Sample Exercise 2.1 Atomic Size

The diameter of a U.S. dime is 17.9 mm, and the diameter of a silver atom is 2.88 Å. How many silver atoms could be arranged side by side across the diameter of a dime?

Solution

The unknown is the number of silver (Ag) atoms. Using the relationship 1 Ag atom = 2.88 Å as a conversion factor relating number of atoms and distance, we start with the diameter of the dime, first converting this distance into angstroms and then using the diameter of the Ag atom to convert distance to number of Ag atoms:

$$\text{Ag atoms} = (17.9\ \cancel{\text{mm}})\left(\frac{10^{-3}\ \cancel{\text{m}}}{1\ \cancel{\text{mm}}}\right)\left(\frac{1\ \cancel{\text{Å}}}{10^{-10}\ \cancel{\text{m}}}\right)\left(\frac{1\ \text{Ag atom}}{2.88\ \cancel{\text{Å}}}\right)$$
$$= 6.22 \times 10^{7}\ \text{Ag atoms}$$

That is, 62.2 million silver atoms could sit side by side across a dime!

Practice Exercise 1

Which of the following factors determines the size of an atom? **(a)** the volume of the nucleus **(b)** the volume of space occupied by the electrons of the atom **(c)** the volume of a single electron, multiplied by the number of electrons in the atom **(d)** the total nuclear charge **(e)** the total mass of the electrons surrounding the nucleus

Practice Exercise 2

The diameter of a carbon atom is 1.54 Å. **(a)** Express this diameter in picometers. **(b)** How many carbon atoms could be aligned side by side across the width of a pencil line that is 0.20 mm wide?

Sample Exercise 2.2 Determining the Number of Subatomic Particles in Atoms

How many protons, neutrons, and electrons are in an atom of **(a)** ^{197}Au, **(b)** strontium-90?

Solution

(a) The superscript 197 is the mass number (protons + neutrons). According to the list of elements given on the front inside cover, gold has atomic number 79. Consequently, an atom of ^{197}Au has 79 protons, 79 electrons, and 197 – 79 = 118 neutrons.

(b) The atomic number of strontium is 38. Thus, all atoms of this element have 38 protons and 38 electrons. The strontium-90 isotope has 90 – 38 =52 neutrons.

Practice Exercise 1

Which of these atoms has the largest number of neutrons?
(a) ^{148}Eu **(b)** ^{157}Dy **(c)** ^{149}Nd **(d)** ^{162}Ho **(e)** ^{159}Gd

Practice Exercise 2

How many protons, neutrons, and electrons are in an atom of
(a) ^{138}Ba, **(b)** phosphorus-31?

Sample Exercise 2.3 Writing Symbols for Atoms

Magnesium has three isotopes with mass numbers 24, 25, and 26. **(a)** Write the complete chemical symbol (superscript and subscript) for each. **(b)** How many neutrons are in an atom of each isotope?

Solution

(a) Magnesium has atomic number 12, so all atoms of magnesium contain 12 protons and 12 electrons. The three isotopes are therefore represented by $^{24}_{12}Mg$, $^{25}_{12}Mg$, and $^{26}_{12}Mg$. **(b)** The number of neutrons in each isotope is the mass number minus the number of protons. The numbers of neutrons in an atom of each isotope are therefore 12, 13, and 14, respectively.

Practice Exercise 1

Which of the following is an incorrect representation for a neutral atom?
(a) $^{6}_{3}Li$ **(b)** $^{13}_{6}C$ **(c)** $^{63}_{30}Cu$ **(d)** $^{30}_{15}P$ **(e)** $^{108}_{47}Ag$

Practice Exercise 2

Give the complete chemical symbol for the atom that contains 82 protons, 82 electrons, and 126 neutrons.

Sample Exercise 2.4 Calculating the Atomic Weight of an Element from Isotopic Abundances

Naturally occurring chlorine is 75.78% ^{35}Cl (atomic mass 34.969 amu) and 24.22% ^{37}Cl (atomic mass 36.966 amu). Calculate the atomic weight of chlorine.

Solution

We can calculate the atomic weight by multiplying the abundance of each isotope by its mass and summing these products. Because 75.78% = 0.7578 and 24.22% = 0.2422, we have

$$\begin{aligned}\text{Atomic weight} &= (0.7578)(34.969\text{ amu}) + (0.2422)(36.966\text{ amu})\\ &= 26.50\text{ amu} + 8.953\text{ amu}\\ &= 35.45\text{ amu}\end{aligned}$$

This answer makes sense: The atomic weight, which is actually the average atomic mass, is between the masses of the two isotopes and is closer to the value of ^{35}Cl, the more abundant isotope.

Practice Exercise 1

There are two stable isotopes of copper found in nature, ^{63}Cu and ^{65}Cu. If the atomic weight of copper Cu is 63.546 amu, which of the following statements are true?

(a) ^{65}Cu contains two more protons than ^{63}Cu.
(b) ^{63}Cu must be more abundant than ^{65}Cu.
(c) All copper atoms have a mass of 63.546 amu.

Sample Exercise 2.4 Calculating the Atomic Weight of an Element from Isotopic Abundances

Continued

Practice Exercise 2

Three isotopes of silicon occur in nature: ^{28}Si (92.23%), atomic mass 27.97693 amu; ^{29}Si (4.68%), atomic mass 28.97649 amu; and ^{30}Si (3.09%), atomic mass 29.97377 amu. Calculate the atomic weight of silicon.

Sample Exercise 2.5 Using the Periodic Table

Which two of these elements would you expect to show the greatest similarity in chemical and physical properties: B, Ca, F, He, Mg, P?

Solution

Elements in the same group of the periodic table are most likely to exhibit similar properties. We therefore expect Ca and Mg to be most alike because they are in the same group (2A, the alkaline earth metals).

Practice Exercise 1

A biochemist who is studying the properties of certain sulfur (S)–containing compounds in the body wonders whether trace amounts of another nonmetallic element might have similar behavior. To which element should she turn her attention? **(a)** F **(b)** As **(c)** Se **(d)** Cr **(e)** P

Practice Exercise 2

Locate Na (sodium) and Br (bromine) in the periodic table. Give the atomic number of each and classify each as metal, metalloid, or nonmetal.

Sample Exercise 2.6 Relating Empirical and Molecular Formulas

Write the empirical formulas for **(a)** glucose, a substance also known as either blood sugar or dextrose—molecular formula $C_6H_{12}O_6$; **(b)** nitrous oxide, a substance used as an anesthetic and commonly called laughing gas—molecular formula N_2O.

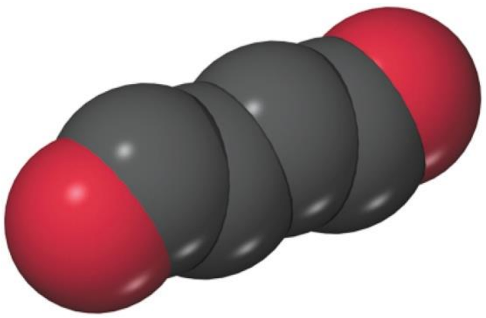
Solution

(a) The subscripts of an empirical formula are the smallest whole-number ratios. The smallest ratios are obtained by dividing each subscript by the largest common factor, in this case 6. The resultant empirical formula for glucose is CH_2O.

(b) Because the subscripts in N_2O are already the lowest integral numbers, the empirical formula for nitrous oxide is the same as its molecular formula, N_2O.

Practice Exercise 1

Tetracarbon dioxide is an unstable oxide of carbon with the following molecular structure:



What are the molecular and empirical formulas of this substance?
(a) C_2O_2, CO_2 **(b)** C_4O, CO **(c)** CO_2, CO_2
(d) C_4O_2, C_2O **(e)** C_2O, CO_2

Practice Exercise 2

Give the empirical formula for decaborane, whose molecular formula is $B_{10}H_{14}$.

Sample Exercise 2.7 Writing Chemical Symbols for Ions

Give the chemical symbol, including superscript indicating mass number, for **(a)** the ion with 22 protons, 26 neutrons, and 19 electrons; and **(b)** the ion of sulfur that has 16 neutrons and 18 electrons.

Solution

(a) The number of protons is the atomic number of the element. A periodic table or list of elements tells us that the element with atomic number 22 is titanium (Ti). The mass number (protons plus neutrons) of this isotope of titanium is 22 + 26 = 48. Because the ion has three more protons than electrons, it has a net charge of 3+ and is designated $^{48}Ti^{3+}$.

(b) The periodic table tells us that sulfur (S) has an atomic number of 16. Thus, each atom or ion of sulfur contains 16 protons. We are told that the ion also has 16 neutrons, meaning the mass number is 16 + 16 = 32. Because the ion has 16 protons and 18 electrons, its net charge is 2– and the ion symbol is $^{32}S^{2-}$.

In general, we will focus on the net charges of ions and ignore their mass numbers unless the circumstances dictate that we specify a certain isotope.

Practice Exercise 1

In which of the following species is the difference between the number of protons and the number of electrons largest?
(a) Ti^{2+} **(b)** P^{3-} **(c)** Mn **(d)** Se^{2-} **(e)** Ce^{4+}

Practice Exercise 2

How many protons, neutrons, and electrons does the $^{79}Se^{2-}$ ion possess?

Sample Exercise 2.8 Predicting Ionic Charge

Predict the charge expected for the most stable ion of barium and the most stable ion of oxygen.

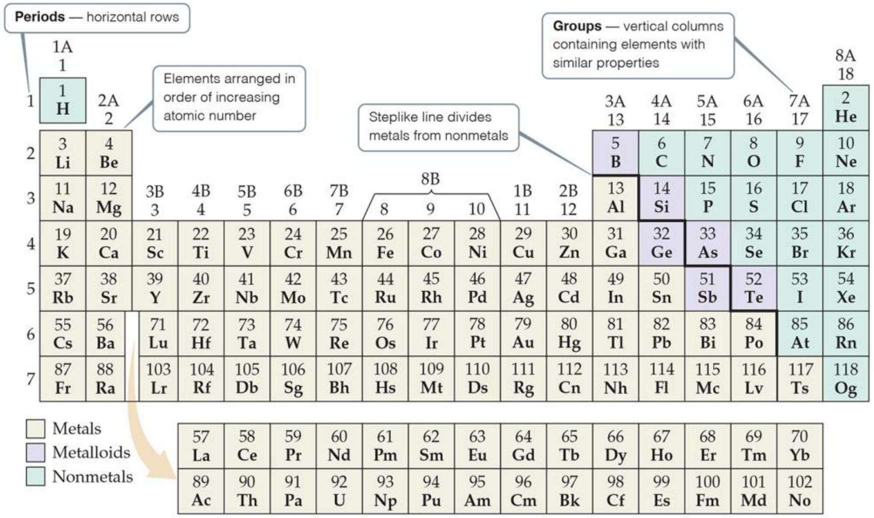
Solution

We will assume that barium and oxygen form ions that have the same number of electrons as the nearest noble-gas atom. From the periodic table, we see that barium has atomic number 56. The nearest noble gas is xenon, atomic number 54. Barium can attain a stable arrangement of 54 electrons by losing two electrons, forming the Ba^{2+} cation.

Oxygen has atomic number 8. The nearest noble gas is neon, atomic number 10. Oxygen can attain this stable electron arrangement by gaining two electrons, forming the O^{2-} anion.

Practice Exercise 1

Although it is helpful to know that many ions have the electron arrangement of a noble gas, many elements, especially among the metals, form ions that do not have a noble-gas electron arrangement. Use the periodic table, Figure 2.14, to determine which of the following ions has a noble-gas electron arrangement, and which do not. For those that do, indicate the noble-gas arrangement they match: **(a)** Ti^{4+}, **(b)** Mn^{2+}, **(c)** Pb^{2+}, **(d)** Te^{2-}, **(e)** Zn^{2+}.



Practice Exercise 2

Predict the charge expected for the most stable ion of **(a)** aluminum and **(b)** fluorine.

Sample Exercise 2.9 Identifying Ionic and Molecular Compounds

Which of these compounds would you expect to be ionic: N_2O, Na_2O, $CaCl_2$, SF_4?

Solution

We predict that Na_2O and $CaCl_2$ are ionic compounds because they are composed of a metal combined with a nonmetal. We predict (correctly) that N_2O and SF_4 are molecular compounds because they are composed entirely of nonmetals.

Practice Exercise 1

Which of these compounds are molecular: CBr_4, FeS, P_4O_6, PbF_2?

Practice Exercise 2

Give a reason why each of the following statements is a safe prediction:

(a) Every compound of Rb with a nonmetal is ionic in character.
(b) Every compound of nitrogen with a halogen element is a molecular compound.
(c) The compound $MgKr_2$ does not exist.
(d) Na and K are very similar in the compounds they form with nonmetals.
(e) If contained in an ionic compound, calcium (Ca) will be in the form of the doubly charged ion, Ca^{2+}.

Sample Exercise 2.10 Using Ionic Charge to Write Empirical Formulas for Ionic Compounds

Write the empirical formula of the compound formed by **(a)** Al^{3+} and Cl^{-} ions, **(b)** Al^{3+} and O^{2-} ions, **(c)** Mg^{2+} and NO_3^{-} ions.

Solution

(a) Three Cl^{-} ions are required to balance the charge of one Al^{3+} ion, making the empirical formula $AlCl_3$.
(b) Two Al^{3+} ions are required to balance the charge of three O^{2-} ions. A 2:3 ratio is needed to balance the total positive charge of 6+ and the total negative charge of 6–. The empirical formula is Al_2O_3.
(c) Two NO_3^{-} ions are needed to balance the charge of one Mg^{2+}, yielding $Mg(NO_3)_2$. Note that the formula for the polyatomic ion, NO_3^{-}, must be enclosed in parentheses so that it is clear that the subscript 2 applies to all the atoms of that ion.

Practice Exercise 1

Which of the following nonmetals will form an ionic compound with Sc^{3+} that has a 1:1 ratio of cations to anions?
(a) Ne **(b)** F **(c)** O **(d)** N

Practice Exercise 2

Write the empirical formula for the compound formed by
(a) Na^{+} and PO_4^{3-}, **(b)** Zn^{2+} and SO_4^{2-}, **(c)** Fe^{3+} and CO_3^{2-}.

Sample Exercise 2.11 Determining the Formula of an Oxyanion from Its Name

Based on the formula for the sulfate ion, predict the formula for **(a)** the selenate ion and **(b)** the selenite ion. (Sulfur and selenium are both in group 6A and form analogous oxyanions.)

Solution

(a) The sulfate ion is SO_4^{2-}. The analogous selenate ion is therefore SeO_4^{2-}.
(b) The ending -*ite* indicates an oxyanion with the same charge but one O atom fewer than the corresponding oxyanion that ends in -*ate*. Thus, the formula for the selenite ion is SeO_3^{2-}.

Practice Exercise 1

Which of the following oxyanions is incorrectly named?
(a) ClO_2^-, chlorate **(b)** IO_4^-, periodate **(c)** SO_3^{2-}, sulfite **(d)** IO_3^-, iodate **(e)** NO_2^-, nitrite

Practice Exercise 2

The formula for the bromate ion is analogous to that for the chlorate ion. Write the formula for the hypobromite and bromite ions.

Sample Exercise 2.12 Determining the Names of Ionic Compounds from Their Formulas

Name the ionic compounds **(a)** K_2SO_4, **(b)** $Ba(OH)_2$, **(c)** $FeCl_3$.

Solution

In naming ionic compounds, it is important to recognize polyatomic ions and to determine the charge of cations with variable charge.

(a) The cation is K^+, the potassium ion, and the anion is SO_4^{2-}, the sulfate ion, making the name potassium sulfate. (If you thought the compound contained S^{2-} and O^{2-} ions, you failed to recognize the polyatomic sulfate ion.)

(b) The cation is Ba^{2+}, the barium ion, and the anion is OH^-, the hydroxide ion: barium hydroxide.

(c) You must determine the charge of Fe in this compound because an iron atom can form more than one cation.

Because the compound contains three chloride ions, Cl^-, the cation must be Fe^{3+}, the iron(III), or ferric, ion. Thus, the compound is iron(III) chloride or ferric chloride.

Practice Exercise 1

Which of the following ionic compounds is incorrectly named? **(a)** $Zn(NO_3)_2$, zinc nitrate **(b)** $TeCl_4$, tellurium(IV) chloride **(c)** Fe_2O_3, diiron oxide **(d)** BaO, barium oxide **(e)** $Mn_3(PO_4)_2$, manganese(II) phosphate

Practice Exercise 2

Name the ionic compounds **(a)** NH_4Br, **(b)** Cr_2O_3, **(c)** $Co(NO_3)_2$.

Sample Exercise 2.13 Relating the Names and Formulas of Acids

Name the acids **(a)** HCN, **(b)** HNO_3, **(c)** H_2SO_4, **(d)** H_2SO_3.

Solution

(a) The anion from which this acid is derived is CN^-, the cyanide ion. Because this ion has an *-ide* ending, the acid is given a *hydro*- prefix and an *-ic* ending: hydrocyanic acid. Only water solutions of HCN are referred to as hydrocyanic acid. The pure compound, which is a gas under normal conditions, is called hydrogen cyanide. Both hydrocyanic acid and hydrogen cyanide are *extremely* toxic.

(b) Because NO_3^- is the nitrate ion, HNO_3 is called nitric acid (the *-ate* ending of the anion is replaced with an *-ic* ending in naming the acid).

(c) Because SO_4^{2-} is the sulfate ion, H_2SO_4 is called sulfuric acid.

(d) Because SO_3^{2-} is the sulfite ion, H_2SO_3 is sulfurous acid (the *-ite* ending of the anion is replaced with an *-ous* ending).

Practice Exercise 1

Which of the following acids are incorrectly named? For those that are, provide a correct name or formula.
(a) hydrofluoric acid, HF **(b)** nitrous acid, HNO_3 **(c)** perbromic acid, $HBrO_4$ **(d)** iodic acid, HI **(e)** selenic acid, H_2SeO_4

Practice Exercise 2

Give the chemical formulas for **(a)** hydrobromic acid, **(b)** carbonic acid.

Sample Exercise 2.14 Relating the Names and Formulas of Binary Molecular Compounds

Name the compounds **(a)** SO_2, **(b)** PCl_5, **(c)** Cl_2O_3.

Solution

The compounds consist entirely of nonmetals, so they are molecular rather than ionic. Using the prefixes in Table 2.6, we have **(a)** sulfur dioxide, **(b)** phosphorus pentachloride, **(c)** dichlorine trioxide.

Practice Exercise 1

Give the name for each of the following binary compounds of carbon: **(a)** CS_2, **(b)** CO, **(c)** C_3O_2, **(d)** CBr_4, **(e)** CF.

Practice Exercise 2

Give the chemical formulas for **(a)** silicon tetrabromide, **(b)** disulfur dichloride, **(c)** diphosphorus hexaoxide.

TABLE 2.6 Prefixes Used in Naming Binary Compounds Formed between Nonmetals

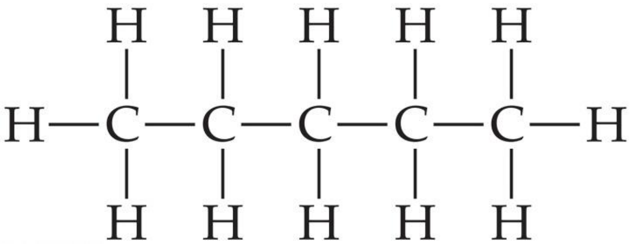
Prefix	Meaning
mono-	*1*
di-	*2*
tri-	*3*
tetra-	*4*
penta-	*5*
hexa-	*6*
hepta-	*7*
octa-	*8*
nona-	*9*
deca-	*10*

Sample Exercise 2.15 Writing Structural and Molecular Formulas for Hydrocarbons

Assuming the carbon atoms in *pentane* are in a linear chain, write **(a)** the structural formula and **(b)** the molecular formula for this alkane.

Solution

(a) Alkanes contain only carbon and hydrogen, and each carbon is attached to four other atoms. The name *pentane* contains the prefix *penta-* for five (Table 2.6), and we are told that the carbons are in a linear chain. If we then add enough hydrogen atoms to make four bonds to each carbon, we obtain the structural formula



This form of pentane is often called *n*-pentane, where the *n*- stands for “normal” because all five carbon atoms are in one line in the structural formula.

(b) Once the structural formula is written, we determine the molecular formula by counting the atoms present. Thus, *n*-pentane has the molecular formula C_5H_{12}.

Practice Exercise 1

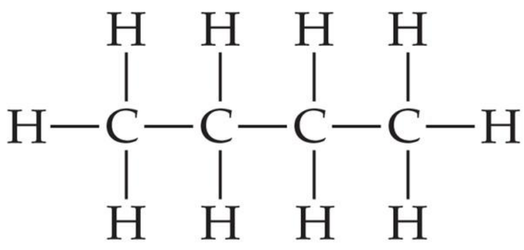
(a) What is the molecular formula of hexane, the alkane with six carbons? **(b)** What are the name and molecular formula of an alcohol derived from hexane?

Sample Exercise 2.15 Writing Structural and Molecular Formulas for Hydrocarbons

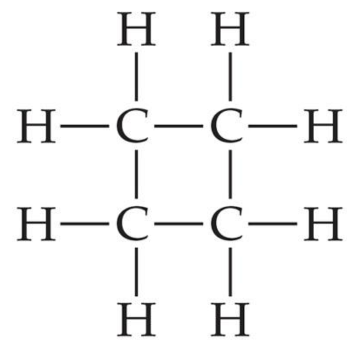
Continued

Practice Exercise 2

These two compounds have “butane” in their name. Are they isomers?



Butane



Cyclobutane