Chapter 1: Chemistry

Overview

Chapter 1 introduces the student to the concepts of science, the ability of science to solve problems as well as its limitations. The student is then introduced to the concept of matter and energy and the physical means by which they are measured.

Lecture Outline

1.1 Science and Technology: The Roots of Knowledge

Many students are confused about the differences between science and technology. Technology is the direct application of knowledge to solve problems. Science seeks an understanding of underlying principles.

1.2 Science: Reproducible, Testable, Tentative, Predictive, and Explanatory

The scientific method, from hypothesis to law, theory, or model, is best explained by example.

1.3 Science and Technology: Risks and Benefits

1.4 Solving Society's Problems: Scientific Research

Research can be basic or applied.

1.5 Chemistry: A Study of Matter and Its Changes

Matter is anything that has mass.
Mass is a measure of the amount of matter present.
Weight is mass times gravitational attraction.
Matter exhibits chemical and physical properties.
Chemical properties tell us how matter will combine to form new and different substances (a chemical change).
Physical properties are directly observable; color, state (solid, liquid, or gas), and texture are examples.
An excellent demonstration is to burn a candle (chemical change) and boil water (physical change).

1.6 Classification of Matter

A. States of Matter

- Solids, liquids, and gases.

B. Substances and Mixtures

- Substances have constant composition.
- The composition of a mixture is variable.
  - Homogeneous mixtures: appear the same throughout (milk, paint, and saltwater are examples).
  - Heterogeneous mixtures: appear different throughout (pizza, raisin bread, and chocolate chip cookies are examples).

C. Elements and Compounds

- Substances are either elements or compounds.
  - Elements: fundamental building blocks of all matter. (lead, silver, gold, carbon, and oxygen).
  - Compounds: two or more elements chemically combined in fixed ratios (water, ammonia, and propane).

D. Atoms and Molecules

1.7 The Measurement of Matter

Most students have been introduced to the metric system during their K-12 education; the SI system used in science is based on the metric system. The difference lies in the base units.

- Base units: kilograms (kg) for mass, meter (m) for length, and seconds (s) for time. The four other base units are shown in Table 1.4.

1.8 Density

Density is the mass-to-volume ratio of matter.

1.9 Energy: Heat and Temperature

The SI unit of temperature is the kelvin (K); however, the temperature scale used in the chemistry laboratory is normally the Celsius scale. The Celsius scale was developed with the freezing and boiling points of pure water at a pressure of 1 atmosphere as the reference frames. (Students find the history of the development of the Fahrenheit scale much more interesting!)

1.10 Critical Thinking

Demonstrations

1. Place samples of various elements (copper, sulfur, zinc, mercury, aluminum, carbon, etc.) in small stoppered bottles or flasks that can be passed around.

2. Compare a yardstick and a meter stick. A meter is slightly bigger than a yard. A sugar cube is approximately 1 mL. An ordinary paper clip weighs about 1 gram. A liter is a little bit (6%) larger than a quart.

3. Use Crispix and Raisin Bran to illustrate the difference between a compound and a mixture. Raisins and bran flakes are easily separated, and the ratio of raisins to flakes can vary. Crispix has a 1:1 ratio of corn and rice flakes, and they cannot be easily separated.

4. Ice floats on water because the density of ice is less than that of water. But alcohol has a much lower density. If you use alcohol instead of water, the ice will sink. Place a glass of water and a glass of alcohol side by side and add an ice cube to each one.

5. The “cartesian diver” is a popular demonstration about density. Completely fill a 2-liter plastic bottle with water and put just enough water into a medicine dropper so that it can barely float. Put the dropper into the bottle and cap the bottle. Squeeze and release the bottle to make the “diver” go up and down.

Review Questions

1. Science is testable, reproducible, explanatory, predictive, and tentative.

2. A hypothesis is a tentative explanation and must be verified or rejected through experiment.

3. The scientific method can only be used when all the variables in a system can be controlled.

4. Technology is the sum total of the processes by which humans modify the materials of nature; technology need not be based on science.

5. Risk-benefit analysis is an analysis of benefits versus risks, involving an attempt to calculate a desirability quotient (DQ).

6. (a) A benefit is anything that promotes well-being or has a positive effect. (b) A risk is any hazard that leads to loss or injury. A risk-benefit analysis is weighing both the risk and the benefit of a certain technology and determining if the hazard is worth the positive outcome. This tends to be a personal decision and can vary from group to group and person to person.

7. A DQ is benefits divided by risk, also known as a desirability quotient. A large DQ is the result of large benefits and small risks. While scientific investigation can help considerably in determining an accurate DQ, the calculation of benefits is almost entirely a social judgment and the risks and benefits are not always known. Benefits and risks are therefore judgments with a qualitative rather than quantitative aspect.

8. The common units used in the laboratory are (a) the gram (g) for mass and (b) the centimeter (cm) or millimeter (mm) for length.

9. The SI unit of volume is the cubic meter (m^3). The volume unit used in the laboratory is the cubic decimeter (dm^3) or the cubic centimeter (cm^3 or cc).

10.

Prefix	Symbol	Definition
Tera	T	10^{12}
Mega	M	10^{6}
Centi	c	10^{-2}
Micro	μ	10^{-6}
Milli	m	10^{-3}
Deci	d	10^{-1}
Kilo	k	10^{3}
Nano	n	10^{-9}

11. Research projects “a” and “b” are applied research. Research project “c” is basic research.

12. Research project “a” is applied research. Research projects “b” and “c” are basic research.

Problems

13. Penicillin has saved thousands of lives, causing harm to a very few. The use of penicillin for society as a whole has been very beneficial; it has a large DQ.

14. The risk of using sodium sulfite is greater in fruit juices than in wines as small children may be sensitive to sulfites and are more likely to consume fruit juice.

15. Hazards are greater than benefits for a person who is exposed daily to the paints than the hobbyist exposed once. The DQ would be increased for the professional painter and the hobbyist if both wore breathing masks capable of filtering out the *isocyanate*.

16. The risk is much higher for the dentist who stays in the room during every X-ray than for the patient receiving one X-ray per year.

17. The DQ for the use of antibiotics in treating common sore throats is low as there is a small risk to the untreated patient. The DQ for treating more serous influenza is higher as the risk to the untreated patient is greater.

18. There is no benefit for the man or the pregnant woman. There is a significant benefit to the unborn child whose mother has AIDS.

19. 100 g, 2 kg

20. A2 sized paper is larger. 1” = 25.4 mm thus:

$$594\ \text{mm} \times \frac{1''}{25.4\ \text{mm}} = 23.4''$$

$$420\ \text{mm} \times \frac{1''}{25.4\ \text{mm}} = 16.5''$$

21. Both a and b are correct. (c) would be more in the range of 100 kg and (d) would be in the range of 10 kg.

22. No. Weight is mass times the force of gravity! The sample weighed on the moon would have 1/6 th the weight of the sample weighed on Earth.

23. 250 mL

24. 40 cm^2

25. Use the following conversions: 1 km = 0.62 mi, $(1\ \text{km})^3 = (0.62\ \text{mi})^3 = 0.24\ \text{mi}^3$

$$3.5\times10^8\ \text{mi}^3 \times \frac{1\ \text{km}^3}{0.24\ \text{mi}^3} = 1.5\times10^9\ \text{km}^3$$

26. Use the following conversions: 1 km = 0.62 mi, $(1\ \text{km})^2 = (0.62\ \text{mi})^2 = 0.38\ \text{mi}^2$

$$1.4 \times 10^8\ \text{mi}^2 \times \frac{1\ \text{km}^2}{0.38\ \text{mi}^2} = 3.7 \times 10^8\ \text{km}^2$$

27. Use the following conversion: 1” = 25.4 mm, The aluminum tube will fit.

$$26.3\ \text{mm} \times \frac{1''}{25.4\ \text{mm}} = 1.03''$$

28. 18.7 mm

29. (a) Physical (b) Chemical (c) Physical (d) Chemical

30. (a) Physical (b) Physical (c) Chemical (d) Chemical

31. (a) Physical (b) Chemical (c) Physical

32. (a) Chemical (b) Physical (c) Physical

33. Substances: a, c, d; mixtures: b

34. Substances: a, b; mixtures: c, d, e, f

35. Homogeneous: a, b, c; heterogeneous: d

36. Homogeneous: a, d; heterogeneous: b, c

37. A substance has a definite, or fixed, composition that does not vary from one sample to another. Glucose samples, regardless of where they are collected, are 8 parts oxygen, 6 parts carbon, and 1 part hydrogen. Therefore, glucose is a substance.

38. Shampoo contains many substances such as water and soap; therefore it is a mixture. "Nothing artificial" reflects the sources of the compounds in the shampoo.

39. Elements: a, b; compounds: c, d

40. Elements: a, c; compounds: b, d

41. (a) Iron (b) Magnesium (c) Helium (d) Nitrogen

42. (a) O (b) P (c) K (d) Ar

43. f

44. d

45. (a) 1.0 dL (b) 8.5 pg (c) 1.05 mm

46. (a) 45 mg = 0.000045 kg = 4.5×10^{-5} kg
(b) 125 ns = 0.000000125 s = 1.25×10^{-7} s
(c) 10.7 µL = 0.0000107 L = 1.07×10^{-5} L
(d) 12.5346 kg

47. (a) 1000 mL = 1 L, $5.52 \times 10^4 \text{ mL} \times \dfrac{1 \text{ L}}{1000 \text{ mL}} = 552 \text{ L}$

(b) 1000 mg = 1 g $325 \text{ mg} \times \dfrac{1 \text{ g}}{1000 \text{ mg}} = 0.325 \text{ g}$

(c) 100 cm = 1 m, $27 \text{ cm} \times \dfrac{1 \text{ m}}{100 \text{ cm}} = 0.27 \text{ m}$

(d) 10 mm = 1 cm, $27 \text{ mm} \times \dfrac{1 \text{ cm}}{10 \text{ mm}} = 2.7 \text{ cm}$

(e) 1 ms = 1000 μs, $78\,\mu\text{s} \times \dfrac{1 \text{ ms}}{1000\,\mu\text{s}} = 0.078 \text{ ms}$

48. (a) 1000 mm = 1 m, $546 \text{ mm} \times \dfrac{1 \text{ m}}{1000 \text{ mm}} = 0.546 \text{ m}$

(b) 1000 ns = 1 μs , $65 \text{ ns} \times \dfrac{1\,\mu\text{s}}{1000 \text{ ns}} = 0.065\,\mu\text{s}$

(c) 1000 mg = 1 g, 1000 g = 1 k,

$87.6 \text{ mg} \times \dfrac{1 \text{ kg}}{1 \text{ x } 10^6 \text{ mg}} = 0.0000876 \text{ mg} = 8.76 \times 10^{-5}\text{kg}$

(d) $1 \text{ dm}^3 = 1\text{L}$, $46.3 \text{ dm}^3 \times \dfrac{1 \text{ L}}{1 \text{ dm}^3} = 46.3 \text{ L}$

(e) 1×10^6 pm = 1μm, $181 \text{ pm} \times \dfrac{1\,\mu\text{m}}{1 \text{ x } 10^6 \text{ pm}} = 0.000181\,\mu\text{m} = 1.81 \times 10^{-4}\mu\text{m}$

49. Larger units: (a) cm - centimeters (b) kg - kilograms (c) dL - deciliters

50. $7 \text{ x } 10^{27}$ atoms

51. 31 cm = 310 mm = 0.31 m = $3.1 \text{ x } 10^8$ nm

52. (a) 352 mL = 0.352 L (b) 26 kL = 26,000 L

53. $D = \dfrac{m}{V}$; $D = \dfrac{500.0 \text{ g}}{53.6 \text{ cm}^3} = 9.33 \text{ g}/\text{cm}^3$

54. $D = \dfrac{m}{V}$; $D = \dfrac{22.4 \text{ g}}{25.0 \text{ mL}} = 0.896 \text{ g}/\text{mL}$

55. $D = \dfrac{m}{V}$; $D \times V = m$; $1.51 \text{ g}/\text{mL} \times 49.1 \text{ mL} = 74.1 \text{ g}$

56. $D = \dfrac{m}{V}$; $D \times V = m$; $1.43 \text{ g}/\text{cm}^3 \times 13.2 \text{ cm}^3 = 18.9 \text{ g}$

57. $D = \frac{m}{V}; V = \frac{m}{D}$

(a) $V = \frac{227\text{ g}}{0.660\ ^{g}\!/_{mL}} = 343\text{ mL}$

(b) $V = \frac{454\text{ g}}{0.917\ ^{g}\!/_{cm^3}} = 495\text{ cm}^3$

Note: Refer to Table 1.6 for the density data.

58. $D = \frac{m}{V},\ V = \frac{m}{D}$

(a) $V = \frac{475\text{g}}{8.94\ ^{g}\!/_{cm^3}} = 53.1\text{ cm}^3$

(b) $V = \frac{253\text{ g}}{13.534\ ^{g}\!/_{mL}} = 18.7\text{ mL}$

59. Three layers will form with mercury on the bottom (greatest density), then water, followed by hexane on the top.

60. The red maple and the balsa wood will float on the hexane, the ice will float on the water, the copper coin will float on the mercury, and the gold coin will sink to the bottom.

61. $D = \frac{m}{V}, \qquad D \times V = m$

$1.03\ ^{g}\!/_{mL} \times 37900\text{ mL} = \ 39037\text{ g} \times \frac{1\text{ lb}}{453.6\text{ g}} = 86.1\text{ lbs}$

$86.1\text{ lbs} + 59.5\text{ lbs} = 145.6\text{ lbs}$

The answer is "yes."

62. $D = \frac{m}{V}, \qquad D \times V = m$

$14.0\text{ gal x } \frac{3.785\text{ L}}{1\text{ gal}} = 53.0\text{L x } \frac{1000\text{ mL}}{1\text{ L}} = 53{,}000\text{ mL}$

$0.758\ ^{g}\!/_{mL} \times 53000\text{ mL} = \ 40200\text{ g} \times \frac{1\text{ kg}}{1000\text{ g}} = 40.2\text{ kg}$

63. Solve the equation for the volume of the crystal ball. The diameter of the crystal ball is 14.8 cm, thus the radius (r) is 7.4 cm.

$$V = \frac{4\pi r^3}{3} = \frac{4\pi \text{ x } (7.4 \text{ cm})^3}{3} = 1.70 \text{ x } 10^3 \text{ cm}^3$$

$$D \times V = m$$

$$3.18 \ ^{g}\!/\!_{cm^3} \times 1.70 \text{ x } 10^3 \text{ cm}^3 = 5.41 \text{ x } 10^3 \text{ g}$$

64. Solve for the total volume required. $D = \frac{m}{V}$, $V = \frac{m}{D}$

$$V = \frac{500\text{g}}{1.031 \ ^{g}\!/\!_{mL}} = 485 \text{ mL} = 485 \text{ cm}^3$$

Solve for height (h) of carton.

7.7 cm x 7.7 cm x h cm = 485 cm^3
59 cm^2 x h cm = 485 cm^3
h cm = 485 cm^3/ 59 cm^2 = 8.2 cm = 82 mm

65. ºC = K – 273, ºC = 77 – 273 = –196 ºC

66. K = ºC + 273, K = 37 + 273 = 310 K

67. 1 cal = 4.184 J, 1 kcal = 4.184 kJ, $161 \text{ kJ} \times \frac{1 \text{ kcal}}{4.184 \text{ kJ}} = 38.5 \text{ kcal}$

68. 1000 cal = 1 kcal, 584 cal = 0.584 kcal $0.584 \text{ kcal} \times \frac{4.184 \text{ kJ}}{1 \text{ kcal}} = 2.44 \text{ kJ}$

69. 1 microcentury = 1 x 10^{-6} centuries = 1x10^{-4} years x 365 days/year = 0.0365 days x 24 hours/day = 0.876 hours x 60 minutes/hour = 52.6 minutes.

70. 1 millihelen = 1.0 x 10^{-3} or 0.001 helens. 1000 ships/helen x 0.001 hellens = 1 ship

71. law or an empirical law

72. A food calorie is 1000 cal or 1 kcal. Thus it takes 79 kcal to melt 1 kg of ice.

73. 200 kilowarhols = 200,000 warhols x 15 min/warhol = 3,000,000 min/60 min/hr = 50,000 hr/24 hrs/day = 2083.3 days/365 days/year = 6 years

74. (1) An experiment (2) A scientific law (3) A hypothesis (4) A theory

75. (1) An observation (2) A theory (3) A hypothesis
(4) An experiment (5) An observation

76. Subtract the weight of the empty glass container from the weight of the glass container plus the weight of the antifreeze to yield the weight of the antifreeze; then calculate the density of the antifreeze,

60.562 g – 48.462 g = 12.100 g antifreeze

$$D = \frac{m}{V} = \frac{12.100\,\text{g}}{8.00\,\text{mL}} = 1.51\,{}^{\text{g}}\!/\!_{\text{mL}}$$

77. Calculate the volume of the block, then calculate the mass.
7.6 cm x 7.6 cm x 94 cm = 5400 cm^3

$$D = \frac{m}{V}, \qquad D \times V = m$$

$$0.11\,{}^{\text{g}}\!/\!_{\text{cm}^3} \times 5400\,\text{cm}^3 = 590\,\text{g}$$

78. yardstick (36 in. = 0.91 m), rattlesnake (1.04 m), 1.21 m chain, 75-in. board (1.9 m)

79. 1.65 kg cabbage, 5 lb bag of potatoes (2.3 kg), 2500 g sugar (2.500 kg)

80. 1.53 m = 5’, 38.5 kg = 104 lb; the woman on the left

81. Find the mass of the chips only by subtracting the paper mass from the total mass.
18.43 g – 1.21 g = 17.22 g

Calculate density using the equation: $D = \frac{m}{V}$

$$D = \frac{17.22\,\text{g}}{3.29\,\text{cm}^3} = 5.23\,{}^{\text{g}}\!/\!_{\text{cm}^3}$$

82. $D = \frac{m}{V}$, solve for volume.

$$V = \frac{m}{D},\ V = \frac{3180\ \text{g}}{7.9\ \text{g/cm}^3} = 4.0 \times 10^2\ \text{cm}^3$$

83. Use $D = \frac{m}{V}$, solve for volume.

$$V = \frac{m}{D},\ V = \frac{0.00579\,\text{g}}{19.3\,\text{g/cm}^3} = 0.00030\ \text{cm}^3$$

Use length (cm) x width (cm) x thickness (cm) = volume (cm^3).
44.6 cm^2 x thickness (cm) = 0.0003 cm^3

$$\text{Thickness (cm)} = \frac{0.0003\,\text{cm}^3}{44.6\,\text{cm}^2} = 6.73 \times 10^{-6}\ \text{cm}$$

84. Calculate the volume of each stainless steel rod:
π x (1.27 cm)^2 x 610 cm = 3090 cm^3

Calculate the mass of each steel rod:

$$DV = m = 7.48\ {}^{g}\!/_{cm^3}\ x\ 3090\ {}^{cm^3}\!/_{\text{steel rod}} = 23100\ {}^{g}\!/_{\text{steel rod}}\ x\ \frac{1\ kg}{1000\ g} = 23.1\ {}^{kg}\!/_{\text{steel rod}}$$

$$\frac{1850\ kg}{23.1\ {}^{kg}\!/_{\text{steel rod}}} = 80\ \text{steel rods}$$

85. V = 36.1 cm x 36.1 cm x 36.1 cm; V = 47,000 cm^3
m = 19.3 g/cm^3 x 47,000 cm^3; *m* = 907,000 g
907,000 g x 1 kg/1000 kg = 907 kg
907 kg x 1 metric ton/1000 g = 0.907 metric tons

86. $D = \frac{m}{V} = \frac{425\ g}{48.0\ cm^3} = 8.85\ {}^{g}\!/_{cm^3}$ this is silver

87. Calculate the volume of each planet.

$$V_{Jupiter} = \frac{4\pi(70{,}000\ km)^3}{3} = 1.44x10^{15}\ km^3$$

$$V_{Earth} = \frac{4\pi(6400\ km)^3}{3} = 1.10x10^{12}\ km^3$$

$$V_{Saturn} = \frac{4\pi(58{,}200\ km)^3}{3} = 8.26x10^{14}\ km^3$$

Calculate the density of each planet.

$$D_{Jupiter} = \frac{1.9x10^{27}\ kg}{1.44x10^{15}\ km^3} = 1.32x10^{12}\ {}^{kg}\!/_{km^3}\ x1000\ {}^{g}\!/_{kg}\ x\ {}^{km^3}\!/_{1x10^{15}\ cm^3} = 1.3\ {}^{g}\!/_{cm^3}$$

$$D_{Earth} = \frac{5.98x10^{24}\ kg}{1.10x10^{12}\ km^3} = 5.44x10^{12}\ {}^{kg}\!/_{km^3}\ x1000\ {}^{g}\!/_{kg}\ x\ {}^{km^3}\!/_{1x10^{15}\ cm^3} = 5.4\ {}^{g}\!/_{cm^3}$$

$$D_{Saturn} = \frac{5.68x10^{26}\ kg}{8.26x10^{14}\ km^3} = 6.87x10^{11}\ {}^{kg}\!/_{km^3}\ x1000\ {}^{g}\!/_{kg}\ x\ {}^{km^3}\!/_{1x10^{15}\ cm^3} = 0.69\ {}^{g}\!/_{cm^3}$$

Saturn would float on water!

88. $V_{HAT\text{-}P\text{-}1} = \frac{4\pi(96{,}600\ km)^3}{3} = 3.78x10^{15}\ km^3$

$$D_{HAT\text{-}P\text{-}1} = \frac{9.50x10^{26}\ kg}{3.78x10^{15}\ km^3} = 2.51x10^{11}\ {}^{kg}\!/_{km^3}\ x1000\ {}^{g}\!/_{kg}\ x\ {}^{km^3}\!/_{1x10^{15}\ cm^3} = 0.251\ {}^{g}\!/_{cm^3}$$

89. Green chemistry uses materials and processes that are intended to prevent or reduce pollution at its source and to meet the needs of the present generation without compromising the needs of future generations.

90**.** The Twelve Principles of Green Chemistry
1) Prevention 2) Atom Economy 3) Less Hazardous Chemical Syntheses 4) Designing Safer Chemicals 5) Safer Solvents and Auxiliaries 6) Design for Energy Efficiency 7) Use of Renewable Feedstocks 8) Reduce Derivatives 9) Catalysis 10) Design for Degradation 11) Real-time Analysis for Pollution Prevention 12) Inherently Safer Chemistry for Accident Prevention

91. a

92. d