# CHAPTER 2

# THE CHEMIST'S TOOL BOX

## ANSWERS TO QUESTIONS:

1. Curiosity is an important part of the scientific enterprise because scientists need a strong desire to investigate and learn about the behavior of nature. Science must start with the question why. The scientific method is then utilized to accumulate systematized knowledge about the physical world. A scientist's curiosity is incapable of being satisfied. Without the curious nature of scientists, the advancement of science would not have occurred as we presently know it.

2. Science is characterized by observations, which are used to develop experimental laws and theories for the workings of nature. Measurement lies at the heart of experiment. Nature appears to be based on a foundation that can be described by mathematics, and measurements provide the bricks to build upon this foundation.

3. Measured quantities are written so that the uncertainty is contained within the last digit of the number. A volume of 30.0 mL means the volume lies in the range 29.9 – 30.1 mL (30.0 ± 0.1 mL).

4. The difference between the quantities 9 inches and 9.00 inches is the amount of certainty or precision. Although numerically equivalent (the results of using 9 inches or 9.00 inches in a calculation will be indistinguishable), 9 inches tells us it is only certain in the range 8 – 10 inches; the quantity 9.00 inches is much more precise, having a certainty in the much narrower range of 8.99 – 9.01 inches.

5. Any measurement consists of a numerical value and the chosen unit. Units inform what is being measured and the scale used. Without a unit, a measurement is virtually useless. For example, if I say it is thirty degrees outside, the response will be thirty what? An American would presume it is cold since he is familiar with Fahrenheit; a European would turn on the air-conditioning presuming the measurement to be in Celsius. The International System of units, or SI, is generally used in the scientific arena.

6. Answers may vary. Three possible units for length are millimeters, centimeters and meters.
   Examples:
   Thickness of a dime - millimeters (mm)
   Length of a finger - centimeters (cm)
   Height of an adult - meters (m)

7. Answers may vary. Three possible units for mass are grams, milligrams and kilograms.
   Examples:
   Mass of a penny - grams (g)
   Mass of a straight pin - milligrams (mg)
   Mass of a bucket of water - kilograms (kg)
8. Answers may vary. Three possible units for time are milliseconds, seconds, and microseconds.

Examples:
Time between heartbeats - milliseconds (ms)
Time to run the 100 m. dash - seconds (s)
Time to blink your eye - microseconds (μs)

9. Answers may vary. Three possible units for volume are milliliters, kiloliters (gallons), and liters.
Examples:
Volume of a child's juice box – milliliters (mL)
Volume of water in a swimming pool – gallons or kiloliters (kL)
Volume of a bottle of soda – liters (L)

10. A conversion factor is an equivalence statement that relates one unit to another. Conversion factors are commonly written in equation form or as a fraction with units in the numerator and denominator. Because it is an equivalence statement, the fraction equals one and the conversion factor can be multiplied by any number with out changing the value of the number, only its units.

11. Graphs are a very convenient and powerful way to illustrate relationships between different quantities. Graphs can be modified to emphasize particular features. It is important to examine the range on the *y* axis to understand the significance of the changes plotted. A change will look much bigger if the scale is smaller, whereas a small change on a large scale could go virtually unnoticed.

12.
a) The decimal part of the number is 9.66
b) The exponential part of the number is $10^{-5}$
c) The exponent is -5.

13. Density is defined as mass per unit volume. Typical units for density are $g/cm^3$ (commonly used for solids), g/mL (used for liquids), or $kg/m^3$ (used for gases).

14. Oil floating on water means that the density of the oil is less than that of the water. Denser substances will sink in less dense substances.

**SOLUTIONS TO PROBLEMS:**

15.
a) $8.51 \times 10^{-4}$ g
b) $3.8041430 \times 10^{7}$
c) $2.9979 \times 10^{8}$ m/s
d) $3.13914040 \times 10^{8}$

16.

a) $1.9570261 \times 10^7$

b) $7.190900000 \times 10^9$

c) $7.461 \times 10^{-11}$ m

d) $1.5 \times 10^{-5}$ m

17.

a) 149,000,000 km

b) 0.000000000079 m

c) 4,540,000,000 yr

d) 6,400,000 m

18.

a) 602,200,000,000,000,000,000,000 carbon atoms in 12.01 grams of carbon

b) 300,000,000 m/s

c) 0.000000450 m

d) 13,700,000,000 yr

19. Convert 40,075 km to a) meters, b) miles, c) feet.

a) $4.0075 \times 10^7$ m $$\frac{40075\ \text{km}}{1} \times \frac{1000\ \text{m}}{1\ \text{km}} = 4.0075\text{x}10^7\ \text{m}$$

b) 24,900 or $2.490 \times 10^4$ mi $$\frac{40075\ \text{km}}{1} \times \frac{0.6214\ \text{mi}}{1\ \text{km}} = 2.490\text{x}10^4\ \text{mi}$$

c) $1.315 \times 10^8$ ft $$\frac{40075\ \text{km}}{1} \times \frac{0.6214\ \text{mi}}{1\ \text{km}} \times \frac{5280\ \text{ft}}{1\ \text{mi}} = 1.315\text{x}10^8\ \text{ft}$$

20. Convert 2,777 miles into a) kilometers, b) meters, c) feet.

a) 4469 km $$\frac{2777\ \text{mi x 1 km}}{0.6214\ \text{mi}} = 4469\ \text{km}$$

b) $4.469 \times 10^6$ m $$\frac{2777\ \text{mi}}{1} \times \frac{1\ \text{km}}{0.6214\ \text{mi}} \times \frac{1000\ \text{m}}{1\ \text{km}} = 4.469\text{x}10^6\ \text{m}$$

c) $1.466 \times 10^7$ ft $$\frac{2777\ \text{mi}}{1} \times \frac{1760\ \text{yd}}{1\ \text{mi}} \times \frac{3\ \text{ft}}{1\ \text{yd}} = 1.466\text{x}10^7\ \text{ft}$$

21. 12 oz is 355 mL. $\frac{12\text{ oz}}{1}\times\frac{1\text{ qt}}{32\text{ oz}}\times\frac{1\text{ gal}}{4\text{ qt}}\times\frac{3.785\text{ L}}{1\text{ gal}}\times\frac{1000\text{ mL}}{1\text{ L}}=355\text{ mL}$

22. 150 mL is 5.07 oz. $\frac{150\text{ mL}}{1}\times\frac{1\text{ L}}{1000\text{ mL}}\times\frac{1.057\text{ qt}}{1\text{ L}}\times\frac{32\text{ oz}}{1\text{ qt}}=5.07\text{ oz}$

23. Convert miles to kilometers: 1 km = 0.6214 mi . $\frac{27\text{ mi}}{1}\times\frac{1\text{ km}}{0.6214\text{ mi}}=43\text{ km}$

Efficiency is 43 km/gal

24. Convert kilometers to miles: 1 km = 0.6214 mi $\frac{17\text{ km}}{1}\times\frac{0.6214\text{ mi}}{1\text{ km}}=11\text{ mi}$

Car will travel 11 miles on one liter of fuel.

25.

a) 4332 mm = 4.332 m $\frac{4332\text{ mm}}{1}\times\frac{1\text{ m}}{1000\text{ mm}}=4.332\text{ m}$

b) 1.76 kg = 1760 g or 1.76 x $10^3$ g $\frac{1.76\text{ kg}}{1}\times\frac{1000\text{ g}}{1\text{ kg}}=1{,}760\text{ g}$

c) 4619 mg = 4.619 x $10^{-3}$ kg $\frac{4619\text{ mg}}{1}\times\frac{1\text{ g}}{1000\text{ mg}}\times\frac{1\text{ kg}}{1000\text{ g}}=4.619\text{x}10^{-3}\text{ kg}$

d) 0.0117 L = 11.7 mL $\frac{0.0117\text{ L}}{1}\times\frac{1000\text{ mL}}{1\text{ L}}=11.7\text{ mL}$

26.

a) 2319 cm = 23.19 m $\frac{2319\text{ cm}}{1}\times\frac{1\text{ m}}{100\text{ cm}}=23.19\text{ m}$

b) 4912.5 g = 4.9125 kg $\frac{4912.5\text{ g}}{1}\times\frac{1\text{ kg}}{1000\text{ g}}=4.9125\text{ kg}$

c) 23.1 cm = 231 mm $\frac{23.1\text{ cm}}{1}\times\frac{10\text{ mm}}{1\text{ cm}}=231\text{ mm}$

d) 561 mL = 0.561 L $\frac{561\text{ mL}}{1}\times\frac{1\text{ L}}{1000\text{ mL}}=0.561\text{ L}$

27.

a) 358 m = 1170 ft (or 1.17 x $10^3$ ft) $\frac{358\text{ m}}{1}\times\frac{39.37\text{ in}}{1\text{ m}}\times\frac{1\text{ ft}}{12\text{ in}}=1170\text{ ft}$

b) 10.0 km = 6.21 mi $\frac{10.0\text{ km}}{1}\times\frac{0.6214\text{ mi}}{1\text{ km}}=6.21\text{ mi}$

c) 1.55 m = 61.0 in $\frac{1.55\text{ m}}{1}\times\frac{39.37\text{ in}}{1\text{ m}}=61.0\text{ in}$

d) 23 cm = 9.1 in $\frac{23\text{ cm}}{1}\times\frac{1\text{ in}}{2.54\text{ cm}}=9.1\text{ in}$

28.

a) 4.92 in = 125 mm $\frac{4.92\text{ in}}{1}\times\frac{25.4\text{ mm}}{1\text{ in}}=125\text{ mm}$

b) 8779 yd = 8.027 km $\frac{8779\text{ yd}}{1}\times\frac{1\text{ mi}}{1760\text{ yd}}\times\frac{1\text{mi}}{0.6214\text{ km}}=8.027\text{ km}$

c) 87 ft = 27 m $\frac{87\text{ ft}}{1}\times\frac{12\text{ in}}{1\text{ ft}}\times\frac{1\text{ m}}{39.37\text{ in}}=27\text{ m}$

d) 3.8 in = 9.7 cm $\frac{3.8\text{ in}}{1}\times\frac{2.54\text{ cm}}{1\text{ in}}=9.7\text{ cm}$

29.

a) 1552 $m^2$ = 1.671 x $10^4$ $ft^2$ $\frac{1552\text{ m}^2}{1}\times\frac{(39.37\text{ in})^2}{1\text{ m}^2}\times\frac{1\text{ ft}^2}{(12\text{ in})^2}=1.671\text{x}10^4\text{ ft}^2$

b) 1552 $m^2$ = 1.552 x $10^{-3}$ $km^2$ $\frac{1552\text{ m}^2}{1}\times\frac{1\text{ km}^2}{(1000\text{ m})^2}=1.552\text{x}10^{-3}\text{ km}^2$

c) 1552 $m^2$ = 1.552 x $10^5$ $dm^2$ $\frac{1552\text{ m}^2}{1}\times\frac{(10\text{ dm})^2}{1\text{ m}^2}=1.552\text{x}10^5\text{ dm}^2$

30.

a) 54 $cm^3$ = 5.4 x $10^4$ $mm^3$ $\frac{54\text{ cm}^3}{1}\times\frac{(10\text{ mm})^3}{1\text{ cm}^3}=5.4\text{x}10^4\text{ mm}^3$

b) 54 $cm^3$ = 3.8 $in^3$ $\frac{54\text{ cm}^3}{1}\times\frac{1\text{ in}^3}{(2.54\text{ cm})^3}=3.3\text{ in}^3$

c) 54 $cm^3$ = 5.4 x $10^{-2}$ $dm^3$ $\frac{54\text{ cm}^3}{1}\times\frac{1\text{ dm}^3}{(10\text{ cm})^3}=5.4\text{x}10^{-2}\text{ dm}^3$

31.

a) 1 square kilometer ($km^2$) = $10^6$ square meters ($m^2$). (1 km = $10^3$ m)

b) 1 $ft^3$ = 2.83 x $10^4$ $cm^3$. $\frac{1\text{ ft}^3}{1}\times\frac{(12\text{ in})^3}{1\text{ ft}^3}\times\frac{(2.54\text{ cm})^3}{1\text{ in}^3}=2.83\text{x}10^4\text{ cm}^3$

c) 1 $yd^2$ = 9 $ft^2$. (1 yd = 3 ft)

32.

a) 1 square meter ($m^2$) = $10^4$ square centimeters ($cm^2$). (1 m = $10^2$ cm)

b) 1 cubic yard ($yd^3$) = 4.6656x$10^4$ $in^3$ $\frac{1\text{ yd}^3}{1}\times\frac{(3\text{ ft})^3}{1\text{ yd}^3}\times\frac{(12\text{ in})^3}{1\text{ ft}^3}=4.6656\text{ x }10^4\text{ in}^3$

c) 1 square foot ($ft^2$) = 929 square centimeters ($cm^2$)

$$\frac{1\ \text{ft}^2}{1} \times \frac{(12\ \text{in})^2}{1\ \text{ft}^2} \times \frac{(2.54\ \text{cm})^2}{1\ \text{in}^2} = 9.29 \text{ x } 10^2\ \text{cm}^2$$

33. 53 min Time = distance/speed $\frac{10\ \text{km}}{1} \times \frac{0.6214\ \text{mi}}{1\ \text{km}} \times \frac{8.5\ \text{min}}{1\ \text{mi}} = 53\ \text{min}$

34. 1.66 hr Time = distance/speed $\frac{155\ \text{km}}{1} \times \frac{0.6214\ \text{mi}}{1\ \text{km}} \times \frac{1\ \text{hr}}{58\ \text{mi}} = 1.66\ \text{hr}$

35. 3.2 mi/L $\frac{12\ \text{mi}}{1\ \text{gal}} \times \frac{1\ \text{gal}}{3.785\ \text{L}} = 3.2\ \text{mi/L}$

5.1 km/L $\frac{12\ \text{mi}}{1\ \text{gal}} \times \frac{1\ \text{km}}{0.6214\ \text{mi}} \times \frac{1\ \text{gal}}{3.785\ \text{L}} = 5.1\ \text{km/L}$

36. 20. mi/L $\frac{75\ \text{mi}}{1\ \text{gal}} \times \frac{1\ \text{gal}}{3.785\ \text{L}} = 20.\ \text{mi/L}$

32 km/L $\frac{75\ \text{mi}}{1\ \text{gal}} \times \frac{1\ \text{km}}{0.6214\ \text{mi}} \times \frac{1\ \text{gal}}{3.785\ \text{L}} = 32\ \text{km/L}$

37.

a) The total decrease in the carbon monoxide is found by subtracting the final concentration in 2012 from the initial concentration in 1990.
6.1 ppm – 1.5 ppm = 4.6 ppm

b) The average yearly decrease is found by dividing the total decrease by the total number of years (1990 – 2012 = 22 years)
4.6 ppm/22 years = 0.21 ppm/yr

c) The total percentage decrease is found by dividing the total decrease by the concentration in 1990 and multiplying by 100 % $\frac{4.6}{6.1} \times 100\,\% = 75\,\%$

d) To find the average yearly percentage decrease, the total percentage decrease (75 %) is divided by the number of years in the period (22 years):

$$\frac{75\,\%}{22\ \text{yr}} = 3.4\ \%/\text{yr}$$

38.

a) The total increase in the carbon dioxide is found by subtracting the initial concentration in 1950 from the final concentration in 2007.
382 ppm – 310 ppm = 72 ppm

b) The average yearly increase is found by dividing the total increase by the total number of years (1950 – 2007 = 57 years)
72 ppm/57 years = 1.3 ppm/yr

c) The total percentage increase is found by dividing the total increase by the concentration in 1950 and multiplying by 100 % $\frac{72\text{ ppm}}{310\text{ ppm}}$ x 100 %=23 %

d) To find the average yearly percentage increase, the total percentage increase (23 %) is divided by the number of years in the period (57 years)

$$\frac{23\ \%}{57\text{ yr}} = 0.41\ \%/\text{yr}$$

39. The density is determined by dividing the mass by the volume: 127.8 g/28.4 $cm^3$
Density of titanium = 4.50 g/$cm^3$

40. The density is determined by dividing the mass by the volume: 3.5 g/1.5 $cm^3$
Density of silicon = 2.3 g/$cm^3$

41. 1.26 g/mL Density is mass/volume: $\frac{6.30\text{x}10^3\text{ g}}{1} \times \frac{1}{5\text{ L}} \times \frac{1\text{ L}}{1000\text{ mL}} = 1.26\text{ g/mL}$

42. 13.5 g/mL Density is mass/volume: $\frac{51.4\text{ g}}{3.80\text{ mL}}$=13.5 g/mL

43.

a) 42.7 g $38.5\text{ mL} \times \frac{1\text{ cm}^3}{1\text{ mL}} \times \frac{1.11\text{ g}}{1\text{ cm}^3} = 42.7\text{ g}$

b) 3.2 L $3.5\text{ k}g \times \frac{1000\text{ g}}{1\text{ kg}} \text{x} \frac{1\text{ cm}^3}{1.11\text{ g}} \times \frac{1\text{ mL}}{1\text{ cm}^3} \text{x} \frac{1\text{ L}}{1000\text{ mL}} = 3.2\text{ L}$

44.

a) Mass of Gold = 6.8 x $10^3$ g $350\text{ mL} \times \frac{1\text{cm}^3}{1\text{mL}} \times \frac{19.32\text{ g}}{1\text{cm}^3} = 6.8 \times 10^3\text{ g}$

Mass of Sand = 1.0 x $10^3$ g $350\text{ mL} \times \frac{1\text{cm}^3}{1\text{mL}} \times \frac{3.00\text{ g}}{1\text{cm}^3} = 1.0 \times 10^3\text{ g}$

b) Yes, the woman would notice the change from gold to sand since the sand weighs much less than the same volume of gold.

45. Density = 9.0 g/$cm^3$

a) $V = \pi r^2 h = 3.14 \times (0.55\text{ cm})^2 \times 2.85\text{ cm} = 2.7\text{ cm}^3$

$$d = \frac{m}{V} = \frac{24.3\text{ g}}{2.7\text{ cm}^3} = 9.0\text{ g/cm}^3$$

b) The metal is copper.

46.

m = 1.7 x $10^{-24}$g, r = 1 x $10^{-13}$cm

a) $V = \frac{4}{3}$ x 3.14 x $(1x10^{-13})^3$ = 4 x $10^{-39}$cm$^3$

$$d = \frac{m}{V} = \frac{1.7 \text{ x } 10^{-24} \text{g}}{4 \text{ x } 10^{-39} \text{cm}^3} = 4 \text{ x } 10^{14} \text{g/cm}^3$$

r = 1 x $10^{-4}$m x 100 cm/1 m = 1 x $10^{-2}$ cm

b) $V = \frac{4}{3}$ x 3.14 x $(1x10^{-2}\text{cm})^3$ = 4 x $10^{-6}$cm$^3$

Mass of the black hole:

Density from part a): d = 4 x $10^{14}$g/cm$^3$

$$\text{Mass} = \text{d x V} = 4 \text{ x } 10^{-6}\text{cm}^3 \text{ x } \frac{4x10^{14}\text{g}}{1\text{cm}^3} = 1.6 \text{ x } 10^9 \text{g x } \frac{1 \text{ kg}}{1000 \text{ g}} = 1.6 \text{ x } 10^6 \text{kg}$$

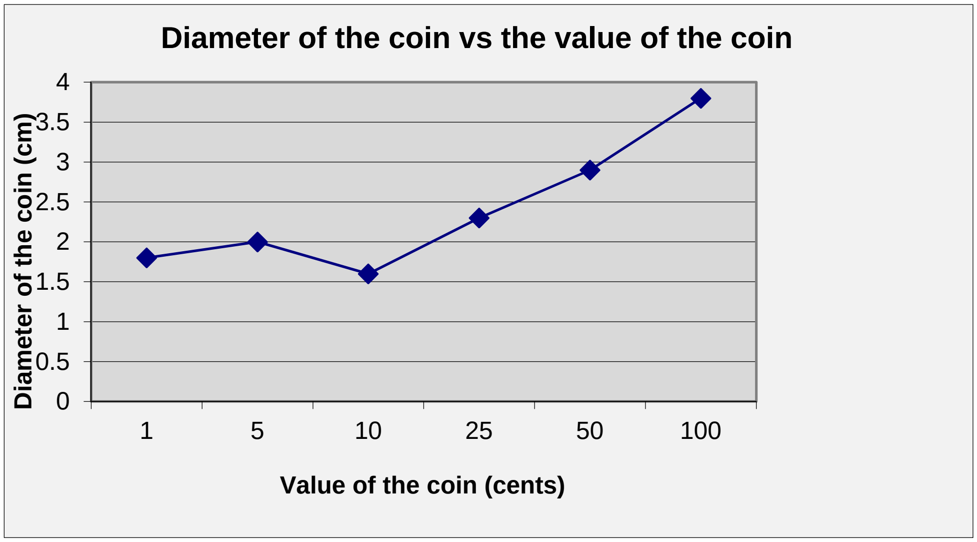
**SOLUTIONS TO POINTS TO PONDER:**

47. – 51. Answers will vary.

**SOLUTIONS TO FEATURE PROBLEMS:**

52. The most precise scale (c) measures 5.4259 g. The least precise scale (a) measures 5.42 g.
The uncertainty of scale a is ± 0.01 g
The uncertainty of scale b is ± 0.001 g
The uncertainty of scale c is ± 0.0001 g.

53. penny – 1.8 cm
    nickel – 2.0 cm
    dime – 1.6 cm
    quarter – 2.3 cm
    half-dollar – 2.9 cm
    dollar – 3.8 cm




The general trend is that as the value of the coin increases, the diameter of the coin also increases. The dime is the only coin that does not fit the general trend; it is too small.