Nuggets: Terms; Density; SI Units; Periodic Table; Dimensional Analysis/Unit Conversions; Sig Figs

TERMS

Matter: has mass and volume; states or phases of matter: solid, liquid, and gas
Substances: containing only one chemical substance with a constant composition, for example, H₂O or NaCl; other texts may refer to this as a Pure Substance
Atom: the smallest chemical substance that has the properties of that element, for example, He or Fe
Element: a substance that contains a single type of atom and cannot be decomposed into two or more substances; one of about 110 unique substances on the periodic table
Compound: a substance with two or more elements bonded together in fixed proportions, for example, CO₂ or NO
Molecule: smallest discrete substance, for example, O₂(g) or CH₄(g) that maintains the chemical characteristics of that species; electrically neutral; held together with covalent bonds;
Salts: held together with ionic bonds (salts = metal + nonmetal)
Ions: charged atoms or compounds

Chemical Change or Chemical Reaction: atoms are rearranged by making and/or breaking chemical bonds; a chemical change is represented with starting materials (reactants) and new materials (products); for example, going from C(s) to CO₂(g) as in C(s) + O₂(g) → CO₂(g)
Chemical Property: how a substance reacts chemically, for example, C(s) can react with O₂(g) to form CO₂(g)
Physical Property: physical characteristic of a chemical such as its solubility, boiling point, melting point, density, etc.
Physical Change: a change in the state of matter; for example, H₂O(s) to H₂O(l); s ⇄ l ⇄ g

MISC

Kinetic Molecular Theory: Matter consists of tiny particles in constant motion; Solids: particles packed in a close regular array, vibrate but do not move; is rigid and volume is fixed; Liquids: particles are randomly arranged, touch and move past one another; Gases: has no fixed shape or volume; fill the container they’re in; can be compressed; particles move quite rapidly.

Phases of Matter (solid, liquid, gas): 🔧💧🧬

H-bonding found in H₂O(l)

H atom in one water molecule interacts with an O atom of another water molecule. The O—H in the diagram below represents the H-bonding and is not the same as the bond between H and O within one molecule. In water, the angle of O—H—O is 180°. This chemical interaction changes the physical properties of water significantly. It’s boiling point, for example, is much higher than expected for such a small molecule.

Law of Conservation of Mass: Mass is neither created nor destroyed

Precision – measure of how close several measurements are to one another
Accuracy – how close a measured value is to the accepted value
DENSITY

\[ \text{density} = \frac{\text{mass}}{\text{volume}} \]

units: g/ml (liquids), g/cm³ (solids), or g/L (gases)

\[ V = l \times w \times h \] (rectangular solid); \[ V = \text{side}^3 \] (cube); \[ V = \frac{4}{3}\pi r^3 \] (sphere with \( r = \text{radius} \))

Example 1: A cubic sample of cobalt has a mass of 75.4 mg (D_{Co} = 8.86g/cm³). What is the side length of the cube in cm?

Answer 1: \( 0.204cm \) \{ \( D = \frac{\text{mass}}{\text{volume}} \); volume (cube) = side³; \( D = \frac{\text{mass}}{\text{side}^3} \); rearrange equation: \( \text{side}^3 = \frac{\text{mass}}{D} \); convert units: \( 75.4 \text{mg} \times (1\text{g}/1000\text{mg}) = 0.0754 \text{g} \); side = \( \left( \frac{0.0754 \text{g}}{8.86 \text{g}/\text{cm}^3} \right)^{1/3} = 0.2042\text{cm} \} \)

SI UNITS (MEMORIZE)

\[ \begin{align*}
G &= \text{giga} = 1 \times 10^9 \text{ (sometimes used)} \\
M &= \text{mega} = 1 \times 10^6 \\
k &= \text{kilo} = 1 \times 10^3 \\
c &= \text{centi} = 1 \times 10^{-2} \\
m &= \text{milli} = 1 \times 10^{-3} \\
\mu &= \text{micro} = 1 \times 10^{-6} \\
p &= \text{pico} = 1 \times 10^{-12}
\end{align*} \]

Other units: 1ml = 1cm³ 1Ångstrom = 1Å = 1 x 10⁻¹⁰m

PERIODIC TABLE

Family or Groups = columns: alkali metals (Group IA), alkaline earth metals (Group IIA), halogens (Group VIIA), noble gases (Group VIIIA); other groups on the Periodic Table: transition metals; actinides; lanthanides

Period = row on the Periodic Table

Three types of elements: metals, non-metals, metalloids (metalloids = B, Si, Ge, As, Sb, Te, sometimes Po and At)

Diatomic Elements: F₂, Cl₂, Br₂, I₂, N₂, O₂, H₂ (memorize)

Phases of elements: (memorize)

Gas elements: noble gases: He(g), Ne(g), Ar(g), Kr(g), Rn(g); F₂(g), Cl₂(g), H₂(g), N₂(g), O₂(g);

Liquid elements: Br₂(l), Hg(l)

Solid elements: All other elements that are not liquids or gases are solids

Element names and symbols: elements 1-36 names and symbols, and Ag, Au, Ba, I, Hg, Pb, and U; other ones sometimes seen in this course include: Sr, Ba, Rb, Cs (memorize)
DIMENSIONAL ANALYSIS (UNIT CONVERSIONS)

Example 2: Convert 5cm into meters. (Example 2 is a one-step conversion: going between the pivot line and another unit.)

\[
\begin{align*}
M &= 1 \times 10^6 \\
\text{k} &= 1 \times 10^3 \\
\text{m, l, g} &= 1 \times 10^3 \\
c &= 1 \times 10^{-2} \\
\text{m} &= 1 \times 10^{-3} \\
\end{align*}
\]

**Example 2:** 5cm \(\rightarrow\) ?m

**Answer 2:** 1 step conversion: directly to pivot line

\[
\frac{1 \text{m}}{1 \times 10^2 \text{cm}} \quad \frac{1 \text{m}}{1 \times 10^2 \text{cm}} \quad \frac{1 \times 10^5 \text{m}}{1 \text{cm}} \quad \frac{1 \times 10^2 \text{m}}{1 \text{cm}}
\]

**Setting up the conversion fractions correctly. Which conversion factor is correct?** (At first glance they all look ok but 2 are incorrect!)

\[
\begin{align*}
\frac{1 \text{m}}{1 \times 10^2 \text{cm}} & \quad \frac{1 \text{m}}{1 \times 10^2 \text{cm}} & & \frac{1 \times 10^5 \text{m}}{1 \text{cm}} & & \frac{1 \times 10^2 \text{m}}{1 \text{cm}} \\
\text{1st one says:} & & \text{A large number of small ones (cm) = 1 large one (m)} & & \text{Correct!} \\
\text{2nd one says:} & & \text{A fraction of a small one (cm) = 1 large one (m)} & & \text{Incorrect!} \\
\text{3rd one says:} & & \text{One small one (cm) = A large number of large ones (m)} & & \text{Wrong!} \\
\text{4th one says:} & & \text{A fraction of the large one (m)} & & \text{Correct!}
\end{align*}
\]

Example 3: Convert 5mm into nanometers. (Example 3 is a two-step conversion: going between one unit and another where neither are on the pivot line. To do this, you must go through the pivot line since all the conversion factors convert units to the pivot line.)

\[
\begin{align*}
M &= 1 \times 10^6 \\
\text{k} &= 1 \times 10^3 \\
\text{m, l, g} &= 1 \times 10^3 \\
c &= 1 \times 10^{-2} \\
\text{m} &= 1 \times 10^{-3} \\
\mu &= 1 \times 10^{-6} \\
\text{n} &= 1 \times 10^{-9} \\
p &= 1 \times 10^{-12} \\
\end{align*}
\]

**Example 3:** 5mm \(\rightarrow\) ?nm

**Answer 3:** 2 step conversion: must go through the pivot line

\[
\begin{align*}
\text{mm} & \rightarrow \text{m} \rightarrow \text{nm} \\
5 \text{nm} & \cdot \frac{1 \mu}{1 \times 10^3 \text{nm}} \cdot \frac{1 \times 10^9 \text{nm}}{1 \mu} = 5 \times 10^6 \text{nm}
\end{align*}
\]

Example 4: Convert 5kg/mm³ into mg/cm³. (Example 4 is a multi-step conversion and includes units raised to exponents. To do this, you must go through the pivot line and take care of the powers/exponents.)

**Example 4:** 5kg/mm³ \(\rightarrow\) ?mg/cm³

**Answer 4:** multi-step conversion: must go through the pivot line and take care of the exponents

re-write as a "vertical" fraction: 5kg/mm³ \(\rightarrow\) \(\frac{5\text{kg}}{\text{mm}^3}\) \(\rightarrow\) \(\frac{5\text{kg}}{\text{mm} \times \text{mm} \times \text{mm}}\) (expanded notation)

work on each unit conversion separately; doesn't matter which conversion is done first;
I'll work on the bottom conversion first (mm³ \(\rightarrow\) cm³)

\[
\begin{align*}
\text{mm}^3 & \rightarrow \text{m}^3 \rightarrow \text{cm}^3 \quad \text{and then} \quad \text{kg} & \rightarrow \text{g} & \rightarrow \text{mg} \\
\frac{5\text{kg}}{\text{mm}^3} & \cdot \frac{1 \times 10^3 \text{m}^3}{1 \text{m}^3} \cdot \frac{1 \times 10^3 \text{m}^3}{1 \text{m}^3} \cdot \frac{1 \times 10^3 \text{m}^3}{1 \text{m}^3} \cdot \frac{1 \text{g}}{1 \text{mg}} \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} = \frac{5 \times 10^9 \text{mg}}{\text{cm}^3}
\end{align*}
\]

Simplified:

\[
\frac{5\text{kg}}{\text{mm}^3} \cdot \left(\frac{1 \times 10^3 \text{m}^3}{1 \text{m}^3}\right)^3 \cdot \left(\frac{1 \text{g}}{1 \times 10^3 \text{mg}}\right)^3 \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} = \frac{5 \times 10^9 \text{mg}}{\text{cm}^3}
\]

Note how the mm³ required three mm \(\rightarrow\) m conversions that can be written separately or by raising one conversion to the 3rd power.

**Common error:**

\[
\frac{5\text{kg}}{\text{mm}^3} \cdot \left(\frac{1 \times 10^3 \text{m}^3}{1 \text{m}^3}\right)^3 \cdot \left(\frac{1 \text{g}}{1 \times 10^3 \text{mg}}\right)^3 \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} \cdot \frac{1 \times 10^3 \text{mg}}{1 \text{g}} = \frac{5 \times 10^7 \text{mg}}{\text{cm}^3} \quad \text{Wrong answer!}
\]

**Common error** is to place the power of 3 for the \(1 \times 10^3 \text{mm}/\text{m}\) conversion inside the parentheses and only on the units instead of outside the parentheses which then also raises the numbers to the power of 3 as well.
Significant Figures (usually emphasized)

- **Number < 1**: digits to the right of decimal are significant (for example, 0.2560 = 4 sig figs); *leading zeros* are not significant, for example, 0.0025 = 2 sig figs; *trailing zeros* are significant, for example, 0.002500 = 4 sig figs

- **Number > 1**
  - *with decimal point*: all zeros right of the decimal point are significant, for example, 547.00 = 5 sig figs; 240.0 = 4 sig figs
  - *without decimal point*: trailing zeros are not significant, for example, 547 = 3 sig figs; 240 = 2 sig figs

- **Defined quantity**: Infinite sig figs, for example, 100cm = 1m → infinite sig figs

- **Scientific notation**: All numbers of the significand or matissa are significant, for example, 2.304 \times 10^{-2} = 4 sig figs; 1.0400 \times 10^{-4} = 5 sig figs)

1. Classify each of the following as a *physical* property or a *chemical* property.
   a. Density of ethanol is lower than the density of water.
   b. The melting temperature of water is 0.0°C at 1.0 atmosphere.
   c. Ammonium chloride, \( \text{NH}_4\text{Cl} \) decomposes into ammonia, \( \text{NH}_3(g) \), and hydrogen chloride, \( \text{HCl}(g) \) upon heating.
   d. Gold at room temperature does not react with sulfur.

2. Classify each of the following as a *physical* or *chemical* change.
   a. Rusting of iron involves changing \( \text{Fe}(s) \) into \( \text{Fe}_2\text{O}_3(s) \).
   b. Burning gasoline yields mainly carbon dioxide, \( \text{CO}_2(g) \), and water vapor, \( \text{H}_2\text{O}(g) \).
   c. Water will evaporate from a lake.

3. Consider the following separations of materials. State whether a *physical* or a *chemical* process is involved in each separation.
   a. Sodium chloride is obtained from sea water by evaporation of the water.
   b. Mercury is obtained by heating the substance mercury (II) oxide; oxygen is also obtained.

4. Do the following unit conversions.
   a. 50.0 ng is equivalent to ____________________ mg.
   b. 1.75 mm is equivalent to _______________ pm.
   c. A density of 50.0 g/cm\(^3\) is equivalent to _______________ kg/m\(^3\).
   d. How many feet are there in 2960 cm? (2.54 cm = 1.00 inch)
   e. The speed of light is 3.00 \times 10^8 m/s. What is this speed in mi/hr? (2.54 cm = 1.00 inch; 5280 feet = 1.00 mile)

5. If a runner ran a 50.6 mile race in 8.00 hours and 23.0 minutes, how long would it take them to run a marathon (26.2 miles) in hours and minutes at the same average speed they ran the longer race?

6. The density of homogenized milk is 1.03 g/ml. How much does 237 ml (1.00 cup) weigh in kg?

7. A cube of metal has a side length of 2.0 cm and a mass of 40.0 grams. What is its density in g/cm\(^3\)?

8. An irregular shaped piece of metal has a density of 3.76 g/cm\(^3\) and when placed in a graduated cylinder containing water, the water rises from 31.25 ml to 32.58 ml. What is the mass of the metal in grams? (recall 1 ml = 1 cm\(^3\))
9. Below is a graph (source: Carbon Counter from MIT) showing greenhouse CO$_2$ emissions versus monthly dollar costs. Five larger-sized internal combustion engine vehicles have been highlighted.
   a. What is their approximate average greenhouse CO$_2$ emissions? (ballpark average is fine; no calculation)
   b. About how many grams CO$_2$ eq/mile on average are they above/below the 2030 emissions target for the average car to keep global warming under 2°C? (ballpark average is fine; no calculation)
   c. What is their approximate cost to operate per year?

![Graph showing greenhouse CO$_2$ emissions versus monthly dollar costs.]

10. A rectangular sample titanium foil has a top surface area of 13.9m$^2$ and has a mass of 681.6g. The density of titanium is 4.506 g/cm$^3$. Calculate the thickness of the titanium foil in cm.

11. If second rectangular sample of titanium in the form of a cube has a mass of 25.7mg (D$_{Ti}$ = 4.506 g/cm$^3$) what is the side length of the cube in cm?

12. If a third sample of titanium is in the form of a sphere and has a mass of 245.1µg (D$_{Ti}$ = 4.506 g/cm$^3$) what is the radius of the sphere in cm? Recall volume of a sphere = $\frac{4}{3}\pi r^3$

13. Draw a separate picture to represent each of the following: H$_2$O(s), H$_2$O(l), and H$_2$O(g).

14. a. Which of the following elements are metals? Ar, Mn, C, O$_2$, Al
   b. What is the name of the family of elements that contains magnesium?
   c. Name one halogen element.

15. I. Write the chemical symbols for the elements:
   a. potassium b. cobalt c. manganese d. iron e. phosphorous
   II. Write the chemical names for the following symbols: a. Cr b. Ca c. Kr d. S e. Si f. V g. Mn h. Na

16. Which of the following compounds would have properties most similar to CaF$_2$?
   a. CO$_2$ b. SF$_2$ c. MgCl$_2$ d. NaCl e. CaO

17. How many sig figs are in the following numbers/calculations?
   a. 124.02 b. 0.00045 c. 120,000,000 d. 10 e. 1.00045 f. 1.20 x 10$^{-5}$
ANSWERS
1. a. physical property  b. physical property  c. chemical property  d. chemical property

2. a. chemical change  b. chemical change  c. physical change

3. a. physical process  b. chemical reaction

4. a. $5.00 \times 10^{-5} \text{mg}$ {50ng $ \left( \frac{1 \text{g}}{1 \times 10^6 \text{ng}} \right) \left( \frac{1000 \text{mg}}{1 \text{g}} \right) = 5.00 \times 10^{-5} \text{mg}$}
   b. $1.75 \times 10^9 \text{pm}$ {1.75mm $ \left( \frac{1 \text{m}}{1000 \text{mm}} \right) \left( \frac{1 \times 10^{12} \text{pm}}{1 \text{m}} \right) = 1.75 \times 10^9 \text{pm}$}
   c. $5.00 \times 10^4 \text{kg/m}^3$ {50g $ \left( \frac{1 \text{kg}}{1000 \text{g}} \right) \left( \frac{1000 \text{cm}^3}{1 \text{m}^3} \right)^3 = 5.00 \times 10^4 \text{kg/m}^3$}
   d. 97.1ft {2960cm $ \left( \frac{1 \text{in}}{2.54 \text{cm}} \right) \left( \frac{1 \text{ft}}{12 \text{in}} \right) = 97.1 \text{ft}$}
   e. $6.71 \times 10^8 \text{mi/hr}$ {3200m $ \left( \frac{60 \text{s}}{1 \text{min}} \right) \left( \frac{60 \text{min}}{1 \text{hr}} \right) \left( \frac{100 \text{cm}}{1 \text{m}} \right) \left( \frac{1 \text{in}}{2.54 \text{cm}} \right) \left( \frac{1 \text{ft}}{12 \text{in}} \right) \left( \frac{1 \text{mi}}{5280 \text{ft}} \right) = 6.71 \times 10^8 \text{mi/hr}$}

5. 4.00 hours and 20.5 minutes {8.00hr x (60min/1hr) = 480min + 23min = 503min total; (503min/50.6mi) x (26.2mi) = 260.45min to run a marathon; 260.45min x (1hr/60min) = 4.3408hr; 4 hours and 0.3408 hr; 0.3408hr x (60min/1hr) = 20.45min; 4.00hr and 20.5min}

6. 0.244kg {D = m/V; m = D(V) = (1.03g/ml)(237ml) = 244.11g x (1kg/1000g) = 0.24411kg}

7. 5.0g/cm$^3$ {D = m/V; V = (2.0cm)$^3 = 8.0cm^3$; D = $\frac{40.0g}{8.0cm^3} = \frac{5.00g}{cm^3}$}

8. 5.00g {D = m/V; m = D(V) = $\left( \frac{3.76g}{cm^3} \right) \left( \frac{1cm^3}{1ml} \right) \left( 32.58ml - 31.25ml \right) = 5.001g$}

9. 1. a. ~650 lifecycle grams CO$_2$ eq/mile
   b. ~350 lifecycle grams CO$_2$ eq/mile above the 2030 emissions target {650 - ~300 = 350}
   c. ~$8400$ {average monthly cost has a wide range from ~$600 to ~$800; ballparking the average without doing a calculation would be ~$700/month; \left( \frac{\$700}{month} \right) \left( \frac{12 \text{months}}{1 \text{year}} \right) = \$8400 / year}

10. 0.00109cm {D = $\frac{\text{mass}}{\text{vol}} = \frac{\text{mass}}{\text{length x width x depth}} = \frac{\text{mass}}{\text{length x width x thickness}}$; rearrange equation:
     thickness = $\frac{\text{mass}}{\text{length x width x D}}$; area = length x width; thickness = $\frac{\text{mass}}{\text{area x D}}$;
     convert units: $13.9m^2 \times (100cm/1m)^2 = 139,000cm^2$; thickness = $\frac{681.6g}{139,000cm^2 \times \frac{4.506g}{cm^3}} = 0.001088cm$}

(For more practice see Practice Sheet #1 for SI unit conversions, and Practice Sheet #2 for element names and symbols practice)
11. 0.179 cm \{D = \text{mass/vol}; \text{volume (cube)} = \text{side}^3; \ D = \text{mass/\text{side}^3}; \text{rearrange equation}: \ \text{side}^3 = \dfrac{\text{mass}}{D}, \}

\text{side} = \sqrt[3]{\dfrac{\text{mass}}{D}} = \left(\dfrac{\text{mass}}{D}\right)^{1/3}; \text{convert units:} \ 25.7 \text{mg} \times \left(\dfrac{1 \text{g}}{1000 \text{mg}}\right) = 0.0257 \text{g}; \ \text{side} = \left(\dfrac{0.0257 \text{g}}{4.506 \text{g/cm}^3}\right)^{1/3} = 0.1787 \text{cm}\}

12. 0.02350 cm \{D = \text{mass/vol}; \text{volume (sphere)} = \dfrac{4}{3}\pi r^3; \ D = \dfrac{\text{mass}}{\dfrac{4}{3}\pi r^3}; \text{rearrange equation}: \ r^3 = \dfrac{\text{mass}}{\dfrac{4}{3}\pi D}; \}

r = \sqrt[3]{\dfrac{\text{mass}}{\dfrac{4}{3}\pi D}} = \left(\dfrac{\text{mass}}{\dfrac{4}{3}\pi D}\right)^{1/3}; \text{convert units:} \ 245.1 \mu \text{g} \times \left(\dfrac{1 \text{g}}{1.0 \times 10^6 \mu \text{g}}\right) = 0.0002451 \text{g}; \ r = \left(\dfrac{0.0002451 \text{g}}{\dfrac{4}{3}\pi 4.506 \text{g/cm}^3}\right)^{1/3}; \ r = \left(\dfrac{0.0002451 \text{g}}{18.875 \text{g/cm}^3}\right)^{1/3} = 0.02350 \text{cm}\}

13. 

\begin{align*}
\text{water} & \quad \text{solid} & \text{liquid} & \text{gas} \\
\end{align*}

14. a. Mn, Al  
   b. alkaline earth metals  
   c. fluorine, chlorine, bromine, iodine (any one of these)

15. I. a. K  
    b. Co  
    c. Mn  
    d. Fe  
    e. P  
    II. a. chromium  
      b. calcium  
      c. krypton  
      d. sulfur  
      e. silicon  
      f. vanadium  
      g. manganese  
      h. sodium

16. c \{\text{elements in the same family/column have similar properties; Mg is in the same column as Ca and Cl is in the same column as F}\}

17. a. 5  
   b. 2  
   c. 2  
   d. 1  
   e. 6  
   f. 3