Sample Exercise 2.1 Illustrating the Size of an Atom

The diameter of a US penny is 19 mm. The diameter of a silver atom, by comparison, is only 2.88 Å. How many silver atoms could be arranged side by side in a straight line across the diameter of a penny?

Solution

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

$$\text{Ag atoms} = (19\ \cancel{\text{mm}})\left(\frac{10^{-3}\ \cancel{\text{m}}}{1\ \cancel{\text{mm}}}\right)\left(\frac{1\ \cancel{\text{Å}}}{10^{-10}\ \cancel{\text{m}}}\right)\left(\frac{1\ \text{Ag atom}}{2.88\ \cancel{\text{Å}}}\right) = 6.6 \times 10^{7}\ \text{Ag atoms}$$

That is, 66 million silver atoms could sit side by side across a penny!

Practice Exercise

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 in a straight line across the width of a pencil line that is 0.20 mm wide?
Answer: **(a)** 154 pm, **(b)** 1.3×10^{6} C atoms

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Sample Exercise 2.2 Determining the Number of Subatomic Particles in Atoms

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

Solution

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

How many protons, neutrons, and electrons are in **(a)** a ^{138}Ba atom, **(b)** an atom of phosphorus-31?
Answer: **(a)** 56 protons, 56 electrons, and 82 neutrons; **(b)** 15 protons, 15 electrons, and 16 neutrons.

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 of them. **(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

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

Answer: $^{208}_{82}Pb$

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

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

Solution

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

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

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

Practice Exercise

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

Answer: 28.09 amu

Sample Exercise 2.5 Using the Periodic Table

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

Solution

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

Practice Exercise

Locate Na (sodium) and Br (bromine) on the periodic table. Give the atomic number of each, and label each a metal, metalloid, or nonmetal.
Answer: Na, atomic number 11, is a metal; Br, atomic number 35, is a nonmetal.

Sample Exercise 2.6 Relating the Empirical and Molecular Formulas

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

Give the empirical formula for the substance called *diborane*, whose molecular formula is B_2H_6.
Answer: BH_3

Sample Exercise 2.7 Writing Chemical Symbols for Ions

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

Solution

(a) The number of protons (22) is the atomic number of the element. By referring to a periodic table or list of elements, we see that the element with atomic number 22 is titanium (Ti). The mass number of this isotope of titanium is 22 + 26 = 48 (the sum of the protons and neutrons). Because the ion has three more protons than electrons, it has a net charge of 3+. Thus, the symbol for the ion is $^{48}Ti^{3+}$.

(b) By referring to a periodic table or a table of elements, we see that sulfur (S) has an atomic number of 16. Thus, each atom or ion of sulfur must contain 16 protons. We are told that the ion also has 16 neutrons, meaning the mass number of the ion is 16 + 16 = 32. Because the ion has 16 protons and 18 electrons, its net charge is 2–. Thus, the symbol for the ion 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

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

Answer: 34 protons, 45 neutrons, and 36 electrons

Sample Exercise 2.8 Predicting the Charges of Ions

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

Solution

We will assume that these elements 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 of its 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, thereby forming the O^{2-} anion.

Practice Exercise

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

Answer: **(a)** 3+; **(b)** 1–

Sample Exercise 2.9 Identifying Ionic and Molecular Compounds

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

Solution

We would predict that Na_2O and $CaCl_2$ are ionic compounds because they are composed of a metal combined with a nonmetal. The other two compounds, composed entirely of nonmetals, are predicted (correctly) to be molecular compounds.

Practice Exercise

Which of the following compounds are molecular: CBr_4, FeS, P_4O_6, PbF_2?
Answer: CBr_4 and P_4O_6

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

What are the empirical formulas of the compounds 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. Thus, the formula is $AlCl_3$.
(b) Two AL^{3+} ions are required to balance the charge of three $O^{2–}$ ions (that is, the total positive charge is 6+, and the total negative charge is 6–). Thus, the formula is Al_2O_3.
(c) Two $NO_3^{–}$ ions are needed to balance the charge of one MG^{2+}. Thus, the formula is $Mg(NO_3)_2$. In this case the formula for the entire 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

Write the empirical formulas for the compounds formed by the following ions:
(a) Na^{+} and $PO_4^{3–}$, **(b)** Zn^{2+} and $SO_4^{2–}$, **(c)** Fe^{3+} and $CO_3^{2–}$.
Answer: **a)** Na_3PO_4, **(b)** $ZnSO_4$, **(c)** $Fe_2(CO_3)_3$

Sample Exercise 2.11 Determining the Formula of an Oxyanion form 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 members of 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

The formula for the bromate ion is analogous to that for the chlorate ion. Write the formula for the hypobromite and perbromate ions.
Answer: BrO^- and BrO_4^-

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

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

Solution

Each compound is ionic and is named using the guidelines we have already discussed. In naming ionic compounds, it is important to recognize polyatomic ions and to determine the charge of cations with variable charge.

(a) The cation in this compound is K^+, and the anion is SO_4^{2-}. (If you thought the compound contained S^{2-} and O^{2-} ions, you failed to recognize the polyatomic sulfate ion.) Putting together the names of the ions, we have the name of the compound, potassium sulfate.

(b) In this case the compound is composed of Ba^{2+} and OH^- ions. Ba^{2+} is the barium ion and OH^- is the hydroxide ion. Thus, the compound is called 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 Cl^- ions, the cation must be Fe^{3+} which is the iron(III), or ferric, ion. The Cl^- ion is the chloride ion. Thus, the compound is iron(III) chloride or ferric chloride.

Practice Exercise

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

Answer: **(a)** ammonium bromide, **(b)** chromium(III) oxide, **(c)** cobalt(II) nitrate

Sample Exercise 2.13 Determining the Formulas of Ionic Compounds from Their Names

Write the chemical formulas for the following compounds: **(a)** potassium sulfide, **(b)** calcium hydrogen carbonate, **(c)** nickel(II) perchlorate.

Solution

In going from the name of an ionic compound to its chemical formula, you must know the charges of the ions to determine the subscripts.

(a) The potassium ion is K^+, and the sulfide ion is S^{2-}. Because ionic compounds are electrically neutral, two K^+ ons are required to balance the charge of one S^{2-} ion, giving the empirical formula of the compound, K_2S.

(b) The calcium ion is Ca^{2+}. The carbonate ion is $CO_3{}^{2-}$, so the hydrogen carbonate ion is $HCO_3{}^-$. Two $HCO_3{}^-$ ions are needed to balance the positive charge of Ca^{2+}, giving $Ca(HCO_3)_2$.

(c) The nickel(II) ion is Ni^{2+}. The perchlorate ion is $ClO_4{}^-$. Two ions are required to balance the charge on one Ni^{2+} ion, giving $Ni(ClO_4)_2$.

Practice Exercise

Give the chemical formula for **(a)** magnesium sulfate, **(b)** silver sulfide, **(c)** lead(II) nitrate.

Answer: **(a)** $MgSO_4$, **(b)** Ag_2S, **(c)** $Pb(NO_3)_2$

Sample Exercise 2.14 Relating the Names and Formulas of Acids

Name the following 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 is the nitrate NO_3^- 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

Give the chemical formulas for **(a)** hydrobromic acid, **(b)** carbonic acid.
Answer: **(a)** HBr, **(b)** H_2CO_3

Sample Exercise 2.15 Relating the Names and Formulas of Binary Molecular Compounds

Name the following compounds: **(a)** SO_2, **(b)** PCl_5, **(c)** N_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, and **(c)** dinitrogen trioxide.

Practice Exercise

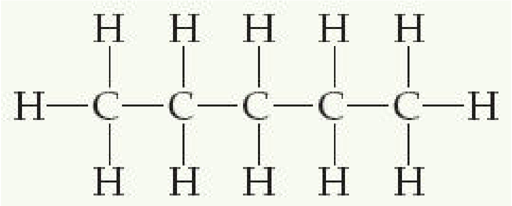
Give the chemical formula for **(a)** silicon tetrabromide, **(b)** disulfur dichloride.
Answer: **(a)** $SiBr_4$, **(b)** S_2Cl_2

Sample Exercise 2.16 Writing Structural and Molecular Formulas for Hydrocarbons

Consider the alkane called *pentane*. **(a)** Assuming that the carbon atoms are in a straight line, write a structural formula for pentane. **(b)** What is the molecular formula for pentane?

Solution

(a) Alkanes contain only carbon and hydrogen, and each carbon atom is attached to four other atoms. Because the name pentane contains the prefix *penta*- for five (Table 2.6), we can assume that pentane contains five carbon atoms bonded in a chain. If we then add enough hydrogen atoms to make four bonds to each carbon atom, we obtain the following 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 can determine the molecular formula by counting the atoms present. Thus, *n*-pentane has the formula C_5H_{12}.

Practice Exercise

Butane is the alkane with four carbon atoms. **(a)** What is the molecular formula of butane? **(b)** What are the name and molecular formula of an alcohol derived from butane?
Answer: **(a)** C_4H_{10}, **(b)** butanol, $C_4H_{10}O$ or C_4H_9OH