elements in the periodic table has similar subshells with similar numbers of electrons in the **outermost shell**. The outermost shell consists

of the subshells that are filled last. This situation serves to explain the (similar, greatly different) _____ chemical properties of elements within the same groups.

Answer: similar

The knowledge of what constitutes an atom is important to the discussion of atomic weights and molecular weights. The arrangement of the electrons around the atom is important to the discussion of chemical bonding, chemical formulas, and chemical properties—all topics of later chapters. What you have learned so far will be the springboard to a greater understanding of chemistry as you continue your study.

Self-Test

This self-test is designed to show how well you have mastered this chapter's objectives. Correct answers and review instructions follow the test.

1. Write the number of the item on the right that *best* describes each item on the left. You may use the periodic table if you wish.

_____	(a) proton	(1) an alkaline earth
_____	(b) Sr	(2) a halogen
_____	(c) Li	(3) a noble gas
_____	(d) Br	(4) an alkali metal
_____	(e) electron	(5) responsible for nuclear charge
		(6) occupies subshells

2. How many electrons, protons, and neutrons does a neutral K atom have?

_____ protons
_____ neutrons
_____ electrons

3. What is the electron configuration of the element in question 2?

4. How many electrons, protons, and neutrons does a neutral Mg atom have?

_____ protons
_____ neutrons
_____ electrons

5. What is the electron configuration of the element in question 4?

6. What is the outermost subshell electron configuration common to all of the halogens? _____
7. What is the outermost subshell electron configuration common to all of the alkali metals? _____
8. A substance that shines and conducts heat and electricity is a (metal, non-metal, metalloid) _____.
9. A substance that is usually very brittle and does not heat well is a (metal, nonmetal, metalloid) _____.
10. Silicon and antimony belong to the class of elements known as the (metals, nonmetals, metalloids) _____.
11. Iodine and xenon belong to the class of elements known as the (metals, nonmetals, metalloids) _____.
12. What element has the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^3$?
_____ In what group would it be found in the periodic table?

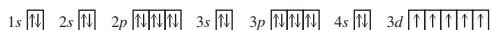
13. What element has the electron configuration $1s^2 2s^2 2p^5$? _____ In what group would it be found in the periodic table? _____
14. How would you write the box and arrow notation for ${}_{25}\text{Mn}$? _____
15. How would you write the box and arrow notation for ${}_{15}\text{P}$? _____

Answers

Compare your answers to the self-test with those given below. If you answer all questions correctly, you are ready to proceed to the next chapter. If you miss any, review the frames indicated in parentheses after the answers. If you miss several questions, you should probably reread the chapter carefully.

1.
 - (a) 5 (frames 12, 13)
 - (b) 1 (frames 28, 76)
 - (c) 4 (frames 27, 30)
 - (d) 2 (frames 31, 75)
 - (e) 6 (frames 54–63)
2. 19; 20; 19 (frames 42–53)

3. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$ (frames 64–76)
4. 6; 6; 6 (frames 42–53)
5. $1s^2 2s^2 2p^2$ (frames 64–76)
6. p^5 (frame 75)
7. s^2 (frame 76)
8. metal (frame 35)
9. nonmetal (frame 38)
10. metalloid (frame 40)
11. nonmetals (frame 37)
12. phosphorus, Group VA (frames 71–77)
13. fluorine, Group VIIA (frames 71–77)
- 14.



(frames 72–76)

- 15.



(frames 72–76)

ELECTRONS IN FORENSIC CHEMISTRY

The electronic structure of an atom can provide us a wide range of information. In this chapter you learned about protons, neutrons, and electrons as well as where these subatomic particles are located within an atom. Not only that, you also learned specifically about electrons and their unique configurations within an atom's orbitals. However, did you know that scientific research, as well as forensic science, makes use of these electrons in performing investigative analyses?

For instance, residue is deposited on the hands and clothing of a person who discharges a firearm. This is known as gunshot residue (GSR). A person's clothing and skin can be analyzed to see whether the person has discharged a firearm. When a gun is fired, burned and unburned particles from the primer are blown back onto the person who pulled the trigger. This residue usually consists of lead, antimony, and barium or at least antimony and barium. The suspect's hand is carefully swabbed, and the residue is collected for analysis by cyclic voltammetry or a potentiometer.

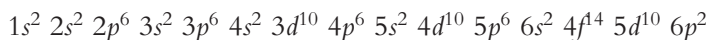
A variety of techniques exists for analyzing GSR, but one older method focuses on exciting the electrons found within lead, antimony, and barium. Once a GSR sample is obtained, it can be analyzed using atomic absorption spectrophotometry (AAS).



Figure 1 An atomic absorption spectrometer

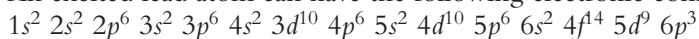
In AAS, the GSR sample is atomized (sprayed as a fine droplet mist) into the AAS's flame or graphite furnace to make gaseous atoms. The atoms within the spray are exposed to ultraviolet or visible light in the hot furnace. As this process occurs, the free atoms of lead, antimony, and barium absorb ultraviolet (UV) or visible light and become excited. Other atoms within the GSR sample will become excited as well.

Before we go any further, let's look at lead's electronic configuration. The lead atom has a total of 82 electrons with the following electronic configuration within its normal, or ground, state:



(Ground state electronic configuration is needed for reference to the excited state. The ground state of an atom is its “resting” state.)

An excited lead atom can have the following electronic configuration:



Notice that an electron from the outer $5d$ orbital was excited to the outer $6p^2$ orbital, resulting in $6p^3$. This excitation of an electron is the result of the lead atom absorbing radiation. In order for the atom to return to its normal state, its promoted electron must return back to the $5d$ orbital.

When this transition occurs, UV or visible light is released by the atom and picked up by the detector. Each atom has its own unique wavelengths of emitted UV or visible light. Based on known standards, chemists can confirm the presence or absence of a particular element in a sample. In this case, lead can be confirmed along with antimony and barium.

Developments in instrumentation continue, and AAS often has been replaced by more advanced techniques. However, AAS utilizes electrons from excited atoms to confirm the presence and quantity of such elements. This technique will always have a home in instrumental analysis as well as in forensic chemistry.

