Chemistry 2e
2: Atoms, Molecules, and Ions
2.1: Early Ideas in Atomic Theory

1. In the following drawing, the green spheres represent atoms of a certain element. The purple spheres represent atoms of another element. If the spheres of different elements touch, they are part of a single unit of a compound. The following chemical change represented by these spheres may violate one of the ideas of Dalton's atomic theory. Which one?

Solution
The starting materials consist of one green sphere and two purple spheres. The products consist of two green spheres and two purple spheres. This violates Dalton's postulate that that atoms are not created during a chemical change, but are merely redistributed.

3. Identify the postulate of Dalton's theory that is violated by the following observations: 59.95% of one sample of titanium dioxide is titanium; 60.10% of a different sample of titanium dioxide is titanium.

Solution
This statement violates Dalton's fourth postulate: In a given compound, the numbers of atoms of each type (and thus also the percentage) always have the same ratio.

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2: Atoms, Molecules, and Ions
2.2: Evolution of Atomic Theory

5. The existence of isotopes violates one of the original ideas of Dalton's atomic theory. Which one?

Solution

Dalton originally thought that all atoms of a particular element had identical properties, including mass. Thus, the concept of isotopes, in which an element has different masses, was a violation of the original idea. To account for the existence of isotopes, the second postulate of his atomic theory was modified to state that atoms of the same element must have identical chemical

7. How are protons and neutrons similar? How are they different?

Solution

Both are subatomic particles that reside in an atom's nucleus. Both have approximately the same mass. Protons are positively charged, whereas neutrons are uncharged.

9. Predict and test the behavior of α particles fired at a Rutherford atom model.

(a) Predict the paths taken by α particles that are fired at atoms with a Rutherford atom model structure. Explain why you expect the α particles to take these paths.

(b) If α particles of higher energy than those in (a) are fired at Rutherford atoms, predict how their paths will differ from the lower-energy α particle paths. Explain your reasoning.

(c) Predict how the paths taken by the α particles will differ if they are fired at Rutherford atoms of elements other than gold. What factor do you expect to cause this difference in paths, and why?

(d) Now test your predictions from (a), (b), and (c). Open the URL: http://phet.colorado.edu/en/simulation/rutherford-scattering and select the "Rutherford Atom" tab. Due to the scale of the simulation, it is best to start with a small nucleus, so select "20" for both protons and neutrons, "min" for energy, show traces, and then start firing α particles. Does this match your prediction from (a)? If not, explain why the actual path would be that shown in the simulation. Pause or reset, set energy to "max," and start firing α particles. Does this match your prediction from (b)? If not, explain the effect of increased energy on the actual path as shown in the simulation. Pause or reset, select "40" for both protons and neutrons, "min" for energy, show traces, and fire away. Does this match your prediction from (c)? If not, explain why the actual path would be that shown in the simulation. Repeat this with larger numbers of protons and neutrons. What generalization can you make regarding the type of atom and effect on the path of α particles? Be clear and specific.

Solution

(a) The Rutherford atom has a small, positively charged nucleus, so most α particles will pass through empty space far from the nucleus and be undeflected. Those α particles that pass near the nucleus will be deflected from their paths due to positive-positive repulsion. The more directly toward the nucleus the α particles are headed, the larger the deflection angle will be. (b) Higher-energy α particles that pass near the nucleus will still undergo deflection, but the faster they travel, the less the expected angle of deflection. (c) If the nucleus is smaller, the positive charge is smaller and the expected deflections are smaller—both in terms of how closely the α particles pass by the nucleus undeflected and the angle of deflection. If the nucleus is larger, the positive charge is larger and the expected deflections are larger—more α particles will be

deflected, and the deflection angles will be larger. (d) The paths followed by the α particles match the predictions from (a), (b), and (c).

Chemistry
2: Atoms, Molecules, and Ions
2.3: Atomic Structure and Symbolism

11. Write the symbol for each of the following ions:
(a) the ion with a 1+ charge, atomic number 55, and mass number 133
(b) the ion with 54 electrons, 53 protons, and 74 neutrons
(c) the ion with atomic number 15, mass number 31, and a 3– charge
(d) the ion with 24 electrons, 30 neutrons, and a 3+ charge

Solution
(a) $^{133}Cs^{+}$; (b) $^{127}I^{-}$; (c) $^{31}P^{3-}$; (d) $^{57}Co^{3+}$

13. Open the URL: http://phet.colorado.edu/en/simulation/build-an-atom and click on the Atom icon.
(a) Pick any one of the first 10 elements that you would like to build and state its symbol.
(b) Drag protons, neutrons, and electrons onto the atom template to make an atom of your element.
State the numbers of protons, neutrons, and electrons in your atom, as well as the net charge and mass number.
(c) Click on "Net Charge" and "Mass Number," check your answers to (b), and correct, if needed.
(d) Predict whether your atom will be stable or unstable. State your reasoning.
(e) Check the "Stable/Unstable" box. Was your answer to (d) correct? If not, first predict what you can do to make a stable atom of your element, and then do it and see if it works. Explain your reasoning.

Solution
(a) Carbon-12, ^{12}C; (b) This atom contains six protons and six neutrons. There are six electrons in a neutral ^{12}C atom. The net charge of such a neutral atom is zero, and the mass number is 12. (c) The above answers are correct. (d) The atom will be stable since C-12 is a stable isotope of carbon. (e) The above answer is correct. Other answers for this exercise are possible if a different element of isotope is chosen.

15. Open the URL: http://phet.colorado.edu/en/simulation/build-an-atom.
(a) Drag protons, neutrons, and electrons onto the atom template to make a neutral atom of Lithium-6 and give the isotope symbol for this atom.
(b) Now remove one electron to make an ion and give the symbol for the ion you have created.

Solution
(a) Lithium-6 contains three protons, three neutrons, and three electrons. The isotope symbol is 6Li or $^{6}_{3}\mathrm{Li}$. (b) $^{6}_{3}\mathrm{Li}$ or $^{6}_{3}\mathrm{Li}$

17. The following are properties of isotopes of two elements that are essential in our diet. Determine the number of protons, neutrons and electrons in each and name them.
(a) atomic number 26, mass number 58, charge of 2+
(b) atomic number 53, mass number 127, charge of 1–

Solution
(a) Iron, 26 protons, 24 electrons, and 32 neutrons; (b) iodine, 53 protons, 54 electrons, and 74 neutrons

19. Give the number of protons, electrons, and neutrons in neutral atoms of each of the following isotopes:
(a) $^{7}_{3}\mathrm{Li}$

(b) $^{125}_{52}\text{Te}$

(c) $^{109}_{47}\text{Ag}$

(d) $^{15}_{7}\text{N}$

(e) $^{31}_{15}\text{P}$

Solution

(a) 3 protons, 3 electrons, 4 neutrons; (b) 52 protons, 52 electrons, 73 neutrons; (c) 47 protons, 47 electrons, 62 neutrons; (d) 7 protons, 7 electrons, 8 neutrons; (e) 15 protons, 15 electrons, 16 neutrons

21. Repeat Exercise 20 using an element that has three naturally occurring isotopes.

Solution

Let us use neon as an example. Since there are three isotopes, there is no way to be sure to accurately predict the abundances to make the total of 20.18 amu average atomic mass. Let us guess that the abundances are 9% Ne-22, 91% Ne-20, and only a trace of Ne-21. The average mass would be 20.18 amu. Checking the nature's mix of isotopes shows that the abundances are 90.48% Ne-20, 9.25% Ne-22, and 0.27% Ne-21, so our guessed amounts have to be slightly adjusted.

23. Average atomic masses listed by IUPAC are based on a study of experimental results. Bromine has two isotopes, ^{79}Br and ^{81}Br, whose masses (78.9183 and 80.9163 amu, respectively) and abundances (50.69% and 49.31%, respectively) were determined in earlier experiments. Calculate the average atomic mass of bromine based on these experiments.

Solution

$$\begin{aligned}\text{average atomic mass} &= (0.5069 \times 78.9183 \text{ amu}) + (0.4931 \times 80.9163 \text{ amu}) \\ &= 79.90 \text{ amu}\end{aligned}$$

25. The average atomic masses of some elements may vary, depending upon the sources of their ores. Naturally occurring boron consists of two isotopes with accurately known masses (^{10}B, 10.0129 amu and ^{11}B, 11.00931 amu). The actual atomic mass of boron can vary from 10.807 to 10.819, depending on whether the mineral source is from Turkey or the United States. Calculate the percent abundances leading to the two values of the average atomic masses of boron from these two countries.

Solution

Two items, the percentage of each isotope, are unknown. As both unknowns are related through an equation that says that the sum of the two fractions is equal to 1, we can write:

Turkey source:

$$\begin{aligned}10.807 \text{ amu} &= 10.0129\,(1-x) + 11.00931x \\ 10.807 - 10.0129 &= -10.0129x + 11.00931x \\ x &= 0.797 \text{ (of 11.00931 amu isotope)} \\ 1-x &= 0.203 \text{ (of 10.0129 amu isotope)}\end{aligned}$$

US source:

$$\begin{aligned}10.819 \text{ amu} &= 10.0129\,(1-x) + 11.00931x \\ 10.819 - 10.0129 &= -10.0129x + 11.00931x \\ x &= 0.809 \text{ (of 11.00931 amu isotope)} \\ 1-x &= 0.191 \text{ (of 10.0129 amu isotope)}\end{aligned}$$

Chemistry 2e
2: Atoms, Molecules, and Ions
2.4: Chemical Formulas

27. Explain why the symbol for an atom of the element oxygen and the formula for a molecule of oxygen differ.

Solution

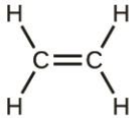
The symbol for the element oxygen, O, represents both the element and one atom of oxygen. A molecule of oxygen, O_2, contains two oxygen atoms; the subscript 2 in the formula must be used to distinguish the diatomic molecule from two single oxygen atoms.

29. Write the molecular and empirical formulas of the following compounds:

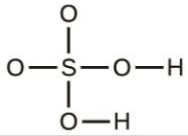
(a)

(b)

(c)



(d)



Solution

(a) molecular CO_2, empirical CO_2; (b) molecular C_2H_2, empirical CH; (c) molecular C_2H_4, empirical CH_2; (d) molecular H_2SO_4, empirical H_2SO_4

31. Determine the empirical formulas for the following compounds:

(a) caffeine, $C_8H_{10}N_4O_2$

(b) sucrose, $C_{12}H_{22}O_{11}$

(c) hydrogen peroxide, H_2O_2

(d) glucose, $C_6H_{12}O_6$

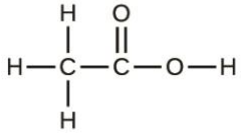
(e) ascorbic acid (vitamin C), $C_6H_8O_6$

Solution

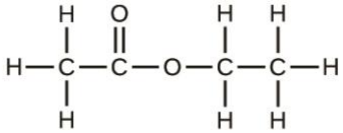
(a) $C_4H_5N_2O$; (b) $C_{12}H_{22}O_{11}$; (c) HO; (d) CH_2O; (e) $C_3H_4O_3$

33. Write the empirical formulas for the following compounds:

(a)



(b)

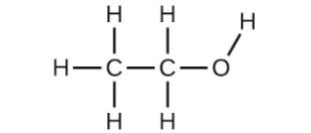


Solution

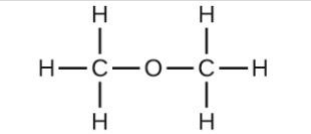
(a) CH_2O; (b) C_2H_4O

35. Use the URL: http://phet.colorado.edu/en/simulation/build-a-molecule to repeat Exercise 34, but build a molecule with two carbons, six hydrogens, and one oxygen.
(a) Draw the structural formula of this molecule and state its name.
(b) Can you arrange these atoms to make a different molecule? If so, draw its structural formula and state its name.
(c) How are the molecules drawn in (a) and (b) the same? How do they differ? What are they called (the type of relationship between these molecules, not their names)?

Solution
(a) ethanol



(b) methoxymethane, more commonly known as dimethyl ether



(c) These molecules have the same chemical composition (types and number of atoms) but different chemical structures. They are structural isomers.

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2: Atoms, Molecules, and Ions
2.5: The Periodic Table

37. Using the periodic table, classify each of the following elements as a metal or a nonmetal, and then further classify each as a main-group (representative) element, transition metal, or inner transition metal:
(a) uranium
(b) bromine
(c) strontium
(d) neon
(e) gold
(f) americium
(g) rhodium
(h) sulfur
(i) carbon
(j) potassium

Solution
(a) metal, inner transition metal; (b) nonmetal, representative element; (c) metal, representative element; (d) nonmetal, representative element; (e) metal, transition metal; (f) metal, inner transition metal; (g) metal, transition metal; (h) nonmetal, representative element; (i) nonmetal, representative element; (j) metal, representative element

39. Using the periodic table, identify the lightest member of each of the following groups:
(a) noble gases
(b) alkaline earth metals
(c) alkali metals
(d) chalcogens

Solution
(a) He; (b) Be; (c) Li; (d) O

41. Use the periodic table to give the name and symbol for each of the following elements:
(a) the noble gas in the same period as germanium
(b) the alkaline earth metal in the same period as selenium
(c) the halogen in the same period as lithium
(d) the chalcogen in the same period as cadmium

Solution
(a) krypton, Kr; (b) calcium, Ca; (c) fluorine, F; (d) tellurium, Te

43. Write a symbol for each of the following neutral isotopes. Include the atomic number and mass number for each.
(a) the alkali metal with 11 protons and a mass number of 23
(b) the noble gas element with and 75 neutrons in its nucleus and 54 electrons in the neutral atom
(c) the isotope with 33 protons and 40 neutrons in its nucleus
(d) the alkaline earth metal with 88 electrons and 138 neutrons

Solution
(a) $^{23}_{11}\text{Na}$; (b) $^{129}_{54}\text{Xe}$; (c) $^{73}_{33}\text{As}$; (d) $^{226}_{88}\text{Ra}$

Chemistry 2e
2: Atoms, Molecules, and Ions
2.6: Ionic and Molecular Compounds

45. Using the periodic table, predict whether the following chlorides are ionic or covalent: KCl, NCl_3, ICl, $MgCl_2$, PCl_5, and CCl_4.

Solution

In general, those elements that are widely separated in the periodic table—that is, at the extreme left and extreme right—will form compounds that are ionic. Those elements that are near one another in the periodic table generally will form covalent compounds. More specifically, when a metal is combined with one or more nonmetals, the compound is usually ionic. Covalent compounds are usually formed by a combination of nonmetals. Ionic: KCl, $MgCl_2$; Covalent: NCl_3, ICl, PCl_5, CCl_4

47. For each of the following compounds, state whether it is ionic or covalent. If it is ionic, write the symbols for the ions involved:

(a) NF_3
(b) BaO
(c) $(NH_4)_2CO_3$
(d) $Sr(H_2PO_4)_2$
(e) IBr
(f) Na_2O

Solution

(a) covalent; (b) ionic, Ba^{2+}, O^{2-}; (c) ionic, NH_4^+, CO_3^{2-}; (d) ionic, Sr^{2+}, $H_2PO_4^-$; (e) covalent; (f) ionic, Na^+, O^{2-}

49. For each of the following pairs of ions, write the symbol for the formula of the compound they will form:

(a) Ca^{2+}, S^{2-}
(b) NH_4^+, SO_4^{2-}
(c) Al^{3+}, Br^-
(d) Na^+, HPO_4^{2-}
(e) Mg^{2+}, PO_4^{3-}

Solution

a) CaS; (b) $(NH_4)_2SO_4$; (c) $AlBr_3$; (d) Na_2HPO_4; (e) $Mg_3(PO_4)_2$

Chemistry 2e
2: Atoms, Molecules, and Ions
2.7: Chemical Nomenclature

51. Name the following compounds:
(a) CsCl
(b) BaO
(c) K_2S
(d) $BeCl_2$
(e) HBr
(f) AlF_3

Solution
(a) cesium chloride; (b) barium oxide; (c) potassium sulfide; (d) beryllium chloride; (e) hydrogen bromide; (f) aluminum fluoride

53. Write the formulas of the following compounds:
(a) rubidium bromide
(b) magnesium selenide
(c) sodium oxide
(d) calcium chloride
(e) hydrogen fluoride
(f) gallium phosphide
(g) aluminum bromide
(h) ammonium sulfate

Solution
(a) RbBr; (b) MgSe; (c) Na_2O; (d) $CaCl_2$; (e) HF; (f) GaP; (g) $AlBr_3$; (h) $(NH_4)_2SO_4$

55. Write the formulas of the following compounds:
(a) chlorine dioxide
(b) dinitrogentetraoxide
(c) potassium phosphide
(d) silver(I) sulfide
(e) aluminum fluoride trihydrate
(f) silicon dioxide

Solution
(a) ClO_2; (b) N_2O_4; (c) K_3P; (d) Ag_2S; (e) $AlF_3 \cdot 3H_2O$; (f) SiO_2

57. Each of the following compounds contains a metal that can exhibit more than one ionic charge. Name these compounds:
(a) Cr_2O_3
(b) $FeCl_2$
(c) CrO_3
(d) $TiCl_4$
(e) $CoCl_2 \cdot 6H_2O$
(f) MoS_2

Solution
(a) chromium(III) oxide; (b) iron(II) chloride; (c) chromium(VI) oxide; (d) titanium(IV) chloride; (e) cobalt(II) chloride hexahydrate; (f) molybdenum(IV) sulfide

59. The following ionic compounds are found in common household products. Write the formulas for each compound:

(a) potassium phosphate
(b) copper(II) sulfate
(c) calcium chloride
(d) titanium dioxide
(e) ammonium nitrate
(f) sodium bisulfate (the common name for sodium hydrogen sulfate)

Solution
(a) K_3PO_4; (b) $CuSO_4$; (c) $CaCl_2$; (d) TiO_2; (e) NH_4NO_3; (f) $NaHSO_4$

61. What are the IUPAC names of the following compounds?
(a) manganese dioxide
(b) mercurous chloride (Hg_2Cl_2)
(c) ferric nitrate [$Fe(NO_3)_3$]
(d) titanium tetrachloride
(e) cupric bromide ($CuBr_2$)

Solution
(a) manganese(IV) oxide; (b) mercury(I) chloride; (c) iron(III) nitrate; (d) titanium(IV) chloride; (e) copper(II) bromide