UNIT X : ORGANIC CHEMISTRY

X.1. INTRODUCTION

Organic chemistry is defined as the chemistry of **CARBON** compounds. Because of the immense number of organic compounds, organic chemistry is considered to be one of the major branches of chemistry.

In spite of the fact that carbon is the focus of organic chemistry, hydrogen atoms are usually, but not always, present in organic molecules. Compounds containing only carbon and hydrogen atoms number in the hundreds of thousands and the option of adding other atoms such as oxygen, nitrogen, chlorine and so on, extends the number of known organic compounds to over 8 million.

The key to this huge number of organic compounds is the fact that carbon forms chains involving several carbon atoms linked to each other in a straight–line fashion, in a "circular" pattern, or in a branched pattern. In addition, the carbon atoms may form single, double or triple bonds to neighbouring atoms, which further extends the range of possible molecules.

Why is organic chemistry so important? A partial answer is found by looking at the organic compounds below.

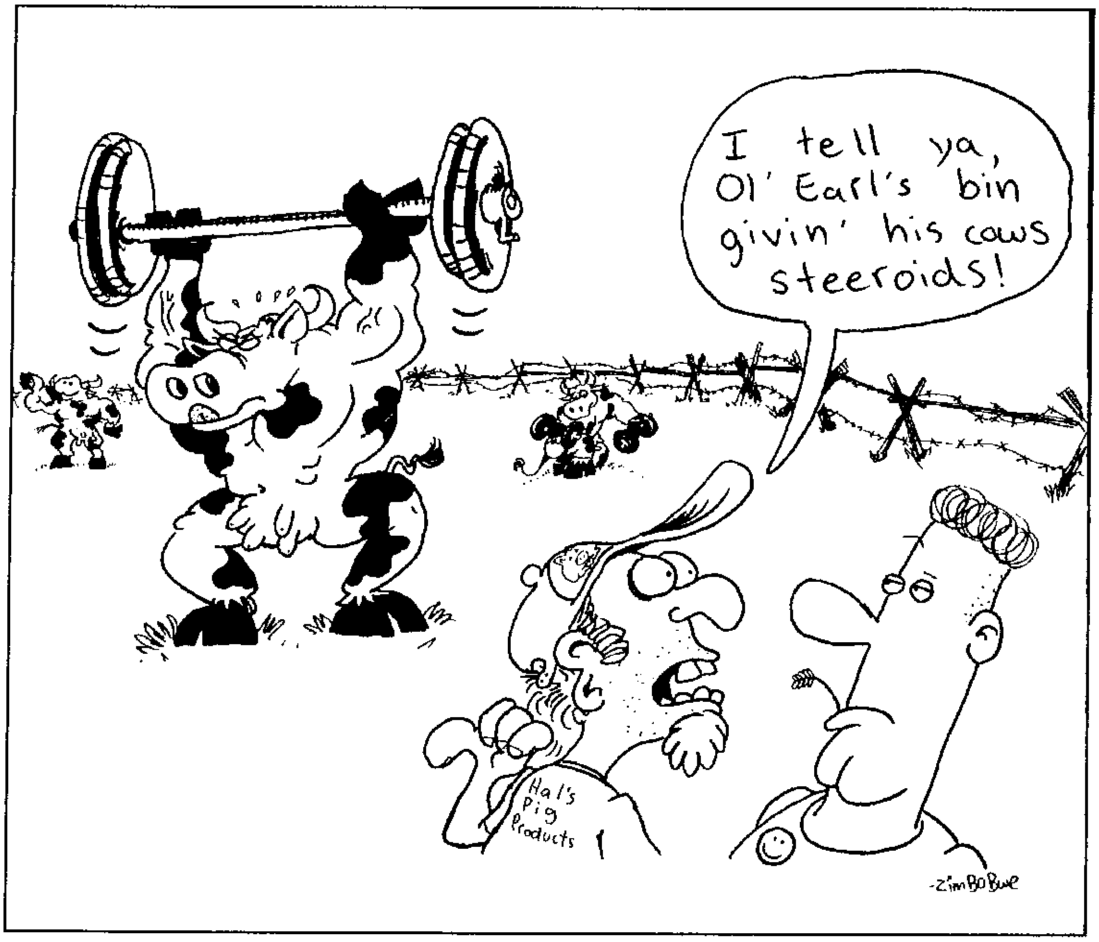
C_8H_{18} = iso–octane (the chief ingredient in gasoline)
CH_4 = methane ("natural gas")
$C_{18}H_{21}NO_3$ = codeine (pain reliever)
$C_{22}H_{25}NO_6$ = colchicine (anti–leukemia drug)
$C_8H_6O_3Cl_2$ = 2,4–D (a herbicide)
$C_{14}H_9Cl_5$ = DDT (a banned pesticide)
$C_{10}H_{19}O_6S_2P$ = malathion (an insecticide)
$C_{19}H_{28}O_2$ = testosterone (a male sex hormone)
$C_{17}H_{21}NO_4$ = cocaine
$C_{10}H_{14}N_2$ = nicotine
$C_6H_{12}O_6$ = glucose (a sugar)
C_2H_4 = ethene (a plant hormone which causes ripening of fruit)
$C_{20}H_{12}$ = 1,2–benzpyrene (a cancer–causing ingredient of cigarette smoke)
$C_{40}H_{56}$ = beta–carotene (the yellow colour in carrots; used as the colouring agent in margarine)
$[C_2H_4]_x$ = polyethylene (plastic) ["x" implies a multiply–repeated unit]
$[C_2F_4]_x$ = Teflon

Looking down the list, you may notice that all these organic compounds contain carbon, and most also contain hydrogen. Organic chemicals have an extensive range of uses and properties. Some organic chemicals occur naturally and some are produced synthetically; some are beneficial and some are hazardous.

Where do we find organic compounds? Look around you! They are found in petroleum, natural gas and all living things including trees, grasses, vegetables, insects, animals and people.

The largest industry involving organic chemistry is the manufacture of petrochemicals. Petroleum is presently the starting material for a vast range of products. Part of the complicated mixture of organic chemicals which makes up petroleum is separated ("fractionated") and refined for use in gasoline and oil, while other "fractions" of petroleum are chemically altered to serve as raw materials for a huge array of industrial processes such as the manufacture of plastics, solvents, pharmaceuticals and personal care products. The food and beverage industry alone uses a substantial amount of organic chemicals in the form of "food additives" — look at the ingredients listed on a package of your favourite "junk food" (most of those unpronouncable names are organic chemicals).

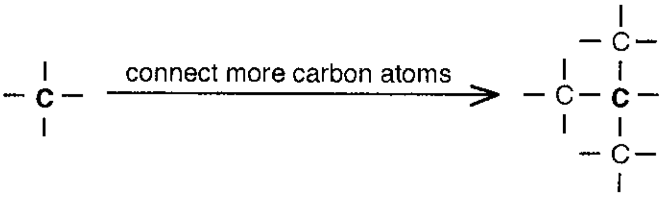
This unit starts by looking at compounds containing only carbon and hydrogen and then looks at the effects of introducing other kinds of atoms.



X.2. ALKANES

Definition: A **HYDROCARBON** is a compound containing only hydrogen and carbon.

A carbon atom, such as the one shown in bold below on the left, can form bonds to four other atoms (carbon has a valence of four) — and this is the key to the wide variety ot possible carbon compounds. If one or more of the four bonds connect to other carbon atoms, each of these attached carbons can connect to three other atoms, and so on. The possible variety and complexity of the molecules increases with each carbon added.



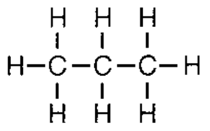
$$\begin{array}{c} | \\ -\mathbf{C}- \\ | \end{array} \xrightarrow{\text{connect more carbon atoms}} \begin{array}{cc} & | \\ & -\mathrm{C}- \\ | & | \\ -\mathrm{C}- & \mathbf{C}- \\ | & | \\ & -\mathrm{C}- \\ & | \end{array}$$

A. UNBRANCHED ("STRAIGHT CHAIN") ALKANES

There is more than one way to represent a hydrocarbon formula, depending on how compact one wants to write the formula.

EXAMPLE: The structure of propane, C_3H_8, can be shown in three ways.

full structure:



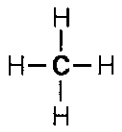
$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & \mid & & \mid & & \mid & & \\ H & - & C & - & C & - & C & - & H \\ & & \mid & & \mid & & \mid & & \\ & & H & & H & & H & & \end{array}$$

or condensed structure: CH_3–CH_2–CH_3 (or even $CH_3CH_2CH_3$)

or molecular formula: C_3H_8

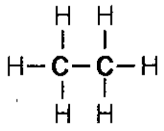
In the following sequence of hydrocarbons, each molecule differs by the number of carbon atoms linked to one another to form a "carbon chain". Because the chain of carbon atoms extends in a straight–line fashion, the hydrocarbons in this section are call "straight–chain" or "unbranched" hydrocarbons.

methane = CH_4 =



$$\begin{array}{ccccc} & & H & & \\ & & \mid & & \\ H & - & \mathbf{C} & - & H \\ & & \mid & & \\ & & H & & \end{array}$$

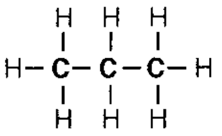
ethane = C_2H_6 =



$$\begin{array}{ccccccc} & & H & & H & & \\ & & \mid & & \mid & & \\ H & - & \mathbf{C} & - & \mathbf{C} & - & H \\ & & \mid & & \mid & & \\ & & H & & H & & \end{array}$$

= CH_3–CH_3

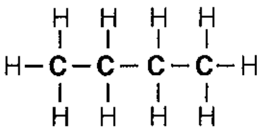
propane = C_3H_8 =



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & \mid & & \mid & & \mid & & \\ H & - & \mathbf{C} & - & \mathbf{C} & - & \mathbf{C} & - & H \\ & & \mid & & \mid & & \mid & & \\ & & H & & H & & H & & \end{array}$$

= CH_3–CH_2–CH_3

butane = C_4H_{10} =



$$\begin{array}{ccccccccccc} & & H & & H & & H & & H & & \\ & & \mid & & \mid & & \mid & & \mid & & \\ H & - & \mathbf{C} & - & \mathbf{C} & - & \mathbf{C} & - & \mathbf{C} & - & H \\ & & \mid & & \mid & & \mid & & \mid & & \\ & & H & & H & & H & & H & & \end{array}$$

= CH_3–CH_2–CH_2–CH_3

and similarly

pentane = C_5H_{12} = CH_3–CH_2–CH_2–CH_2–CH_3

hexane = C_6H_{14} = CH_3–CH_2–CH_2–CH_2–CH_2–CH_3

heptane = C_7H_{16} = CH_3–CH_2–CH_2–CH_2–CH_2–CH_2–CH_3

octane = C_8H_{18} = CH_3–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_3

nonane = C_9H_{20} = CH_3–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_3

decane = $C_{10}H_{22}$ = CH_3–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_2–CH_3

Definition: An **ALKANE** is a hydrocarbon in which all the carbon atoms are connected by **single** bonds.

Note: 1. The names of the above hydrocarbons end in "ane" because they are "alkanes".

2. An alkane is also called a "**SATURATED**" hydrocarbon because each carbon atom is bonded to the maximum possible number of other atoms; that is, the carbon's ability to bond to other atoms is "saturated".

EXERCISE:

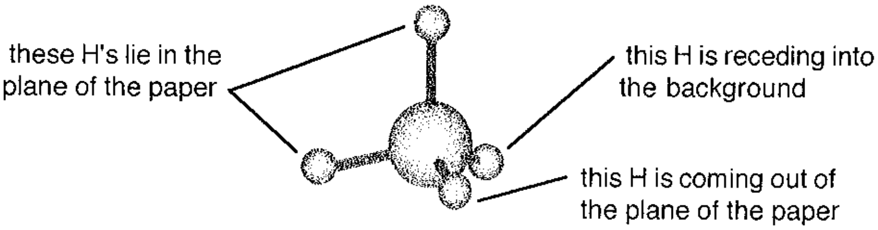
1. Look at the sequence of hydrogen atoms connected to carbon atoms in the list below.

   CH_4, C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, etc.

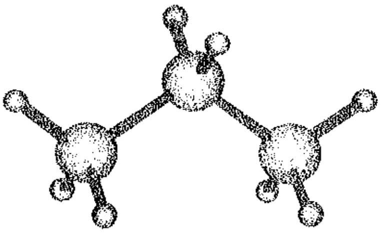
   Suggest a general formula for all straight–chain alkanes. That is, if there are "N" carbons, how many hydrogens will be present?

THE GEOMETRY OF ALKANES

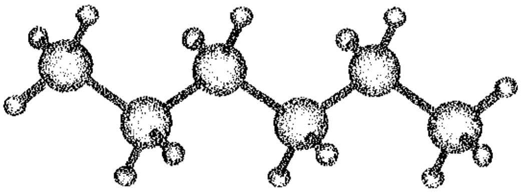
Although the bonds on a carbon atom are usually drawn as if they were run over by a steam roller, lying flat on a page at right angles to each other, the bonds are actually arranged in the shape of a 4–cornered pyramid (a "TETRAHEDRON") as shown below. All the bonds have equal lengths and all the H–C–H angles are 109°.



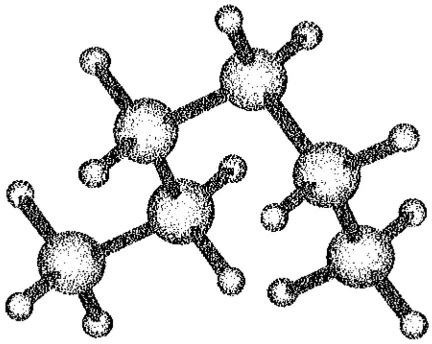
Therefore the actual shape of the propane molecule can be shown as



and a molecule of hexane might look something like the following.



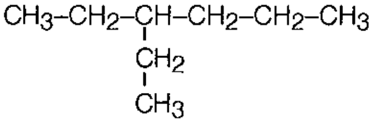
Each of the single bonds between the carbon atoms is able to rotate freely, leading to a highly flexible chain which can wave about and take many shapes. The above arrangement is one shape hexane can assume; another might be the arrangement shown below.



B. ALKYL GROUPS AND BRANCHED HYDROCARBONS

A hydrocarbon chain can have "side branches" which are also hydrocarbon chains.

EXAMPLE:



$$CH_3–CH_2–\underset{\underset{CH_3}{|}}{\underset{CH_2}{\underset{|}{C}}}H–CH_2–CH_2–CH_3$$

These attached "groups" are called ALKYL GROUPS.

A short digression on the "organic language"

This unit introduces some complicated words which seem like a foreign language to an outsider. In fact, the words ARE part of another language – the "organic language". As in other languages, the basic "words" are placed together to make complete names for organic molecules, similar to the way in which basic words are placed together to make complete sentences in English. The "organic" words can have their endings modified and be used like adjectives, verbs or adverbs. As you procede, always be sure you know the "syntax" or set of rules for constructing the organic "sentences" which make up the complete organic names of molecules. The rules are simple .... and there are NO IRREGULAR VERBS!

Definition: An **ALKYL GROUP** is an alkane which has lost one hydrogen atom.

EXAMPLE: $CH_4 \xrightarrow{\text{remove one H}} CH_3–$

$CH_3–CH_3 \xrightarrow{\text{remove one H}} CH_3–CH_2–$

$CH_3–CH_2–CH_3 \xrightarrow{\text{remove one H}} CH_3–CH_2–CH_2–$ or $CH_3–\underset{|}{C}H–CH_3$

(remove end H) (remove middle H)

The "unused" bond on the carbon atom can be connected to another hydrocarbon chain. **This unit only uses alkyl groups formed by taking a hydrogen off the END carbon of a hydrocarbon chain.**

RULE: An alkyl group is named by changing the "ane" ending of the original hydrocarbon to "yl".

EXAMPLES:

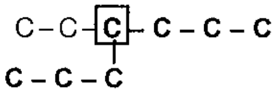
Original hydrocarbon	Alkyl group
methane = CH_4	methyl = $CH_3–$
ethane = $CH_3–CH_3$	ethyl = $CH_3–CH_2–$
propane = $CH_3–CH_2–CH_3$	propyl = $CH_3–CH_2–CH_2–$
butane = $CH_3–CH_2–CH_2–CH_3$	butyl = $CH_3–CH_2–CH_2–CH_2–$

When an alkyl group is attached to another hydrocarbon, the resulting molecule is called a **SUBSTITUTED HYDROCARBON** or a **BRANCHED HYDROCARBON.**

RULE: The first step in naming a substituted hydrocarbon is to find the longest continuous chain of carbon atoms. This longest chain is called the "***PARENT***" hydrocarbon.

EXAMPLES: To find the longest carbon chain, look at every "branch point" carbon (in a box in the examples below) and decide which TWO branches create the longest overall path (shown in bold). Only carbons are shown so as to make the various branches easier to see.

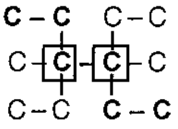
a)



The carbon in the box has 3 branches: the longest route involves the right branch (3 carbons) and the lower branch (3 carbons).

Longest path length = 7 carbons = **heptane**

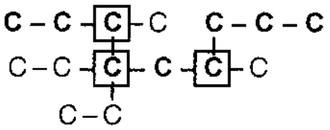
b)



Here, no unique "longest path" exists. The longest chain involves either the upper or lower pair of carbons on the left side and either the upper or lower group of two carbons on the right. The bold path shown was selected randomly from the 4 possible choices.

Longest path length = 6 carbons = **hexane**

c)



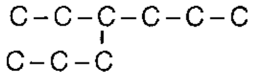
Do you agree with the bold path shown?

Longest path length = 9 carbons = **nonane**

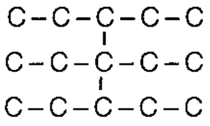
EXERCISE:

2. Determine the number of carbon atoms in the longest chain of each of the following, and name the parent hydrocarbon represented by the longest chain.

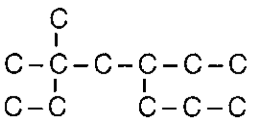
(a)



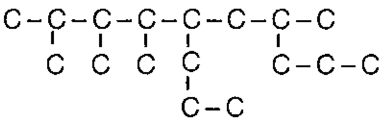
(b)



(c)



(d)

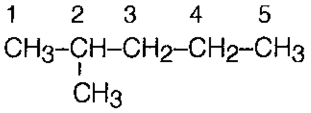


To name a substituted hydrocarbon, the basic idea is to name the longest (parent) hydrocarbon chain and then name the various alkyl groups which are attached to the parent hydrocarbon.

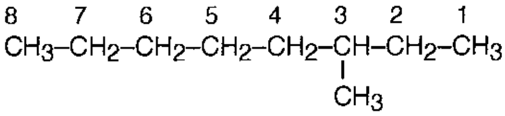
RULE: A substituted hydrocarbon is named by writing the following one after another
- the carbon number at which the alkyl group is attached,
- a dash,
- the name of the alkyl group, and finally
- the name of the longest or "parent" hydrocarbon chain, to which the alkyl group is attached.

Note: The carbon atoms in the parent hydrocarbon are numbered consecutively from the end of the hydrocarbon which gives the LOWEST POSSIBLE SET OF NUMBERS to the attached groups.

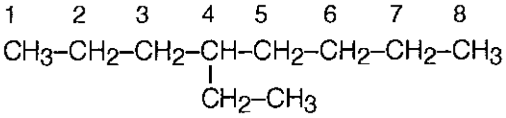
EXAMPLES:



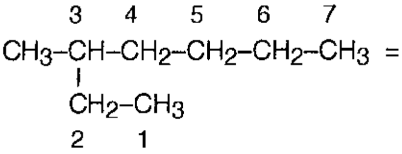
$\overset{1}{\mathrm{CH_3}}-\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\overset{2}{\mathrm{CH}}}-\overset{3}{\mathrm{CH_2}}-\overset{4}{\mathrm{CH_2}}-\overset{5}{\mathrm{CH_3}}$ = 2–methylpentane



$\overset{8}{\mathrm{CH_3}}-\overset{7}{\mathrm{CH_2}}-\overset{6}{\mathrm{CH_2}}-\overset{5}{\mathrm{CH_2}}-\overset{4}{\mathrm{CH_2}}-\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\overset{3}{\mathrm{CH}}}-\overset{2}{\mathrm{CH_2}}-\overset{1}{\mathrm{CH_3}}$ = 3–methyloctane



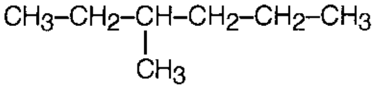
$\overset{1}{\mathrm{CH_3}}-\overset{2}{\mathrm{CH_2}}-\overset{3}{\mathrm{CH_2}}-\underset{\underset{\displaystyle \mathrm{CH_2{-}CH_3}}{|}}{\overset{4}{\mathrm{CH}}}-\overset{5}{\mathrm{CH_2}}-\overset{6}{\mathrm{CH_2}}-\overset{7}{\mathrm{CH_2}}-\overset{8}{\mathrm{CH_3}}$ = 4–ethyloctane



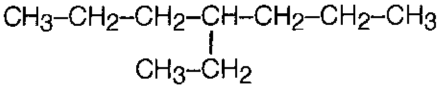
$\mathrm{CH_3}-\underset{\underset{\displaystyle \underset{2}{\mathrm{CH_2}}-\underset{1}{\mathrm{CH_3}}}{|}}{\overset{3}{\mathrm{CH}}}-\overset{4}{\mathrm{CH_2}}-\overset{5}{\mathrm{CH_2}}-\overset{6}{\mathrm{CH_2}}-\overset{7}{\mathrm{CH_3}}$ = 3–methylheptane

EXERCISE:

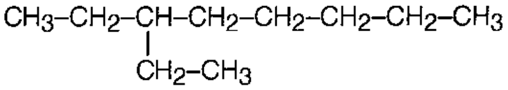
3. Name the following hydrocarbons. Care: e and f are tricky!

(a) 

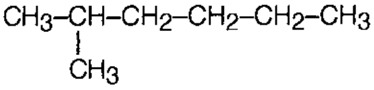
$\mathrm{CH_3{-}CH_2{-}}\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\mathrm{CH}}\mathrm{{-}CH_2{-}CH_2{-}CH_3}$

(b) 

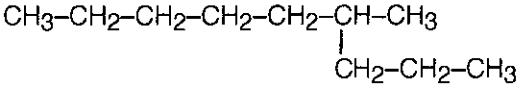
$\mathrm{CH_3{-}CH_2{-}CH_2{-}}\underset{\underset{\displaystyle \mathrm{CH_3{-}CH_2}}{|}}{\mathrm{CH}}\mathrm{{-}CH_2{-}CH_2{-}CH_3}$

(c) 

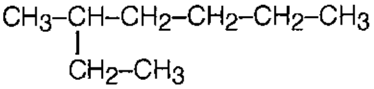
$\mathrm{CH_3{-}CH_2{-}}\underset{\underset{\displaystyle \mathrm{CH_2{-}CH_3}}{|}}{\mathrm{CH}}\mathrm{{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3}$

(d) 

$\mathrm{CH_3{-}}\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\mathrm{CH}}\mathrm{{-}CH_2{-}CH_2{-}CH_2{-}CH_3}$

(e) 

$\mathrm{CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}}\underset{\underset{\displaystyle \mathrm{CH_2{-}CH_2{-}CH_3}}{|}}{\mathrm{CH}}\mathrm{{-}CH_3}$

(f) 

$\mathrm{CH_3{-}}\underset{\underset{\displaystyle \mathrm{CH_2{-}CH_3}}{|}}{\mathrm{CH}}\mathrm{{-}CH_2{-}CH_2{-}CH_2{-}CH_3}$

Since carbons have FOUR bonds, count the bonds between a given carbon atom and its neighbours and subtract that number from 4. The difference equals the number of hydrogen atoms which must be attached to each carbon. That is, the number of bonds to hydrogens PLUS the number of bonds to other carbons equals four. The required number of hydrogens is then written into the formula.

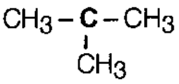
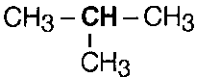
EXAMPLES: When a carbon is attached to ONE other carbon –

4 bonds – 1 bond used = 3 H's added and $\mathbf{C}-\mathrm{CH_3}$ becomes $\mathbf{CH_3}-\mathrm{CH_3}$

When a carbon is attached to TWO other carbons –

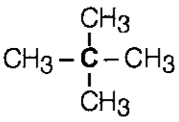
4 bonds – 2 bonds used = 2 H's added and $\mathrm{CH_3}-\mathbf{C}-\mathrm{CH_3}$ becomes $\mathrm{CH_3}-\mathbf{CH_2}-\mathrm{CH_3}$

When a carbon is attached to THREE other carbons –

4 bonds – 3 bonds used = 1 H added and  becomes 

$\mathrm{CH_3}-\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\mathbf{C}}-\mathrm{CH_3}$ becomes $\mathrm{CH_3}-\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\mathbf{CH}}-\mathrm{CH_3}$

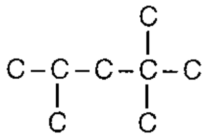
When a carbon is attached to FOUR other carbons –

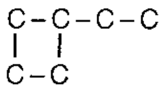
4 bonds – 4 bonds used = ***NO*** H's added and  needs ***no*** extra H's on the central C

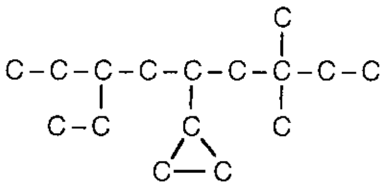
$\mathrm{CH_3}-\overset{\overset{\displaystyle \mathrm{CH_3}}{|}}{\underset{\underset{\displaystyle \mathrm{CH_3}}{|}}{\mathbf{C}}}-\mathrm{CH_3}$

EXERCISES:

4. Re–write the following structures to show the hydrogens attached.

(a)

$C-\underset{C}{\underset{|}{C}}-C-\underset{C}{\underset{|}{\overset{C}{\overset{|}{C}}}}-C$

(b)


(c)


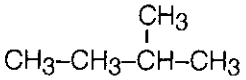
5. Draw the following hydrocarbons. Include all hydrogens.

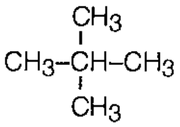
(a) 3–methylhexane	(c) 2–methylpentane	(e) 3–ethylheptane
(b) 4–ethyloctane	(d) 4–propylnonane	(f) 5–propyldecane

6. What is wrong with each of the following? (You may have to sketch the molecule to see the error in some cases.)

(a) 6–methylheptane

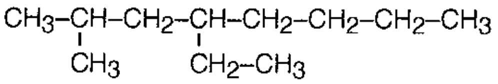
(b) 1–ethylbutane

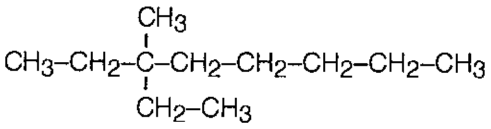
(c)

$CH_3-CH_3-\overset{CH_3}{\overset{|}{C}}H-CH_3$

(d)

$CH_3-\underset{CH_3}{\underset{|}{\overset{CH_3}{\overset{|}{C}}}}H-CH_3$

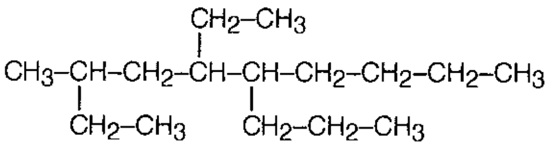
RULE: If more than one DIFFERENT alkyl group is attached to a hydrocarbon, then
- list the alkyl groups alphabetically,
- precede each alkyl group by its number, and
- put a dash between each alkyl group and its number.

EXAMPLES:


$CH_3-\underset{CH_3}{\underset{|}{C}}H-CH_2-\underset{CH_2-CH_3}{\underset{|}{C}}H-CH_2-CH_2-CH_2-CH_3$ = 4–ethyl–2–methyloctane


$CH_3-CH_2-\underset{CH_2-CH_3}{\underset{|}{\overset{CH_3}{\overset{|}{C}}}}-CH_2-CH_2-CH_2-CH_2-CH_3$ = 3–ethyl–3–methyloctane

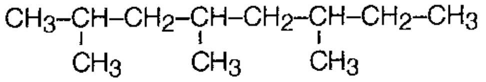
(note that there can be 2 groups attached to the same carbon)


$CH_3-\underset{CH_2-CH_3}{\underset{|}{C}}H-CH_2-\overset{CH_2-CH_3}{\overset{|}{C}}H-\underset{CH_2-CH_2-CH_3}{\underset{|}{C}}H-CH_2-CH_2-CH_2-CH_3$ = 5–ethyl–3–methyl–6–propyldecane

(TRICKY! Can you see why?)

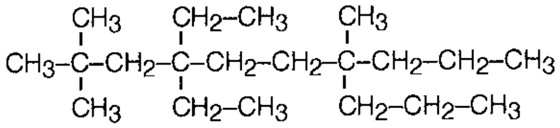
RULE: If an alkyl group is repeated, then
- list each carbon number where the repeated group is attached, separated by commas, and
- prefix the repeated group name by **di**, **tri**, **tetra**, etc. to show how many identical groups are attached.

EXAMPLES:



$$CH_3-\underset{\underset{CH_3}{|}}{CH}-CH_2-\underset{\underset{CH_3}{|}}{CH}-CH_2-\underset{\underset{CH_3}{|}}{CH}-CH_2-CH_3$$

= 2,4,6-trimethyloctane



$$CH_3-\overset{CH_3}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}-CH_2-\overset{CH_2-CH_3}{\overset{|}{\underset{\underset{CH_2-CH_3}{|}}{C}}}-CH_2-CH_2-\overset{CH_3}{\overset{|}{\underset{\underset{CH_2-CH_2-CH_3}{|}}{C}}}-CH_2-CH_2-CH_3$$

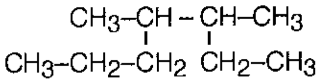
= 4,4-diethyl-2,2,7-trimethyl-7-propyldecane

EXERCISES:

7. Count up the number of carbons and hydrogens in the two example molecules above. The general formula for a simple straight–chain hydrocarbon (methane, ethane, etc.) is C_NH_{2N+2}. What is the general formula for a branched hydrocarbon?

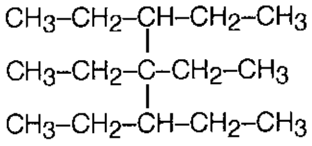
8. Name the following molecules.

(a)



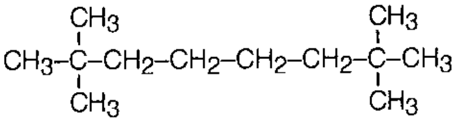
$$CH_3-\underset{\underset{CH_3-CH_2-CH_2}{|}}{CH}-\underset{\underset{CH_2-CH_3}{|}}{CH}-CH_3$$

(b)



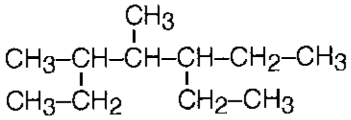
$$\begin{array}{c} CH_3-CH_2-CH-CH_2-CH_3 \\ | \\ CH_3-CH_2-C-CH_2-CH_3 \\ | \\ CH_3-CH_2-CH-CH_2-CH_3 \end{array}$$

(c)



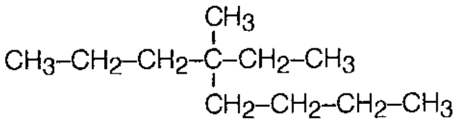
$$CH_3-\overset{CH_3}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}-CH_2-CH_2-CH_2-CH_2-\overset{CH_3}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}-CH_3$$

(d)



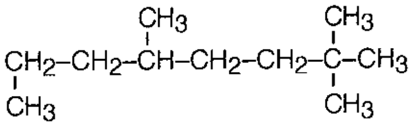
$$CH_3-\underset{\underset{CH_3-CH_2}{|}}{CH}-\overset{CH_3}{\overset{|}{CH}}-\underset{\underset{CH_2-CH_3}{|}}{CH}-CH_2-CH_3$$

(e)



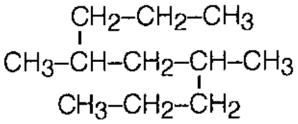
$$CH_3-CH_2-CH_2-\overset{CH_3}{\overset{|}{\underset{\underset{CH_2-CH_2-CH_2-CH_3}{|}}{C}}}-CH_2-CH_3$$

(f)



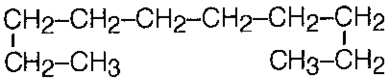
$$\underset{\underset{CH_3}{|}}{CH_2}-CH_2-\overset{CH_3}{\overset{|}{CH}}-CH_2-CH_2-\overset{CH_3}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}-CH_3$$

(g)



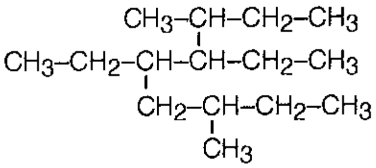
$$CH_3-\overset{CH_2-CH_2-CH_3}{\overset{|}{CH}}-CH_2-\underset{\underset{CH_3-CH_2-CH_2}{|}}{CH}-CH_3$$

(h)



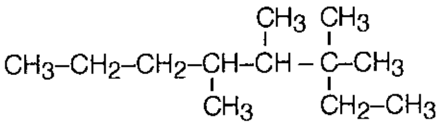
$$\underset{\underset{CH_2-CH_3}{|}}{CH_2}-CH_2-CH_2-CH_2-CH_2-\underset{\underset{CH_3-CH_2}{|}}{CH_2}$$

(i)



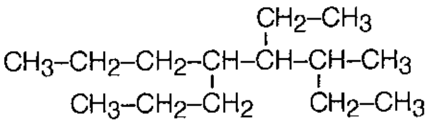
$$CH_3-CH_2-\underset{\underset{CH_2-\underset{\underset{CH_3}{|}}{CH}-CH_2-CH_3}{|}}{CH}-\overset{CH_3-CH-CH_2-CH_3}{\overset{|}{CH}}-CH_2-CH_3$$

(j)



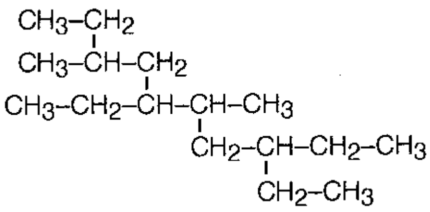
$$CH_3-CH_2-CH_2-\underset{\underset{CH_3}{|}}{CH}-\overset{CH_3}{\overset{|}{CH}}-\overset{CH_3}{\overset{|}{\underset{\underset{CH_2-CH_3}{|}}{C}}}-CH_3$$

(k)



$$CH_3-CH_2-CH_2-\underset{\underset{CH_3-CH_2-CH_2}{|}}{CH}-\overset{CH_2-CH_3}{\overset{|}{CH}}-\underset{\underset{CH_2-CH_3}{|}}{CH}-CH_3$$

(l)



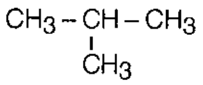
$$\begin{array}{l} CH_3-CH_2 \\ \qquad\quad | \\ CH_3-CH-CH_2 \\ \qquad\qquad\quad | \\ CH_3-CH_2-CH-CH-CH_3 \\ \qquad\qquad\qquad | \\ \qquad\qquad\quad CH_2-CH-CH_2-CH_3 \\ \qquad\qquad\qquad\qquad | \\ \qquad\qquad\qquad\quad CH_2-CH_3 \end{array}$$

9. Sketch the following molecules.
   (a) 3-ethyl-2,3-dimethylhexane
   (b) 2,2-dimethyl-5,6-dipropylnonane
   (c) 4-ethyl-3-methyl-5-propyloctane
   (d) 2,2,3,3-tetramethylpentane
   (e) 3,4-diethylhexane
   (f) 5-butyl-6,6-diethyl-3,3,7-trimethyldecane
   (g) dimethylpropane (why were no numbers used?)
   (h) 4-ethyl-2-methyloctane
   (i) hexamethylpentane
   (j) 3,6-diethyl-4-methyl-5-propyloctane

STRUCTURAL ISOMERS

Definition: **STRUCTURAL ISOMERS** are compounds which have the same molecular formula but a different arrangement of atoms.

EXAMPLE: C_4H_{10} can refer to either $CH_3-CH_2-CH_2-CH_3$ or



$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3$

Each structural isomer has a set of chemical and physical properties which differ from those of other isomers with the same chemical formula.

EXERCISES:

10. Write the condensed structure and name for the three structural isomers having the molecular formula C_5H_{12}.
11. Write the condensed structure and name for the two structural isomers that involve a single methyl group attached to hexane.
12. Write the condensed structure and name of the four structural isomers that involve two methyl groups attached to pentane.
13. How many isomers of C_8H_{18} contain no side chains other than a single methyl group?

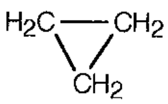
THE PROPERTIES OF ALKANES

- Alkanes are very unreactive because C–C and C–H bonds are strong and not easily broken.
- Methane, ethane, propane and butane are gases at room temperature (butane is easily liquified under pressure). Pentane and longer chains are liquids.
- Very long chains ($C_{16}H_{34}$ and longer) are solids and are commonly called WAXES or PARAFFINS.

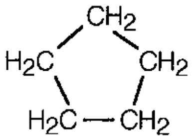
C. CYCLOALKANES

Hydrocarbon chains which connect in a head–to–tail "circle" are called CYCLIC HYDROCARBONS or CYCLOALKANES. The first members of the cycloalkane series are shown below.

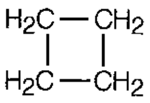
cyclopropane = C_3H_6 =



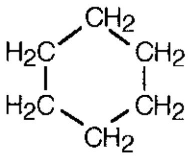
cyclopentane = C_5H_{10} =



cyclobutane = C_4H_8 =



cyclohexane = C_6H_{12} =



EXERCISE:

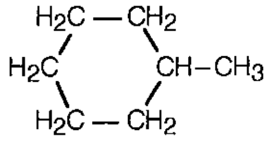
14. What is the general formula for a cycloalkane?

SUBSTITUTED CYCLOALKANES

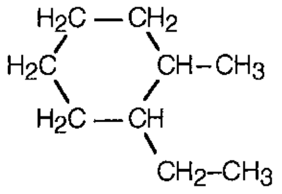
RULE: Substituted cycloalkanes follow the same rules as straight–chain alkanes, except that

- a ***single*** substituent does not use a number to indicate the position of attachment (all carbons in the cycloalkyl group are identical).
- if there is more than one substituent, the first substituent is assumed to be at the "1" position and the remaining substituents are numbered either clockwise or anticlockwise so as to have the lowest set of overall values.

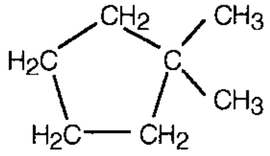
EXAMPLE:



= methylcyclohexane



= 1–ethyl–2–methylcyclohexane

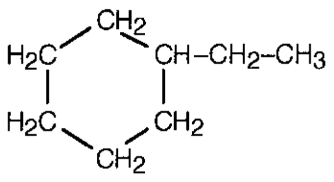


= 1, 1–dimethylcyclopentane

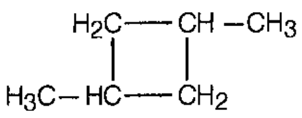
EXERCISES:

15. Name the following compounds.

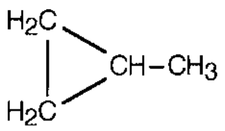
(a)



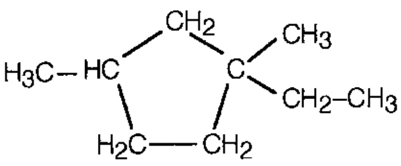
(b)



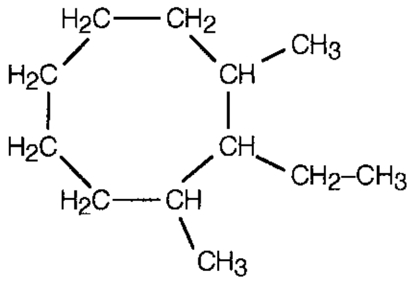
(c)



(d)



(e)



16. Sketch the following compounds.

(a) 1,2–dimethylcyclobutane
(b) 1,1,2–trimethylcyclopropane
(c) 1,3–dipropylcyclopentane
(d) propylcyclopropane
(e) 1,3–diethyl–2,2–dimethylcyclooctane
(f) 1,2,4–triethylcycloheptane

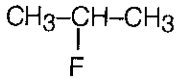
X.3 ALKYL HALIDES

The naming of alkyl halides (halogens – F, Cl, Br or I – attached to alkanes) is straightforward.

RULE: Name **alkyl halides** in the same manner used for alkyl groups.

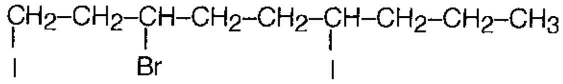
- Attached F, Cl, Br and I atoms are called "fluoro", "chloro", "bromo" and "iodo" groups. (The general term for an attached halogen atom is a "halo" group.) Use a number to indicate the position of attachment on the hydrocarbon chain.
- If more than one of the same kind of halogen is present, use the prefixes di, tri, etc.
- If a compound contains both alkyl and halo groups, list the attached groups in alphabetical order. Start numbering from the end which gives the lowest set of numbers.

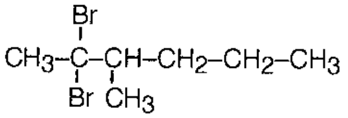
EXAMPLES: $CH_3\text{–}Cl$ = chloromethane

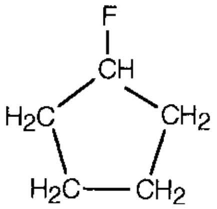

$CH_3\text{–}\underset{\displaystyle F}{\underset{|}{C}H}\text{–}CH_3$ (or $CH_3\text{–}CHF\text{–}CH_3$) = 2–fluoropropane

Note: Unlike the situation involving the addition of alkyl groups to a straight–chain hydrocarbon, halo groups can be placed at the 1–position.

$CCl_3\text{–}CF_3$ = 1,1,1–trichloro–2,2,2–trifluoroethane


$\underset{\displaystyle I}{\underset{|}{C}H_2}\text{–}CH_2\text{–}\underset{\displaystyle Br}{\underset{|}{C}H}\text{–}CH_2\text{–}CH_2\text{–}\underset{\displaystyle I}{\underset{|}{C}H}\text{–}CH_2\text{–}CH_2\text{–}CH_3$ = 3–bromo–1,6–diiodononane


$CH_3\text{–}\overset{\displaystyle Br}{\overset{|}{\underset{\displaystyle Br}{\underset{|}{C}}}}\text{–}\underset{\displaystyle CH_3}{\underset{|}{C}H}\text{–}CH_2\text{–}CH_2\text{–}CH_3$ = 2,2–dibromo–3–methylhexane



= fluorocyclopentane

PROPERTIES OF ALKYL HALIDES

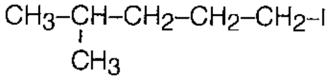
- Alkyl halides tend to be insoluble in water (similar to alkanes).
- Compounds with many fluorine atoms tend to be unreactive ("inert"). "Teflon" is a highly fluorinated hydrocarbon which is inert to almost all chemical attack.
- Chloro and bromo compounds are susceptible to chemical attack, but require relatively drastic conditions. Iodo compounds are more reactive.

EXERCISES:

17. Name the following molecules.

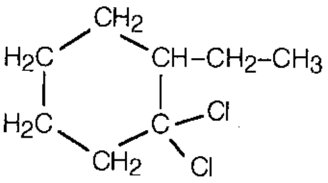
(a) CH_3-CH_2-Cl

(b) $Br-CH_2-CH_2-CH_2-Br$

(c) 

$CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}H}-CH_2-CH_2-CH_2-I$

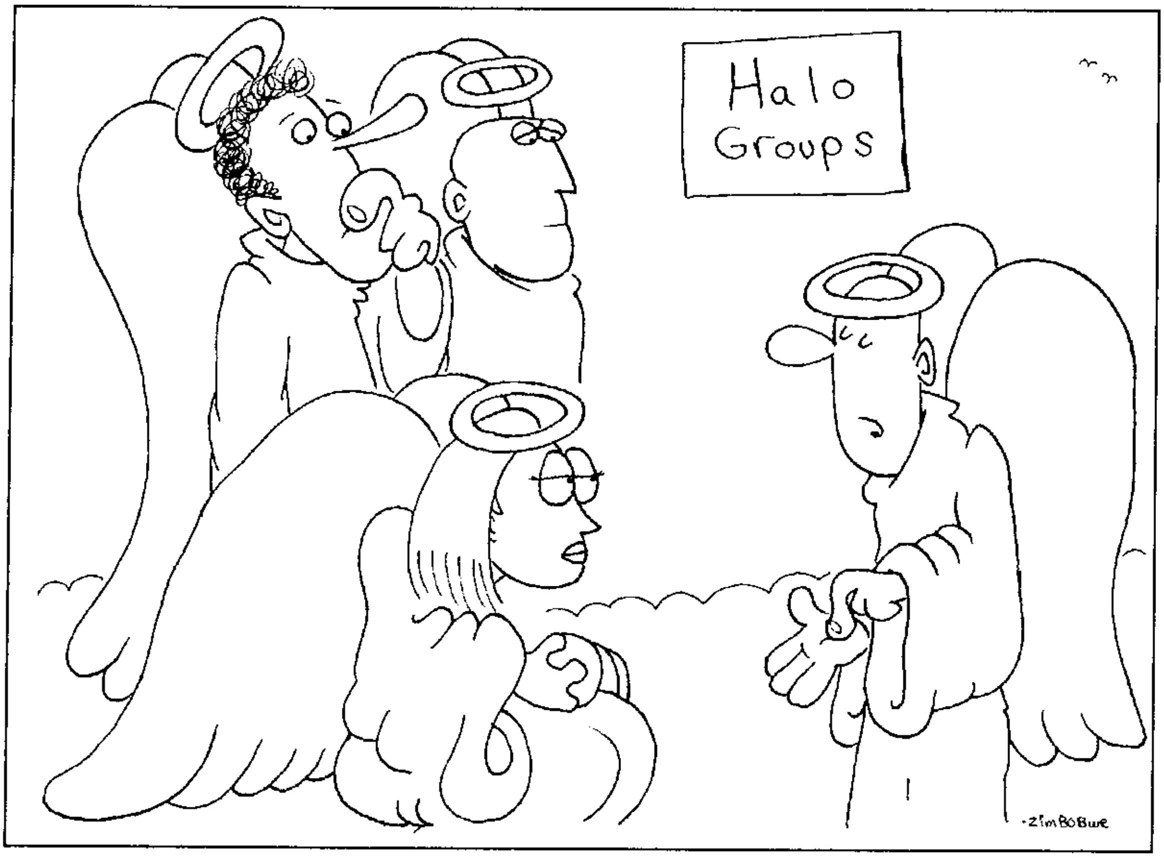
(d) $CH_2F-CHCl_2$

(e) 

18. Draw the following molecules.
    (a) trichloromethane (common name = chloroform)
    (b) 1,2–dichloroethane
    (c) 1,3,5–tribromocyclohexane
    (d) 4–bromo–2–chloro–3–ethyloctane
    (e) 1,1,1–trifluoro–2–methylpentane

19. Draw and name the 8 structural isomers of $C_5H_{11}Cl$.

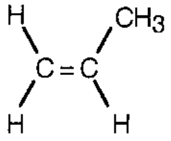
20. Draw and name the 9 structural isomers of $C_5H_{10}Cl_2$ that have no methyl groups.



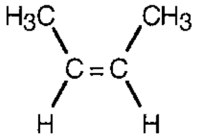
X.4. MULTIPLE BONDS ("ALKENES and ALKYNES")

Definitions: An **ALKENE** is an organic compound containing a carbon–carbon double bond.
An **ALKYNE** is an organic compound containing a carbon–carbon triple bond.
(Double and triple bonds can be either at the end of a carbon chain or in the middle.)

EXAMPLES:



or simply $CH_2 = CH–CH_3$



or simply $CH_3–CH = CH–CH_3$

$H-C\equiv C-CH_3$ or simply $CH\equiv C–CH_3$

$CH_3-C\equiv C-CH_3$ or simply $CH_3C\equiv CCH_3$

The naming of compounds with double and triple bonds is quite straightforward.

RULE: If a double bond is present, change the "ane" ending of the parent hydrocarbon to "ene".
If a triple bond is present, change the "ane" ending of the parent hydrocarbon to "yne".

- Use a number to indicate the lower numbered carbon atom involved in the bond (the bond goes FROM the lower numbered carbon TO the higher numbered one). The number goes immediately in front of the name of the parent hydrocarbon, separated by a hyphen.
- Number the parent hydrocarbon to give the double/triple bond the lowest possible number. If the number is the same starting from either end, start the numbering from the end closest to the 1st branch point (where a group is attached).

Note: 1. There is an easy way to remember the bond endings.

single bonds	double bonds	triple bonds
ANE	ENE	YNE

The 1st letters (underlined) are in alphabetical order and sound like the long vowels a, e and i. (We can't use "ine" since this is used to indicate the presence of an amine group, $–NH_2$.)

2. Alkenes and alkynes are called **UNSATURATED** hydrocarbons because they have less hydrogen atoms than equivalent alkanes. Alkanes are said to be **SATURATED** hydrocarbons because they contain the maximum number of hydrogens possible.

WRITING THE CONDENSED STRUCTURE OF ALKENES AND ALKYNES

When you are given the name of an alkene or alkyne, the following process is used to arrive at the correct condensed structure.

EXAMPLES: Write the condensed formula for 2–hexene.

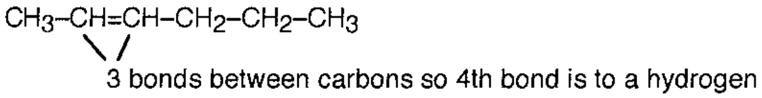
- Since "hex" means 6 carbon atoms are present, start by writing 6 carbons in a row.

  C C C C C C

- The "ene" ending means a C=C bond is present, and the "2" means the bond **starts** at carbon #2 and goes to carbon #3. The other carbon–carbon bonds are single.

  C – C = C – C – C – C

- Since all carbons have FOUR bonds, count the bonds between each carbon and its neighbours and subtract that number from 4. The difference is the number of hydrogens attached to each carbon. The appropriate number of hydrogens are now written into the formula.

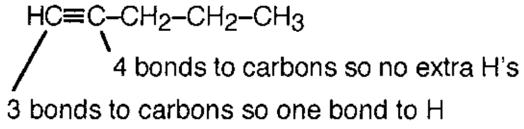


$CH_3–CH=CH–CH_2–CH_2–CH_3$

3 bonds between carbons so 4th bond is to a hydrogen

Write the condensed formula for 1–pentyne .

- Similar to the reasoning above, the "yne" ending means a triple bond is present and the "1" indicates that the bond starts at carbon #1 and goes to carbon #2.



$HC\equiv C–CH_2–CH_2–CH_3$

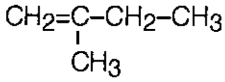
4 bonds to carbons so no extra H's

3 bonds to carbons so one bond to H

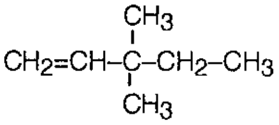
EXAMPLES: $H_2C=CH_2$ (or, $CH_2=CH_2$) = ethene (common name = ethylene)

$CH_2=CH–CH_3$ = propene

$CH_3–CH=CH–CH_3$ = 2–butene



$CH_2=\underset{\displaystyle CH_3}{\underset{|}{C}}–CH_2–CH_3$ = 2–methyl–1–butene

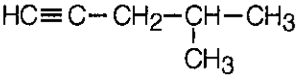


$CH_2=CH–\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}–CH_2–CH_3$ = 3,3–dimethyl–1–pentene

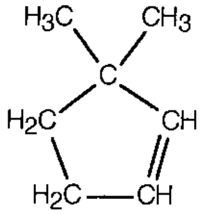
$HC\equiv CH$ = ethyne (common name = acetylene)

$HC\equiv C–CH_3$ = propyne

$CH_3–C\equiv C–CH_3$ = 2–butyne



$HC\equiv C–CH_2–\underset{\displaystyle CH_3}{\underset{|}{CH}}–CH_3$ = 4–methyl–1–pentyne



= 3,3–dimethyl–1–cyclopentene

Note: the double (or triple) bond starts at carbon #1 and attached groups are numbered so as to have the lowest possible numbers

EXERCISES:

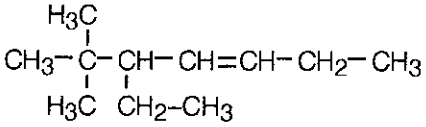
21. Look at the examples above (except for the cyclopentene) and decide on the general formula relating the ratio of carbons to hydrogens for each of the following.
    (a) an alkene (b) an alkyne
    Express your answer in a form similar to the expression C_NH_{2N+2} which was found for alkanes.

22. Draw the condensed structure for the following.
    (a) 1–hexene (c) 3–decene (e) 2–octene
    (b) 4–nonyne (d) 2–heptyne (f) 1–octyne

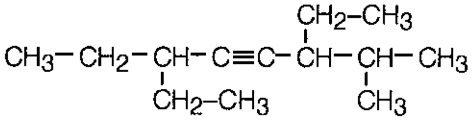
23. Name the following.
    (a) $CH_3–CH_2–CH=CH–CH_2–CH_3$
    (b) $CH_3–CH_2–CH_2–CH_2–CH_2–C\equiv CH$
    (c) $CH_3–CH_2–CH_2–C\equiv C–CH_2–CH_2–CH_2–CH_2–CH_3$
    (d) $CH_3–CH_2–CH=CH–CH_2–CH_2–CH_3$

24. Draw the condensed structure for each of the following.
    (a) 4–ethyl–3–methyl–2–hexene (e) dimethyl–2–butene
    (b) 3–methyl–4–octyne (f) 3,6–dimethyl–1–cyclohexene
    (c) 1–ethyl–1–cyclononene (g) cyclopropyne
    (d) 3–ethyl–4–methyl–1–hexyne (h) 1,3–dimethyl–1–cyclopentene

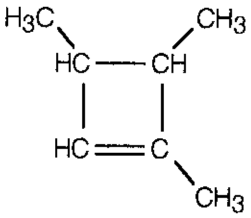
25. Name the following compounds.

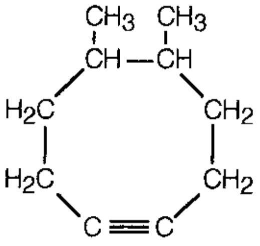
(a)


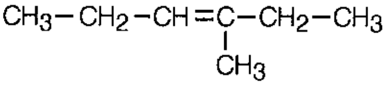
$CH_3-\underset{H_3C}{\overset{H_3C}{C}}-\underset{CH_2-CH_3}{CH}-CH=CH-CH_2-CH_3$

(b)


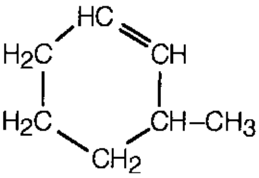
$CH_3-CH_2-\underset{CH_2-CH_3}{CH}-C\equiv C-\overset{CH_2-CH_3}{CH}-\underset{CH_3}{CH}-CH_3$

(c)


(d)


(e)


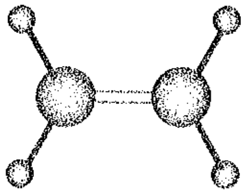
$CH_3-CH_2-CH=\underset{CH_3}{C}-CH_2-CH_3$

(f)


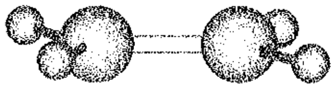
THE GEOMETRY OF ALKENES AND ALKYNES

In alkanes, each carbon atom is bonded to four other atoms in a tetrahedral shape. The resulting structure is very flexible as a result of atoms being able to rotate freely around the axis of each single bond.

Alkenes have a geometry in which the three atoms connected to each carbon lie flat, arranged 120° from each other in a plane.



which looks like this from the side:



Alkynes have a geometry in which the two atoms attached to the central carbon lie in a straight line, such that the attached atoms are 180° from each other.

Whereas alkanes have flexible structures, alkenes have very rigid structures. The double bonds effectively "lock" the structure to prevent the attached atoms from "twisting" around the double bond.

The triple bond in alkynes is also very rigid, and a series of triple bonds will form straight "needle–like" structures. For example, molecules similar to the following have been detected in interstellar space, where the molecules act as radio antennae.

$$H-C\equiv C-C\equiv C-C\equiv C-C\equiv C-C\equiv C-C\equiv C-C\equiv C-H$$

On the other hand, in a molecule such as

$$CH_3-C\equiv C-CH_3$$

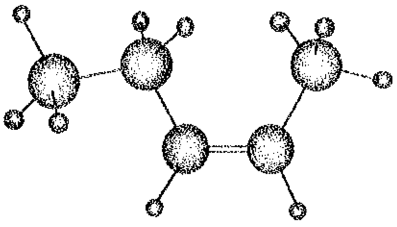
the carbons involved in the triple bond are locked to each other, but the single bonds extending from the triply–bonded carbons to the methyl carbons allow free rotation of the methyl groups.

The rigid structure of the alkene carbons has an immediate and important consequence: a new kind of isomerism.

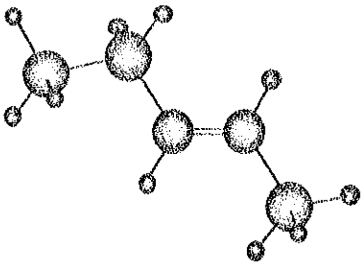
This kind of isomerism, called **CIS–TRANS ISOMERISM**, is possible whenever a molecule has:

- a double bond present, AND
- groups (other than a hydrogen atom) which are attached to each of the carbons involved in the double bond. (The attached groups do not have to be identical; all that is required is that they not be hydrogen atoms.)

EXAMPLE: 2–pentene has two different isomers possible.



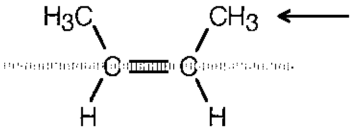
cis–2–pentene



trans–2–pentene

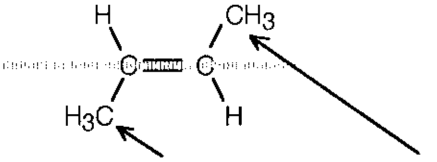
In the above example, the methyl and ethyl groups on opposite ends of the double bond are either "cis" or "trans" to each other.

Note: In a "**CIS**" isomer, the two groups are on the **<u>S</u>AME <u>S</u>IDE** of the double bond.



both CH_3's are on the upper side

In a "**TRANS**" isomer, the two groups are "**TRANSVERSE**" to each other (that is, on opposite sides of the double bond).



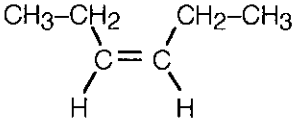
the CH_3's are on opposite sides

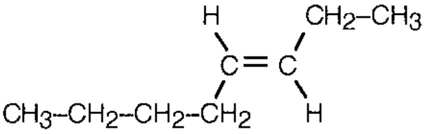
EXERCISES:

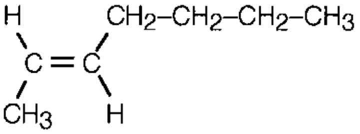
26. Draw the actual shape of the following molecules using condensed structures.
    - (a) trans–2–hexene
    - (b) 3–hexyne
    - (c) cis–3–octene
    - (d) trans–4–decene
    - (e) 2–butyne
    - (f) 4–methyl–cis–2–pentene

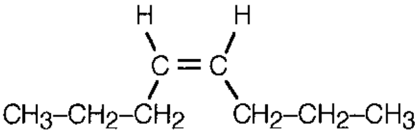
27. Which of the following molecules can exhibit cis–trans isomerism?
    - (a) 1–butene
    - (b) 3–hexene
    - (c) 4–heptyne
    - (d) 2–octene
    - (e) 3–ethyl–3–hexene
    - (f) 2,5–dimethyloctane

28. Name the following as "cis" or "trans" isomers.

(a)


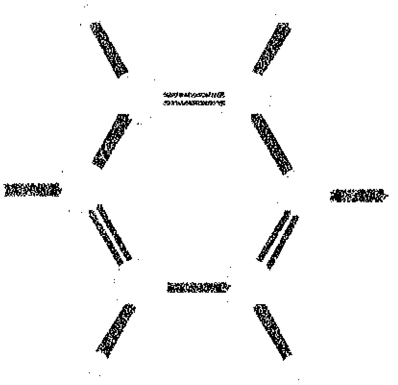
(b)


(c)


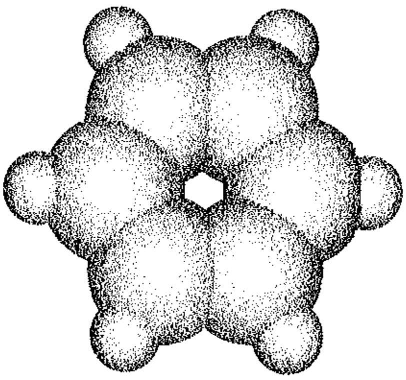
(d)


X.5. AROMATIC COMPOUNDS

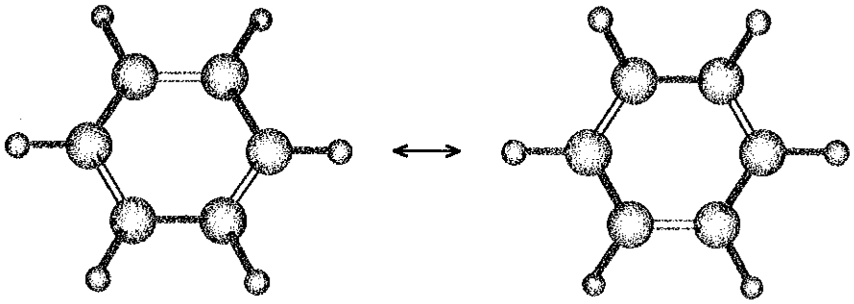
Benzene, C_6H_6, is an important molecule having the following structure.



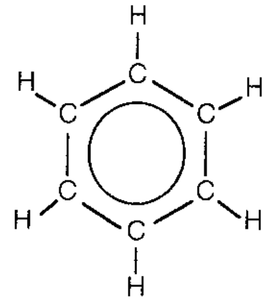
or, using a "space–fillling" form



The ring--like structure of benzene can be written in either of two **RESONANCE STRUCTURES**, differing only in the placement of the double bonds. Each resonance structure consists of alternating single and double bonds between carbon atoms.



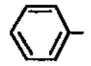
Strictly speaking, drawing benzene in either of its two resonance structures is not correct. The actual arrangement of electrons in the carbon ring is a mixture of both resonance structures. In order to better show the situation which occurs, benzene is frequently represented as follows.



Benzene's resonance structures give it unusual stability; that is, it is highly resistant to chemical attack. Atoms attached to the benzene ring can be replaced, but only the strongest chemical attack (such as combustion) will affect the ring itself.

The benzene ring, also known as an "aromatic ring", is present in a large number of molecules and many molecules contain two or more aromatic rings joined together.

Definition: An **AROMATIC MOLECULE** is a molecule containing one or more benzene rings.

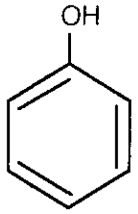
The aromatic ring (benzene ring) is frequently shown as:  .

The origin of the term "aromatic" comes from the fact that many molecules containing benzene rings are quite fragrant and pleasant smelling (although many others are quite disagreeable). In the past, aromatic molecules were obtained primarily from the distillation of coal, but modern industry obtains them from a process called the **catalytic reforming** of petroleum.

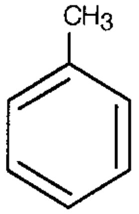
The naming of simple aromatic compounds formed by adding groups to a benzene ring is almost identical to the naming procedure used for other cyclic hydrocarbons. Two exercises on the next page allow you to apply what you know to naming aromatic compounds.

The example molecules which follow do not have to be memorized; they are shown for your information.

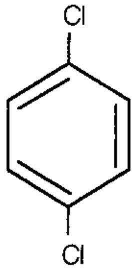
EXAMPLES:



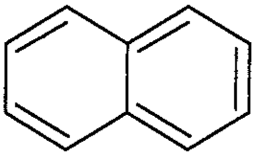
hydroxybenzene
or "phenol"



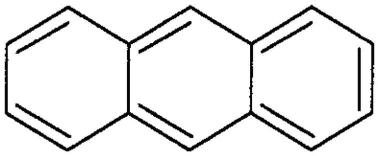
methylbenzene
or "toluene"



1,4-dichlorobenzene
or "paradichlorobenzene"



naphthalene



anthracene

EXERCISES:

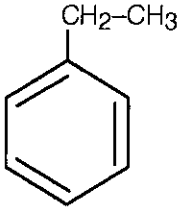
29. (a) One resonance structure was drawn for naphthalene (above). Draw two other resonance structures.
    (b) One resonance structure was drawn for anthracene (above). Draw three other resonance structures.

30. Draw the structures of the following compounds.

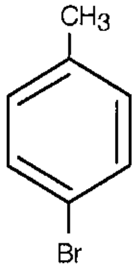
(a) 1,3,5-trimethylbenzene	(d) 1,4-dibromo-2-methylbenzene
(b) 1-bromo-4-chlorobenzene	(e) 1,3-diethylbenzene
(c) fluorobenzene	(f) hexylbenzene

31. Name the following compounds.

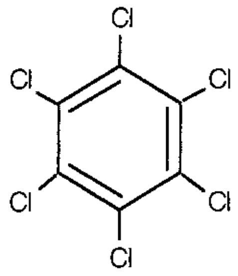
(a)



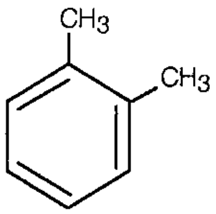
(b)



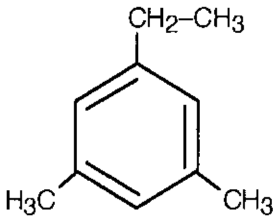
(c)



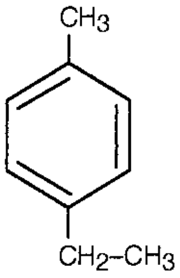
(d)



(e)



(f)



X.6. FUNCTIONAL GROUPS

Definition: A **FUNCTIONAL GROUP** is a specific group of atoms which exists in a molecule and gives a molecule an ability to react in a specific manner or gives it special properties.

Hydrocarbons have a limited range of properties and uses. Functional groups allow the addition of specific properties to a molecule. For example, by carefully choosing the functional groups present in a molecule, a chemist can

- make a molecule act as a base, an acid, or both;
- give the molecule a particular solubility;
- give a molecule a pleasant or unpleasant smell;
- make a molecule react with specific chemicals;
- make a molecule explosive.

The previous sections have already introduced some functional groups: halides, carbon–carbon double bonds (in alkenes) and carbon–carbon triple bonds (in alkynes). This section examines some other important functional groups and how their presence changes the properties of the parent hydrocarbon.

A. ALCOHOLS

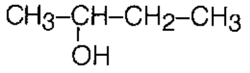
Definition: An **ALCOHOL** is an organic compound containing an OH group.

RULE: When naming an **ALCOHOL**

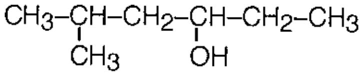
- number the hydrocarbon chain to give the LOWEST possible number to the OH group.
- place the number immediately before the name of the parent hydrocarbon, separated by a dash. Alkyl groups (and their numbers) are placed in front of the number for the OH.
- indicate the presence of an OH group by changing the "e" ending of the hydrocarbon chain to "ol". (The ending "ol" comes from "alcoh***ol*** ".)

EXAMPLES: CH_3-OH = methanol (commercial name = methyl hydrate)

CH_3-CH_2-OH = ethanol ("beverage alcohol")



$CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CH_3$ = 2–butanol



$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CH_3$ = 5–methyl–3–hexanol

PROPERTIES OF ALCOHOLS

- There are two opposing solubility tendencies which exist in all alcohols.
  - – the OH group tends to make alcohols soluble in water
  - – the non–polar hydrocarbon chain tends to make alcohols insoluble in water

Methanol, ethanol and propanol are highly soluble in water ("miscible") because the hydrocarbon chain is small and the hydrogen–bonding of the OH group to water molecules "wins out".

Butanol is moderately soluble in water as a result of a "tie" between the tendency of the OH group to promote solubility and the tendency of the longer hydrocarbon chain to resist dissolving.

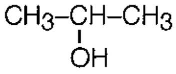
Pentanol and higher alcohols are effectively insoluble in water as a result of the increasing dominance of the hydrocarbon chain.

- All alcohols are poisonous; ethanol is no exception – it is simply less poisonous than other alcohols.

EXERCISES:

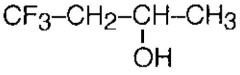
32. Draw the following compounds.
    - (a) 1–butanol
    - (b) 2–methyl–1–cyclopentanol
    - (c) 2,2–dichloro–3–methyl–4–nonanol
    - (d) 2,5–diethyl–1–cyclohexanol
    - (e) 3–methyl–1–pentanol
    - (f) 1,1,1–trifluoro–2–propanol
33. Name the following compounds.

(a)



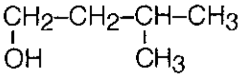
$CH_3\text{-}\underset{\underset{\displaystyle OH}{|}}{C}H\text{-}CH_3$

(b)



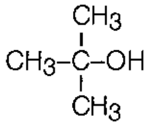
$CF_3\text{-}CH_2\text{-}\underset{\underset{\displaystyle OH}{|}}{C}H\text{-}CH_3$

(c)



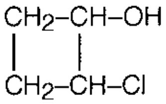
$\underset{\underset{\displaystyle OH}{|}}{C}H_2\text{-}CH_2\text{-}\underset{\underset{\displaystyle CH_3}{|}}{C}H\text{-}CH_3$

(d)

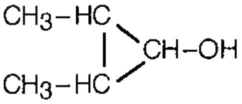


$CH_3\text{-}\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}\text{-}OH$

(e)



(f)



B. OTHER FUNCTIONAL GROUPS

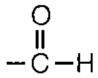
In addition to alcohols there are several other functional groups which can change the properties of a hydrocarbon chain. You are not required to know how to name compounds containing the functional groups listed below. It is sufficient that you can recognize and name the groups present in a given compound. (The names of the compounds in the examples are given for your interest only.)

In section C, you will be shown how to name an additional functional group called an "ester".

ALDEHYDES

An ***aldehyde*** is an organic compound containing a C=O group at the end of a hydrocarbon chain.

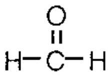
The aldehyde group actually looks like



$-\overset{\overset{\displaystyle O}{\|}}{C}-H$

or simply –CHO.

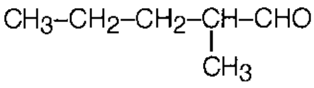
EXAMPLES: Some typical aldehydes are shown below.



$H-\overset{\overset{\displaystyle O}{\|}}{C}-H$

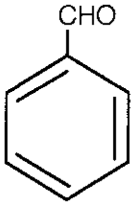
or HCHO (name = methanal; common name = formaldehyde)

$CH_3\text{-}CHO$ (name = ethanal)



$CH_3\text{-}CH_2\text{-}CH_2\text{-}\underset{\underset{\displaystyle CH_3}{|}}{C}H\text{-}CHO$

(name = 2–methylpentanal)

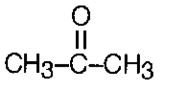


(name = benzaldehyde)

KETONES

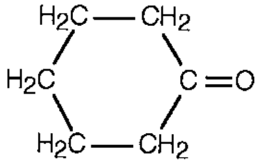
A ***ketone*** is an organic compound containing a C=O group at a position OTHER THAN AT THE END OF A HYDROCARBON CHAIN.

EXAMPLES: Some typical ketones are shown below.



$CH_3-\overset{\overset{O}{\|}}{C}-CH_3$ or CH_3COCH_3 (name = propanone; common name = acetone)

$CH_3CH_2COCH_2CH_2CH_3$ (name = 3–hexanone)



(name = cyclohexanone)

ETHERS

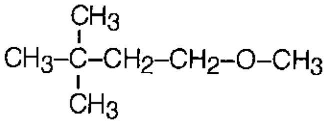
An ***ether*** is a compound in which an oxygen joins two hydrocarbon groups.

Several ethers have anaesthetic properties: ethoxyethane was formerly used in hospitals and is still used by biologists to "quiet" or anaesthetize insects.

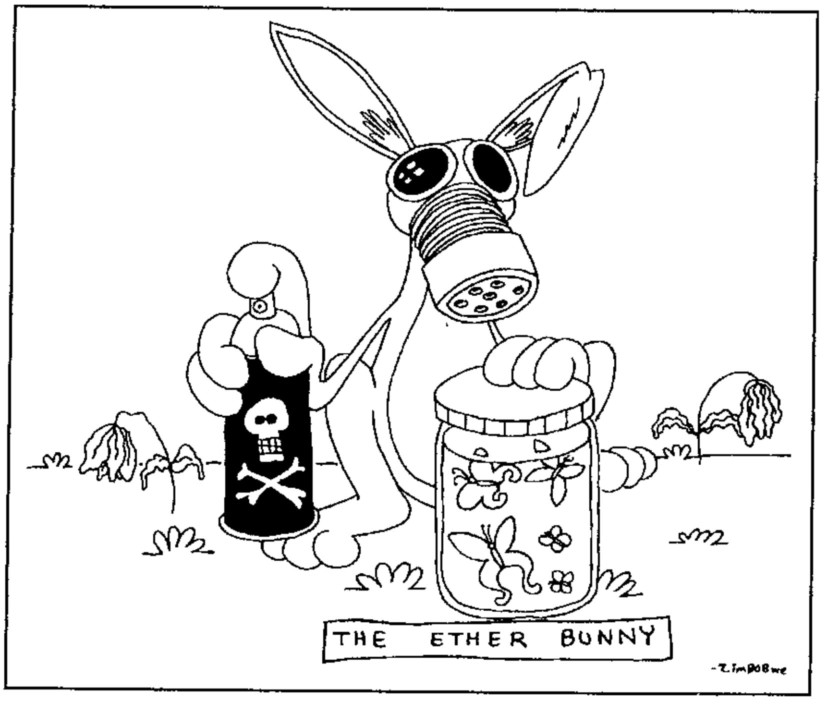
EXAMPLES: Some typical ethers are shown below.

$CH_3CH_2-O-CH_2CH_3$ (name = ethoxyethane; common name is "hospital ether")

$CH_3-O-CH_2CH_2CH_3$ (name = 1–methoxypropane; an anaesthetic)



$CH_3-\underset{CH_3}{\overset{CH_3}{C}}-CH_2-CH_2-O-CH_3$ (name = 1–methoxy–3,3–dimethylbutane)



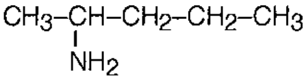
AMINES

An ***amine*** is an organic compound containing an NH_2 group. Amines are organic bases and react with acids. Typically, amines have a "fish–like" odour.

EXAMPLES: Some typical amines are shown below.

$CH_3\text{–}CH_2\text{–}NH_2$ (name = aminoethane)

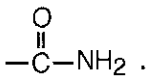
$H_2N\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}NH_2$ (name = 1,4–diaminobutane; common name is putrescine, produced by decomposing meat)



$CH_3\text{–}\underset{\underset{\displaystyle NH_2}{|}}{C}H\text{–}CH_2\text{–}CH_2\text{–}CH_3$ (name = 2–aminopentane)

AMIDES

An ***amide*** is an organic compound containing a $CONH_2$ group. The $CONH_2$ group is also sometimes shown as

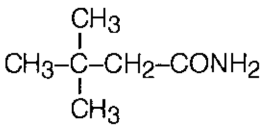


$$\text{—}\overset{\overset{\displaystyle O}{\|}}{C}\text{—}NH_2\ .$$

EXAMPLES: Some typical amides are shown below.

$CH_3\text{–}CONH_2$ (name = ethanamide)

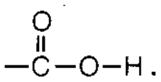
$CH_3\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CONH_2$ (name = hexanamide)



$CH_3\text{–}\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}\text{–}CH_2\text{–}CONH_2$ (name = 3,3–dimethylbutanamide)

CARBOXYLIC ACIDS

A ***carboxylic acid*** is an organic compound which contains a COOH group. The COOH group is also sometimes shown as



$$\text{—}\overset{\overset{\displaystyle O}{\|}}{C}\text{—}O\text{—}H\ .$$

Carboxylic acids are commonly referred to as "organic acids".

EXAMPLES: Some typical carboxylic acids are shown below.

CH_3COOH (name = ethanoic acid; commonly called acetic acid)

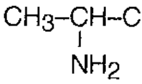
HCOOH (name = methanoic acid; common name = formic acid, found in red ant venom)

$CH_3\text{–}CH_2\text{–}CH_2\text{–}COOH$ (name = butanoic acid; common name = butyric acid, responsible for the odour of "smelly feet")

A Digression on Amino Acids

An ***amino acid*** is a carboxylic acid with an amine group at the 2–position. Although there are numerous amino acids, only 20 different amino acids are essential biological "building blocks".

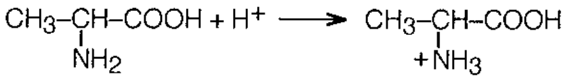
EXAMPLE:



$CH_3\text{–}\underset{NH_2}{CH}\text{–}COOH$ = 2–aminopropanoic acid (common name = alanine)

Amino acids can react with both acids and bases.

EXAMPLE: Reaction with acids –



$CH_3\text{–}\underset{NH_2}{CH}\text{–}COOH + H^+ \longrightarrow CH_3\text{–}\underset{+NH_3}{CH}\text{–}COOH$

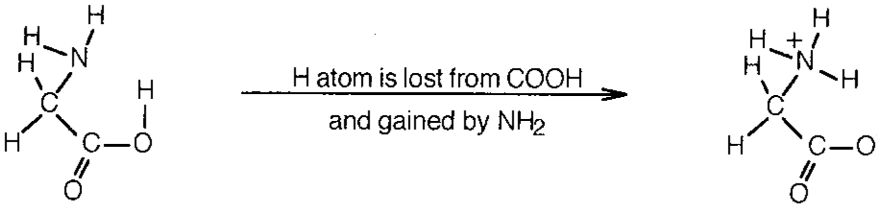
Reaction with bases –

$CH_3\text{–}\underset{NH_2}{CH}\text{–}COOH + OH^- \longrightarrow CH_3\text{–}\underset{NH_2}{CH}\text{–}COO^- + H_2O$

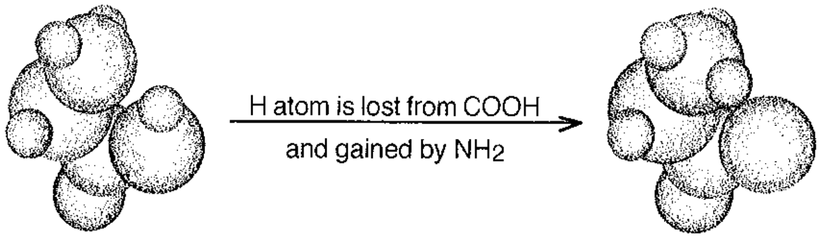
After reacting with either an acid or base the amino acid is ionic and remains soluble in water.

There are two properties of amino acids which are especially important.

a) **Amino acids are highly soluble in water** because amino acids have both acid and base groups arranged such that the acid and base groups can "neutralize" each other.

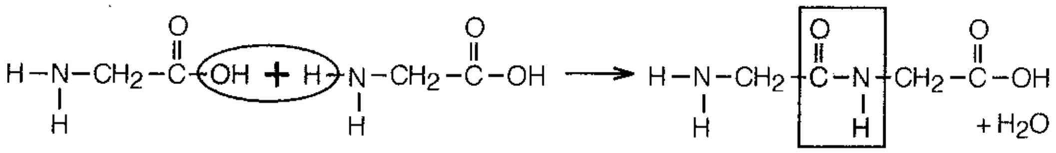


or, using space–filling models



The resulting ionic compound is highly soluble in water.

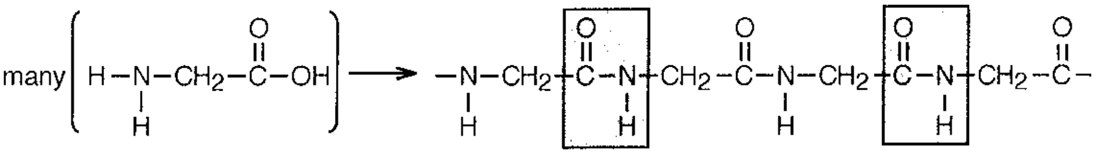
b) **Amino acids link with each other to form "dipeptides" and "polypeptides".**



$$H\text{–}\underset{H}{N}\text{–}CH_2\text{–}\overset{O}{\overset{\|}{C}}\text{–}OH + H\text{–}\underset{H}{N}\text{–}CH_2\text{–}\overset{O}{\overset{\|}{C}}\text{–}OH \longrightarrow H\text{–}\underset{H}{N}\text{–}CH_2\text{–}\boxed{\overset{O}{\overset{\|}{C}}\text{–}\underset{H}{N}}\text{–}CH_2\text{–}\overset{O}{\overset{\|}{C}}\text{–}OH + H_2O$$

a "dipeptide"

The shaded oval, above, shows how water is removed from two molecules and allows the molecules to link together. The box indicates that the molecules are now joined together by an "amide linkage" (or "peptide bond" or "peptide linkage")



$$\text{many}\left(H-\underset{\underset{H}{|}}{N}-CH_2-\overset{\overset{O}{\|}}{C}-OH\right) \longrightarrow -\underset{\underset{H}{|}}{N}-CH_2\boxed{-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{N}-}CH_2-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{N}-CH_2\boxed{-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{N}-}CH_2-\overset{\overset{O}{\|}}{C}-$$

a "polypeptide"

As seen above, a series of amino acid molecules can be joined by a series of amide linkages to form a polypeptide.

C. ESTERS

An ***ester*** is a compound in which a COO group ($-\mathrm{C}\begin{matrix}{/\!\!/}^{\mathrm{O}}\\ {\backslash}_{\mathrm{O}}\end{matrix}$) joins two hydrocarbon chains.

RULE: To name an **ESTER**

- the hydrocarbon chain attached directly to the carbon side of the COO group has its "e" ending changed to "oate". The C in the COO group is considered to be part of the parent hydrocarbon chain.
- the hydrocarbon chain attached to the oxygen side of the COO group is named as an alkyl group; the name of the alkyl group is used as a separate, initial word.

EXAMPLES: Some typical esters are shown below.

$CH_3-CH_2-CH_2-COO-CH_3$ = methyl butanoate

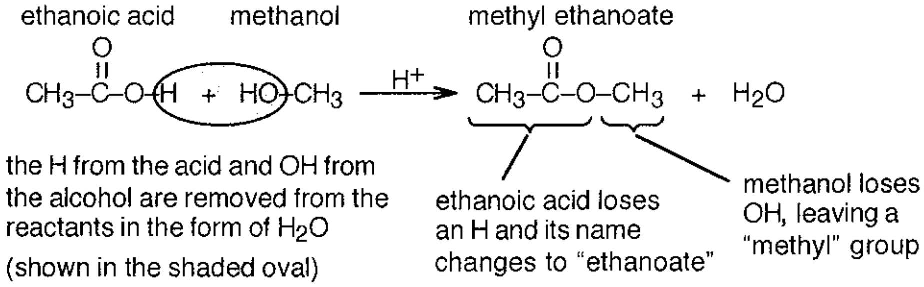
$HCOO-CH_2-CH_2-CH_2-CH_3$ = butyl methanoate

$CH_3-CH_2-COO-CH_2-CH_3$ = ethyl propanoate

$CH_3-COO-CH_2-CH_2-CH_3$ = propyl ethanoate

Preparation and Properties of Esters

Esters are prepared by reacting an organic acid and an alcohol in the presence of an inorganic acid such as HCl or H_2SO_4. In the example below, ethanoic acid reacts with methanol (written backwards); the "H^+" over the reaction arrow indicates that H^+ is used as a catalyst.



$$\overset{\text{ethanoic acid}}{CH_3-\overset{\overset{O}{\|}}{C}-O-H} + \overset{\text{methanol}}{HO-CH_3} \xrightarrow{H^+} \overset{\text{methyl ethanoate}}{\underbrace{CH_3-\overset{\overset{O}{\|}}{C}-O}-\underbrace{CH_3}} + H_2O$$

the H from the acid and OH from the alcohol are removed from the reactants in the form of H_2O (shown in the shaded oval)

ethanoic acid loses an H and its name changes to "ethanoate"

methanol loses OH, leaving a "methyl" group

The actual experimental procedure for producing small amounts of impure esters is quite simple.

Mix a few millilitres of the desired carboxylic acid and a few millilitres of the desired alcohol in a test tube. Add a few drops of concentrated sulphuric acid and heat over a bunsen burner for a minute or so. Be sure not to overheat the liquid and cause it to spurt out the end of the tube. [The distinctive presence of the ester is detected by cautiously smelling the contents of the tube.]

Organic acids have a "sharp, pungent and biting" odour which is often quite unpleasant. (Butanoic acid has the odour of "rancid sneakers", only FAR MORE CONCENTRATED!) Alcohols also have a "sharp" odour, although generally less so than that of acids having a similar number of carbon atoms. Methanol and ethanol have very little odour but their smell tends to "catch" in the nasal passage. Propanol and higher alcohols have more intense and often unpleasant odours which also tend to "catch" in the nasal passage.

The odour of esters, on the other hand, is generally very pleasant. In small amounts, esters form the basis of many fragrant fruit and flower smells.

EXAMPLE:

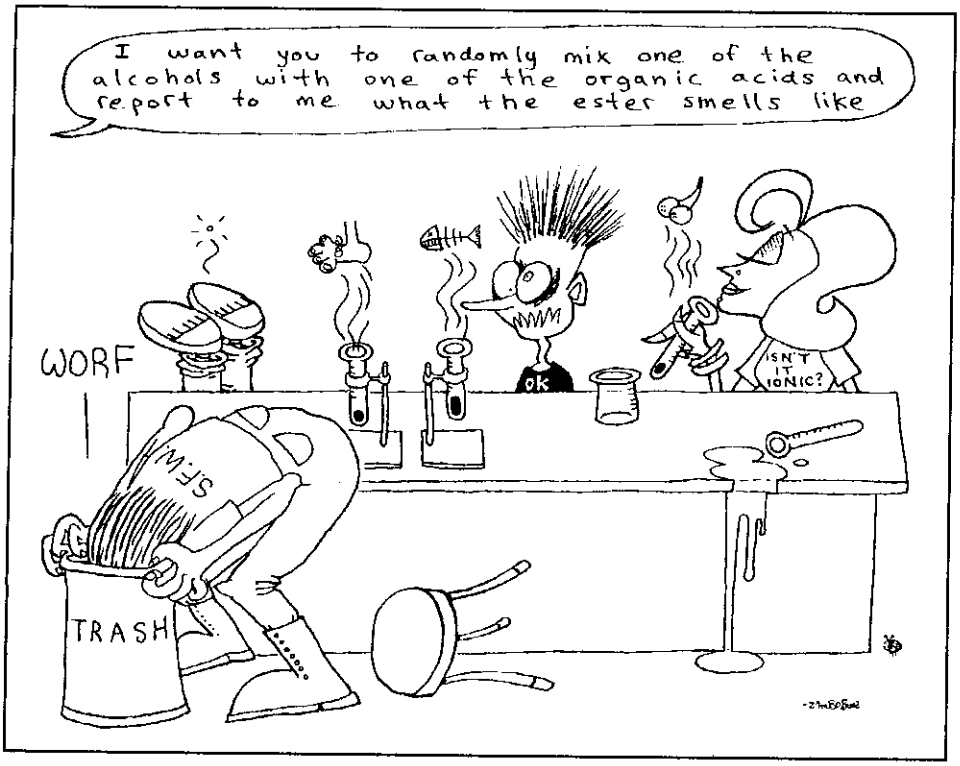
Ester	Odour	Ester	Odour
methyl butanoate	pineapples	pentyl propanoate	apricots
pentyl ethanoate	bananas	ethyl methanoate	rum
octyl ethanoate	orange rind		

EXERCISES:

34. Name the following molecules.
    (a) $CH_3-CH_2-COO-CH_3$
    (b) $HCOO-CH_2-CH_2-CH_3$
    (c) $CH_3-CH_2-CH_2-COO-CH_2-CH_3$
    (d) $CH_3-COO-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$
    (e) $CH_3-CH_2-CH_2-CH_2-COO-CH_2-CH_2-CH_2-CH_3$

35. Draw the following molecules.
    (a) propyl pentanoate
    (b) methyl hexanoate
    (c) ethyl propanoate
    (d) butyl butanoate
    (e) hexyl methanoate

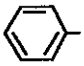
36. Draw the carboxylic acid molecule and alcohol molecule which are used to make each ester in exercise 34.



The new Chemistry 11 teacher is about to find that not all esters have a pleasant smell.

D. A SUMMARY OF THE FUNCTIONAL GROUPS

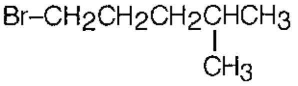
The functional groups which have been introduced in this unit are shown in the table below. The exercise which follows is designed to help you learn to recognize the presence of specific functional groups in a given molecule.

Name	Functional Group	Name	Functional Group
alkene	$C=C$	ether	$-O-$
alkyne	$C{\equiv}C$	amine	$-NH_2$
halide	$-F$, $-Cl$, $-Br$ or $-I$	amide	$-CONH_2$
alcohol	$-OH$	carboxylic acid	$-COOH$
aldehyde	$-CHO$	ester	$-COO-$
ketone	$-CO-$	aromatic ring	

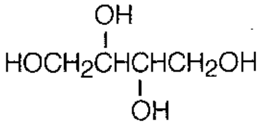
EXERCISE:

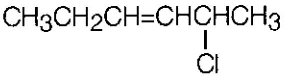
37. Circle the functional groups which exist in each of the following molecules and label each group as one of:

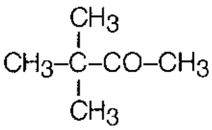
DOU = double bond , TRI = triple bond , ARO = aromatic ring , HAL = halide ,
ALC = alcohol , ALD = aldehyde , KET = ketone , ETH = ether ,
AMN = amine , AMD = amide , CAR = carboxylic acid , EST = ester.

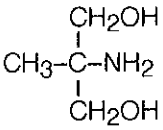
(a) 
$Br\text{-}CH_2CH_2CH_2\underset{\substack{|\\CH_3}}{C}HCH_3$

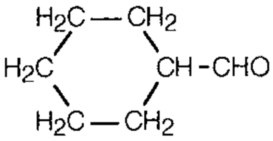
(b) $HC{\equiv}CCH_2C{\equiv}CH$

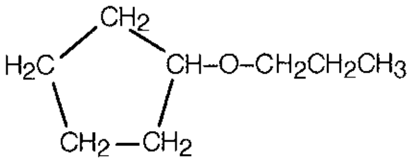
(c) 
$HOCH_2\overset{\substack{OH\\|}}{C}H\underset{\substack{|\\OH}}{C}HCH_2OH$

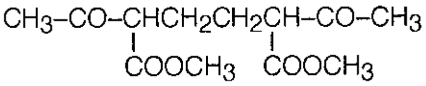
(d) 
$CH_3CH_2CH{=}CH\underset{\substack{|\\Cl}}{C}HCH_3$

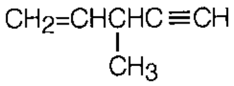
(e) 
$CH_3\text{-}\overset{\substack{CH_3\\|}}{\underset{\substack{|\\CH_3}}{C}}\text{-}CO\text{-}CH_3$

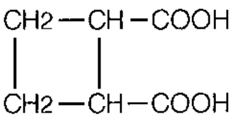
(f) 
$CH_3\text{-}\overset{\substack{CH_2OH\\|}}{\underset{\substack{|\\CH_2OH}}{C}}\text{-}NH_2$

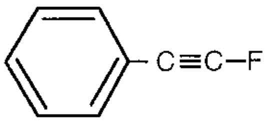
(g) 

(h) 

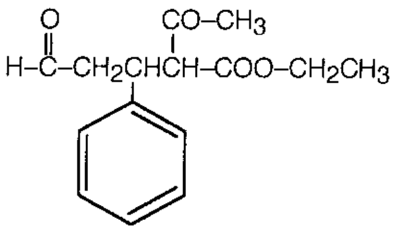
(i) 
$CH_3\text{-}CO\text{-}\underset{\substack{|\\COOCH_3}}{C}HCH_2CH_2\underset{\substack{|\\COOCH_3}}{C}H\text{-}CO\text{-}CH_3$

(j) 
$CH_2{=}CH\underset{\substack{|\\CH_3}}{C}HC{\equiv}CH$

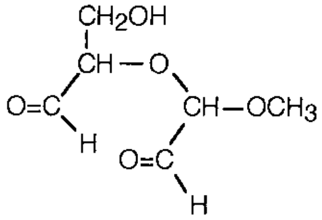
(k) 

(l) 

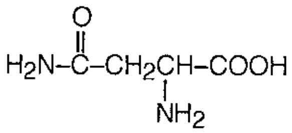
(m)



(n)

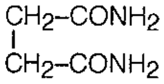


(o)



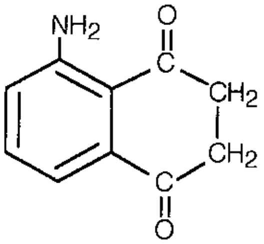
$H_2N-\overset{\overset{O}{\|}}{C}-CH_2\underset{\underset{NH_2}{|}}{C}H-COOH$

(p)

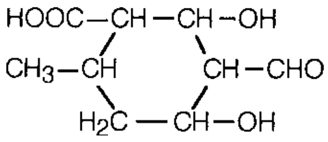


$\begin{array}{l}CH_2-CONH_2\\ |\\ CH_2-CONH_2\end{array}$

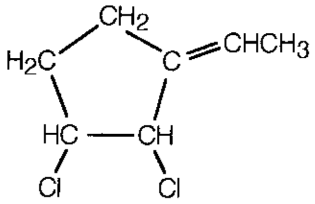
(q)



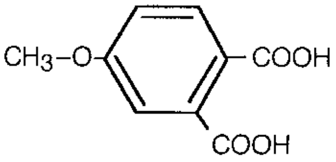
(r)



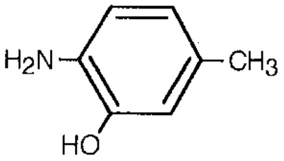
(s)



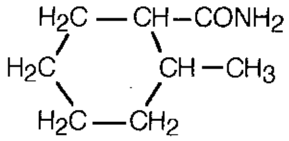
(t)



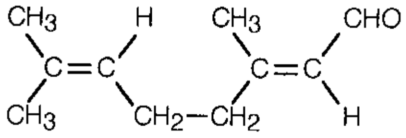
(u)



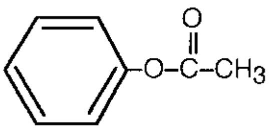
(v)



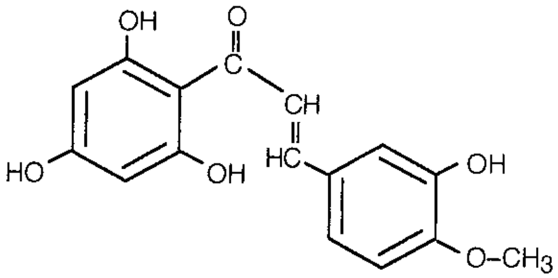
(w)



(x)



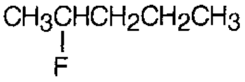
(y)



X.7. SUMMARY EXERCISES

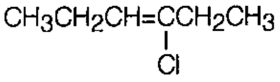
38. Name the following molecules.

(a)



$CH_3\underset{\displaystyle F}{C}HCH_2CH_2CH_3$

(b)

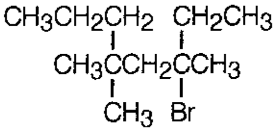


$CH_3CH_2CH{=}\underset{\displaystyle Cl}{C}CH_2CH_3$

(c) $I{-}CH_2C{\equiv}CCH_2{-}I$

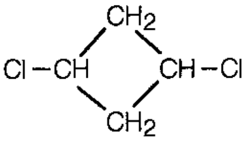
(d) $HCOOCH_2CH_2CH_2CH_2CH_3$

(e)

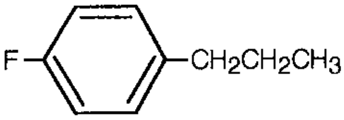


$CH_3\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3CH_2CH_2}{C}}CH_2\underset{\displaystyle Br}{\overset{\displaystyle CH_2CH_3}{C}}CH_3$

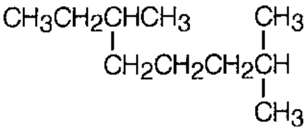
(f)



(g)

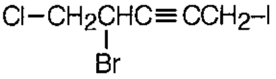


(h)



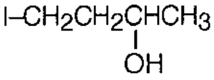
$CH_3CH_2\underset{\displaystyle CH_2CH_2CH_2\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{C}}H}{C}HCH_3$

(i)



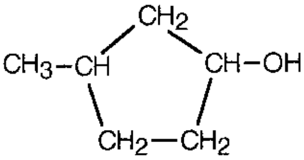
$Cl{-}CH_2\underset{\displaystyle Br}{C}HC{\equiv}CCH_2{-}I$

(j)

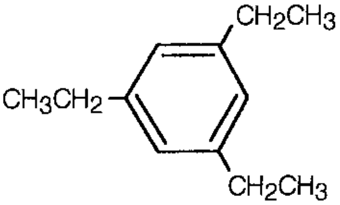


$I{-}CH_2CH_2\underset{\displaystyle OH}{C}HCH_3$

(k)



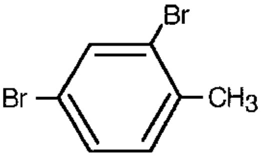
(l)



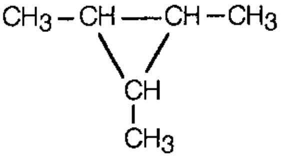
(m) $Br{-}CH_2CH{=}CH_2$

(n) $CH_3COOCH_2CH_2CH_2CH_2CH_3$

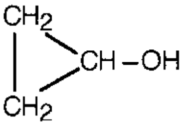
(o)



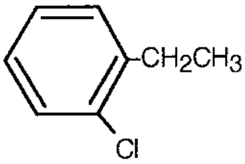
(p)



(q)



(r)



39. Draw the following molecules.

(a) 1,4,4–trifluoro–2–pentanol
(b) 4–chloro–2–hexyne
(c) ethyl pentanoate
(d) 3,4,5,6–tetramethylnonane
(e) 3–octyne
(f) 1,3–diethylbenzene
(g) 1,3–dibromo–3–hexene
(h) 3,5–diethyl–4,4–dimethylheptane
(i) 2,3–dichloro–2–butene
(j) methyl octanoate
(k) 3,3–diiodo–4–ethyl–2–methyl–1–hexene
(l) cyclooctene
(m) 2–methyl–3–heptyne
(n) 3–methyl–1–cyclobutanol
(o) 1–ethyl–3–propylbenzene
(p) cyclohexyne
(q) 2–methyl–2–butanol
(r) 2,2,3,3–tetrabromobutane

40. A hydrocarbon has the formula C_NH_{2N-2}. Which of the following are possible?
  - (a) The compound is branched but has no multiple bonds or cyclic groups.
  - (b) The compound has a single double bond.
  - (c) The compound has a single triple bond.
  - (d) The compound has a single cyclic group.
  - (e) The compound has two double bonds.
  - (f) The compound has two triple bonds.
  - (g) The compound has two cyclic groups.
  - (h) The compound has a double bond and a triple bond.
  - (i) The compound has a double bond and a single cyclic group.
  - (j) The compound has a cyclic group and a triple bond.

41. Draw and name the 9 isomers of C_5H_{10}. (Hint: think what you were doing in the previous exercise.)

42. What class of organic compounds
  - (a) can neutralize bases?
  - (b) often smell "fishy"?
  - (c) can be prepared by combining an acid and an alcohol?
  - (d) form waxes?
  - (e) can form polypeptides?
  - (f) have fruity odours?

43. Draw the following cis and trans isomers.
  - (a) trans–3,4–dichloro–3–hexene
  - (b) trans–2–octene
  - (c) cis–2,3–dibromo–2–butene
  - (d) trans–1,1,1–trifluoro–2–pentene
  - (e) cis–1,1,1,7,7,7–hexachloro–3–heptene
  - (f) cis–2–nonene

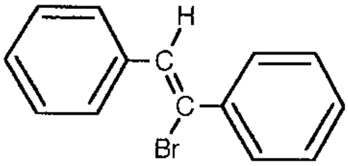
44. Circle the functional groups in each of the following molecules and label each group as one of:

DOU = double bond , TRI = triple bond , ARO = aromatic ring , HAL = halide ,
ALC = alcohol , ALD = aldehyde , KET = ketone , ETH = ether ,
AMN = amine , AMD = amide , CAR = carboxylic acid , EST = ester.

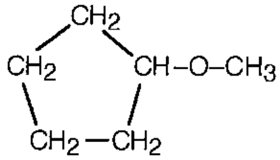
(a) $F_3CCOOCH_3$

(b) $CH_3COCH_2CH_2OH$

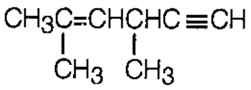
(c)



(d)

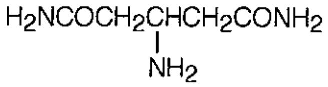


(e)



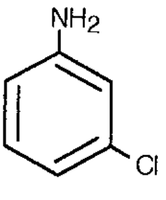
$CH_3\underset{CH_3}{\underset{|}{C}}=CH\underset{CH_3}{\underset{|}{C}}HC\equiv CH$

(f)

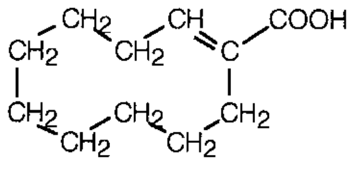


$H_2NCOCH_2\underset{NH_2}{\underset{|}{C}}HCH_2CONH_2$

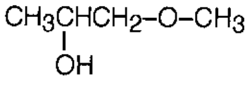
(g)



(h)

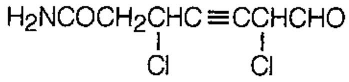


(i)



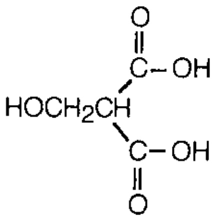
$CH_3\underset{OH}{\underset{|}{C}}HCH_2-O-CH_3$

(j)

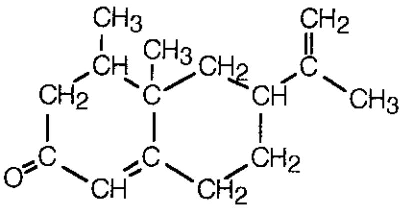


$H_2NCOCH_2\underset{Cl}{\underset{|}{C}}HC\equiv C\underset{Cl}{\underset{|}{C}}HCHO$

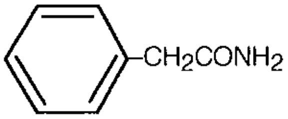
(k)



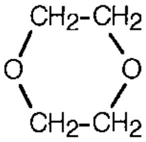
(l)



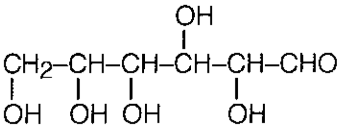
(m)



(n)

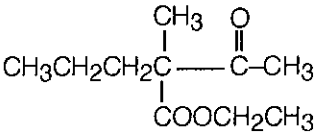


(o)



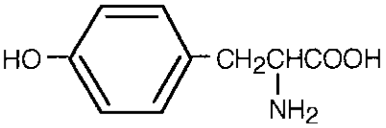
$$\underset{\mathrm{OH}}{\mathrm{CH_2}}-\underset{\mathrm{OH}}{\mathrm{CH}}-\underset{\mathrm{OH}}{\mathrm{CH}}-\overset{\mathrm{OH}}{\mathrm{CH}}-\underset{\mathrm{OH}}{\mathrm{CH}}-\mathrm{CHO}$$

(p)

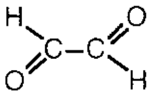


$$\mathrm{CH_3CH_2CH_2}\underset{\mathrm{COOCH_2CH_3}}{\overset{\mathrm{CH_3}}{\mathrm{C}}}-\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-\mathrm{CH_3}$$

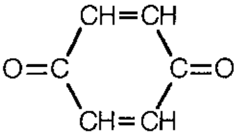
(q)



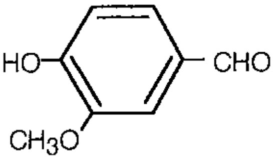
(r)



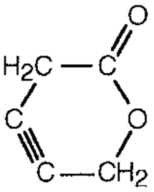
(s)



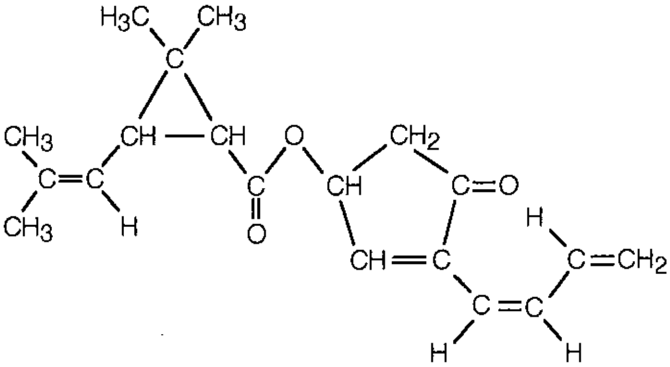
(t)



(u)



(v)




Well, I hope you had fun. I'll see you next year in Chem 12

ANSWERS TO UNIT I : SAFETY IN THE CHEMICAL LABORATORY

1. (a) Yell to alert others that you have a problem and immediately "stop, drop and roll". In other words, don't run around (you can't escape the flames); just roll on the floor to put out the flames. If a large amount of chemical has landed on you, other students should quickly get the fire blanket to cover you.
   (b) Yell to alert others that you have a problem and get to the eyewash fountain or station as soon as possible. You may need someone to guide you to the eyewash fountain.
   (c) Immediately stand back out of harm's way, yell to alert others that you have a problem, and then assess the situation to decide if the fire is controlled and can be put out by smothering the fire.
   (d) Alert other students in the vicinity and notify the teacher for specific cleanup instructions.
   (e) Quickly wash the acid or base off your hands and then rinse with some neutralizing solution.

2. Turn off the gas! Then, while waiting for the gas to dissipate, check that the device used to ignite the gas is working correctly and that the air collar of the bunsen burner is closed. If necessary, seek help from the teacher.

3. The spray is swept back and forth across the base of the flames.

4. If the flame is in a container such as a beaker of test tube, smother the flames by placing a watch glass or inverted beaker over the top. If a somewhat larger area is involved, smother the flame with the fire blanket.

5. Emergency equipment needs to be used as soon as possible; wasting time trying to get the teacher's permission might worsen the situation.

6. About 10 s; (larger ones spray for about 20 s)

7. Save the life, save the sight, save the skin. First extinguish the flames by rolling the student on the floor because the flames are life–threatening. Then wash the eyes to try to save the eyesight. Only then should you worry about washing chemicals off the rest of the skin.

8. If you cut yourself on the glass you might get the chemical on the glass into the cut.

ANSWERS TO UNIT II : INTRODUCTION TO CHEMISTRY

1. (a) unknown amount = cost in dollars or # of dollars
   initial amount = 100 g
   conversion factor = \$50/g, or 1 g/\$50

   (b) unknown amount = # of disks
   initial amount = \$36.00
   conversion factor = \$6.00/10 disks, or 10 disks/\$6.00

   (c) unknown amount = volume in millilitres or # of millilitres
   initial amount = 20 g
   conversion factor = 0.35 g/mL, or 1 mL/0.35 g

   (d) unknown amount = # of kiwi fruit
   initial amount = \$5
   conversion factor = 3 kiwi fruit/\$1, or \$1/3 kiwi fruit

   (e) unknown amount = # of bims
   initial amount = 30 tuds
   conversion factor = 4 bims/5 tuds, or 5 tuds/4 bims

   (f) unknown amount = # of goats
   initial amount = 10 cows
   conversion factor = 2 cows/7 goats, or 7 goats/2 cows

   (g) unknown amount = mass of oxygen or # of grams
   initial amount = 5.5 moles
   conversion factor = 32 g/mole, or 1 mole/32 g

   (h) unknown amount = # of sulphur molecules
   initial amount = 104 sulphur atoms
   conversion factor = 8 sulphur atoms/1 sulphur molecule, or 1 sulphur molecule/8 sulphur atoms

   (i) unknown amount = length of time or # of seconds
   initial amount = 200 coulombs
   conversion factor = 35 coulombs/s, or 1 s/35 coulombs

   (j) unknown amount = temperature increase or # of ^{0}C
   initial amount = 100 kJ
   conversion factor = 4.18 kJ/1^{0}C, or 1^{0}C/4.18 kJ

2. (a) $\# \text{ of atoms} = 5.5 \text{ mol} \times \frac{6.02 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = \mathbf{3.3 \times 10^{24} \text{ atoms}}$

   (b) $\# \text{ of moles} = 25.0 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} = \mathbf{1.12 \text{ mol}}$

   (c) $\# \text{ of moles} = 7.0 \text{ g} \times \frac{1 \text{ mol}}{28 \text{ g}} = \mathbf{0.25 \text{ mol}}$

   (d) $\# \text{ of seconds} = 200.0 \text{ coulombs} \times \frac{1 \text{ s}}{35 \text{ coulombs}} = \mathbf{5.7 \text{ s}}$

   (e) $\# \text{ of atmospheres} = 4 \times 10^{-8} \text{ kPa} \times \frac{1 \text{ atm}}{101.3 \text{ kPa}} = \mathbf{4 \times 10^{-10} \text{ atmospheres}}$

   (f) $\# \text{ of kilograms} = 3.20 \times 10^{4} \text{ troy ounce} \times \frac{0.0311 \text{ kg}}{1 \text{ troy ounce}} = \mathbf{995 \text{ kg}}$

   (g) $\# \text{ of milliseconds} = 5.0 \times 10^{-4} \text{ s} \times \frac{1 \text{ ms}}{10^{-3} \text{ s}} = \mathbf{0.50 \text{ ms}}$

   (h) $\# \text{ of moles} = 15\,100 \text{ kJ} \times \frac{1 \text{ mol}}{5450 \text{ kJ}} = \mathbf{2.77 \text{ mol}}$

(i) $\text{\# of millimetres} = 0.05\ \text{micron} \times \dfrac{10^{-3}\ \text{mm}}{1\ \text{micron}} = \mathbf{5 \times 10^{-5}\ mm}$

(j) $\text{\# of litres} = 0.0358\ \text{mol} \times \dfrac{1\ \text{L}}{11.7\ \text{mol}} = \mathbf{0.00306\ L}$

3. $\text{\# of kilopascals} = 27.0\ \text{inches} \times \dfrac{0.0334\ \text{atm}}{1\ \text{inch}} \times \dfrac{101.3\ \text{kPa}}{1\ \text{atm}} = 91.4\ \text{kPa}$

4. (a) $\text{amount of heat} = 3.1 \times 10^{13}\ \text{m}^3 \times \dfrac{917\ \text{kg}}{1\ \text{m}^3} \times \dfrac{334\ \text{kJ}}{1\ \text{kg}} = \mathbf{9.5 \times 10^{18}\ kJ}$

(b) $\text{\# of kilograms} = 9.5 \times 10^{18}\ \text{kJ} \times \dfrac{1\ \text{kg}}{1.51 \times 10^{4}\ \text{kJ}} = \mathbf{6.3 \times 10^{14}\ kg}$

5. $\text{\# of tonnes} = \$350 \times \dfrac{1\ \text{kg}}{\$0.980} \times \dfrac{1\ \text{t}}{1000\ \text{kg}} = \mathbf{0.357\ t}$

6. $\text{\# of carats} = 177\ \text{mL} \times \dfrac{3.51\ \text{g}}{1\ \text{mL}} \times \dfrac{1\ \text{carat}}{0.200\ \text{g}} = \mathbf{3110\ carats}$

7. (a) $\text{\# of kilometres} = 0.25\ \text{h} \times \dfrac{120\ \text{km}}{\text{h}} = \mathbf{30\ km}$

(b) $\text{\# of kilometres} = 12\ \text{min} \times \dfrac{1\ \text{h}}{60\ \text{min}} \times \dfrac{120\ \text{km}}{1\ \text{h}} = \mathbf{24\ km}$

8. (a) $\text{\# of dollars} = 3\ \text{doz} \times \dfrac{\$8.40}{1\ \text{doz}} = \mathbf{\$25.20}$

(b) $\text{\# of hamburgers} = 5\ \text{doz} \times \dfrac{\$8.40}{1\ \text{doz}} \times \dfrac{1\ \text{hamburger}}{\$1.50} = \mathbf{28\ hamburgers}$

(c) $\text{\# of beakers} = \$13.30 \times \dfrac{1\ \text{doz}}{\$8.40} \times \dfrac{12\ \text{beakers}}{1\ \text{doz}} = \mathbf{19\ beakers}$

9. $\text{\# of chickens} = 1\ \text{gift} \times \dfrac{2\ \text{horses}}{1\ \text{gift}} \times \dfrac{5\ \text{cows}}{3\ \text{horses}} \times \dfrac{4\ \text{hogs}}{1\ \text{cow}} \times \dfrac{4\ \text{goats}}{3\ \text{hogs}} \times \dfrac{9\ \text{chickens}}{1\ \text{goat}} = \mathbf{160\ chickens}$

10. $\text{\# of centimetres} = 5\ \text{yard} \times \dfrac{3\ \text{feet}}{1\ \text{yard}} \times \dfrac{12\ \text{inches}}{1\ \text{foot}} \times \dfrac{1\ \text{cm}}{0.3937\ \text{inch}} = \mathbf{457.2\ cm}$

11. (a) 2.5 cm ; 2.5×10^{-2} m
(b) 1.3 kg ; 1.3×10^{3} g
(c) 25.2 mmol ; 25.2×10^{-3} mol (or 2.52×10^{-2} mol)
(d) 5.1 dg ; 5.1×10^{-1} g
(e) 0.25 ML ; 0.25×10^{6} L (or 2.5×10^{5} L)
(f) 6.38 μg ; 6.38×10^{-6} g

12. (a) 2.5 millimetres ; 2.5×10^{-3} m
(b) 6.5 decilitres ; 6.5×10^{-1} L
(c) 1.9 kilomoles ; 1.9×10^{3} mol
(d) 4 megatonnes ; 4×10^{6} t
(e) 9.94 centigrams ; 9.94×10^{-2} g
(f) 1.25 microseconds ; 1.25×10^{-6} s

13. (a) 4.5 mmol ; 4.5 millimoles
(b) 1.6 km ; 1.6 kilometres
(c) 0.50 μL ; 0.50 microlitre
(d) 2.68 dg ; 2.68 decigrams
(e) 8.85 Mt; 8.85 megatonnes
(f) 7.25 cm ; 7.25 centimetres

14. (a) 50 mL
(b) 22.5×10^{3} kg (or 2.25×10^{4} kg)
(c) 0.125×10^{3} L (or 1.25×10^{2} L)

15. (a) 1 kg = 10^{3} g
(b) 1 Mm = 10^{6} m
(c) 1 μL = 10^{-6} L
(d) 1 dm = 10^{-1} m
(e) 1 cs = 10^{-2} s
(f) 1 mmol = 10^{-3} mol
(g) 1 kL = 10^{3} L
(h) 1 μs = 10^{-6} s
(i) 1 Mg = 10^{6} g
(j) 1 cL = 10^{-2} L
(k) 1 dmol = 10^{-1} mol
(l) 1 mg = 10^{-3} g

16. (a) # of milligrams $= 0.25\ \text{Mg} \times \frac{10^{6}\ \text{g}}{1\ \text{Mg}} \times \frac{1\ \text{mg}}{10^{-3}\ \text{g}} = \mathbf{2.5 \times 10^{8}\ mg}$

(b) # of centiseconds $= 10\ \mu\text{s} \times \frac{10^{-6}\ \text{s}}{1\ \mu\text{s}} \times \frac{1\ \text{cs}}{10^{-2}\ \text{s}} = \mathbf{1 \times 10^{-3}\ cs}$

(c) # of millimetres $= 15.8\ \text{cm} \times \frac{10^{-2}\ \text{m}}{1\ \text{cm}} \times \frac{1\ \text{mm}}{10^{-3}\ \text{m}} = \mathbf{158\ mm}$

(d) # of kilograms $= 250\ \text{mg} \times \frac{10^{-3}\ \text{g}}{1\ \text{mg}} \times \frac{1\ \text{kg}}{10^{3}\ \text{g}} = \mathbf{2.5 \times 10^{-4}\ kg}$

(e) # of decilitres $= 0.5\ \text{kL} \times \frac{10^{3}\ \text{L}}{1\ \text{kL}} \times \frac{1\ \text{dL}}{10^{-1}\ \text{L}} = \mathbf{5 \times 10^{3}\ dL}$

17. (a) # of milliseconds $= 3\ \text{s} \times \frac{1\ \text{ms}}{10^{-3}\ \text{s}} = \mathbf{3 \times 10^{3}\ ms}$

(b) # of litres $= 50.0\ \text{mL} \times \frac{10^{-3}\ \text{L}}{1\ \text{mL}} = \mathbf{5.0 \times 10^{-2}\ L}$

(c) # of microlitres $= 2\ \text{L} \times \frac{1\ \mu\text{L}}{10^{-6}\ \text{L}} = \mathbf{2 \times 10^{6}\ \mu L}$

(d) # of grams $= 25\ \text{kg} \times \frac{10^{3}\ \text{g}}{1\ \text{kg}} = \mathbf{2.5 \times 10^{4}\ g}$

(e) # of metres $= 3\ \text{Mm} \times \frac{10^{6}\text{m}}{1\ \text{Mm}} = \mathbf{3 \times 10^{6}\ m}$

(f) # of decilitres $= 2\ \text{L} \times \frac{1\ \text{dL}}{10^{-1}\ \text{L}} = \mathbf{2 \times 10^{1}\ dL}$

(g) # of milliseconds $= 7\ \mu\text{s} \times \frac{10^{-6}\ \text{s}}{1\ \mu\text{s}} \times \frac{1\ \text{ms}}{10^{-3}\ \text{s}} = \mathbf{7 \times 10^{-3}\ ms}$

(h) # of milligrams $= 51\ \text{kg} \times \frac{10^{3}\ \text{g}}{1\ \text{kg}} \times \frac{1\ \text{mg}}{10^{-3}\ \text{g}} = \mathbf{5.1 \times 10^{7}\ mg}$

(i) # of kilolitres $= 3125\ \mu\text{L} \times \frac{10^{-6}\ \text{L}}{1\ \mu\text{L}} \times \frac{1\ \text{kL}}{10^{3}\ \text{L}} = \mathbf{3.125 \times 10^{-6}\ kL}$

(j) # of centigrams $= 1.7\ \mu\text{g} \times \frac{10^{-6}\ \text{g}}{1\ \mu\text{g}} \times \frac{1\ \text{cg}}{10^{-2}\ \text{g}} = \mathbf{1.7 \times 10^{-4}\ cg}$

(k) # of seconds $= 1\ \text{yr} \times \frac{365\ \text{d}}{1\ \text{y}} \times \frac{24\ \text{h}}{1\ \text{d}} \times \frac{60\ \text{min}}{1\ \text{h}} \times \frac{60\ \text{s}}{1\ \text{min}} = \mathbf{3.15 \times 10^{7}\ s}$

(l) # of $\frac{\text{grams}}{\text{litre}} = \frac{1\ \text{mg}}{\text{dL}} \times \frac{10^{-3}\ \text{g}}{1\ \text{mg}} \times \frac{1\ \text{dL}}{10^{-1}\ \text{L}} = \mathbf{1 \times 10^{-2}\, \frac{g}{L}}$

(m) # of $\frac{\text{kilometres}}{\text{second}} = \frac{1\ \text{cm}}{\mu\text{s}} \times \frac{10^{-2}\ \text{m}}{1\ \text{cm}} \times \frac{1\ \text{km}}{10^{3}\ \text{m}} \times \frac{1\ \mu\text{s}}{10^{-6}\ \text{s}} = \mathbf{1 \times 10^{1}\, \frac{km}{s}}$

(n) # of $\frac{\text{decigrams}}{\text{litre}} = \frac{1\ \text{cg}}{\text{mL}} \times \frac{10^{-2}\ \text{g}}{1\ \text{cg}} \times \frac{1\ \text{dg}}{10^{-1}\ \text{g}} \times \frac{1\ \text{mL}}{10^{-3}\ \text{L}} = \mathbf{1 \times 10^{2}\, \frac{dg}{L}}$

(o) # of $\frac{\text{mg}}{\text{s}} = \frac{5\ \text{cg}}{\text{ds}} \times \frac{10^{-2}\ \text{g}}{\text{cg}} \times \frac{1\ \text{mg}}{10^{-3}\ \text{g}} \times \frac{\text{ds}}{10^{-1}\ \text{s}} = \mathbf{5 \times 10^{2}\, \frac{mg}{s}}$

18. (a) $$\#\text{ of metres} = 8.3\text{ min} \times \frac{60\text{ s}}{1\text{ min}} \times \frac{3.00 \times 10^{8}\text{ m}}{1\text{ s}} = \mathbf{1.5 \times 10^{11}\ m}$$

(b) $$\#\text{ of seconds} = 3.8 \times 10^{5}\text{ km} \times \frac{10^{3}\text{ m}}{1\text{ km}} \times \frac{1\text{ s}}{3.00 \times 10^{8}\text{ m}} = \mathbf{1.3\ s}$$

(c) $$\#\text{ of minutes} = 7.83 \times 10^{7}\text{ km} \times \frac{10^{3}\text{ m}}{1\text{ km}} \times \frac{1\text{ s}}{3.00 \times 10^{8}\text{ m}} \times \frac{1\text{ min}}{60\text{ s}} = \mathbf{4.35\ min}$$

19. $$\#\text{ of }\frac{\text{kg}}{\text{m}^{3}} = \frac{9.0\text{ lb}}{\text{in}^{3}} \times \frac{1\text{ kg}}{2.2\text{ lb}} \times \left(\frac{39\text{ in}}{1\text{ m}}\right)^{3} = \mathbf{2.4 \times 10^{5}\ \frac{kg}{m^{3}}}$$

20. (a) $$\#\text{ of dollars} = 90.0\text{ kg} \times \frac{\$9.80}{10\text{ kg}} = \mathbf{\$88.2}$$

(b) $$\#\text{ of dollars} = 6.00\text{ t} \times \frac{10^{3}\text{ kg}}{1\text{ t}} \times \frac{\$9.80}{10\text{ kg}} = \mathbf{\$5880}$$

21. (a) $$\#\text{ of centimetres} = 20.0\text{ inch} \times \frac{2.54\text{ cm}}{1\text{ inch}} = \mathbf{50.8\ cm}$$

(b) $$\#\text{ of metres} = 36\text{ inch} \times \frac{2.54\text{ cm}}{1\text{ inch}} \times \frac{10^{-2}\text{ m}}{1\text{ cm}} = \mathbf{0.914\ m}$$

22. $$\#\text{ of centigrams} = 90\ \mu\text{g} \times \frac{10^{-6}\text{ g}}{1\ \mu\text{g}} \times \frac{1\text{ cg}}{10^{-2}\text{ g}} = \mathbf{9 \times 10^{-3}\ cg}$$

23. (a) $$\#\text{ of hours} = 450\text{ km} \times \frac{1\text{ h}}{105\text{ km}} = \mathbf{4.3\ h}$$

(b) $$\#\text{ of seconds} = 2.0 \times 10^{2}\text{ m} \times \frac{1\text{ km}}{10^{3}\text{ m}} \times \frac{1\text{ h}}{105\text{ km}} \times \frac{60\text{ min}}{1\text{ h}} \times \frac{60\text{ s}}{1\text{ min}} = \mathbf{6.9\ s}$$

(c) $$\#\text{ of kilometres} = 10.0\text{ min} \times \frac{1\text{ h}}{60\text{ min}} \times \frac{105\text{ km}}{1\text{ h}} = \mathbf{17.5\ km}$$

(d) $$\#\text{ of centimetres} = 1.00\text{ ms} \times \frac{10^{-3}\text{ s}}{1\text{ ms}} \times \frac{1\text{ min}}{60\text{ s}} \times \frac{1\text{ h}}{60\text{ min}} \times \frac{105\text{ km}}{1\text{ h}} \times \frac{10^{3}\text{ m}}{1\text{ km}} \times \frac{1\text{ cm}}{10^{-2}\text{ m}} = \mathbf{2.92\ cm}$$

24. (a) $$\#\text{ of kilograms} = 7.00\text{ L} \times \frac{5.50\text{ kg}}{1\text{ L}} = \mathbf{38.5\ kg}$$

(b) $$\#\text{ of litres} = 22\text{ kg} \times \frac{1\text{ L}}{5.50\text{ kg}} = \mathbf{4.0\ L}$$

(c) $$\#\text{ of grams} = 5.00\text{ mL} \times \frac{10^{-3}\text{ L}}{1\text{ mL}} \times \frac{5.50\text{ kg}}{\text{L}} \times \frac{10^{3}\text{ g}}{1\text{ kg}} = \mathbf{27.5\ g}$$

25. (a) $$\#\text{ of grams} = 10.0\text{ kJ} \times \frac{1.00\text{ g}}{0.334\text{ kJ}} = \mathbf{29.9\ g}$$

(b) $$\#\text{ of kilojoules} = 50.0\text{ g} \times \frac{0.334\text{ kJ}}{1.00\text{ g}} = \mathbf{16.7\ kJ}$$

(c) $$\#\text{ of joules} = 2.00\text{ kg} \times \frac{10^{3}\text{ g}}{1\text{ kg}} \times \frac{0.334\text{ kJ}}{1.00\text{ g}} \times \frac{1000\text{ J}}{1\text{ kJ}} = \mathbf{6.68 \times 10^{5}\ J}$$

26. $\#\text{ of micrograms} = 80\text{ Mg} \times \frac{10^6\text{ g}}{1\text{ Mg}} \times \frac{1\ \mu\text{g}}{10^{-6}\text{ g}} = \mathbf{8 \times 10^{13}\ \mu g}$

27. $\#\text{ of } \frac{\text{kilolitres}}{\text{second}} = \frac{2\text{ cL}}{\text{ms}} \times \frac{10^{-2}\text{ L}}{1\text{ cL}} \times \frac{1\text{ kL}}{10^3\text{ L}} \times \frac{1\text{ ms}}{10^{-3}\text{ s}} = \mathbf{2 \times 10^{-2}\ \frac{kL}{s}}$

28. $\#\text{ of } \frac{\text{microlitres}}{\text{second}} = \frac{50.0\text{ mL}}{\text{min}} \times \frac{10^{-3}\text{ L}}{1\text{ mL}} \times \frac{1\ \mu\text{L}}{10^{-6}\text{ L}} \times \frac{1\text{ min}}{60\text{ s}} = \mathbf{833\ \frac{\mu L}{s}}$

29. (a) $c = \frac{n}{V} = \frac{0.250\text{ mol}}{0.500\text{ L}} = \mathbf{0.500\ \frac{mol}{L}}$

(b) i) $R = \frac{P \cdot V}{n \cdot T} = \frac{1\text{ atm} \times 22.4\text{ L}}{1\text{ mol} \times 273\text{ K}} = \mathbf{0.0821\ \frac{atm \cdot L}{mol \cdot K}}$

ii) $R = \frac{P \cdot V}{n \cdot T} = \frac{202.6\text{ kPa} \times 24.45\text{ L}}{2\text{ mol} \times 298\text{ K}} = \mathbf{8.31\ \frac{kPa \cdot L}{mol \cdot K}}$

(c) $\Delta S = \frac{\Delta H}{T} = \frac{44.0\text{ kJ}}{373\text{ K}} = \mathbf{0.118\ \frac{kJ}{K}}$

(d) $\text{KE} = \frac{1}{2}\text{ m} \cdot \text{v}^2 = \frac{1}{2}(3.35 \times 10^{-27}\text{ kg}) \times (1692\ \frac{\text{m}}{\text{s}})^2 = \mathbf{4.80 \times 10^{-21}\ \frac{kg \cdot m^2}{s^2}}$

30. $d = \frac{m}{V} = \frac{(\text{g})}{(\text{L})}$, and the units of d are g/L.

31. $d = \frac{m}{V} = \frac{8.19\text{ g}}{3.50\text{ mL}} = \mathbf{2.34\ \frac{g}{mL}}$, or: $d = \frac{8.19\text{ g}}{3.50 \times 10^{-3}\text{ L}} = \mathbf{2.34 \times 10^3\ \frac{g}{L}}$

32. $V = \frac{m}{d} = \frac{125\text{ g}}{7.86 \times 10^3\text{ g/L}} = \mathbf{0.0159\ L}$

33. $m = d \cdot V = 961\ \frac{\text{g}}{\text{L}} \times 0.2000\text{ L} = \mathbf{192\ g}$

34. $V = \frac{m}{d} = \frac{46\text{ g}}{789\text{ g/L}} = \mathbf{0.058\ L}$

35. $m = d \cdot V = 0.900\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = \mathbf{20.2\ g}$

36. $V_{\text{SPHERE}} = \frac{m}{d} = \frac{70.0\text{ g}}{7.20 \times 10^3\text{ g/L}} = 0.00972\text{ L} = 9.72\text{ mL}$

$V_{\text{TOTAL}} = V_{\text{SPHERE}} + V_{\text{START}} = 9.72 + 54.0 = \mathbf{63.7\ mL}$

37. Since less dense liquids float on more dense liquids, the least dense layer will be at the top and the most dense layer will be at the bottom, as shown below. The order is: Z, Y, W and X on the bottom.

$d_Z = \frac{m}{V} = \frac{74.8\text{ g}}{115.0\text{ mL}} = 0.650\ \frac{\text{g}}{\text{mL}}$ $d_W = \frac{m}{V} = \frac{107.3\text{ g}}{55.0\text{ mL}} = 1.95\ \frac{\text{g}}{\text{mL}}$

$d_Y = \frac{m}{V} = \frac{46.8\text{ g}}{42.5\text{ mL}} = 1.10\ \frac{\text{g}}{\text{mL}}$ $d_X = \frac{m}{V} = \frac{51.8\text{ g}}{12.0\text{ mL}} = 4.32\ \frac{\text{g}}{\text{mL}}$

38. Although the density of iron is greater than the density of water, the fact that the boat floats means the density of the boat must be less than the density of the water. Since $d = m/V$, then in order for the density of the boat to be less than 1 g/mL (water's density), the volume occupied by the boat must be quite large, relative to its mass. This situation is obtained by having a shape which keeps water out of

the center of the boat, allowing most of the interior volume to be air (and other stuff inside the boat). The AVERAGE density of the entire boat, including iron hull, air, etc. is then less than 1 g/mL.

39. $V_{\text{COPPER}} = \frac{m}{d} = \frac{100.0\text{ g}}{8.92\times10^{3}\text{ g/L}} = 0.01121\text{ L} = \text{V}_{\text{MAGNESIUM}}$

$m_{\text{MAGNESIUM}} = d \cdot V = 1.74\times10^{3}\,\frac{\text{g}}{\text{L}} \times 0.01121\text{ L} = \mathbf{19.5\ g}$

40. mass of sun $= d \cdot V = 1.407\,\frac{\text{g}}{\text{mL}} \times \frac{1\text{ kg}}{10^{3}\text{ g}} \times \frac{1\text{ t}}{10^{3}\text{ kg}} \times \frac{1\text{ mL}}{10^{-3}\text{ L}} \times 1.41\times10^{30}\text{ L} = 1.98\times10^{27}\text{ t}$

time required $= 1.98\times10^{27}\text{ t} \times \frac{1\text{ s}}{4.0\times10^{6}\text{ t}} \times \frac{1\text{ y}}{3.15\times10^{7}\text{ s}} = 1.6\times10^{13}\text{ y}$

41. $V_{\text{SODIUM}} = \frac{m}{d} = \frac{90.0\text{ g}}{970.0\text{ g/L}} = 0.0928\text{ L} = 92.8\text{ mL}$

After inserting the cube, the remaining volume is less.

$V_{\text{REMAINING}} = V_{\text{START}} - V_{\text{SODIUM}} = 250.0 - 92.8 = 157.2\text{ mL};\ d_{\text{ARGON}} = \frac{m}{V} = \frac{4.60\text{ g}}{157.2\text{ mL}} = \mathbf{0.0293\ \frac{g}{mL}}$

42. (a) 3 (b) 4 (c) 2 (d) 2 (e) 4 (f) 6 (g) 1 (h) 4

43. The balanced has been damaged or mis–calibrated in such a way that all the readings are a few grams too high or too low, for example.

44. (a) A, B (b) A, D (c) A

45. (a) A time reading with lots of digits, most of which are incorrect; for example: 75.987 654 s
(b) A time reading with few digits, but the digits are close to the correct time; for example: 121.3 s
(c) A time reading with few digits, most of which are incorrect; for example: 88 s
(d) A time reading with lots of digits, and a value which is quite close to the accepted value; for example: 121.315 593 s

46. (a) 2 (b) 4 (c) 2 (d) 5

47. (a) C (b) M (c) M (d) C (e) M

48. (a) Numbered division difference = 1 cm ; Unnumbered subdivision difference $= \frac{1\text{ cm}}{10} = 0.1\text{ cm}$

Reading A: Pointer is $^{4}/_{10}$ of the way from one subdivision to the next: $^{4}/_{10} \times 0.1\text{ cm} = 0.04\text{ cm}$
The reading is $15.20 + 0.04 =$ **15.24 cm.**

Reading B: Pointer is $^{7}/_{10}$ of the way from one subdivision to the next: $^{7}/_{10} \times 0.1\text{ cm} = 0.07\text{ cm}$
The reading is $15.80 + 0.07 =$ **15.87 cm.**

(b) Numbered division difference = 10 cm ; Unnumbered subdivision difference $= \frac{10\text{ cm}}{5} = 2\text{ cm}$

Reading A: Pointer is $^{3}/_{10}$ of the way from one subdivision to the next: $^{3}/_{10} \times 2\text{ cm} = 0.6\text{ cm}$
The reading is $10.0 + 0.6 =$ **10.6 cm.**

Reading B: Pointer is $^{5}/_{10}$ of the way from one subdivision to the next: $^{5}/_{10} \times 2\text{ cm} = 1.0\text{ cm}$
The reading is $14.0 + 1.0 =$ **15.0 cm.**

(c) Numbered division difference = 1 cm ; Unnumbered subdivision difference $= \frac{1\text{ cm}}{2} = 0.5\text{ cm}$

Reading A: Pointer is $^{5}/_{10}$ of the way from one subdivision to the next: $^{5}/_{10} \times 0.5\text{ cm} = 0.25\text{ cm}$
The reading is $5.50 + 0.25 =$ **5.75 cm.**

Reading B: Pointer is $^{3}/_{10}$ of the way from one subdivision to the next: $^{3}/_{10} \times 0.5\text{ cm} = 0.15\text{ cm}$
The reading is $7.00 + 0.15 =$ **7.15 cm.**

(d) Numbered division difference = 10 cm ; Unnumbered subdivision difference = $\frac{10\,\text{cm}}{5}$ = 2 cm

Reading A: Pointer is $^{8}/_{10}$ of the way from one subdivision to the next: $^{8}/_{10}$ x 2 cm = 1.6 cm
The reading is 114.0 + 1.6 = **115.6 cm.**

Reading B: Pointer is $^{4}/_{10}$ of the way from one subdivision to the next: $^{4}/_{10}$ x 2 cm = 0.8 cm
The reading is 122.0 + 0.8 = **122.8 cm.**

(e) Numbered division difference = 0.1 cm ; Unnumbered subdivision difference = $\frac{0.1\,\text{cm}}{10}$ = 0.01 cm

Reading A: Pointer is $^{7}/_{10}$ of the way from one subdivision to the next: $^{7}/_{10}$ x 0.01 cm = 0.007 cm
The reading is 0.410 + 0.007 = **0.417 cm.**

Reading B: Pointer is $^{4}/_{10}$ of the way from one subdivision to the next: $^{4}/_{10}$ x 0.01 cm = 0.004 cm
The reading is 0.450 + 0.004 = **0.454 cm.**

49. (a) i = 2.00 cm   ii = 3.20 cm   iii = 4.60 cm   iv = 5.00 cm
(b) i = 99.16 cm   ii = 99.60 cm   iii = 100.00 cm   iv = 100.50 cm

50. (a) 20.32 mL   (c) 24.11 mL   (e) 43.80 mL   (g) 0.01 mL
(b) 10.50 mL   (d) 8.00 mL   (f) 17.54 mL   (h) 30.30 mL

51. (a) 51.32 ± 0.01 g   (c) 455 ± 3 g   (e) 98.9 ± 0.7 s
(b) 55 ± 1 mL   (d) 0.5130 ± 0.0002 g   (f) 49.8 ± 0.9 g

52. (a) 15.24 mL to 15.26 mL   (b) 109.8 mL to 110.2 mL   (c) 1.523 x 10^{-6} s to 1.533 x 10^{-6} s

53. The contents of the table will depend on the equipment available.

54. #48 (a) A = 15.24 ± 0.01 cm , B = 15.87 ± 0.01 cm
(b) A = 10.6 ± 0.2 cm , B = 15.0 ± 0.2 cm
(c) A = 5.75 ± 0.05 cm , B = 7.15 ± 0.05 cm
(d) A = 115.6 ± 0.2 cm , B = 122.8 ± 0.2 cm
(e) A = 0.417 ± 0.001 cm , B = 0.454 ± 0.001 cm

#49 (a) i = 2.00 ± 0.02 cm   (b) i = 99.16 ± 0.01 cm
ii = 3.20 ± 0.02 cm   ii = 99.60 ± 0.01 cm
iii = 4.60 ± 0.02 cm   iii = 100.00 ± 0.01 cm
iv = 5.00 ± 0.02 cm   iv = 100.50 ± 0.01 cm

#50 (a) 20.32 ± 0.01 mL   (e) 43.80 ± 0.01 mL
(b) 10.50 ± 0.01 mL   (f) 17.54 ± 0.01 mL
(c) 24.11 ± 0.01 mL   (g) 0.01 ± 0.01 mL
(d) 8.00 ± 0.01 mL   (h) 30.30 ± 0.01 mL

55. (a) 3   (b) 5   (c) 5   (d) 2   (e) 3   (f) 3   (g) 4   (h) 4   (i) 6   (j) 4

56. (a) 6.3   (c) 1.33   (e) 3 x 10^{14} (g) 202   (i) 20   (k) 2
(b) 0.000 24   (d) 1.3 x 10^{2} (f) 5.11 x 10^{5} (h) 90   (j) 1 x 10^{-4} (l) 2.2 x 10^{-6}

57. (a) 90.4   (f) −0.000 769
(b) 53.0991   (g) 7.002 x 10^{5}
(c) 7.7 x 10^{-5} (h) −35.55
(d) 4.0076   (i) 0.1368 x 10^{-6} or 1.368 x 10^{-7}
(e) 1.864 x 10^{4} (j) 6.2055 x 10^{-9}

58. (a) 8.53   (c) −29.7   (e) 1.67 x 10^{4} (g) 5.6 x 10^{2} (i) 3.1 x 10^{2}
(b) 0.64   (d) 4.0 x 10^{2} (f) 30.9   (h) −8.72 x 10^{-3} (j) 0.004 000

59. (a) 0.856   (c) 0.69   (e) −23.9   (g) 1.1
(b) 102.1   (d) 610   (f) 96   (h) 0.109

ANSWERS TO UNIT III : THE PHYSICAL PROPERTIES AND PHYSICAL CHANGES OF SUBSTANCES

1. (a) any description using a **number**; for example: 5 s, 10 min, 3 h, 2 d.
   (b) any description using a **number**; for example: 5°C, 10 degrees hotter than room temperature.

2. (a) any **non–numerical** description; for example: in a moment, after a short while, a lifetime, quickly.
   (b) any **non–numerical** description; for example: hot, cold, room temperature.

3. The quantitative descriptions are in bold and the qualitative descriptions are underlined.

   Copper is a <u>reddish–coloured</u> element with a <u>metallic lustre</u>. It is an <u>excellent conductor of heat and electricity</u>, **melts at 1085°C and boils at 2563°C.** Archeological evidence shows that it has been mined for the past **5000 years** and presently is considered to be <u>one of the most important metals</u> available. Copper is <u>insoluble in water and virtually all other solvents</u>, <u>reacts easily with nitric acid but only slightly with sulphuric and hydrochloric acids</u>. It has a **density of 8.92 g/mL**, which makes it <u>more dense than iron</u>.

4. The tube could have been white–hot, **or** the tube could have been illuminated by a spotlight, **or** the tube could have been covered with a fluorescent white paint, **or** the tube could have been an operating fluorescent light bulb. You could cautiously feel if the tube is giving off heat **or** you could see if the tube still glows when shaded from light **or** investigate whether the tube has a source of electrical power.

5. (a) Observations are qualitative (non–numerical) facts whereas data are quantitative (numerical) facts.
   (b) An "observation" is a single qualitative fact whereas a "description" is a series of observations used to characterize something.
   (c) An observation is a fact recorded by our senses whereas an interpretation is the meaning which our mind gives to an observation.

6. Any of the terms listed can be wrong; even observations can be incorrect because our senses can be tricked (as magicians will tell you).

7. You might be biased in the way you interpret some of the observations. In fact, you might see only what you expect to see, even if something different actually occurred. Also, you might tend to use only data which agrees with your pre–conceived ideas and disregard data which contradicts your ideas.

8. A hypothesis; it is called an "assumption" and it is only a single idea.

9. This statement is not testable and makes no predictions. It could be a "belief" but not a scientific theory.

10. A law; the statement simply says what always occurs in a given situation.

11. (a) ***Hypothesis*** – a temporary idea put forward to explain the results of an experiment and based on initial experiments; intended to explain a narrow set of experimental results; initial confidence in a hypothesis may be low.
    Theory – a refined and extensively tested explanation of how and why related results are found; intended to explain a wide–ranging set of experimental results; level of confidence in a theory is generally very high.

    (b) ***Theory*** – attempts to explain why something occurs and to predict what is expected to happen in new circumstances; does not attempt to summarize past results of experiments.
    Law – summarizes experiments by describing what happens if a known situation occurs; does not predict what will happen in new situations and makes no attempt to explain **why** something occurs.

12. (a) & (b) – ask your Chem teacher to let you set up such an experiment. Science doesn't give "THE ANSWER" and you aren't going to get one here either. What happens inside an atom cannot be seen directly so scientists must be satisfied with their models. It can be tough on people who must have a "definite answer", but one has to get used to intrinsic uncertainties in science. No; whining won't help!

13. (a) physical property (The glass is not altered when light passes through it.)
    (b) physical property (Melted salt is still salt and solidifies to exhibit the same properties it had originally.)
    (c) chemical property (The properties of soap differ from those of lye and fat; soap is a new substance.)
    (d) physical property (Copper is not changed when electricity passes through it.)
    (e) chemical property (The white smoke is a new substance.)

14. light, heat, sound, etc. – in other words **ENERGY**!

15. Intensive = b, d, e, g   Extensive = a, c, f

16. (a) density, melting temperature, lustre, malleability, ductility, electrical and heat conductivity, hardness, smell, taste
    (b) density, boiling temperature, freezing temperature, diffusion rate, viscosity, vapour pressure, electrical and heat conductivity, smell, taste
    (c) density, condensation temperature, diffusion rate, heat conductivity, smell, viscosity

17. (a) acetone
    (b) The lower the boiling temperature of a liquid, the higher its vapour pressure.
    (c) The higher the vapour pressure of a liquid, the faster its evaporation rate.
    (d) Iron is known to melt at a very high temperature and to boil at an even higher temperature. The relationship for part (b), above, implies that iron has a very low vapour pressure.
    (e) Since diethyl ether boils at a lower temperature than acetone, the relationship for parts (b) and (c) implies that diethyl ether has a higher vapour pressure and evaporation rate than acetone.

18. (a) The higher the temperature, the greater the diffusion rate.
    (b) ammonia
    (c) The smaller the mass of a molecule, the faster the diffusion rate.

19. (a) viscosity: hexane < carbon tetrachloride < glycerol
    (b) density: hexane < glycerol < carbon tetrachloride
    (c) There is no relationship between viscosity and density.

20. (a) the pressure increases
    (b) the volume decreases
    (c) When the pressure exerted on a gas increases, the volume of the gas **decreases.**
    (d) i) the volume decreases   ii) the volume stays small when the pressure is released
    (e) i) the volume decreases   ii) the volume increases back to its original value
    (f) The volume of a gas "recovers" back to its original value when an applied pressure is released.

21. Corn syrup has a HIGH viscosity because it has a high RESISTANCE to flow.
    Gasoline has a LOW viscosity because it has a low RESISTANCE to flow.
    If you heat a glass of syrup, the viscosity of the syrup decreases.

22. (a) intensive   (b) extensive   (c) extensive

23. The vapour pressure is quite low since very little ice evaporates and forms a vapour.

24. (a) liquid and gas   (b) solid, liquid and gas   (c) gas   (d) solid   (e) solid and liquid

25. liquid

26. (a) 22.4 mL   (b) 22.4 L

27. (a) The pressure inside the balloon is equal to the pressure exerted by the atmosphere.
    (b) The balloon should expand because the pressure inside the balloon (pushing outward) is greater than the pressure outside (pushing inward).

28. Nothing regarding the densities can be predicted from a knowledge of the viscosities.

29. (a) According to exercise 18, the higher the temperature the greater the diffusion rate of a fluid (in this case the gaseous "scent" of the aftershave lotion). Therefore the scent of John's aftershave should travel faster to Juanita because of the higher temperature of the air carrying the scent.
    (b) According to exercise 18, lighter particles travel faster than heavier ones at the same temperature. Therefore, if the particles having a scent in John's aftershave are lighter in **mass**, Juanita will smell them first. (The property will be "diffusion rate" or "mass of particle".)

30. The sphere falls faster in chlorine gas. Chlorine has a lower viscosity, that is, a lower resistance to flow, and therefore the sphere will fall ("flow") faster in the chlorine.

31. Chloroform forms a VAPOUR because it boils above room temperature (20°C).

32. According to exercise 17, since ethanol has a higher vapour pressure it has a lower boiling point.

33. (a) ion   (b) molecule   (c) atom   (d) atom   (e) ion   (f) molecule

34. Four phases are mentioned: 1 = white sand, 2 = nails, 3 = salt water with some dye in it, 4 = gasoline. A 5th phase (air) may be above the phases described but is not mentioned as part of "this system".

35. Visible boundaries separating one phase from another must be present in a heterogeneous system. In a homogeneous system everything should look the same no matter which part of the system is examined.

36. (a) homogeneous
    (b) heterogeneous (bark, leaves, roots, etc.)
    (c) heterogeneous (shell, yolk, white)
    (d) homogeneous

37. An element; the term "atom" is reserved for the smallest possible particle of gold and a 10 g piece of gold can be extensively subdivided.

38. They are similar in being homogeneous; they differ in that a compound is a pure substance while a solution is made of two or more pure substances.

39. (a) true solution
    (b) mechanical mixture
    (c) element, compound or true solution (a solid solution in this case)
    (d) element, compound or true solution (such as air)
    (e) element, compound or true solution (such as salt water)
    (f) The first statement implies we have either an element or a compound. The second statement shows that at least two different substances can be produced and therefore we have at least two different types of atoms present. Conclusion: the substance was a COMPOUND.

40. (a) acetic acid
    (b) iodine
    (c) chloroform (present in smaller amount)
    (d) silver nitrate (water is always the solvent, if present)

41. Sugar is a pure substance; dirt and air are mixtures

42. KCl(aq) refers to aqueous KCl or KCl dissolved in water

43. 6 (wood, lead, 2 colours of paint, metal end, eraser)

44. (a) compound (a single type of molecule)
    (b) mixture (crust, cheese, etc.)
    (c) mixture (water, carbonation, flavouring, etc.)
    (d) compound (single type of molecule)
    (e) mixture (two types of molecules)

45. The layer having the lower density will be on the top; that is, the water.

46. (a) distillation (b) evaporation, recrystallization, distillation (distillate can be discarded)

47. (a) distillation; solvent extraction may also work
    (b) hand separation (pour off the top layer or use a separatory funnel), distillation (but why bother?)
    (c) filtration, gravity separation (using a centrifuge)
    (d) paper, column or thin–layer chromatography; you might try solvent extraction
    (e) Filtration (separate sand from salt water); distillation (separate water from salt)

48. Recrystallization

49. amount left after one extraction = 0.10 = 10 %
    amount left after two extractions = 0.10 x 0.10 = 0.010 = **1 %**

50. amount left after one extraction = 0.40 = 40 %
    amount left after four extractions = 0.40 x 0.40 x 0.40 x 0.40 = 0.0256 = 2.6 %
    therefore, amount removed = 100 % – 2.6 % = **97.4 %**

51. The idea is to let only one substance form crystals while the others remain in solution. If all the solvent evaporates, all the solids are deposited together and no separation occurs.

52. hand separation (pick out the good crystals by hand)

53. There may be more than one way to do this, but one way is:
    - use filtration to remove the liquids from the sand and iron filings
    - use a magnet to separate the iron filings from the sand
    - use hand separation to pour off the gasoline from the water (or use a separatory funnel)
    - distil off the water, leaving a mixture of dyes
    - re–dissolve the dyes and use chromatography to separate them.

54. There may be more than one way to do this, but one way is:
    - use filtration to separate the liquids from the solids
    - use a gravity separation method to separate the two types of sand (put in a mechanical shaker and shake the dry sand; the heavier black sand will accumulate at the bottom of the container)
    - distil the methanol–hexanol mixture to separate the liquids.

55.
    - Solvent extract the mixture with alcohol. Only the naphthalene will dissolve. The alcohol can later be distilled off or evaporated to leave solid naphthalene.
    - Solvent extract the remaining solids with water. Only the potassium sulphate will dissolve. The water can then be distilled off or evaporated to leave solid potassium sulphate.
    - The calcium carbonate is the only solid left in the original mixture.

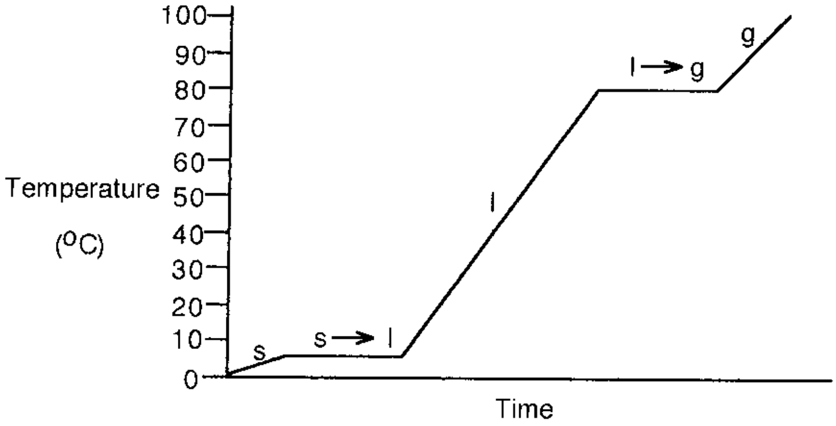
56. The mixture will appear as separate layers of aluminum powder, a solution of benzene and chloroform and a final layer consisting of a solution of sugar and water.
    - Filter off the aluminum, leaving two layers: benzene–chloroform solution and sugar–water solution.
    - Use hand separation or a separatory funnel to remove the benzene–chloroform layer from the sugar–water layer.
    - Distil the benzene–chloroform solution; the chloroform will come off first, leaving the benzene behind.
    - Distil the water, leaving the sugar behind (if the water was not wanted, the sugar–water solution could just be left in the open or on a hot plate to let the water evaporate.

57. Dissolve the powdered crystals in an appropriate solvent and use chromatography to separate the coloured chemicals from each other. This is appropriate because there is only a little of each chemical.

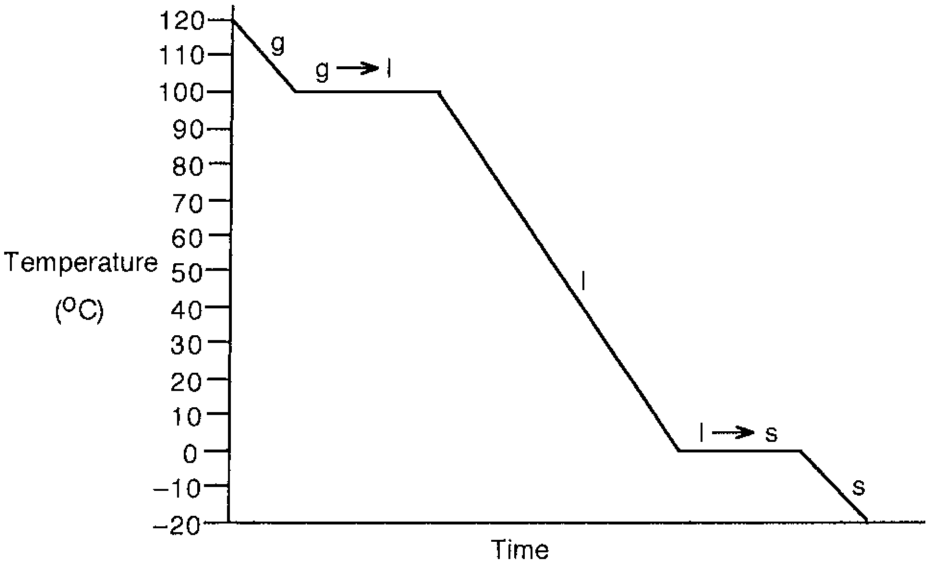
58.
    - First, use a magnet to remove the nails.
    - Next, put the remaining mixture through a sieve which allows the white sand and platinum to pass through while holding back the pennies.
    - Finally, use a mechanical shaker to allow the high density platinum to settle to the bottom while the white sand stays on top.

59. (a) physical change (water vapour condenses into droplets of moisture)
(b) chemical change (new substances are formed: smoke and various cancer–causing chemicals)
(c) chemical change (growth involves chemicals being produced and used up)
(d) chemical change (rust is a new substance formed by the combination of iron, air and water)
(e) physical change (no reaction has occurred to make new substances)
(f) physical change (we are only separating substances, not producing new ones)

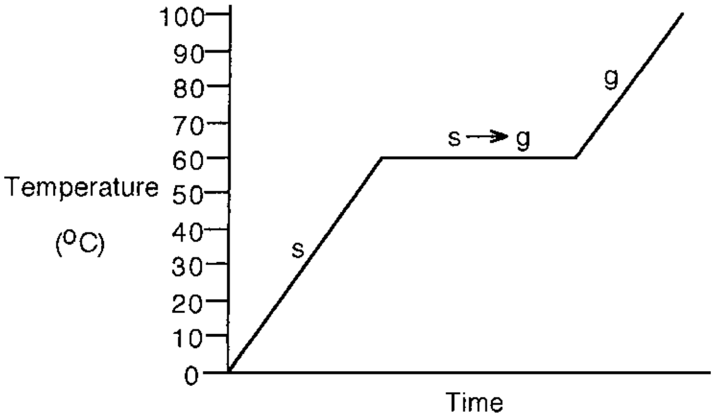
60.



61.



62.



63. (a) At 5 minutes, the sample was about 75% ice and 25% water.
    (b) At 10 minutes, the sample was about 50% ice and 50% water.

64. The kinetic energy of the particles increases.

65. translational

66. translational

67. translational and rotational

68. rotational and translational

69. The viscosity should decrease as the temperature increases. As temperature increases, the translational energy increases. This allows the molecules to move past one another faster and therefore they must have less resistance to "flow" past one another and possess a lower viscosity.

70. Many bonds in the molecules are identical to each other, so those parts of their spectra are identical.

71. The volume increases (recall that as the translational energy increases we change phase from solid to liquid to gas, and that the volume increases as we go from solid to liquid to gas).

ANSWERS TO UNIT IV : INORGANIC NOMENCLATURE

Self–Test
(a) Na
(b) potassium
(c) Tl
(d) mercury
(e) Si
(f) krypton
(g) F
(h) chromium
(i) S
(j) cesium
(k) Cd
(l) beryllium
(m) As
(n) molybdenum
(o) Pt
(p) copper
(q) W
(r) lead
(s) At
(t) boron

1. (a) A, P (b) N, T, P (c) C, M (d) A, D, P (e) C, P (f) N, M

2. (a) copper(I) ion (b) chromium(III) ion (c) tungsten(VI) ion

3. (a) Co^{3+} (b) Ni^{2+} (c) V^{5+}

4. (a) $Sn(SO_4)_2$
(b) $(NH_4)_2C_2O_4$
(c) Li_2O
(d) Cu_3N
(e) $Hg_2(NO_2)_2$
(f) $Fe(OH)_3$
(g) Ag_2SO_4
(h) $Pb(ClO_4)_2$
(i) Cr_2O_3
(j) MnF_2
(k) KH_2PO_4
(l) $U(SO_4)_2$
(m) $(NH_4)_2Cr_2O_7$
(n) Cu_3PO_4
(o) $Ca(ClO)_2$
(p) $NaHSO_3$
(q) $Mg(MnO_4)_2$
(r) WBr_5
(s) $(NH_4)_3PO_4$
(t) $Hg(CH_3COO)_2$

5. (a) silver phosphate
(b) aluminum sulphate
(c) iron(III) sulphide
(d) copper(I) chloride
(e) ammonium carbonate
(f) vanadium(III) chloride
(g) mercury(I) carbonate
(h) copper(II) sulphate
(i) ammonium sulphide
(j) ammonium hydrogen carbonate
(k) iron(II) oxalate
(l) magnesium hydrogen sulphite
(m) lithium chlorite
(n) sodium monohydrogen phosphate
(o) aluminum hydroxide
(p) chromium(III) iodide
(q) tin(IV) oxide
(r) zinc dichromate
(s) vanadium(V) oxide
(t) strontium nitride

6. (a) iron(III) bromide hexahydrate
(b) lithium dichromate dihydrate
(c) aluminum oxide trihydrate
(d) cobalt(II) fluoride tetrahydrate
(e) sodium carbonate monohydrate
(f) sodium sulphide nonahydrate
(g) sodium sulphate decahydrate
(h) nickel(II) phosphate octahydrate
(i) magnesium monohydrogen phosphate heptahydrate

7. (a) $FePO_4{\cdot}8H_2O$
(b) $Cd(NO_3)_2{\cdot}4H_2O$
(c) $Cu_3(PO_4)_2{\cdot}3H_2O$
(d) $CrC_2O_4{\cdot}H_2O$
(e) $NiCl_2{\cdot}6H_2O$
(f) $Al(NO_3)_3{\cdot}9H_2O$

8. (a) nitrogen dioxide
(b) chlorine trifluoride
(c) tetrasulphur dinitride
(d) diphosphorus hexoxide
(e) dinitrogen trioxide
(f) sulphur tetrafluoride
(g) bromine monofluoride
(h) sulphur hexafluoride

9. (a) SO_3 (b) PCl_5 (c) XeF_6 (d) OF_2 (e) CO (f) CCl_4 (g) P_4S_3 (h) N_2S_5 (i) Si_3N_4

10. yellow = chromate; blue = copper(II). Therefore: $CuCrO_4$ = copper(II) chromate

11. iron(II) became iron(III)

12. (a) colourless (b) purple (c) blue (d) colourless (e) orange (f) pale pink

13. bright green = nickel(II); this positive ion will have to react with the negative ion, carbonate, in the potassium carbonate solution. Therefore: nickel carbonate = $NiCO_3$

14. magnesium oxide
15. copper(II) sulphate
16. sodium acetate
17. ammonium nitrite
18. molybdenum(V) chloride
19. lithium hydroxide monohydrate
20. platinum(IV) chloride
21. ammonium perchlorate
22. aluminum nitride
23. potassium permanganate
24. copper(I) sulphate
25. sulphuric acid
26. sodium carbonate decahydrate
27. sodium sulphite
28. lead(IV) hydrogen sulphate
29. tungsten(VI) fluoride
30. sodium dihydrogen phosphate
31. barium sulphide
32. ammonium chlorite
33. iron(II) hypochlorite
34. tin(II) cyanide
35. krypton difluoride
36. sodium phosphate
37. calcium sulphide
38. manganese(II) thiocyanate
39. silver permanganate

40. platinum(III) oxide trihydrate
41. phophorus pentabromide
42. copper(II) acetate
43. aluminum perchlorate
44. ammonia
45. aluminum sulphide
46. sodium hydroxide
47. barium hydrogen sulphide tetrahydrate
48. dinitrogen monoxide
49. nitric acid
50. cesium hydrogen carbonate
51. copper(I) sulphide
52. tricarbon disulphide
53. copper(II) nitrate hexahydrate
54. cobalt(II) chlorate
55. manganese(III) oxide
56. zinc acetate
57. acetic acid
58. manganese(III) phosphate
59. chromium(III) nitrate nonahydrate
60. strontium hypochlorite
61. vanadium(III) nitride
62. lead(IV) oxalate
63. cobalt(III) fluoride
64. barium sulphite
65. copper(II) dichromate
66. nitrogen triiodide
67. chromium(II) bromide
68. magnesium phosphide
69. iron(II) sulphate pentahydrate
70. calcium hydroxide
71. phosphoric acid
72. radium sulphate
73. potassium hydrogen oxalate
74. dichlorine monoxide
75. titanium(IV) oxide
76. nickel(II) sulphate heptahydrate
77. magnesium chlorite
78. lead(IV) chloride
79. iron(III) hydrogen oxalate
80. diiodine pentoxide
81. mercury(II) nitrate
82. zinc hydroxide
83. hydrogen sulphide
84. xenon trioxide
85. titanium(II) chloride
86. hydrofluoric acid
87. tin(IV) chromate
88. cobalt(II) phosphate octahydrate
89. platinum(IV) sulphide

90. $AgCl$
91. SO_2
92. $Fe_2(C_2O_4)_3$
93. BeO
94. $Pb(CH_3COO)_2\cdot 10H_2O$
95. K_2CrO_4
96. $Hg_2(CH_3COO)_2$
97. $MoCl_3$
98. NH_3
99. Au_2S_3
100. $Ag_2Cr_2O_7$
101. $Ca(CH_3COO)_2$
102. $Cr_2(C_2O_4)_3$
103. $Ca(NO_2)_2$
104. F_2O_2
105. Mo_2O_5
106. SiF_4
107. $Cd(CH_3COO)_2$
108. $HgCl_2$
109. $LiHSO_3$
110. CH_3COOH
111. $Mg(ClO_3)_2\cdot 6H_2O$
112. PF_3
113. CuI_2
114. Ca_3N_2
115. $Mg(OH)_2$
116. $Mo_2S_5\cdot 3H_2O$
117. $Fe(H_2PO_4)_2$
118. CI_4
119. $ZnSO_4$
120. Hg_2S
121. H_2SO_3
122. $FeF_2\cdot 8H_2O$
123. $Mg(HSO_4)_2$
124. Al_2S_3
125. $RaCO_3$
126. XeF_4
127. Na_2O
128. $Ba_3(PO_4)_2$
129. $Hg_2(NO_3)_2\cdot 2H_2O$
130. $NaClO$
131. $AuCN$
132. $SnBr_4$
133. HI
134. S_4N_4
135. $Fe(OH)_2$
136. CuF
137. $Sn(HCO_3)_2$
138. N_2O_5
139. $Zn(HSO_3)_2$
140. $Zn(ClO_4)_2\cdot 6H_2O$
141. $Au(NO_3)_3$
142. $Mn_2(SO_4)_3$
143. HCl
144. CrO
145. $Zn(HS)_2$
146. MoS_3
147. $Fe_2(CO_3)_3$
148. IF_5
149. MnO_2
150. HCN
151. $Fe_2(SO_4)_3\cdot 9H_2O$
152. KNO_2
153. CrP
154. $Ni(OH)_2$
155. ClO_4
156. $Hg(SCN)_2$
157. HNO_2
158. $PbCO_3$
159. $NaHC_2O_4$
160. $AlBr_3\cdot 6H_2O$
161. PbI_2
162. Ag_2O
163. $Mn(HPO_4)_2$

ANSWERS TO UNIT V : THE MOLE CONCEPT

1. Since oxygen is $\frac{88.9\text{ g}}{11.1\text{ g}}$ = 8 times heavier than hydrogen (which has a mass of 1), oxygen has a mass of 8. Since nitrogen is $\frac{46.7\text{ g}}{53.3\text{ g}}$ = 0.876 times heavier than oxygen, nitrogen has a mass of 0.876 x 8 = 7. Finally, since carbon is $\frac{42.9\text{ g}}{57.1\text{ g}}$ = 0.751 times heavier than oxygen, carbon has a mass of 0.751 x 8 = 6.

2. Since there is 3 times the volume of chlorine gas compared to nitrogen, the reaction involves 3 times as many chlorine molecules as nitrogen molecules. Therefore, the formula is **NCl_3** . The name of the compound is nitrogen trichloride.

3. The volume of oxygen is twice the volume of sulphur so that the product contains twice as many oxygen atoms as sulphur atoms. The formula of the product is SO_2, sulphur dioxide.

4. The volume of fluorine is three times the volume of chlorine so that the formula contains three times as many fluorine atoms as chlorine atoms: ClF_3, chlorine trifluoride.

5. Since the volume of oxygen is five times the volume of unknown gas X, there are five times as many oxygen molecules as gas X molecules; that is, $5 \times 3.0 \times 10^{23} = 1.5 \times 10^{24}$ molecules.

6. (a) 1 N = 1 x 14.0 = 14.0 g
1 O = 1 x 16.0 = 16.0 g
molar mass = **30.0 g**

(b) 2 H = 2 x 1.0 = 2.0 g
1 O = 1 x 16.0 = 16.0 g
molar mass = **18.0 g**

(c) 1 N = 1 x 14.0 = 14.0 g
3 H = 3 x 1.0 = 3.0 g
molar mass = **17.0 g**

(d) 1 C = 1 x 12.0 = 12.0 g
2 O = 2 x 16.0 = 32.0 g
molar mass = **44.0 g**

(e) 1 C = 1 x 12.0 = 12.0 g
4 H = 4 x 1.0 = 4.0 g
molar mass = **16.0 g**

(f) 1 Ag = 1 x 107.9 = 107.9 g
1 N = 1 x 14.0 = 14.0 g
3 O = 3 x 16.0 = 48.0 g
molar mass = **169.9 g**

(g) 1 Ca = 1 x 40.1 = 40.1 g
2 O = 2 x 16.0 = 32.0 g
2 H = 2 x 1.0 = 2.0 g
molar mass = **74.1 g**

(h) 1 Al = 1 x 27.0 = 27.0 g
3 N = 3 x 14.0 = 42.0 g
9 O = 9 x 16.0 = 144.0 g
molar mass = **213.0 g**

(i) 1 Fe = 1 x 55.8 = 55.8 g
3 Cl = 3 x 35.5 = 106.5 g
molar mass = **162.3 g**

(j) 1 Sn = 1 x 118.7 = 118.7 g
2 C = 2 x 12.0 = 24.0 g
4 O = 4 x 16.0 = 64.0 g
molar mass = **206.7 g**

(k) 1 Sn = 1 x 118.7 = 118.7 g
4 C = 4 x 12.0 = 48.0 g
8 O = 8 x 16.0 = 128.0 g
molar mass = **294.7 g**

(l) 3 N = 3 x 14.0 = 42.0 g
12 H = 12 x 1.0 = 12.0 g
1 P = 1 x 31.0 = 31.0 g
4 O = 4 x 16.0 = 64.0 g
molar mass = **149.0 g**

(m) 2 C = 2 x 12.0 = 24.0 g
4 H = 4 x 1.0 = 4.0 g
2 O = 2 x 16.0 = 32.0 g
molar mass = **60.0 g**

(n) 4 C = 4 x 12.0 = 48.0 g
10 H = 10 x 1.0 = 10.0 g
molar mass = **58.0 g**

(o) 1 Ni = 1 x 58.7 = 58.7 g
16 H = 16 x 1.0 = 16.0 g
2 O = 2 x 16.0 = 32.0 g
4 N = 4 x 14.0 = 56.0 g
2 Cl = 2 x 35.5 = 71.0 g
molar mass = **233.7 g**

(p) 2 Al = 2 x 27.0 = 54.0 g
3 S = 3 x 32.1 = 96.3 g
12 O = 12 x 16.0 = 192.0 g
molar mass = **342.3 g**

7. (a) 3 Co = 3 x 58.9 = 176.7 g
2 As = 2 x 74.9 = 149.8 g
16 O = 16 x 16.0 = 256.0 g
16 H = 16 x 1.0 = 16.0 g

molar mass = **598.5 g**

(b) 1 Pb = 1 x 207.2 = 207.2 g
4 C = 4 x 12.0 = 48.0 g
12 H = 12 x 1.0 = 12.0 g
7 O = 7 x 16.0 = 112.0 g

molar mass = **379.2 g**

(c) 1 Mg = 1 x 24.3 = 24.3 g
1 S = 1 x 32.1 = 32.1 g
11 O = 11 x 16.0 = 176.0 g
14 H = 14 x 1.0 = 14.0 g

molar mass = **246.4 g**

(d) 1 K = 1 x 39.1 = 39.1 g
1 Al = 1 x 27.0 = 27.0 g
2 S = 2 x 32.1 = 64.2 g
20 O = 20 x 16.0 = 320.0 g
24 H = 24 x 1.0 = 24.0 g

molar mass = **474.3 g**

8. (a) mass = 1.00 mol x $\frac{53.5 \text{ g}}{1 \text{ mol}}$ = **53.5 g**

(b) mass = 4.50 mol x $\frac{53.5 \text{ g}}{1 \text{ mol}}$ = **241 g**

(c) mass = 3.25 mol x $\frac{137.5 \text{ g}}{1 \text{ mol}}$ = **447 g**

(d) mass = 0.00355 mol x $\frac{142.0 \text{ g}}{1 \text{ mol}}$ = **0.504 g**

(e) mass = 0.0125 mol x $\frac{207.3 \text{ g}}{1 \text{ mol}}$ = **2.59 g**

(f) mass = 2.60 mol x $\frac{30.0 \text{ g}}{1 \text{ mol}}$ = **78.0 g**

(g) mass = 3.25×10^{2} mol x $\frac{17.0 \text{ g}}{1 \text{ mol}}$ = **5.53×10^{3} g**

(h) mass = 7.90×10^{-4} mol x $\frac{82.1 \text{ g}}{1 \text{ mol}}$ = **0.0649 g**

(i) mass = 1.00×10^{-3} mol x $\frac{40.0 \text{ g}}{1 \text{ mol}}$ = **0.0400 g**

(j) mass = 1.75×10^{-4} mol x $\frac{55.8 \text{ g}}{1 \text{ mol}}$ = **9.77×10^{-3} g**

9. (a) # of moles = 17.0 g x $\frac{1 \text{ mol}}{98.1 \text{ g}}$ = **0.173 mol**

(b) # of moles = 91.5 g x $\frac{1 \text{ mol}}{18.0 \text{ g}}$ = **5.08 mol**

(c) # of moles = 53.0 g x $\frac{1 \text{ mol}}{12.0 \text{ g}}$ = **4.42 mol**

(d) # of moles = 1.25×10^{-4} g x $\frac{1 \text{ mol}}{95.6 \text{ g}}$ = **1.31×10^{-6} mol**

(e) # of moles = 4.50 kg x $\frac{10^{3} \text{ g}}{1 \text{ kg}}$ x $\frac{1 \text{ mol}}{16.0 \text{ g}}$ = **281 mol**

(f) # of moles = 225 g x $\frac{1 \text{ mol}}{132.1 \text{ g}}$ = **1.70 mol**

(g) # of moles = 55.2 mg x $\frac{10^{-3} \text{ g}}{1 \text{ mg}}$ x $\frac{1 \text{ mol}}{71.0 \text{ g}}$ = **7.77×10^{-4} mol**

(h) # of moles = 128.2 g x $\frac{1 \text{ mol}}{64.1 \text{ g}}$ = **2.00 mol**

(i) # of moles = 2955 kg x $\frac{10^{3} \text{ g}}{1 \text{ kg}}$ x $\frac{1 \text{ mol}}{107.9 \text{ g}}$ = **2.739×10^{4} mol**

(j) # of moles = 0.0845 g x $\frac{1 \text{ mol}}{158.0 \text{ g}}$ = **5.35×10^{-4} mol**

10. (a) $\text{molar mass} = \dfrac{4.00\text{ g}}{0.250\text{ mol}} = \mathbf{16.0\ g/mol}$ (c) $\text{molar mass} = \dfrac{7.76 \times 10^{-3}\text{ g}}{6.47 \times 10^{-4}\text{ mol}} = \mathbf{12.0\ g/mol}$

(b) $\text{molar mass} = \dfrac{0.947\text{ g}}{0.00248\text{ mol}} = \mathbf{382\ g/mol}$ (d) $\text{molar mass} = \dfrac{74.8\text{ g}}{3.44 \times 10^{-5}\text{ mol}} = \mathbf{2.17 \times 10^{6}\ g/mol}$

11. (a) $\text{volume} = 12.5\text{ mol} \times \dfrac{22.4\text{ L}}{1\text{ mol}} = \mathbf{2.80 \times 10^{2}\ L}$ (c) $\text{volume} = 4.25\text{ mol} \times \dfrac{22.4\text{ L}}{1\text{ mol}} = \mathbf{95.2\ L}$

(b) $\text{volume} = 0.350\text{ mol} \times \dfrac{22.4\text{ L}}{1\text{ mol}} = \mathbf{7.84\ L}$

12. (a) $\#\text{ of moles} = 85.9\text{ L} \times \dfrac{1\text{ mol}}{22.4\text{ L}} = \mathbf{3.83\ mol}$

(b) $\#\text{ of moles} = 375\text{ mL} \times \dfrac{10^{-3}\text{ L}}{1\text{ mL}} \times \dfrac{1\text{ mol}}{22.4\text{ L}} = \mathbf{0.0167\ mol}$

(c) $\#\text{ of moles} = 5.00\text{ mL} \times \dfrac{10^{-3}\text{ L}}{1\text{ mL}} \times \dfrac{1\text{ mol}}{22.4\text{ L}} = \mathbf{2.23 \times 10^{-4}\ mol}$

13. $\#\text{ of seconds in 1 year} = 365 \times 24 \times 60 \times 60 = 3.15 \times 10^{7}\text{ s}$

$\text{amount spent in 1 yr} = 3.15 \times 10^{7}\text{ s} \times \dfrac{\$10^{3}}{1\text{ s}} = \$3.15 \times 10^{10}$

$\text{amount given to each person} = \dfrac{\$6.02 \times 10^{23}}{4.5 \times 10^{9}} = \$1.34 \times 10^{14}$

$\text{percentage spent} = \dfrac{\$3.15 \times 10^{10}}{\$1.34 \times 10^{14}} \times 100\,\% = \mathbf{0.0236\ \%}$

14. $\#\text{ of pennies/layer} = \dfrac{1\text{ penny}}{3.61\text{ cm}^2} \times \dfrac{10^{10}\text{ cm}^2}{1\text{ km}^2} \times 1.49 \times 10^{8}\text{ km}^2 = 4.13 \times 10^{17}$

$\text{thickness} = 6.02 \times 10^{23}\text{ pennies} \times \dfrac{1\text{ layer}}{4.13 \times 10^{17}\text{ pennies}} \times \dfrac{1.50\text{ mm}}{1\text{ layer}} \times \dfrac{10^{-3}\text{ m}}{1\text{ mm}} \times \dfrac{1\text{ km}}{10^{3}\text{ m}} = \mathbf{2.19\ km}$

15. (a) $\#\text{ of moles} = 10.6\text{ L} \times \dfrac{1\text{ mol}}{22.4\text{ L}} = \mathbf{0.473\ mol}$

(b) $\#\text{ of moles} = 7.50 \times 10^{21}\text{ molecules} \times \dfrac{1\text{ mol molecules}}{6.02 \times 10^{23}\text{ molecules}} = \mathbf{0.0125\ mol}$

(c) $\#\text{ of moles} = 425\text{ mg} \times \dfrac{10^{-3}\text{ g}}{1\text{ mg}} \times \dfrac{1\text{ mol}}{74.1\text{ g}} = \mathbf{5.74 \times 10^{-3}\ mol}$

(d) $\#\text{ of moles} = 4.25 \times 10^{12}\text{ molecule} \times \dfrac{1\text{ mol molecules}}{6.02 \times 10^{23}\text{ molecules}} = \mathbf{7.06 \times 10^{-12}\ mol}$

(e) $\#\text{ of moles} = 0.950\text{ kg} \times \dfrac{10^{3}\text{ g}}{1\text{ kg}} \times \dfrac{1\text{ mol}}{40.0\text{ g}} = \mathbf{23.8\ mol}$

(f) $\#\text{ of moles} = 25.0\text{ mL} \times \dfrac{10^{-3}\text{ L}}{1\text{ mL}} \times \dfrac{1\text{ mol}}{22.4\text{ L}} = \mathbf{1.12 \times 10^{-3}\ mol}$

(g) $\#\text{ of moles} = 5.50 \times 10^{25}\text{ molecules} \times \dfrac{1\text{ mol molecules}}{6.02 \times 10^{23}\text{ molecules}} = \mathbf{91.4\ mol}$

(h) # of moles = $0.120\text{ L} \times \dfrac{1\text{ mol}}{22.4\text{ L}} = \mathbf{5.36 \times 10^{-3}\ mol}$

16. (a) volume = $0.235\text{ mol} \times \dfrac{22.4\text{ L}}{1\text{ mol}} = \mathbf{5.26\ L}$

(b) volume = $9.36\text{ mol} \times \dfrac{22.4\text{ L}}{1\text{ mol}} = \mathbf{2.10 \times 10^{2}\ L}$

(c) volume = $2.55 \times 10^{3}\text{ mol} \times \dfrac{22.4\text{ L}}{1\text{ mol}} = \mathbf{5.71 \times 10^{4}\ L}$

17. (a) mass = $0.125\text{ mol} \times \dfrac{44.0\text{ g}}{1\text{ mol}} = \mathbf{5.50\ g}$

(b) mass = $5.48\text{ mol} \times \dfrac{162.3\text{ g}}{1\text{ mol}} = \mathbf{889\ g}$

(c) mass = $6.54 \times 10^{-4}\text{ mol} \times \dfrac{27.0\text{ g}}{1\text{ mol}} = \mathbf{0.0177\ g}$

(d) mass = $15.4\text{ mol} \times \dfrac{92.7\text{ g}}{1\text{ mol}} = \mathbf{1.43 \times 10^{3}\ g}$

18. (a) 2 Na = 2 x 23.0 = 46.0 g
4 B = 4 x 10.8 = 43.2 g
17 O = 17 x 16.0 = 272.0 g
20 H = 20 x 1.0 = 20.0 g

molar mass = **381.2 g**

(b) mass of 1 mol of grannies = $6.02 \times 10^{23} \times 52\text{ kg} = \mathbf{3.1 \times 10^{25}\ kg}$

(c) mass of 1 mol = $3.52 \times 10^{-22}\text{ g} \times 6.02 \times 10^{23} = \mathbf{212\ g}$

(d) mass of 1 mol of electrons = $6.02 \times 10^{23} \times 9.1 \times 10^{-28}\text{ g} = \mathbf{5.5 \times 10^{-4}\ g}$

(e) 3 Cu = 3 x 63.5 = 190.5 g
8 O = 8 x 16.0 = 128.0 g
2 H = 2 x 1.0 = 2.0 g
2 C = 2 x 12.0 = 24.0 g

molar mass = **344.5 g**

(f) mass of 1 mol of books = $6.02 \times 10^{23} \times 1.34\text{ kg} = \mathbf{8.07 \times 10^{23}\ kg}$

19. mass of 1 mol of unknown = $6.02 \times 10^{23} \times 1.18 \times 10^{-22}\text{ g} = 71.0\text{ g}$

molar masses of known gases: SO_3 = 80.1 g
CH_4 = 16.0 g
NF_3 = 71.0 g (this is the unknown)
C_2H_2 = 26.0 g

20. (a) # of drumsticks = $2\text{ mol} \times \dfrac{6.02 \times 10^{23}\text{ chickens}}{1\text{ mol chickens}} \times \dfrac{2\text{ drumsticks}}{1\text{ chicken}} = \mathbf{2.41 \times 10^{24}\ drumsticks}$

(b) each chicken has 2 drumsticks + 2 wings + 2 thighs = 6 "parts"

# of parts = $2\text{ mol} \times \dfrac{6.02 \times 10^{23}\text{ chickens}}{1\text{ mol chickens}} \times \dfrac{6\text{ parts}}{1\text{ chicken}} = \mathbf{7.22 \times 10^{24}\ parts}$

21. (a) 8 (b) 6 (c) 10 (d) 15 (e) 46 (f) 23

22. (a) mass = $2 \times 10^{6}\text{ molecules} \times \dfrac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \dfrac{28.0\text{ g}}{1\text{ mol}} = \mathbf{9 \times 10^{-17}\ g}$

(b) mass = $1.25\text{ L} \times \dfrac{1\text{ mol}}{22.4\text{ L}} \times \dfrac{17.0\text{ g}}{1\text{ mol}} = \mathbf{0.949\ g}$

(c) mass = $5 \times 10^{14}\text{ molecules} \times \dfrac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \dfrac{28.0\text{ g}}{1\text{ mol}} = \mathbf{2 \times 10^{-8}\ g}$

(d) $\text{mass} = 1\ \text{molecule} \times \frac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{molecules}} \times \frac{56.1\ \text{g}}{1\ \text{mol}} = \mathbf{9.32 \times 10^{-23}\ g}$

(e) $\text{mass} = 125\ \text{atoms} \times \frac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{atoms}} \times \frac{4.0\ \text{g}}{1\ \text{mol}} = \mathbf{8.3 \times 10^{-22}\ g}$

(f) $\text{mass} = 1\ \text{atom} \times \frac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{atoms}} \times \frac{107.9\ \text{g}}{1\ \text{mol}} = \mathbf{1.79 \times 10^{-22}\ g}$

(g) $\text{mass} = 4.15 \times 10^{15}\ \text{molec} \times \frac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{molecules}} \times \frac{16.0\ \text{g}}{1\ \text{mol}} = \mathbf{1.10 \times 10^{-7}\ g}$

(h) $\text{mass} = 175\ \text{atoms} \times \frac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{atoms}} \times \frac{14.0\ \text{g}}{1\ \text{mol}} = \mathbf{4.07 \times 10^{-21}\ g}$

(i) $\text{mass} = 3.45\ \text{mL} \times \frac{10^{-3}\ \text{L}}{1\ \text{mL}} \times \frac{1\ \text{mol}}{22.4\ \text{L}} \times \frac{32.0\ \text{g}}{1\ \text{mol}} = \mathbf{4.93 \times 10^{-3}\ g}$

(j) $\text{mass} = 1.00 \times 10^{8}\ \text{L} \times \frac{1\ \text{mol}}{22.4\ \text{L}} \times \frac{2.0\ \text{g}}{1\ \text{mol}} = \mathbf{8.93 \times 10^{6}\ g}$

23. (a) $\#\ \text{of atoms} = 1.00\ \text{mol} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{6\ \text{atoms}}{1\ \text{molecule}} = \mathbf{3.61 \times 10^{24}\ atoms}$

(b) $\#\ \text{of atoms} = 2.5\ \text{mol} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{3\ \text{atoms}}{1\ \text{molecule}} = \mathbf{4.5 \times 10^{24}\ atoms}$

(c) $\#\ \text{of atoms} = 8.00\ \text{g} \times \frac{1\ \text{mol}}{55.8\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = \mathbf{8.63 \times 10^{22}\ atoms}$

(d) $\#\ \text{of atoms} = 15.0\ \text{L} \times \frac{1\ \text{mol}}{22.4\ \text{L}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = \mathbf{4.03 \times 10^{23}\ atoms}$

(e) $\#\ \text{of atoms} = 12\ \text{g} \times \frac{1\ \text{mol}}{34.0\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{4\ \text{atoms}}{1\ \text{molecule}} = \mathbf{8.5 \times 10^{23}\ atoms}$

(f) $\#\ \text{of atoms} = 55.0\ \text{mL} \times \frac{10^{-3}\ \text{L}}{1\ \text{mL}} \times \frac{1\ \text{mol}}{22.4\ \text{L}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{3\ \text{atoms}}{1\ \text{molecule}}$
$= \mathbf{4.43 \times 10^{21}\ atoms}$

(g) $\#\ \text{of atoms} = 40.0\ \text{g} \times \frac{1\ \text{mol}}{39.1\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = \mathbf{6.16 \times 10^{23}\ atoms}$

(h) $\#\ \text{of atoms} = 5.0\ \text{g} \times \frac{1\ \text{mol}}{58.5\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{2\ \text{atoms}}{1\ \text{molecule}} = \mathbf{1.0 \times 10^{23}\ atoms}$

(i) $\#\ \text{of atoms} = 125\ \text{g} \times \frac{1\ \text{mol}}{50.5\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{5\ \text{atoms}}{1\ \text{molecule}} = \mathbf{7.45 \times 10^{24}\ atoms}$

(j) $\#\ \text{of atoms} = 8.30 \times 10^{-4}\ \text{mL} \times \frac{10^{-3}\ \text{L}}{1\ \text{mL}} \times \frac{1\ \text{mol}}{22.4\ \text{L}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{4\ \text{atoms}}{1\ \text{molecule}}$
$= \mathbf{8.92 \times 10^{16}\ atoms}$

(k) $\#\ \text{of atoms} = 6.5 \times 10^{-6}\ \text{g} \times \frac{1\ \text{mol}}{83.8\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} = \mathbf{4.7 \times 10^{16}\ atoms}$

(l) $\#\ \text{of atoms} = 9.5 \times 10^{-3}\ \text{g} \times \frac{1\ \text{mol}}{17.0\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} \times \frac{4\ \text{atoms}}{1\ \text{molecule}} = \mathbf{1.3 \times 10^{21}\ atoms}$

24. (a) volume = $16.5\text{ g} \times \frac{1\text{ mol}}{77.9\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{4.74\ L}$

(b) volume = $5.65 \times 10^{22}\text{ molecules} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{2.10\ L}$

(c) volume = $0.750\text{ g} \times \frac{1\text{ mol}}{48.0\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{0.350\ L}$

(d) volume = $9.04 \times 10^{24}\text{ atoms} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ atoms}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{336\ L}$

(e) volume = $8.65 \times 10^{21}\text{ molecules} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{0.322\ L}$

(f) volume = $6.98 \times 10^{15}\text{ atoms} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ atoms}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{2.60 \times 10^{-7}\ L}$

(g) volume = $28.4\text{ mg} \times \frac{10^{-3}\text{ g}}{1\text{ mg}} \times \frac{1\text{ mol}}{129.6\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{4.91 \times 10^{-3}\ L}$

(h) volume = $3.25\text{ kg} \times \frac{10^{3}\text{ g}}{1\text{ kg}} \times \frac{1\text{ mol}}{30.0\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{2.43 \times 10^{3}\ L}$

25. density of $CO_2(g) = \frac{44.0\text{ g}}{22.4\text{ L}} = \mathbf{1.96\ \frac{g}{L}}$

26. # of N atoms = $30.0\text{ g} \times \frac{1\text{ mol}}{80.0\text{ g}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{1\text{ mol}} \times \frac{2\text{ N–atoms}}{1\text{ molecule}} = \mathbf{4.52 \times 10^{23}\ atoms}$

27. # of molecules = $2.50\text{ L} \times \frac{1.59\text{ g}}{10^{-3}\text{ L}} \times \frac{1\text{ mol}}{154.0\text{ g}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{1\text{ mol}} = \mathbf{1.55 \times 10^{25}\ molecules}$

28. density = $\frac{1.67\text{ g}}{1.35\text{ L}} = 1.237\text{ g/L}$, and mass of 1 mol = $1.237\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = \mathbf{27.7\ g}$

29. density = $\frac{30.0\text{ g}}{22.4\text{ L}} = \mathbf{1.34\ \frac{g}{L}}$

30. volume = $8.50 \times 10^{24}\text{ C–atoms} \times \frac{1\text{ molecule}}{6\text{ C–atoms}} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{78.0\text{ g}}{1\text{ mol}} \times \frac{1\text{ mL}}{0.877\text{ g}} = \mathbf{209\ mL}$

31. density = $\frac{0.358\text{ g}}{0.2500\text{ L}} = 1.432\text{ g/L}$, and mass of 1 mol = $1.432\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = \mathbf{32.1\ g}$

Silane molecules have at least one Si and one H atom. The molar mass of Si is 28.1 g and of H is 1.0 g. Silane has a molar mass of 32.1 g, which is not big enough to allow 2 atoms of Si per molecule. Hence, there is exactly 1 Si per molecule and 32.1 −28.1 = 4.0 H atoms. The formula must be $\mathbf{SiH_4}$.

32. volume = $4.50 \times 10^{22}\text{ molecules} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{76.2\text{ g}}{1\text{ mol}} \times \frac{1\text{ mL}}{1.26\text{ g}} = \mathbf{4.52\ mL}$

33. molar mass = 60.1 g; volume of 1 mol = $60.1\text{ g} \times \frac{1\text{ mL}}{2.64\text{ g}} = \mathbf{22.8\ mL}$

34. density = $\frac{0.02780\text{ mol}}{0.2836 \times 10^{-3}\text{ L}} \times \frac{197.0\text{ g}}{1\text{ mol}} = \mathbf{1.931 \times 10^{4}\ g/L}$

35. (a) 60 (b) 290

36. (a) # of molecules $= 0.0500 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol}} = \mathbf{1.34 \times 10^{21} \textbf{ molecules}}$

(b) # of molecules $= 25.0 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol}} = \mathbf{6.72 \times 10^{23} \textbf{ molecules}}$

(c) # of molecules $= 75.0 \text{ g} \times \frac{1 \text{ mol}}{342.0 \text{ g}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol}} = \mathbf{1.32 \times 10^{23} \textbf{ molecules}}$

(d) # of molecules $= 0.125 \text{ g} \times \frac{1 \text{ mol}}{124.0 \text{ g}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol}} = \mathbf{6.07 \times 10^{20} \textbf{ molecules}}$

37. (a) volume $= 10.0 \text{ g} \times \frac{1 \text{ mol}}{34.1 \text{ g}} \times \frac{22.4 \text{ L}}{1 \text{ mol}} = \mathbf{6.57 \textbf{ L}}$

(b) volume $= 0.0150 \text{ g} \times \frac{1 \text{ mol}}{124.8 \text{ g}} \times \frac{22.4 \text{ L}}{1 \text{ mol}} = \mathbf{0.00269 \textbf{ L}}$

(c) volume $= 5.0 \times 10^{20} \text{ molecules} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}} \times \frac{22.4 \text{ L}}{1 \text{ mol}} = \mathbf{0.019 \textbf{ L}}$

(d) volume $= 8.5 \times 10^{25} \text{molecules} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}} \times \frac{22.4 \text{ L}}{1 \text{ mol}} = \mathbf{3.2 \times 10^{3} \textbf{ L}}$

38. (a) mass $= 1 \text{ atom} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ atoms}} \times \frac{197.0 \text{ g}}{1 \text{ mol}} = \mathbf{3.27 \times 10^{-22} \textbf{ g}}$

(b) mass $= 1.5 \times 10^{15} \text{ molecules} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}} \times \frac{143.4 \text{ g}}{1 \text{ mol}} = \mathbf{3.6 \times 10^{-7} \textbf{ g}}$

(c) mass $= 0.2500 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} \times \frac{42.0 \text{ g}}{1 \text{ mol}} = \mathbf{0.469 \textbf{ g}}$

(d) mass $= 2.00 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} \times \frac{146.1 \text{ g}}{1 \text{ mol}} = \mathbf{13.0 \textbf{ g}}$

39. (a) # of moles $= 5.00 \text{ g} \times \frac{1 \text{ mol}}{128.0 \text{ g}} = \mathbf{0.0391 \textbf{ mol}}$

(b) # of moles $= 0.525 \text{ g} \times \frac{1 \text{ mol}}{212.3 \text{ g}} = \mathbf{0.00247 \textbf{ mol}}$

(c) # of moles $= 6.00 \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} = \mathbf{0.268 \textbf{ mol}}$

(d) # of moles $= 1.00 \times 10^{-3} \text{ L} \times \frac{1 \text{ mol}}{22.4 \text{ L}} = \mathbf{4.46 \times 10^{-5} \textbf{ mol}}$

(e) # of moles $= 4.55 \times 10^{12} \text{ atoms} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ atoms}} = \mathbf{7.56 \times 10^{-12} \textbf{ mol}}$

(f) # of moles $= 6.02 \times 10^{16} \text{ molecules} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}} = \mathbf{1.00 \times 10^{-7} \textbf{ mol}}$

40. (a) $\text{molar mass} = 6.02 \times 10^{23}\ \text{molecules} \times \dfrac{1.25 \times 10^{-17}\ \text{g}}{\text{molecule}} = \mathbf{7.53 \times 10^{6}\ g}$

(b) $\text{molar mass} = \dfrac{74.0\ \text{g}}{0.179\ \text{mol}} = \mathbf{413\ g/mol}$

(c) $\text{molar mass} = 6.02 \times 10^{23}\ \text{molecules} \times \dfrac{2.96 \times 10^{-22}\ \text{g}}{\text{molecule}} = \mathbf{178\ g}$

(d) $\text{molar mass} = 248.2\ \text{g}$

(e) $\text{molar mass} = \dfrac{2.13\ \text{g}}{0.0229\ \text{mol}} = \mathbf{93.0\ g/mol}$

(f) $\text{molar mass} = 329.6\ \text{g}$

41. (a) $\text{density} = \dfrac{34.0\ \text{g}}{22.4\ \text{L}} = \mathbf{1.52\ g/L}$

(b) $\text{volume of 1 mol} = 197.0\ \text{g} \times \dfrac{1\ \text{mL}}{19.31\ \text{g}} = \mathbf{10.2\ mL}$

(c) $\#\ \text{of moles} = 1.25\ \text{mL} \times \dfrac{1.26\ \text{g}}{\text{mL}} \times \dfrac{1\ \text{mol}}{76.2\ \text{g}} = \mathbf{0.0207\ mol}$

(d) $\text{density} = \dfrac{0.100\ \text{mol}}{16.2\ \text{mL}} \times \dfrac{114.0\ \text{g}}{1\ \text{mol}} = \mathbf{0.704\ g/mL}$

(e) $\text{density} = \dfrac{65.5\ \text{g}}{22.4\ \text{L}} = \mathbf{2.92\ g/L}$

(f) $\text{volume} = 0.0875\ \text{mol} \times \dfrac{107.9\ \text{g}}{1\ \text{mol}} \times \dfrac{1\ \text{mL}}{10.5\ \text{g}} = \mathbf{0.899\ mL}$

(g) $\text{density} = \dfrac{0.0275\ \text{mol}}{3.01\ \text{mL}} \times \dfrac{249.6\ \text{g}}{1\ \text{mol}} = \mathbf{2.28\ g/mL}$

(h) $\#\ \text{of moles} = 7.50\ \text{L} \times \dfrac{1\ \text{mL}}{10^{-3}\ \text{L}} \times \dfrac{0.789\ \text{g}}{1\ \text{mL}} \times \dfrac{1\ \text{mol}}{46.0\ \text{g}} = \mathbf{129\ mol}$

(i) $\text{density} = \dfrac{1.14\ \text{g}}{0.7500\ \text{L}} = 1.52\ \text{g/L}$ and mass of 1 mol $= 1.52\ \dfrac{\text{g}}{\text{L}} \times 22.4\ \text{L} = \mathbf{34.0\ g}$

(j) $\text{volume} = 0.0155\ \text{mol} \times \dfrac{58.5\ \text{g}}{1\ \text{mol}} \times \dfrac{1\ \text{mL}}{2.17\ \text{g}} = \mathbf{0.418\ mL}$

(k) $\text{density} = \dfrac{3.47\ \text{g}}{1.25\ \text{L}} = 2.776\ \text{g/L}$ and mass of 1 mol $= 2.776\ \dfrac{\text{g}}{\text{L}} \times 22.4\ \text{L} = \mathbf{62.2\ g}$

(l) $\text{volume of 1 mol} = 6.9\ \text{g} \times \dfrac{1\ \text{L}}{534\ \text{g}} = \mathbf{0.013\ L}$

42. (a) $\#\ \text{of atoms} = 2\ \text{molecules} \times \dfrac{9\ \text{atoms}}{1\ \text{molecule}} = \mathbf{18\ atoms}$

(b) $\text{volume} = 1.45 \times 10^{30}\ \text{molecules} \times \dfrac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{molecules}} \times \dfrac{22.4\ \text{L}}{1\ \text{mol}} = \mathbf{5.40 \times 10^{7}\ L}$

(c) $\#\ \text{of molecules} = 64.0\ \text{g} \times \dfrac{1\ \text{mol}}{87.9\ \text{g}} \times \dfrac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol}} = \mathbf{4.38 \times 10^{23}\ molecules}$

(d) $\#\ \text{of moles} = 0.0250\ \text{L} \times \dfrac{1\ \text{mol}}{22.4\ \text{L}} = \mathbf{1.12 \times 10^{-3}\ mol}$

(e) volume = $43.5\text{ g} \times \frac{1\text{ mol}}{92.5\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{10.5\ L}$

(f) # of moles = $2.75 \times 10^{23}\text{ atoms} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ atoms}} = \mathbf{0.457\ mol}$

(g) # of molecules = $0.125\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{1\text{ mol}} = \mathbf{3.36 \times 10^{21}\ molecules}$

(h) mass = $3.01 \times 10^{22}\text{ atoms} \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ atoms}} \times \frac{195.1\text{ g}}{1\text{ mol}} = \mathbf{9.76\ g}$

(i) molar mass = 136.5 g

(j) density = $\frac{52.0\text{ g}}{22.4\text{ L}} = \mathbf{2.32\ g/L}$

(k) mass = $0.0250\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} \times \frac{83.8\text{ g}}{1\text{ mol}} = \mathbf{0.0935\ g}$

(l) volume of 1 mol = $192.2\text{ g} \times \frac{1\text{ mL}}{22.42\text{ g}} = \mathbf{8.573\ mL}$

(m) molar mass = $\frac{0.888\text{ g}}{0.0139\text{ mol}} = \mathbf{63.9\ g/mol}$

(n) density = $\frac{0.250\text{ mol}}{14.3\text{ mL}} \times \frac{60.0\text{ g}}{1\text{ mol}} = \mathbf{1.05\ g/mL}$

(o) # of moles = $0.0850\text{ g} \times \frac{1\text{ mol}}{121.6\text{ g}} = \mathbf{6.99 \times 10^{-4}\ mol}$

(p) volume = $0.145\text{ mol} \times \frac{102.0\text{ g}}{1\text{ mol}} \times \frac{1\text{ mL}}{3.97\text{ g}} = \mathbf{3.73\ mL}$

(q) molar mass = $6.02 \times 10^{23}\text{ particles} \times \frac{9.11 \times 10^{-28}\text{ g}}{\text{particle}} = \mathbf{5.48 \times 10^{-4}\ g}$

(r) density = $\frac{313\text{ g}}{135\text{ L}} = 2.319\text{ g/L}$ and mass of 1 mol = $2.319 \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = \mathbf{51.9\ g}$

(s) # of moles = $50.0\text{ mL} \times \frac{8.10\text{ g}}{1\text{ mL}} \times \frac{1\text{ mol}}{232.7\text{ g}} = \mathbf{1.74\ mol}$

43. (a) volume = $5.75 \times 10^{10}\text{ molecules} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{2.14 \times 10^{-12}\ L}$

(b) # of molecules = $75.0\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{1\text{ mol}} = \mathbf{2.02 \times 10^{24}\ molecules}$

(c) mass = $2.50\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} \times \frac{126.0\text{ g}}{1\text{ mol}} = \mathbf{14.1\ g}$

(d) molar mass = 390.0 g

(e) # of moles = $15.0\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} = \mathbf{0.670\ mol}$

(f) mass = $1\text{ molecule} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{132.1\text{ g}}{1\text{ mol}} = \mathbf{2.19 \times 10^{-22}\ g}$

(g) density = $\frac{56.0\text{ g}}{22.4\text{ L}} = \mathbf{2.50\ g/L}$

(h) molar mass = $6.02 \times 10^{23}\text{ molecules} \times \frac{6.23 \times 10^{-22}\text{ g}}{\text{molecule}} = \mathbf{375\ g}$

(i) $\#\text{ of atoms} = 3\text{ molecules} \times \frac{14\text{ atoms}}{1\text{ molecule}} = \mathbf{42\ atoms}$

(j) $\text{density} = \frac{0.0149\text{ g}}{0.00554\text{ L}} = 2.690\text{ g/L}$ and $\text{mass of 1 mol} = 2.690\,\frac{\text{g}}{\text{L}} \times 22.4\text{ L} = \mathbf{60.2\ g}$

(k) $\#\text{ of moles} = 125\text{ g} \times \frac{1\text{ mol}}{295.2\text{ g}} = \mathbf{0.423\ mol}$

(l) $\text{molar mass} = \frac{73.1\text{ g}}{0.546\text{ mol}} = \mathbf{134\ g/mol}$

(m) $\#\text{ of moles} = 1.85 \times 10^{24}\text{ molecules} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ molecules}} = \mathbf{3.07\ mol}$

(n) $\text{volume} = 0.0694\text{ mol} \times \frac{160.1\text{ g}}{1\text{ mol}} \times \frac{1\text{ mL}}{4.80\text{ g}} = \mathbf{2.31\ mL}$

(o) $\#\text{ of molecules} = 5.00\text{ g} \times \frac{1\text{ mol}}{54.0\text{ g}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{1\text{ mol}} = \mathbf{5.57 \times 10^{22}\ molecules}$

(p) $\text{density} = \frac{0.0316\text{ mol}}{1.167\text{ mL}} \times \frac{100.1\text{ g}}{1\text{ mol}} = \mathbf{2.71\ g/mL}$

(q) $\#\text{ of moles} = 100.0\text{ mL} \times \frac{1.58\text{ g}}{1\text{ mL}} \times \frac{1\text{ mol}}{342.0\text{ g}} = \mathbf{0.462\ mol}$

(r) $\text{volume} = 0.275\text{ g} \times \frac{1\text{ mol}}{76.6\text{ g}} \times \frac{22.4\text{ L}}{1\text{ mol}} = \mathbf{0.0804\ L}$

(s) $\text{volume of 1 mol} = 200.6\text{ g} \times \frac{1\text{ mL}}{13.55\text{ g}} = \mathbf{14.80\ mL}$

44. (a) molar mass = 30.0 g

$\%\text{C} = \frac{24.0\text{ g}}{30.0\text{ g}} \times 100\,\% = 80.0\,\%$

$\%\text{H} = \frac{6.0\text{ g}}{30.0\text{ g}} \times 100\,\% = 20.0\,\%$

(b) molar mass = 126.8 g

$\%\text{Fe} = \frac{55.8\text{ g}}{126.8\text{ g}} \times 100\,\% = 44.0\,\%$

$\%\text{Cl} = \frac{71.0\text{ g}}{126.8\text{ g}} \times 100\,\% = 56.0\,\%$

(c) molar mass = 162.3 g

$\%\text{Fe} = \frac{55.8\text{ g}}{162.3\text{ g}} \times 100\,\% = 34.4\,\%$

$\%\text{Cl} = \frac{106.5\text{ g}}{162.3\text{ g}} \times 100\,\% = 65.6\,\%$

(d) molar mass = 60.0 g

$\%\text{C} = \frac{24.0\text{ g}}{60.0\text{ g}} \times 100\,\% = 40.0\,\%$

$\%\text{H} = \frac{4.0\text{ g}}{60.0\text{ g}} \times 100\,\% = 6.7\,\%$

$\%\text{O} = \frac{32.0\text{ g}}{60.0\text{ g}} \times 100\,\% = 53.3\,\%$

(e) molar mass = 100.1 g

$\%\text{Ca} = \frac{40.1\text{ g}}{100.1\text{ g}} \times 100\,\% = 40.0\,\%$

$\%\text{C} = \frac{12.0\text{ g}}{100.1\text{ g}} \times 100\,\% = 12.0\,\%$

$\%\text{O} = \frac{48.0\text{ g}}{100.1\text{ g}} \times 100\,\% = 48.0\,\%$

(f) molar mass = 40.0 g

$\%\text{Na} = \frac{23.0\text{ g}}{40.0\text{ g}} \times 100\,\% = 57.5\,\%$

$\%\text{O} = \frac{16.0\text{ g}}{40.0\text{ g}} \times 100\,\% = 40.0\,\%$

$\%\text{H} = \frac{1.0\text{ g}}{40.0\text{ g}} \times 100\,\% = 2.5\,\%$

(g) molar mass = 147.1 g

$$\% Ca = \frac{40.1\text{ g}}{147.1\text{ g}} \times 100\% = 27.3\%$$

$$\% Cl = \frac{71.0\text{ g}}{147.1\text{ g}} \times 100\% = 48.3\%$$

$$\% H = \frac{4.0\text{ g}}{147.1\text{ g}} \times 100\% = 2.7\%$$

$$\% O = \frac{32.0\text{ g}}{147.1\text{ g}} \times 100\% = 21.8\%$$

(h) molar mass = 149.0 g

$$\% N = \frac{42.0\text{ g}}{149.0\text{ g}} \times 100\% = 28.2\%$$

$$\% H = \frac{12.0\text{ g}}{149.0\text{ g}} \times 100\% = 8.1\%$$

$$\% P = \frac{31.0\text{ g}}{149.0\text{ g}} \times 100\% = 20.8\%$$

$$\% O = \frac{64.0\text{ g}}{149.0\text{ g}} \times 100\% = 43.0\%$$

(i) molar mass = 177.4 g

$$\% Ag = \frac{107.9\text{ g}}{177.4\text{ g}} \times 100\% = 60.8\%$$

$$\% N = \frac{28.0\text{ g}}{177.4\text{ g}} \times 100\% = 15.8\%$$

$$\% H = \frac{6.0\text{ g}}{177.4\text{ g}} \times 100\% = 3.4\%$$

$$\% Cl = \frac{35.5\text{ g}}{177.4\text{ g}} \times 100\% = 20.0\%$$

(j) molar mass = 328.5 g

$$\% C = \frac{204.0\text{ g}}{328.5\text{ g}} \times 100\% = 62.1\%$$

$$\% H = \frac{15.0\text{ g}}{328.5\text{ g}} \times 100\% = 4.6\%$$

$$\% N = \frac{42.0\text{ g}}{328.5\text{ g}} \times 100\% = 12.8\%$$

$$\% O = \frac{32.0\text{ g}}{328.5\text{ g}} \times 100\% = 9.7\%$$

$$\% Cl = \frac{35.5\text{ g}}{328.5\text{ g}} \times 100\% = 10.8\%$$

(k) molar mass = 346.9 g

$$\% Sn = \frac{118.7\text{ g}}{346.9\text{ g}} \times 100\% = 34.2\%$$

$$\% S = \frac{64.2\text{ g}}{346.9\text{ g}} \times 100\% = 18.5\%$$

$$\% O = \frac{160.0\text{ g}}{346.9\text{ g}} \times 100\% = 46.1\%$$

$$\% H = \frac{4.0\text{ g}}{346.9\text{ g}} \times 100\% = 1.2\%$$

(l) molar mass = 256.7 g

$$\% N = \frac{28.0\text{ g}}{256.7\text{ g}} \times 100\% = 10.9\%$$

$$\% H = \frac{14.0\text{ g}}{256.7\text{ g}} \times 100\% = 5.4\%$$

$$\% Sn = \frac{118.7\text{ g}}{256.7\text{ g}} \times 100\% = 46.2\%$$

$$\% O = \frac{96.0\text{ g}}{256.7\text{ g}} \times 100\% = 37.4\%$$

(m) molar mass = 120.0 g

$$\% C = \frac{24.0\text{ g}}{120.0\text{ g}} \times 100\% = 20.0\%$$

$$\% H = \frac{4.0\text{ g}}{120.0\text{ g}} \times 100\% = 3.3\%$$

$$\% N = \frac{28.0\text{ g}}{120.0\text{ g}} \times 100\% = 23.3\%$$

$$\% O = \frac{64.0\text{ g}}{120.0\text{ g}} \times 100\% = 53.3\%$$

(n) molar mass = 329.1 g

$$\% K = \frac{117.3\text{ g}}{329.1\text{ g}} \times 100\% = 35.6\%$$

$$\% Fe = \frac{55.8\text{ g}}{329.1\text{ g}} \times 100\% = 17.0\%$$

$$\% C = \frac{72.0\text{ g}}{329.1\text{ g}} \times 100\% = 21.9\%$$

$$\% N = \frac{84.0\text{ g}}{329.1\text{ g}} \times 100\% = 25.5\%$$

45. (a) $\% H_2O = \frac{36.0\text{ g}}{147.1\text{ g}} \times 100\% = 24.5\%$

(b) $\% H_2O = \frac{126.0\text{ g}}{280.8\text{ g}} \times 100\% = 44.9\%$

(c) $\% H_2O = \frac{162.0\text{ g}}{706.2\text{ g}} \times 100\% = 22.9\%$

(d) $\% H_2O = \frac{324.0\text{ g}}{666.3\text{ g}} \times 100\% = 48.6\%$

(e) $\% NH_3 = \frac{102.0\text{ g}}{278.5\text{ g}} \text{ x } 100\ \% = 36.6\ \%$ (f) $\% H_2O = \frac{18.0\text{ g}}{278.5\text{ g}} \text{ x } 100\ \% = 6.46\ \%$

(g) $\% C_2H_3O_2 = \frac{118.0\text{ g}}{215.5\text{ g}} \text{ x } 100\ \% = 54.8\ \%$ (h) $\% SO_4 = \frac{288.3\text{ g}}{561.9\text{ g}} \text{ x } 100\ \% = 51.3\ \%$

46. (a) $\text{moles B} = 15.9\text{ g x } \frac{1\text{ mol}}{10.8\text{g}} = 1.47\text{ mol} \;\Big|\; 1$

$\text{moles F} = 84.1\text{ g x } \frac{1\text{ mol}}{19.0\text{ g}} = 4.43\text{ mol} \;\Big|\; 3$

and empirical formula = **BF_3**

(b) $\text{moles Si} = 87.5\text{ g x } \frac{1\text{ mol}}{28.1\text{ g}} = 3.11\text{ mol} \;\Big|\; 1$

$\text{moles H} = 12.5\text{ g x } \frac{1\text{ mol}}{1.0\text{ g}} = 12.5\text{ mol} \;\Big|\; 4$

and empirical formula = **SiH_4**

(c) $\text{moles P} = 43.7\text{ g x } \frac{1\text{ mol}}{31.0\text{ g}} = 1.41\text{ mol} \;\Big|\; 1 \;\Big|\; 2$

$\text{moles O} = 56.3\text{ g x } \frac{1\text{ mol}}{16.0\text{ g}} = 3.52\text{ mol} \;\Big|\; 2.50 \;\Big|\; 5$

and empirical formula = **P_2O_5**

(d) $\text{moles I} = 77.9\text{ g x } \frac{1\text{ mol}}{126.9\text{ g}} = 0.614\text{ mol} \;\Big|\; 1 \;\Big|\; 4$

$\text{moles O} = 22.1\text{ g x } \frac{1\text{ mol}}{16.0\text{ g}} = 1.38\text{ mol} \;\Big|\; 2.25 \;\Big|\; 9$

and empirical formula = **I_4O_9**

(e) $\text{moles Fe} = 77.7\text{ g x } \frac{1\text{ mol}}{55.8\text{ g}} = 1.39\text{ mol} \;\Big|\; 1$

$\text{moles O} = 22.3\text{ g x } \frac{1\text{ mol}}{16.0\text{ g}} = 1.39\text{ mol} \;\Big|\; 1$

and empirical formula = **FeO**

(f) $\text{moles Fe} = 70.0\text{ g x } \frac{1\text{ mol}}{55.8\text{ g}} = 1.25\text{ mol} \;\Big|\; 1 \;\Big|\; 2$

$\text{moles O} = 30.0\text{ g x } \frac{1\text{ mol}}{16.0\text{ g}} = 1.875\text{ mol} \;\Big|\; 1.5 \;\Big|\; 3$

and empirical formula = **Fe_2O_3**

(g) $\text{moles Fe} = 72.4\text{ g x } \frac{1\text{ mol}}{55.8\text{ g}} = 1.30\text{ mol} \;\Big|\; 1 \;\Big|\; 3$

$\text{moles O} = 27.6\text{ g x } \frac{1\text{ mol}}{16.0\text{ g}} = 1.725\text{ mol} \;\Big|\; 1.33 \;\Big|\; 4$

and empirical formula = **Fe_3O_4**

(h) $\text{moles Li} = 46.3\text{ g x } \frac{1\text{ mol}}{6.9\text{ g}} = 6.71\text{ mol} \;\Big|\; 2$

$\text{moles O} = 53.7\text{ g x } \frac{1\text{ mol}}{16.0\text{ g}} = 3.36\text{ mol} \;\Big|\; 1$

and empirical formula = **Li_2O**

(i) moles C = $24.4\text{ g} \times \frac{1\text{ mol}}{12.0\text{ g}} = 2.03\text{ mol}$	1	3	
moles H = $3.39\text{ g} \times \frac{1\text{ mol}}{1.0\text{ g}} = 3.39\text{ mol}$	1.67	5	and empirical formula = $\mathbf{C_3H_5Cl_3}$
moles Cl = $72.2\text{ g} \times \frac{1\text{ mol}}{35.5\text{ g}} = 2.03\text{ mol}$	1	3	

(j) moles K = $26.6\text{ g} \times \frac{1\text{ mol}}{39.1\text{ g}} = 0.680\text{ mol}$	1	2	
moles Cr = $35.4\text{ g} \times \frac{1\text{ mol}}{52.0\text{ g}} = 0.681\text{ mol}$	1	2	empirical formula = $\mathbf{K_2Cr_2O_7}$
moles O = $38.0\text{ g} \times \frac{1\text{ mol}}{16.0\text{ g}} = 2.375\text{ mol}$	3.49	7	

(k) moles Mg = $21.8\text{ g} \times \frac{1\text{ mol}}{24.3\text{ g}} = 0.897\text{ mol}$	1	2	
moles P = $27.9\text{ g} \times \frac{1\text{ mol}}{31.0\text{ g}} = 0.900\text{ mol}$	1	2	and empirical formula = $\mathbf{Mg_2P_2O_7}$
moles O = $50.3\text{ g} \times \frac{1\text{ mol}}{16.0\text{ g}} = 3.14\text{ mol}$	3.50	7	

(l) moles H = $3.66\text{ g} \times \frac{1\text{ mol}}{1.0\text{ g}} = 3.66\text{ mol}$	3	
moles P = $37.8\text{ g} \times \frac{1\text{ mol}}{31.0\text{ g}} = 1.22\text{ mol}$	1	and empirical formula = $\mathbf{H_3PO_3}$
moles O = $58.4\text{ g} \times \frac{1\text{ mol}}{16.0\text{ g}} = 3.65\text{ mol}$	3	

(m) moles C = $46.2\text{ g} \times \frac{1\text{ mol}}{12.0\text{ g}} = 3.85\text{ mol}$	1.33	4	
moles H = $7.69\text{ g} \times \frac{1\text{ mol}}{1.0\text{ g}} = 7.69\text{ mol}$	2.66	8	and empirical formula = $\mathbf{C_4H_8O_3}$
moles O = $46.2\text{ g} \times \frac{1\text{ mol}}{16.0\text{ g}} = 2.89\text{ mol}$	1	3	

(n) moles C = $50.5\text{ g} \times \frac{1\text{ mol}}{12.0\text{ g}} = 4.21\text{ mol}$	1.33	4	
moles H = $5.26\text{ g} \times \frac{1\text{ mol}}{1.0\text{ g}} = 5.26\text{ mol}$	1.66	5	and empirical formula = $\mathbf{C_4H_5N_3}$
moles N = $44.2\text{ g} \times \frac{1\text{ mol}}{14.0\text{ g}} = 3.16\text{ mol}$	1	3	

47. density = $\frac{1.59\text{ g}}{0.850\text{ L}} = 1.871\text{ g/L}$, and mass of 1 mol = $1.871\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = 41.9\text{ g}$

empirical mass of $CH_2 = 12.0 + 2 \times 1.0 = 14.0\text{ g}$

$N = \frac{41.9\text{ g}}{14.0\text{ g}} = 2.99$. Therefore the molecular formula = $3 \times (CH_2) = \mathbf{C_3H_6}$.

48. $$\begin{array}{l|l} \text{moles N} = 30.4\text{ g} \times \dfrac{1\text{ mol}}{14.0\text{ g}} = 2.17\text{ mol} & 1 \\ \text{moles O} = 69.6\text{ g} \times \dfrac{1\text{ mol}}{16.0\text{ g}} = 4.35\text{ mol} & 2 \end{array}$$

and empirical formula = $\mathbf{NO_2}$, empirical mass = 14.0 + 2 x 16.0 = 46.0 g

$\text{molar mass} = 4.11\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = 92.1\text{ g}$

$N = \frac{92.1\text{ g}}{46.0\text{ g}} = 2.0$. Therefore the molecular formula = 2 x (NO_2) = $\mathbf{N_2O_4}$.

49. Empirical mass of C_5H_{11} = 71.0 g

$\text{molar mass} = \frac{3.91\text{ g}}{0.0275\text{ mol}} = 142\text{ g/mol}$

$N = \frac{142\text{ g}}{71.0\text{ g}} = 2.0$. Therefore the molecular formula = 2 x (C_5H_{11}) = $\mathbf{C_{10}H_{22}}$.

50. $\text{density} = \frac{0.522\text{ g}}{0.450\text{ L}} = 1.16\text{ g/L}$, and $\text{mass of 1 mol} = 1.16\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = 26.0\text{ g}$

empirical mass = 1 x 12.0 + 1 x 1.0 = 13.0 g

$N = \frac{26.0\text{ g}}{13.0\text{ g}} = 2.0$. Therefore the molecular formula = 2 x (CH) = $\mathbf{C_2H_2}$.

51. Percentage O = 100% – 42.9% = 57.1%

$$\begin{array}{l|l} \text{moles C} = 42.9\text{ g} \times \dfrac{1\text{ mol}}{12.0\text{ g}} = 3.58\text{ mol} & 1 \\ \text{moles O} = 57.1\text{ g} \times \dfrac{1\text{ mol}}{16.0\text{ g}} = 3.57\text{ mol} & 1 \end{array}$$

empirical formula = CO and empirical mass = 28.0 g

$\text{molar mass} = \frac{1.68\text{ g}}{0.0600\text{ mol}} = 28.0\text{ g/mol}$

$N = \frac{28.0\text{ g}}{28.0\text{ g}} = 1$ and the molecular formula is **CO**

52. $$\begin{array}{l|l} \text{moles Si} = 33.0\text{ g} \times \dfrac{1\text{ mol}}{28.1\text{ g}} = 1.17\text{ mol} & 1 \\ \text{moles F} = 67.0\text{ g} \times \dfrac{1\text{ mol}}{19.0\text{ g}} = 3.53\text{ mol} & 3 \end{array}$$

empirical formula = SiF_3 and empirical mass = 85.1 g

$\text{molar mass} = 7.60\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = 1.70 \times 10^2\text{ g}$

$N = \frac{1.70 \times 10^2\text{ g}}{85.1\text{ g}} = 2.0$ and the molecular formula = 2 x (SiF_3) = $\mathbf{Si_2F_6}$

53. $$\begin{array}{l|l} \text{moles B} = 78.3\text{ g} \times \dfrac{1\text{ mol}}{10.8\text{ g}} = 7.25\text{ mol} & 1 \\ \text{moles H} = 21.7\text{ g} \times \dfrac{1\text{ mol}}{1.0\text{ g}} = 21.7\text{ mol} & 3 \end{array}$$

empirical formula = BH_3 and empirical mass = 13.8 g

molar mass = 0.986 x 28.0 g = 27.6 g

$N = \frac{27.6\text{ g}}{13.8\text{ g}} = 2.0$ and the molecular formula = 2 x (BH_3) = $\mathbf{B_2H_6}$

54. empirical mass = 14.0 g

$$\text{density} = \frac{0.938\text{ g}}{0.500\text{ L}} = 1.876\text{ g/L} \quad \text{and} \quad \text{mass of 1 mol} = 1.876\ \frac{\text{g}}{\text{L}} \times 22.4\text{ L} = 42.0\text{ g}$$

$$N = \frac{42.0\text{ g}}{14.0\text{ g}} = 3.0 \quad \text{and molecular formula} = 3 \times (CH_2) = \mathbf{C_3H_6}$$

55. empirical mass = 16.0 g ; molar mass = 3 x 16.0 g = 48.0 g

$$N = \frac{48.0\text{ g}}{16.0\text{ g}} = 3.0 \quad \text{and} \quad \text{molecular formula} = 3 \times (O) = \mathbf{O_3}$$

56. The total volume of water plus dissolved salt would be greater than 1.000 L.

57. Ask for instructions regarding disposal of the solution. There is no quick way to "save" the solution and be sure of the concentration.

58. When pouring samples from the volumetric flask, some of the samples will have different concentrations from other samples. The samples taken from the top of the flask will be less concentrated than those taken from the bottom.

59. (a) $[HCl] = \frac{0.26\text{ mol}}{1.0\text{ L}} = \mathbf{0.26\ M}$

(b) $[HNO_3] = \frac{2.8\text{ mol}}{4.0\text{ L}} = \mathbf{0.70\ M}$

(c) $[NH_4Cl] = \frac{0.0700\text{ mol}}{0.0500\text{ L}} = \mathbf{1.40\ M}$

(d) $[NaCl] = \frac{25.0\text{ g}}{0.2500\text{ L}} \times \frac{1\text{ mol}}{58.5\text{ g}} = \mathbf{1.71\ M}$

(e) $[CoBr_2{\cdot}6H_2O] = \frac{1.50\text{ g}}{0.6000\text{ L}} \times \frac{1\text{ mol}}{326.7\text{ g}} = \mathbf{0.00765\ M}$

(f) $[Cr(NO_3)_3{\cdot}9H_2O] = \frac{10.0\text{ g}}{0.325\text{ L}} \times \frac{1\text{ mol}}{400.0\text{ g}} = \mathbf{0.0769\ M}$

60. (a) $\text{moles } NH_4Cl = 3.00\ \frac{\text{mol}}{\text{L}} \times 1.00\text{ L} = 3.00\text{ mol}$

$\text{mass } NH_4Cl = 3.00\text{ mol} \times \frac{53.5\text{ g}}{1\text{ mol}} = 161\text{ g}$

Dissolve 161 g of NH_4Cl in less than 1.00 L of water and dilute to 1.00 L.

(b) $\text{moles } Hg(NO_3)_2 = 0.250\ \frac{\text{mol}}{\text{L}} \times 0.5000\text{ L} = 0.125\text{ mol}$

$\text{mass } Hg(NO_3)_2 = 0.125\text{ mol} \times \frac{324.6\text{ g}}{1\text{ mol}} = 40.6\text{ g}$

Dissolve 40.6 g of $Hg(NO_3)_2$ in less than 500 mL of water and dilute to 500.0 mL.

(c) $\text{moles } Ba(NO_3)_2 = 0.500\ \frac{\text{mol}}{\text{L}} \times 0.125\text{ L} = 0.0625\text{ mol}$

$\text{mass } Ba(NO_3)_2 = 0.0625\text{ mol} \times \frac{261.3\text{ g}}{1\text{ mol}} = 16.3\text{ g}$

Dissolve 16.3 g of $Ba(NO_3)_2$ in less than 125 mL of water and dilute to 125 mL.

(d) moles $SbCl_3 = 0.100 \frac{\text{mol}}{\text{L}} \times 0.2500 \text{ L} = 0.0250 \text{ mol}$

mass $SbCl_3 = 0.0250 \text{ mol} \times \frac{228.3 \text{ g}}{1 \text{ mol}} = 5.71 \text{ g}$

Dissolve 5.71 g of $SbCl_3$ in less than 250 mL of water and then dilute to 250 mL.

(e) moles NaOH $= 0.0120 \frac{\text{mol}}{\text{L}} \times 2.75 \text{ L} = 0.0330 \text{ mol}$

mass NaOH $= 0.0330 \text{ mol} \times \frac{40.0 \text{ g}}{1 \text{ mol}} = 1.32 \text{ g}$

Dissolve 1.32 g of NaOH in less than 2.75 L of water and then dilute to 2.75 L.

(f) moles $CuSO_4{\cdot}5H_2O$ = moles $CuSO_4 = 0.0300 \frac{\text{mol}}{\text{L}} \times 2.00 \text{ L} = 0.0600 \text{ mol}$

mass $CuSO_4{\cdot}5H_2O = 0.0600 \text{ mol} \times \frac{249.6 \text{ g}}{1 \text{ mol}} = 15.0 \text{ g}$

Dissolve 15.0 g of $CuSO_4{\cdot}5H_2O$ in less than 2.00 L of water and then dilute to 2.00 L.

(g) moles $BaI_2{\cdot}2H_2O$ = moles $BaI_2 = 0.225 \frac{\text{mol}}{\text{L}} \times 0.0500 \text{ L} = 0.01125 \text{ mol}$

mass $BaI_2{\cdot}2H_2O = 0.01125 \text{ mol} \times \frac{427.1 \text{ g}}{1 \text{ mol}} = 4.80 \text{ g}$

Dissolve 4.80 g of $BaI_2{\cdot}2H_2O$ in less than 50.0 mL of water and then dilute to 50.0 mL.

61. moles $AlCl_3 = 0.250 \frac{\text{mol}}{\text{L}} \times 0.3500 \text{ L} = \mathbf{0.0875\ mol}$

62. moles HCl $= 100.0 \text{ g} \times \frac{1 \text{ mol}}{36.5 \text{ g}} = 2.74 \text{ mol}$

$c = \frac{n}{V}$, so $V = \frac{n}{c} = \frac{2.74 \text{ mol}}{2.40 \text{ mol/L}} = \mathbf{1.14\ L}$

63. moles $Sr(NO_3)_2 = 1.30 \times 10^{-3} \frac{\text{mol}}{\text{L}} \times 0.0550 \text{ L} = \mathbf{7.15 \times 10^{-5}\ mol}$

64. moles NaF $= 0.15 \text{ g} \times \frac{1 \text{ mol}}{42.0 \text{ g}} = 3.57 \times 10^{-3} \text{ mol}$

$c = \frac{n}{V}$, so $V = \frac{n}{c} = \frac{3.57 \times 10^{-3} \text{ mol}}{2.8 \times 10^{-2} \text{ mol/L}} = \mathbf{0.13\ L}$

65. $[H_2O] = 1000 \frac{\text{g}}{\text{L}} \times \frac{1 \text{ mol}}{18.0 \text{ g}} = \mathbf{55.6\ M}$

66. $[CH_3COOH] = 1049 \frac{\text{g}}{\text{L}} \times \frac{1 \text{ mol}}{60.0 \text{ g}} = \mathbf{17.5\ M}$

67. $d = 17.6 \frac{\text{mol}}{\text{L}} \times \frac{100.5 \text{ g}}{1 \text{ mol}} = \mathbf{1.77 \times 10^3 \frac{g}{L}}$

68. $d = 16.6 \frac{\text{mol}}{\text{L}} \times \frac{76.2 \text{ g}}{1 \text{ mol}} = \mathbf{1.26 \times 10^3 \frac{g}{L}}$

69. moles $CaCl_2 = 0.0350\ \frac{mol}{L} \times 0.225\ L = 7.88 \times 10^{-3}\ mol$

$mass = 7.88 \times 10^{-3}\ mol \times \frac{111.1\ g}{1\ mol} = \mathbf{0.875\ g}$

70. moles Na_3PO_4 = moles $Na_3PO_4{\cdot}12H_2O = 0.175\ \frac{mol}{L} \times 3.45\ L = 0.604\ mol$

mass $Na_3PO_4 = 0.604\ mol \times \frac{164.0\ g}{1\ mol} = \mathbf{99.0\ g}$

71. moles $C_6H_5COOH = 0.0100\ \frac{mol}{L} \times 0.3500\ L = 3.50 \times 10^{-3}\ mol$

mass $C_6H_5COOH = 3.50 \times 10^{-3}\ mol \times \frac{122.0\ g}{1\ mol} = \mathbf{0.427\ g}$

Now to find the mass of the acetone. Since $d = \frac{m}{V}$, then $m = d{\cdot}V$

and mass acetone $= 0.790\ \frac{g}{mL} \times 350.0\ mL = \mathbf{277\ g.}$

Since the volume of solvent used was 350 mL (about a "pop-can-full"), the addition of less than half a gram of solid (about a "pinch") would not appreciably change the volume.

72. (a) $\frac{1}{3}$ OJ (b) $\frac{1}{4}$ OJ (c) $\frac{1}{10}$ OJ (d) $\frac{2}{4}$ OJ = $\frac{1}{2}$ OJ (e) $\frac{1}{5}$ OJ (f) $\frac{3}{8}$ OJ

73. diluted concentration = $\frac{\mathbf{C}}{\mathbf{C + W}}$ OJ

74. (a) The amount of orange juice is not changed and the total volume is unchanged from that produced when water is used instead of apple juice. Therefore the orange juice is diluted to the same extent, regardless of whether apple juice or water is added.

(b) diluted concentration of apple juice = $\frac{1}{2}$ AJ

(c) i) diluted orange = $\frac{1}{2}$ OJ ; diluted apple = $\frac{1}{2}$ AJ

ii) diluted orange = $\frac{1}{3}$ OJ ; diluted apple = $\frac{2}{3}$ AJ

iii) diluted orange = $\frac{1}{4}$ OJ ; diluted apple = $\frac{3}{4}$ AJ

iv) diluted orange = $\frac{2}{5}$ OJ ; diluted apple = $\frac{3}{5}$ AJ

v) diluted orange = $\frac{1}{2}$ OJ ; diluted apple = $\frac{1}{2}$ AJ

vi) diluted orange = $\frac{2}{5}$ OJ ; diluted apple = $\frac{3}{5}$ AJ

75. diluted orange = $\frac{\mathbf{O}}{\mathbf{O + A}}$ OJ ; diluted apple = $\frac{\mathbf{A}}{\mathbf{O + A}}$ AJ

76. diluted orange = $\frac{\mathbf{O}}{\mathbf{O + A}} \times 0.8$ OJ ; diluted apple = $\frac{\mathbf{A}}{\mathbf{O + A}} \times 0.7$ AJ

77. (a) diluted El Cheapo = $\frac{2}{5} \times 0.5\ \text{OJ} = 0.20\ \text{OJ}$

(b) diluted Expensive = $\frac{3}{5} \times 1.0\ \text{OJ} = 0.60\ \text{OJ}$

(c) total concentration = 0.20 OJ + 0.60 OJ = 0.80 OJ

(d) total concentration = $\frac{5}{8} \times 1.0\ \text{OJ} + \frac{3}{8} \times 0.50\ \text{OJ} = 0.81\ \text{OJ}$

(e) total concentration = $\frac{4}{11} \times 1.0\ \text{OJ} + \frac{7}{11} \times 0.50\ \text{OJ} = 0.68\ \text{OJ}$

78. $[\text{HBr}] = 0.75\ \text{M} \times \frac{20.0\ \text{mL}}{90.0\ \text{mL}} = \mathbf{0.17\ M}$

79. $[\text{KOH}]_{\text{DIL}}(\#1) = 0.15\ \text{M} \times \frac{55\ \text{mL}}{130\ \text{mL}} = 0.063\ \text{M}$

$[\text{KOH}]_{\text{DIL}}(\#2) = 0.25\ \text{M} \times \frac{75\ \text{mL}}{130\ \text{mL}} = 0.14\ \text{M}$

[KOH] (total) = 0.063 + 0.14 = **0.21 M**

80. $[\text{NaBr}] = 0.20\ \text{M} \times \frac{0.050\ \text{mL}}{100.05\ \text{mL}} = \mathbf{1.0 \times 10^{-4}\ M}$

81. $[\text{HNO}_3]_{\text{DIL}}(\#1) = 3.5\ \text{M} \times \frac{5.0\ \text{mL}}{100\ \text{mL}} = 0.18\ \text{M}$

$[\text{HNO}_3]_{\text{DIL}}(\#2) = 0.20\ \text{M} \times \frac{95\ \text{mL}}{100\ \text{mL}} = 0.19\ \text{M}$

$[\text{HNO}_3]$ (total) = 0.18 + 0.19 = **0.37 M**

82. $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.375\ \text{M} \times 2.50\ \text{L}}{15.4\ \text{M}} = 0.0609\ \text{L}$

Dilute 0.0609 L of concentrated HNO_3 to a total volume of 2.50 L.

83. $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.0600\ \text{M} \times 45.0\ \text{L}}{14.6\ \text{M}} = 0.185\ \text{L}$

Dilute 0.185 L of concentrated H_3PO_4 to a total volume of 45.0 L.

84. $[\text{KCl}] = \frac{\text{total moles}}{\text{total volume}}$, total mass KCl = 25.0 + 60.0 = 85.0 g

$[\text{KCl}] = \frac{85.0\ \text{g}}{0.5500\ \text{L}} \times \frac{1\ \text{mol}}{74.6\ \text{g}} = \mathbf{2.07\ M}$

85. $[\text{NaCl}] = 0.750\ \text{M} \times \frac{500.0\ \text{mL}}{300.0\ \text{mL}} = \mathbf{1.25\ M}$

86. $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.350\ \text{M} \times 0.2500\ \text{L}}{6.00\ \text{M}} = 0.0146\ \text{L} = 14.6\ \text{mL}$

Dilute 14.6 mL of concentrated HCl to a total volume of 250.0 mL.

87. moles NaCl needed = $0.400\ \frac{\text{mol}}{\text{L}} \times 0.5000\ \text{L} = 0.200\ \text{mol}$

mass NaCl = $0.200\ \text{mol} \times \frac{58.5\ \text{g}}{1\ \text{mol}} = \mathbf{11.7\ g}$

88. $[\text{NaOH}]_{\text{DIL}}(\#1) = 0.250\text{ M} \times \frac{125.0\text{ mL}}{325.0\text{ mL}} = 0.0962\text{ M}$

$[\text{NaOH}]_{\text{DIL}}(\#2) = 0.175\text{ M} \times \frac{200.0\text{ mL}}{325.0\text{ mL}} = 0.108\text{ M}$

[NaOH] (total) = 0.0962 + 0.108 = **0.204 M**

89. $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.750\text{ M} \times 3.00\text{ L}}{12.0\text{ M}} = \mathbf{0.188\text{ L}}$

90. $[\text{CaCl}_2] = 0.550\text{ M} \times \frac{80.0\text{ mL}}{135.0\text{ mL}} = 0.326\text{ M}$

91. $[\text{MgCl}_2] = 0.250\text{ M} \times \frac{350.0\text{ mL}}{275.0\text{ mL}} = 0.318\text{ M}$

92. $[\text{NaCl}]_{\text{DIL}}(\#1) = 0.350\text{ M} \times \frac{20.0\text{ mL}}{60.0\text{ mL}} = 0.117\text{ M}$

$[\text{NaCl}]_{\text{DIL}}(\#2) = 0.875\text{ M} \times \frac{75.0\text{ mL}}{60.0\text{ mL}} = 1.09\text{ M}$

[NaCl] (total) = 0.117 M + 1.09 M = **1.21 M**

93. $[\text{NaCl}] = 0.400\text{ M} \times \frac{150.0\text{ mL}}{250.0\text{ mL}} = 0.240\text{ M}$

94. $[\text{Na}_3\text{PO}_4] = 0.200\text{ M} \times \frac{75.0\text{ mL}}{100.0\text{ mL}} = 0.150\text{ M}$

95. (a) $[\text{NaHCO}_3] = \frac{5.62\text{ g}}{0.2500\text{ L}} \times \frac{1\text{ mol}}{84.0\text{ g}} = \mathbf{0.268\text{ M}}$

(b) $[\text{K}_2\text{CrO}_4] = \frac{0.1846\text{ g}}{0.5000\text{ L}} \times \frac{1\text{ mol}}{194.2\text{ g}} = \mathbf{1.901 \times 10^{-3}\text{ M}}$

(c) $[\text{H}_2\text{C}_2\text{O}_4] = \frac{0.584\text{ g}}{0.1000\text{ L}} \times \frac{1\text{ mol}}{90.0\text{ g}} = \mathbf{0.0649\text{ M}}$

96. (a) moles NaCl = $0.100\ \frac{\text{mol}}{\text{L}} \times 1.00\text{ L} = 0.100\text{ mol}$

mass NaCl = $0.100\text{ mol} \times \frac{58.5\text{ g}}{1\text{ mol}} = 5.85\text{ g}$

Dissolve 5.85 g of NaCl in less than 1 L and then dilute to 1.00 L.

(b) moles KBr = $0.09000\ \frac{\text{mol}}{\text{L}} \times 0.2500\text{ L} = 0.02250\text{ mol}$

mass KBr = $0.02250\text{ mol} \times \frac{119.0\text{ g}}{1\text{ mol}} = 2.678\text{ g}$

Dissolve 2.678 g of KBr in less than 250 mL and then dilute to 250.0 mL.

(c) moles $\text{Ca(NO}_3)_2 = 0.125\ \frac{\text{mol}}{\text{L}} \times 0.5000\text{ L} = 0.0625\text{ mol} = \text{moles Ca(NO}_3)_2\text{•}3\text{H}_2\text{O}$

mass $\text{Ca(NO}_3)_2\text{•}3\text{H}_2\text{O} = 0.0625\text{ mol} \times \frac{218.1\text{ g}}{1\text{ mol}} = 13.6\text{ g}$

Dissolve 13.6 g of $\text{Ca(NO}_3)_2\text{•}3\text{H}_2\text{O}$ in less than 500 mL and dilute to 500.0 mL.

97\. (a) $[\text{LiOH}]_{\text{DIL}}\ (\#1) = 3.55\ \text{M} \times \frac{125\ \text{mL}}{600\ \text{mL}} = 0.740\ \text{M}$

$[\text{LiOH}]_{\text{DIL}}\ (\#2) = 2.42\ \text{M} \times \frac{475\ \text{mL}}{600\ \text{mL}} = 1.92\ \text{M}$

$[\text{LiOH}]\ (\text{total}) = 0.740\ \text{M} + 1.92\ \text{M} = \mathbf{2.66\ M}$

(b) $[\text{NaCl}] = 0.250\ \text{M} \times \frac{200.0\ \text{mL}}{350.0\ \text{mL}} = \mathbf{0.143\ M}$

(c) $[\text{KBr}]_{\text{DIL}}\ (\#1) = 12.0\ \text{M} \times \frac{100.0\ \text{mL}}{1050.0\ \text{mL}} = 1.14\ \text{M}$

$[\text{KBr}]_{\text{DIL}}\ (\#2) = 0.200\ \text{M} \times \frac{950.0\ \text{mL}}{1050.0\ \text{mL}} = 0.181\ \text{M}$

$[\text{KBr}]\ (\text{total}) = 1.14\ \text{M} + 0.181\ \text{M} = \mathbf{1.32\ M}$

(d) $[\text{KBr}] = 2.50\ \text{M} \times \frac{5.0\ \text{mL}}{80\ \text{mL}} = \mathbf{0.16\ M}$

(e) $[\text{HCl}] = 0.1105\ \text{M} \times \frac{850.0\ \text{mL}}{900.0\ \text{mL}} = \mathbf{0.1044\ M}$

(f) $[\text{HCl}]_{\text{DIL}}\ (\#1) = 0.125\ \text{M} \times \frac{50.0\ \text{mL}}{125.0\ \text{mL}} = 0.0500\ \text{M}$

$[\text{HCl}]_{\text{DIL}}\ (\#2) = 0.350\ \text{M} \times \frac{75.0\ \text{mL}}{125.0\ \text{mL}} = 0.210\ \text{M}$

$[\text{HCl}]\ (\text{total}) = 0.0500\ \text{M} + 0.210\ \text{M} = \mathbf{0.260\ M}$

98\. (a) $[\text{KBr}] = 0.750\ \text{M} \times \frac{250.0\ \text{mL}}{175.0\ \text{mL}} = \mathbf{1.07\ M}$

(b) $[\text{NaNO}_3] = 0.125\ \text{M} \times \frac{75.0\ \text{mL}}{325.0\ \text{mL}} = \mathbf{0.0288\ M}$

(c) $[\text{LiBr}]_{\text{DIL}}\ (\#1) = 0.325\ \text{M} \times \frac{150.0\ \text{mL}}{275.0\ \text{mL}} = 0.177\ \text{M}$

$[\text{LiBr}]_{\text{DIL}}\ (\#2) = 0.500\ \text{M} \times \frac{225.0\ \text{mL}}{275.0\ \text{mL}} = 0.409\ \text{M}$

$[\text{LiBr}]\ (\text{total}) = 0.177\ \text{M} + 0.409\ \text{M} = \mathbf{0.586\ M}$

99\. (a) $\text{moles KBr} = 2.5\ \frac{\text{mol}}{\text{L}} \times 5.0\ \text{L} = 12.5\ \text{mol}$

$\text{mass KBr} = 12.5\ \text{mol} \times \frac{119.0\ \text{g}}{1\ \text{mol}} = \mathbf{1.5 \times 10^3\ g}$

(b) $\text{moles MgI}_2 = 0.135\ \frac{\text{mol}}{\text{L}} \times 0.225\ \text{L} = 0.0304\ \text{mol}$

$\text{mass MgI}_2 = 0.0304\ \text{mol} \times \frac{278.1\ \text{g}}{1\ \text{mol}} = \mathbf{8.45\ g}$

(c) $\text{moles NaCl} = 0.250\ \frac{\text{mol}}{\text{L}} \times 0.3500\ \text{L} = 0.0875\ \text{mol}$

$\text{mass NaCl} = 0.0875\ \text{mol} \times \frac{58.5\ \text{g}}{1\ \text{mol}} = \mathbf{5.12\ g}$

100. (a) $[C_8H_{18}] = 702.5\,\frac{g}{L} \times \frac{1\text{ mol}}{114.0\text{ g}} = \mathbf{6.162\ M}$

(b) $[CH_3COCH_3] = 789.9\,\frac{g}{L} \times \frac{1\text{ mol}}{58.0\text{ g}} = \mathbf{13.6\ M}$

(c) $[POCl_3] = 1675\,\frac{g}{L} \times \frac{1\text{ mol}}{153.5\text{ g}} = \mathbf{10.91\ M}$

101. (a) $d = 13.8\,\frac{\text{mol}}{L} \times \frac{216.8\text{ g}}{1\text{ mol}} = \mathbf{2.99 \times 10^3\ g/L}$ or $\mathbf{2.99\ g/mL}$

(b) $d = 12.73\,\frac{\text{mol}}{L} \times \frac{135.2\text{ g}}{1\text{ mol}} = \mathbf{1721\ g/L}$ or $\mathbf{1.721\ g/mL}$

(c) $d = 9.825\,\frac{\text{mol}}{L} \times \frac{106.0\text{ g}}{1\text{ mol}} = \mathbf{1041\ g/L}$ or $\mathbf{1.041\ g/mL}$

102. (a) $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.250\text{ M} \times 5.00\text{ L}}{3.00\text{ M}} = \mathbf{0.417\ L}$

(b) $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.100\text{ M} \times 0.5000\text{ L}}{15.4\text{ M}} = 0.00325\text{ L} = \mathbf{3.25\ mL}$

(c) $V_{\text{DIL}} = \frac{c_{\text{CONC}} \times V_{\text{CONC}}}{c_{\text{DIL}}} = \frac{5.00\text{ M} \times 0.2500\text{ L}}{0.150\text{ M}} = \mathbf{8.33\ L}$

(d) $c_{\text{DIL}} = \frac{c_{\text{CONC}} \times V_{\text{CONC}}}{V_{\text{DIL}}} = \frac{0.850\text{ M} \times 3.00\text{ L}}{12.5\text{ L}} = \mathbf{0.204\ M}$

(e) $c_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{V_{\text{CONC}}} = \frac{0.100\text{ M} \times 5.00\text{ L}}{0.1000\text{ L}} = \mathbf{5.00\ M}$

(f) moles KBr $= 0.235\,\frac{\text{mol}}{L} \times 0.5000\text{ L} = 0.118\text{ mol}$

mass KBr $= 0.118\text{ mol} \times \frac{119.0\text{ g}}{1\text{ mol}} = \mathbf{14.0\ g}$

(g) moles HCl $= 50.0\text{ g} \times \frac{1\text{ mol}}{36.5\text{ g}} = 1.37\text{ mol}$

volume $= \frac{1.37\text{ mol}}{0.550\text{ mol/L}} = \mathbf{2.49\ L}$

(h) moles LiCl $= 0.850\,\frac{\text{mol}}{L} \times 5.50\text{ L} = \mathbf{4.68\ mol}$

(i) $[CaCl_2] = \frac{75.0\text{ g}}{0.9500\text{ L}} \times \frac{1\text{ mol}}{111.1\text{ g}} = \mathbf{0.710\ M}$

(j) density $= 11.4\,\frac{\text{mol}}{L} \times \frac{252.7\text{ g}}{1\text{ mol}} = \mathbf{2.88 \times 10^3\ g/L}$ or $\mathbf{2.88\ g/mL}$

(k) moles $Ba(NO_3)_2 = 2.55\text{ g} \times \frac{1\text{ mol}}{261.3\text{ g}} = 9.76 \times 10^{-3}\text{ mol}$

volume $= \frac{9.76 \times 10^{-3}\text{ mol}}{0.0675\text{ mol/L}} = \mathbf{0.144\ L}$

(l) $\text{moles FeCl}_3 = 0.368\ \frac{\text{mol}}{\text{L}} \times 1.50\ \text{L} = \mathbf{0.552\ mol}$

(m) $[\text{SnCl}_2] = \frac{25.00\ \text{g}}{0.7500\ \text{L}} \times \frac{1\ \text{mol}}{225.7\ \text{g}} = \mathbf{0.1477\ M}$

(n) $V_{\text{CONC}} = \frac{c_{\text{DIL}} \times V_{\text{DIL}}}{c_{\text{CONC}}} = \frac{0.0450\ \text{M} \times 3.50\ \text{L}}{0.995\ \text{M}} = \mathbf{0.158\ L}$

(o) $[\text{NaCl}] = 0.543\ \text{M} \times \frac{55.0\ \text{mL}}{240.0\ \text{mL}} = \mathbf{0.124\ M}$

(p) $\text{moles BaCl}_2{\cdot}2\text{H}_2\text{O} = \text{moles BaCl}_2 = 0.250\ \frac{\text{mol}}{\text{L}} \times 1.35\ \text{L} = 0.338\ \text{mol}$

$\text{mass BaCl}_2{\cdot}2\text{H}_2\text{O} = 0.338\ \text{mol} \times \frac{244.3\ \text{g}}{1\ \text{mol}} = \mathbf{82.4\ g}$

(q) $[\text{CaCl}_2]_{\text{DIL}}\ (\#1) = 0.550\ \text{M} \times \frac{145\ \text{mL}}{200\ \text{mL}} = 0.399\ \text{M}$

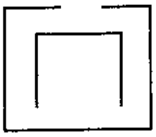
$[\text{CaCl}_2]_{\text{DIL}}\ (\#2) = 0.135\ \text{M} \times \frac{55\ \text{mL}}{200\ \text{mL}} = 0.0371\ \text{M}$

$[\text{CaCl}_2]\ (\text{total}) = 0.399\ \text{M} + 0.0371\ \text{M} = \mathbf{0.436\ M}$

(r) $[\text{C}_6\text{H}_6] = 878.7\ \frac{\text{g}}{\text{L}} \times \frac{1\ \text{mol}}{78.0\ \text{g}} = \mathbf{11.3\ M}$

ANSWERS TO UNIT VI : CHEMICAL REACTIONS

1. (a) A system that is enclosed by an opaque box. (Light can't get in.)
   (b) A system that is enclosed by a transparent box. (Material can't get in or out, but light can.)
   (c) A system that is enclosed by a sound–absorbing box (transparent or opaque).
   (d) A system that, for example, is surrounded by two boxes, one that is open at the top and one that is open at the bottom, as shown below.



   (e) A system in a container with heat–insulation. (This is not truly "closed"; see exercise 2; below.)

2. The only system which might be closed is the universe itself (and astronomers are still arguing about this point). In general approximately closed systems can be made; but even the best heat insulation cannot keep a liquid hot forever. The problem is making a container through which energy cannot pass.

3. (a) What is CONSERVED: the composition (the material is still paper); total mass and properties such as colour, volume and density
   (b) What is NOT CONSERVED: the number of pieces present, shape
   (c) What is CONSERVED: composition and properties such as colour and density
   What is NOT CONSERVED: total mass; volume, surface area, shape and number of pieces

4. (a) Conservation of atoms (primarily) and conservation of mass will also be violated since Fe atoms have a different mass from Cu atoms.
   (b) Conservation of mass (15 g of reactants cannot make 16 g of products)
   (c) Conservation of charge: total charge on left = +1; total charge on right = 0.
   (d) No conservation laws violated.
   (e) Conservation of atoms (different numbers of Cr's and O's on either side). Conservation of mass will also be violated as a result.
   (f) No conservation laws violated

5. Only (b) is **always** conserved. The others occasionally may be conserved in particular reactions.

6. (a) Left hand side contains: 1 C + 4 H + 4 O ; molar mass of reactants = 1 x 16.0 + 2 x 32.0 = 80.0 g
   Right hand side contains: 1 C + 4 O + 4 H ; molar mass of products = 1 x 44.0 + 2 x 18.0 = 80.0 g
   Since left and right sides have the same number and types of atoms and the same mass, atoms and mass are conserved.

   (b) Left hand side contains: 1 Na + 1 O + 2 H + 1 Cl ; molar mass of reactants = 40.0 + 36.5 = 76.5 g
   Right hand side contains: 1 Na + 1 Cl + 2 H + 1 O ; molar mass of products = 58.5 + 18.0 = 76.5 g
   Since left and right sides have the same number and types of atoms and the same mass, atoms and mass are conserved.

7. $2\,Sn + O_2 \longrightarrow 2\,SnO$
8. $H_2 + Cl_2 \longrightarrow 2\,HCl$
9. $N_2 + 3\,H_2 \longrightarrow 2\,NH_3$
10. $2\,Na + 2\,H_2O \longrightarrow 2\,NaOH + H_2$
11. $4\,NH_3 + 3\,O_2 \longrightarrow 2\,N_2 + 6\,H_2O$
12. $2\,C_6H_{14} + 19\,O_2 \longrightarrow 12\,CO_2 + 14\,H_2O$
13. $2\,KNO_3 \longrightarrow 2\,KNO_2 + O_2$
14. $CaC_2 + 2\,O_2 \longrightarrow Ca + 2\,CO_2$
15. $C_5H_{12} + 8\,O_2 \longrightarrow 5\,CO_2 + 6\,H_2O$
16. $K_2SO_4 + BaCl_2 \longrightarrow 2\,KCl + BaSO_4$
17. $2\,KOH + H_2SO_4 \longrightarrow K_2SO_4 + 2\,H_2O$
18. $Ca(OH)_2 + 2\,NH_4Cl \longrightarrow 2\,NH_3 + CaCl_2 + 2\,H_2O$
19. $5\,C + 2\,SO_2 \longrightarrow CS_2 + 4\,CO$

20. $Mg_3N_2 + 6\,H_2O \longrightarrow 3\,Mg(OH)_2 + 2\,NH_3$
21. $V_2O_5 + 5\,Ca \longrightarrow 5\,CaO + 2\,V$
22. $2\,Na_2O_2 + 2\,H_2O \longrightarrow 4\,NaOH + O_2$
23. $Fe_3O_4 + 4\,H_2 \longrightarrow 3\,Fe + 4\,H_2O$
24. $Cu + 2\,H_2SO_4 \longrightarrow CuSO_4 + 2\,H_2O + SO_2$
25. $2\,Al + 3\,H_2SO_4 \longrightarrow 3\,H_2 + Al_2(SO_4)_3$
26. $2\,Si_4H_{10} + 13\,O_2 \longrightarrow 8\,SiO_2 + 10\,H_2O$
27. $4\,NH_3 + O_2 \longrightarrow 2\,N_2H_4 + 2\,H_2O$
28. $2\,C_{15}H_{30} + 45\,O_2 \longrightarrow 30\,CO_2 + 30\,H_2O$
29. $2\,BN + 3\,F_2 \longrightarrow 2\,BF_3 + N_2$
30. $CaSO_4{\cdot}2H_2O + 2\,SO_3 \longrightarrow CaSO_4 + 2\,H_2SO_4$
31. $4\,C_3H_7N_2O_7 + 5\,O_2 \longrightarrow 12\,CO_2 + 14\,H_2O + 4\,N_2$
32. $C_7H_{16}O_4S_2 + 11\,O_2 \longrightarrow 7\,CO_2 + 8\,H_2O + 2\,SO_2$
33. $9\,Na + 4\,ZnI_2 \longrightarrow 8\,NaI + NaZn_4$
34. $HBrO_3 + 5\,HBr \longrightarrow 3\,H_2O + 3\,Br_2$
35. $Al_4C_3 + 12\,H_2O \longrightarrow 4\,Al(OH)_3 + 3\,CH_4$
36. $2\,Ca(NO_3)_2{\cdot}3H_2O + 3\,LaC_2 \longrightarrow 2\,Ca(NO_3)_2 + 3\,La(OH)_2 + 3\,C_2H_2$
37. $CH_3NO_2 + 3\,Cl_2 \longrightarrow CCl_3NO_2 + 3\,HCl$
38. $Ca_3(PO_4)_2 + 3\,SiO_2 + 5\,C \longrightarrow 3\,CaSiO_3 + 5\,CO + 2\,P$
39. $Al_2C_6 + 6\,H_2O \longrightarrow 2\,Al(OH)_3 + 3\,C_2H_2$
40. $2\,NaF + CaO + H_2O \longrightarrow CaF_2 + 2\,NaOH$
41. $4\,LiH + AlCl_3 \longrightarrow LiAlH_4 + 3\,LiCl$
42. $2\,CaF_2 + 2\,H_2SO_4 + SiO_2 \longrightarrow 2\,CaSO_4 + SiF_4 + 2\,H_2O$
43. $3\,CaSi_2 + 2\,SbCl_3 \longrightarrow 6\,Si + 2\,Sb + 3\,CaCl_2$
44. $2\,TiO_2 + B_4C + 3\,C \longrightarrow 2\,TiB_2 + 4\,CO$
45. $4\,NH_3 + 5\,O_2 \longrightarrow 4\,NO + 6\,H_2O$
46. $SiF_4 + 8\,NaOH \longrightarrow Na_4SiO_4 + 4\,NaF + 4\,H_2O$
47. $2\,NH_4Cl + CaO \longrightarrow 2\,NH_3 + CaCl_2 + H_2O$
48. $4\,NaPb + 4\,C_2H_5Cl \longrightarrow Pb(C_2H_5)_4 + 3\,Pb + 4\,NaCl$
49. $Be_2C + 4\,H_2O \longrightarrow 2\,Be(OH)_2 + CH_4$
50. $4\,NpF_3 + O_2 + 4\,HF \longrightarrow 4\,NpF_4 + 2\,H_2O$
51. $3\,NO_2 + H_2O \longrightarrow 2\,HNO_3 + NO$
52. $3\,LiAlH_4 + 4\,BF_3 \longrightarrow 3\,LiF + 3\,AlF_3 + 2\,B_2H_6$
53. $3\,Cu + 8\,HNO_3 \longrightarrow 3\,Cu(NO_3)_2 + 2\,NO + 4\,H_2O$
54. $3\,FeCl_2 + KNO_3 + 4\,HCl \longrightarrow 3\,FeCl_3 + NO + 2\,H_2O + KCl$
55. $2\,KMnO_4 + 16\,HBr \longrightarrow 2\,MnBr_2 + 5\,Br_2 + 2\,KBr + 8\,H_2O$
56. $K_2Cr_2O_7 + 14\,HCl \longrightarrow 2\,KCl + 2\,CrCl_3 + 7\,H_2O + 3\,Cl_2$
57. (a) $2\,K + 2\,H_2O \longrightarrow 2\,KOH + H_2$
    (b) $Sr + 2\,H_2O \longrightarrow Sr(OH)_2 + H_2$
    (c) $2\,Al + 3\,Cl_2 \longrightarrow 2\,AlCl_3$
    (d) $2\,Cu_2O + C \longrightarrow 4\,Cu + CO_2$
    (e) $2\,NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$
58. $2\,H_3PO_4(l) + 3\,Ba(OH)_2(aq) \longrightarrow Ba_3(PO_4)_2(s) + 6\,H_2O(l)$
59. $Al_2O_3(s) + 3\,H_2SO_4(aq) \longrightarrow 3\,H_2O(l) + Al_2(SO_4)_3(aq)$
60. $2\,NF_3(g) + 3\,H_2(g) \longrightarrow N_2(g) + 6\,HF(g)$
61. $Na_2CO_3(s) + 2\,HBr(aq) \longrightarrow CO_2(g) + 2\,NaBr(aq) + H_2O(l)$

62. $2\,NaNO_3(s) + 10\,Na(s) \longrightarrow 6\,Na_2O(s) + N_2(g)$
63. $BCl_3(g) + 3\,H_2O(g) \longrightarrow B(OH)_3(s) + 3\,HCl(g)$
64. $XeF_6(g) + 3\,H_2O(l) \longrightarrow XeO_3(s) + 6\,HF(g)$
65. (a) $H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$
    (b) $H_3PO_4 + 3\,KOH \longrightarrow K_3PO_4 + 3\,H_2O$
    (c) $3\,H_2SO_4 + 2\,Fe(OH)_3 \longrightarrow Fe_2(SO_4)_3 + 6\,H_2O$
    (d) $H_4P_2O_7 + 2\,Ca(OH)_2 \longrightarrow Ca_2P_2O_7 + 4\,H_2O$
    (e) $H_2SO_4 + Ba(OH)_2 \longrightarrow BaSO_4 + 2\,H_2O$

66. (a) $2\,C_2H_2 + 5\,O_2 \longrightarrow 4\,CO_2 + 2\,H_2O$ (combustion)
    (b) $Mg + CuSO_4 \longrightarrow MgSO_4 + Cu$ (single replacement)
    (c) $4\,Na + O_2 \longrightarrow 2\,Na_2O$ (synthesis)
    (d) $2\,Fe(NO_3)_3 + 3\,MgS \longrightarrow Fe_2S_3 + 3\,Mg(NO_3)_2$ (double replacement)
    (e) $2\,N_2O \longrightarrow 2\,N_2 + O_2$ (decomposition)
    (f) $Sn(OH)_4 + 4\,HBr \longrightarrow 4\,H_2O + SnBr_4$ (neutralization)
    (g) $Cl_2 + 2\,KI \longrightarrow 2\,KCl + I_2$ (single replacement)
    (h) $2\,Al + 3\,S \longrightarrow Al_2S_3$ (synthesis)
    (i) $C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$ (combustion)
    (j) $3\,HF + Fe(OH)_3 \longrightarrow FeF_3 + 3\,H_2O$ (neutralization)
    (k) $2\,H_2O_2 \longrightarrow 2\,H_2O + O_2$ (decomposition)
    (l) $FeCl_2 + K_2S \longrightarrow FeS + 2\,KCl$ (double replacement)
    (m) $2\,Ca + O_2 \longrightarrow 2\,CaO$ (synthesis)
    (n) $H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O$ (neutralization)
    (o) $C_2H_5OH + 3\,O_2 \longrightarrow 2\,CO_2 + 3\,H_2O$ (combustion)
    (p) $4\,Cr + 3\,SnCl_4 \longrightarrow 4\,CrCl_3 + 3\,Sn$ (single replacement)
    (q) $Pb(NO_3)_2 + K_2CrO_4 \longrightarrow PbCrO_4 + 2\,KNO_3$ (double replacement)
    (r) $Fe + I_2 \longrightarrow FeI_2$ (synthesis)
    (s) $C_3H_6OS_2 + 6\,O_2 \longrightarrow 3\,CO_2 + 3\,H_2O + 2\,SO_2$ (combustion)
    (t) $MgCl_2 \longrightarrow Mg + Cl_2$ (decomposition)
    (u) $Co(NO_3)_2 + H_2S \longrightarrow CoS + 2\,HNO_3$ (double replacement)
    (v) $H_4P_2O_7 + 4\,KOH \longrightarrow K_4P_2O_7 + 4\,H_2O$ (neutralization)
    (w) $Mg + 2\,HCl \longrightarrow H_2 + MgCl_2$ (single replacement)
    (x) $2\,HI \longrightarrow H_2 + I_2$ (decomposition)

67. (a) $2\,HNO_3 + Sr(OH)_2 \longrightarrow Sr(NO_3)_2 + 2\,H_2O$ (neutralization)
    (b) $2\,C_6H_4(OH)_2 + 13\,O_2 \longrightarrow 12\,CO_2 + 6\,H_2O$ (combustion)
    (c) $Zn + Ni(NO_3)_2 \longrightarrow Ni + Zn(NO_3)_2$ (single replacement)
    (d) $2\,AlCl_3 + 3\,Na_2CO_3 \longrightarrow Al_2(CO_3)_3 + 6\,NaCl$ (double replacement)
    (e) $4\,Al + 3\,O_2 \longrightarrow 2\,Al_2O_3$ (synthesis)
    (f) $Ba(OH)_2 + H_2SO_4 \longrightarrow BaSO_4 + 2\,H_2O$ (neutralization)
    (g) $2\,NO_2 \longrightarrow N_2 + 2\,O_2$ (decomposition)
    (h) $Cl_2 + CaBr_2 \longrightarrow Br_2 + CaCl_2$ (single replacement)
    (i) $C_9H_{20}O_4S_2 + 14\,O_2 \longrightarrow 9\,CO_2 + 10\,H_2O + 2\,SO_2$ (combustion)
    (j) $ZnSO_4 + SrCl_2 \longrightarrow SrSO_4 + ZnCl_2$ (double replacement)
    (k) $8\,Zn + S_8 \longrightarrow 8\,ZnS$ (synthesis)
    (l) $2\,NH_3 \longrightarrow N_2 + 3\,H_2$ (decomposition)
    (m) $HCl + KOH \longrightarrow KCl + H_2O$ (neutralization)
    (n) $2\,ICl \longrightarrow I_2 + Cl_2$ (decomposition)

(o) $2\,Na_3PO_4 + 3\,Ca(OH)_2 \longrightarrow Ca_3(PO_4)_2 + 6\,NaOH$ (double replacement)
(p) $C_4H_8S + 7\,O_2 \longrightarrow 4CO_2 + 4\,H_2O + SO_2$ (combustion)
(q) $Mg + ZnSO_4 \longrightarrow Zn + MgSO_4$ (single replacement)
(r) $4\,Li + O_2 \longrightarrow 2\,Li_2O$ (synthesis)

68. (a) Step 1 absorbs energy to break bonds.
(b) Step 2 gives off energy as bonds are made.
(c) Step 2 gives off more energy than step 1 absorbs.

69. $H + Cl \longrightarrow HCl + 432\,kJ$. The two reactions are exact opposites of each other, including the heat term.

70. Exothermic; heat is produced

71. Endothermic; heat is absorbed by the sugar in order to melt

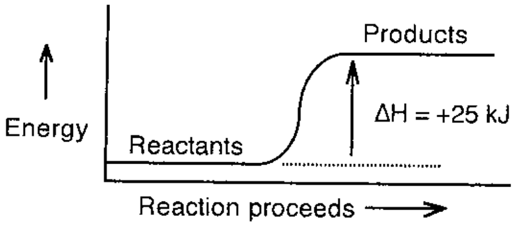
72. Chemicals are **losing** energy to the surrounding beaker. The reaction is exothermic.

73. Products. The reactants gain energy and become high energy products.

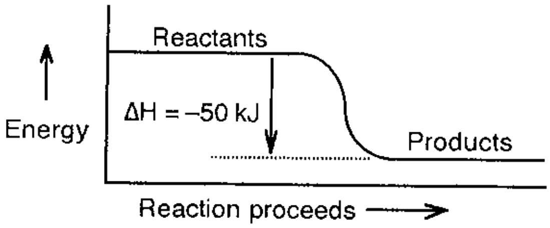
74. Energy is removed from reactants as lower energy products are formed.

75. Since $H_{REACTANTS} < H_{PRODUCTS}$; then $\Delta H = H_{PRODUCTS} - H_{REACTANTS} > 0$ for an endothermic reaction.
Since $H_{REACTANTS} > H_{PRODUCTS}$; then $\Delta H = H_{PRODUCTS} - H_{REACTANTS} < 0$ for an exothermic reaction.

76. The actual energies of the reactants and products are not important; only the energy difference matters.



77. Again; only the energy difference of the reactants and products matters.



78. $F \longrightarrow G + 50\,kJ$

79. $\Delta H = +30\,kJ$

80. $\Delta H = -25\,kJ$; the reactants have more energy.

ANSWERS TO UNIT VII : CALCULATIONS INVOLVING REACTIONS (STOICHIOMETRY)

1. (a) $\#\text{ of } O_2 \text{ molecules} = 6 \text{ molecules } C_2H_6 \times \frac{7 \text{ molecules } O_2}{2 \text{ molecules } C_2H_6}$ = **21 molecules**

   (b) $\#\text{ of } H_2O \text{ molecules} = 12 \text{ molecules } C_2H_6 \times \frac{6 \text{ molecules } H_2O}{2 \text{ molecules } C_2H_6}$ = **36 molecules**

   (c) $\#\text{ of moles of } O_2 = 18 \text{ mol } CO_2 \times \frac{7 \text{ mol } O_2}{4 \text{ mol } CO_2}$ = **31.5 mol**

   (d) $\#\text{ of moles of } CO_2 = 13 \text{ mol } C_2H_6 \times \frac{4 \text{ mol } CO_2}{2 \text{ mol } C_2H_6}$ = **26 mol**

2. (a) $\#\text{ of molecules } Fe_3O_4 = 12 \text{ atoms Fe} \times \frac{1 \text{ molecule } Fe_3O_4}{3 \text{ atoms Fe}}$ = **4 molecules**

   (b) $\#\text{ of moles of Fe} = 16 \text{ mol } H_2 \times \frac{3 \text{ mol Fe}}{4 \text{ mol } H_2}$ = **12 mol**

   (c) $\#\text{ of molecules } H_2 = 40 \text{ molecules } Fe_3O_4 \times \frac{4 \text{ molecules } H_2}{1 \text{ molecule } Fe_3O_4}$ = **160 molecules**

   (d) $\#\text{ of moles of } H_2O = 14.5 \text{ mol Fe} \times \frac{4 \text{ mol } H_2O}{3 \text{ mol Fe}}$ = **19.3 mol**

3. $\#\text{ of moles of } H_2O = 9.6 \text{ mol } O_2 \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}$ = **19 mol**

4. (a) $\#\text{ of moles of } I_4F_2 = 5.40 \text{ mol } F_2 \times \frac{1 \text{ mol } I_4F_2}{6 \text{ mol } F_2}$ = **0.900 mol**

   (b) $\#\text{ of moles of } F_2 = 4.50 \text{ mol } IF_5 \times \frac{6 \text{ mol } F_2}{2 \text{ mol } IF_5}$ = **13.5 mol**

   (c) $\#\text{ of moles of } I_2 = 7.60 \text{ mol } F_2 \times \frac{3 \text{ mol } I_2}{6 \text{ mol } F_2}$ = **3.80 mol**

5. Since 2 mol of reactants make a total of 3 mol of products, then O_2 represents $1/5$ of the total moles involved. Therefore:

   $\#\text{ of moles of } O_2 = \frac{0.125 \text{ mol}}{5}$ = **0.025 mol**

   Alternately: $\#\text{ of moles of } O_2 = 0.125 \text{ mol molecules} \times \frac{1 \text{ mol } O_2}{5 \text{ mol molecules}}$ = **0.025 mol**

6. (a) $\text{mass of NO} = 2.00 \text{ mol } NH_3 \times \frac{4 \text{ mol NO}}{4 \text{ mol } NH_3} \times \frac{30.0 \text{ g NO}}{1 \text{ mol NO}}$ = **60.0 g**

   (b) $\text{mass of } H_2O = 4.00 \text{ mol } O_2 \times \frac{6 \text{ mol } H_2O}{5 \text{ mol } O_2} \times \frac{18.0 \text{ g } H_2O}{1 \text{ mol } H_2O}$ = **86.4 g**

   (c) $\text{volume of } NH_3 = 3.00 \text{ mol } O_2 \times \frac{4 \text{ mol } NH_3}{5 \text{ mol } O_2} \times \frac{22.4 \text{ L } NH_3}{1 \text{ mol } NH_3}$ = **53.8 L**

   (d) $\text{volume of } NH_3 = 0.750 \text{ mol } H_2O \times \frac{4 \text{ mol } NH_3}{6 \text{ mol } H_2O} \times \frac{22.4 \text{ L } NH_3}{1 \text{ mol } NH_3}$ = **11.2 L**

7. (a) $\text{mass of } CO_2 = 100.0\text{ g } C_5H_{12} \times \frac{1\text{ mol } C_5H_{12}}{72.0\text{ g } C_5H_{12}} \times \frac{5\text{ mol } CO_2}{1\text{ mol } C_5H_{12}} \times \frac{44.0\text{ g } CO_2}{1\text{ mol } CO_2} = \mathbf{306\ g}$

(b) $\text{mass of } O_2 = 60.0\text{ g } H_2O \times \frac{1\text{ mol } H_2O}{18.0\text{ g } H_2O} \times \frac{8\text{ mol } O_2}{6\text{ mol } H_2O} \times \frac{32.0\text{ g } O_2}{1\text{ mol } O_2} = \mathbf{142\ g}$

(c) $\text{mass of } C_5H_{12} = 90.0\text{ L } CO_2 \times \frac{1\text{ mol } CO_2}{22.4\text{ L } CO_2} \times \frac{1\text{ mol } C_5H_{12}}{5\text{ mol } CO_2} \times \frac{72.0\text{ g } C_5H_{12}}{1\text{ mol } C_5H_{12}} = \mathbf{57.9\ g}$

(d) $\text{volume of } O_2 = 70.0\text{ g } CO_2 \times \frac{1\text{ mol } CO_2}{44.0\text{ g } CO_2} \times \frac{8\text{ mol } O_2}{5\text{ mol } CO_2} \times \frac{22.4\text{ L } O_2}{1\text{ mol } O_2} = \mathbf{57.0\ L}$

(e) $\text{volume of } O_2 = 48.0\text{ L } CO_2 \times \frac{1\text{ mol } CO_2}{22.4\text{ L } CO_2} \times \frac{8\text{ mol } O_2}{5\text{ mol } CO_2} \times \frac{22.4\text{ L } O_2}{1\text{ mol } O_2} = \mathbf{76.8\ L}$

(f) $\text{mass of } H_2O = 106\text{ L } CO_2 \times \frac{1\text{ mol } CO_2}{22.4\text{ L } CO_2} \times \frac{6\text{ mol } H_2O}{5\text{ mol } CO_2} \times \frac{18.0\text{ g } H_2O}{1\text{ mol } H_2O} = \mathbf{102\ g}$

8. (a) $\text{volume of } O_2 = 100.0\text{ g PbO} \times \frac{1\text{ mol PbO}}{223.2\text{ g PbO}} \times \frac{27\text{ mol } O_2}{2\text{ mol PbO}} \times \frac{22.4\text{ L } O_2}{1\text{ mol } O_2} = \mathbf{135\ L}$

(b) $\#\text{ of molecules of } CO_2 = 1.00 \times 10^{-6}\text{ g } Pb(C_2H_5)_4 \times \frac{1\text{ mol } Pb(C_2H_5)_4}{323.2\text{ g } Pb(C_2H_5)_4} \times \frac{16\text{ mol } CO_2}{2\text{ mol } Pb(C_2H_5)_4}$

$\times \frac{6.02 \times 10^{23}\text{ molecules } CO_2}{1\text{ mol } CO_2} = \mathbf{1.49 \times 10^{16}\ molecules}$

(c) $\#\text{ of molecules of } H_2O = 135\text{ molecules } O_2 \times \frac{20\text{ molecules } H_2O}{27\text{ molecules } O_2} = \mathbf{100\ molecules}$

(d) $\text{volume of } O_2 = 1.00 \times 10^{15}\text{ molec } Pb(C_2H_5)_4 \times \frac{1\text{ mol } Pb(C_2H_5)_4}{6.02 \times 10^{23}\text{ molec } Pb(C_2H_5)_4} \times \frac{27\text{ mol } O_2}{2\text{ mol } Pb(C_2H_5)_4}$

$\times \frac{22.4\text{ L } O_2}{1\text{ mol } O_2} \times \frac{1\text{ mL}}{10^{-3}\text{ L}} = \mathbf{5.02 \times 10^{-4}\ mL}$

9. (a) $\text{mass of } H_2O = 0.150\text{ g } CH_3NO_2 \times \frac{1\text{ mol } CH_3NO_2}{61.0\text{ g } CH_3NO_2} \times \frac{6\text{ mol } H_2O}{4\text{ mol } CH_3NO_2} \times \frac{18.0\text{ g } H_2O}{1\text{ mol } H_2O} = \mathbf{0.0664\ g}$

(b) First, note that 4 mol of CH_3NO_2 produce 4 mol $CO_2(g)$ and 2 mol $N_2(g)$; that is, 6 mol of gas.

$\text{volume of gas} = 0.316\text{ g } CH_3NO_2 \times \frac{1\text{ mol } CH_3NO_2}{61.0\text{ g } CH_3NO_2} \times \frac{6\text{ mol gas}}{4\text{ mol } CH_3NO_2} \times \frac{22.4\text{ L gas}}{1\text{ mol gas}} = \mathbf{0.174\ L}$

(c) $\text{volume of } O_2 = 0.250\text{ g } CO_2 \times \frac{1\text{ mol } CO_2}{44.0\text{ g } CO_2} \times \frac{3\text{ mol } O_2}{4\text{ mol } CO_2} \times \frac{22.4\text{ L } O_2}{1\text{ mol } O_2} = \mathbf{0.0955\ L}$

(d) $\text{mass of } H_2O = 0.410\text{ g } CO_2 \times \frac{1\text{ mol } CO_2}{44.0\text{ g } CO_2} \times \frac{6\text{ mol } H_2O}{4\text{ mol } CO_2} \times \frac{18.0\text{ g } H_2O}{1\text{ mol } H_2O} = \mathbf{0.252\ g}$

10. $\text{mass of } SiCl_4 = 1.00\text{ g Si} \times \frac{1\text{ mol Si}}{28.1\text{ g Si}} \times \frac{1\text{ mol } SiCl_4}{1\text{ mol Si}} \times \frac{170.1\text{ g } SiCl_4}{1\text{ mol } SiCl_4} = \mathbf{6.05\ g}$

$\text{mass of } H_2 = 1.00\text{ g Si} \times \frac{1\text{ mol Si}}{28.1\text{ g Si}} \times \frac{2\text{ mol } H_2}{1\text{ mol Si}} \times \frac{2.0\text{ g } H_2}{1\text{ mol } H_2} = \mathbf{0.14\ g}$

11. volume of $NH_3 = 1.25 \times 10^4$ kg $N_2H_4 \times \frac{10^3 \text{ g } N_2H_4}{1 \text{ kg } N_2H_4} \times \frac{1 \text{ mol } N_2H_4}{32.0 \text{ g } N_2H_4} \times \frac{2 \text{ mol } NH_3}{1 \text{ mol } N_2H_4} \times \frac{22.4 \text{ L } NH_3}{1 \text{ mol } NH_3}$

$= \mathbf{1.75 \times 10^7 \text{ L}}$

12. mass of $H_2SO_4 = 25.0 \text{ mL} \times 1.84 \frac{\text{g}}{\text{mL}} = 46.0 \text{ g}$

mass of $P_4O_{10} = 46.0 \text{ g } H_2SO_4 \times \frac{1 \text{ mol } H_2SO_4}{98.1 \text{ g } H_2SO_4} \times \frac{1 \text{ mol } P_4O_{10}}{6 \text{ mol } H_2SO_4} \times \frac{284.0 \text{ g } P_4O_{10}}{1 \text{ mol } P_4O_{10}} = \mathbf{22.2 \text{ g}}$

volume of $SO_3 = 46.0 \text{ g } H_2SO_4 \times \frac{1 \text{ mol } H_2SO_4}{98.1 \text{ g } H_2SO_4} \times \frac{6 \text{ mol } SO_3}{6 \text{ mol } H_2SO_4} \times \frac{22.4 \text{ L } SO_3}{1 \text{ mol } SO_3} = \mathbf{10.5 \text{ L}}$

13. mass of $Cl = 1.5 \times 10^{15} \text{ L } O_3 \times \frac{1 \text{ mol } O_3}{22.4 \text{ L } O_3} \times \frac{1 \text{ mol Cl}}{1.0 \times 10^5 \text{ mol } O_3} \times \frac{35.5 \text{ g Cl}}{1 \text{ mol Cl}} = \mathbf{2.4 \times 10^{10} \text{ g}}$

14. We know that 0.150 mol of R_4 reacts with 143.8 g of Q_2, but the reaction ($R_4 + 6\,Q_2 \longrightarrow 4\,RQ_3$) shows 1 mol of R_4 reacting with 6 mol of Q_2. The amount of Q_2 formed by 0.150 mol of R_4 is

moles of $Q_2 = 0.150 \text{ mol } R_4 \times \frac{6 \text{ mol } Q_2}{1 \text{ mol } R_4} = 0.900 \text{ mol.}$

But, if 0.15 mol of R_4 reacts with 0.900 mol of Q_2 and with 143.8 g of Q_2, then

$0.900 \text{ mol } Q_2 = 143.8 \text{ g } Q_2$, so that: $1 \text{ mol } Q_2 = 159.8 \text{ g.}$

Hence, the molar mass of Q is 159.8 g / 2 = **79.9 g**. (A check of the periodic chart shows that Q is "Br".)

15. First find how many MOLES of atoms are in 100.0 g of Ne.

moles of Ne $= 100.0 \text{ g} \times \frac{1 \text{ mol Ne}}{20.2 \text{ g Ne}} = 4.95 \text{ mol}$

moles of atoms from decomposing HgO = 4.95 mol / 3 = 1.65 mol.

Now, 2 HgO molecules decompose to form 4 atoms of products (2 Hg atoms and 2 O atoms).

moles of HgO needed $= 1.65 \text{ moles products} \times \frac{2 \text{ mol HgO}}{4 \text{ mol products}} = 0.825 \text{ mol}$

and: mass of HgO $= 0.825 \text{ mol} \times \frac{216.6 \text{ g}}{1 \text{ mol}} = \mathbf{179 \text{ g}}$

16. Balance the equation: $2\,XZO_3 \longrightarrow 3\,O_2 + 2\,XZ$. Using the mass of O_2, find the moles of XZ produced.

moles of XZ $= 2.208 \text{ g } O_2 \times \frac{1 \text{ mol } O_2}{32.0 \text{ g } O_2} \times \frac{2 \text{ mol XZ}}{3 \text{ mol } O_2} = 0.0460 \text{ mol}$

Now: molar mass of XZ $= \frac{5.474 \text{ g}}{0.0460 \text{ mol}} = 119 \text{ g/mol}$

Balance the double replacement equation: $XZ + AgNO_3 \longrightarrow AgZ + XNO_3$. The double replacement implies that 1 mol XZ produces 1 mol AgZ (or that 0.0460 mol XZ produces 0.0460 mol AgZ). Hence: 0.0460 mol AgZ = 8.639 g (from problem statement) and

molar mass of AgZ $= \frac{8.639 \text{ g}}{0.0460 \text{ mol}} = 188 \text{ g/mol}$

Since the molar mass of Ag is 107.9, then molar mass of Z = 188 − 107.9 = $\mathbf{8.0 \times 10^1}$ **g/mol** (= Br)

and: molar mass X = molar mass XZ − molar mass Z = 119 − 8.0×10^1 = **39 g/mol** (= K)

17. Moles of NaOH $= 50.0 \text{ L } H_2 \times \frac{1 \text{ mol } H_2}{22.4 \text{ L } H_2} \times \frac{2 \text{ mol NaOH}}{3 \text{ mol } H_2} = 1.488 \text{ mol}$

volume of NaOH $= \frac{n}{c} = \frac{1.488 \text{ mol}}{3.00 \text{ mol/L}} = \mathbf{0.496 \text{ L}}$

18. The neutralization equation is: $HCl + NaOH \longrightarrow NaCl + H_2O$.

$$\text{moles of NaOH} = 0.318\ \frac{\text{mol}}{\text{L}} \times 0.0250\ \text{L} = 7.95 \times 10^{-3}\ \text{mol} = \text{moles HCl}$$

$$\text{volume of HCl} = \frac{n}{c} = \frac{0.00795\ \text{mol}}{0.250\ \text{mol/L}} = \mathbf{0.0318\ L\ \ (31.8\ mL)}$$

19. (a) $$\text{moles of } Cl^- = 0.0148\ \frac{\text{mol}}{\text{L}} \times 0.0154\ \text{L} = 2.279 \times 10^{-4}\ \text{mol}$$

$$\text{moles of } Hg^{2+} = 2.279 \times 10^{-4}\ \text{mol } Cl^- \times \frac{1\ \text{mol } Hg^{2+}}{2\ \text{mol } Cl^-} = 1.140 \times 10^{-4}\ \text{mol}$$

$= \text{moles } HgCl_2$ (for second part of problem)

$$[Hg^{2+}] = \frac{n}{V} = \frac{1.140 \times 10^{-4}\ \text{mol}}{0.0250\ \text{L}} = \mathbf{4.56 \times 10^{-3}\ M}$$

(b) $$\text{mass of } HgCl_2 = 1.140 \times 10^{-4}\ \text{mol} \times \frac{271.6\ \text{g}}{1\ \text{mol}} = \mathbf{0.0310\ g}$$

20. (a) The neutralization reaction is: $Ca(OH)_2 + 2\,HCl \longrightarrow CaCl_2 + 2\,H_2O$.

$$\text{moles of HCl} = 0.0156\ \frac{\text{mol}}{\text{L}} \times 0.0235\ \text{L} = 3.666 \times 10^{-4}\ \text{mol}$$

$$\text{moles of } Ca(OH)_2 = 3.666 \times 10^{-4}\ \text{mol HCl} \times \frac{1\ \text{mol } Ca(OH)_2}{2\ \text{mol HCl}} = 1.833 \times 10^{-4}\ \text{mol}$$

$$[Ca(OH)_2] = \frac{n}{V} = \frac{1.833 \times 10^{-4}\ \text{mol}}{0.0100\ \text{L}} = \mathbf{0.0183\ M}$$

(b) $$\text{mass of } Ca(OH)_2 = 0.01833\ \frac{\text{mol}}{\text{L}} \times 0.2500\ \text{L} \times \frac{74.1\ \text{g}}{1\ \text{mol}} = \mathbf{0.340\ g}$$

21. (a) $$\text{moles of } H_2O_2 = 1.24\ \frac{\text{mol}}{\text{L}} \times 0.00200\ \text{L} = 2.48 \times 10^{-3}\ \text{mol}$$

$$\text{moles of } MnO_4^- = 2.48 \times 10^{-3}\ H_2O_2 \times \frac{2\ \text{mol } MnO_4^-}{5\ \text{mol } H_2O_2} = 9.92 \times 10^{-4}\ \text{mol}$$

$$\text{volume of } MnO_4^- = \frac{n}{c} = \frac{9.92 \times 10^{-4}\ \text{mol}}{0.0496\ \text{mol/L}} = \mathbf{0.0200\ L\ \ (20.0\ mL)}$$

(b) $$\text{volume of } O_2 = 9.92 \times 10^{-4}\ \text{mol } MnO_4^- \times \frac{5\ \text{mol } O_2}{2\ \text{mol } MnO_4^-} \times \frac{22.4\ \text{L } O_2}{1\ \text{mol } O_2} = \mathbf{0.0556\ L}$$

22. (a) $$\text{moles of NaOH} = 0.853\ \frac{\text{mol}}{\text{L}} \times 0.0438\ \text{L} = 0.03736\ \text{mol}$$

$$\text{moles of } H_3PO_4 = 0.03736\ \text{mol NaOH} \times \frac{1\ \text{mol } H_3PO_4}{2\ \text{mol NaOH}} = 0.01868\ \text{mol}$$

$$[H_3PO_4] = \frac{n}{V} = \frac{0.01868\ \text{mol}}{0.00100\ \text{L}} = \mathbf{18.7\ M}$$

(b) $$\text{density} = 18.68\ \frac{\text{mol}}{\text{L}} \times \frac{98.0\ \text{g}}{1\ \text{mol}} = \mathbf{1.83 \times 10^{3}\ \frac{g}{L}}$$

23. (a) moles of $Cr_2O_7^{2-}$ $= 0.125 \frac{\text{mol}}{\text{L}} \times 0.0176\ \text{L} = 2.20 \times 10^{-3}\ \text{mol}$

moles of $Fe^{2+} = 2.20 \times 10^{-3}\ \text{mol}\ Cr_2O_7^{2-} \times \frac{6\ \text{mol}\ Fe^{2+}}{1\ \text{mol}\ Cr_2O_7^{2-}} = 0.0132\ \text{mol}$

$[Fe^{2+}] = \frac{n}{V} = \frac{0.0132\ \text{mol}}{0.0250\ \text{L}} = \mathbf{0.528\ M}$

(b) mass of Fe = mass of $Fe^{2+} = 0.01320\ \text{mol} \times \frac{55.8\ \text{g}}{1\ \text{mol}} = \mathbf{0.737\ g}$

24. (a) $[NH_4NO_3] = \frac{15.5\ \text{g}}{0.5000\ \text{L}} \times \frac{1\ \text{mol}}{80.0\ \text{g}} = 0.3875\ \text{M}$

moles of $NH_4NO_3 = 0.3875 \frac{\text{mol}}{\text{L}} \times 0.0100\ \text{L} = 3.875 \times 10^{-3}\ \text{mol}$ = moles NaOH

$[NaOH] = \frac{n}{V} = \frac{3.875 \times 10^{-3}\ \text{mol}}{0.0250\ \text{L}} = \mathbf{0.155\ M}$

(b) volume of $NH_3 = 3.875 \times 10^{-3}\ \text{mol NaOH} \times \frac{1\ \text{mol}\ NH_3}{1\ \text{mol NaOH}} \times \frac{22.4\ \text{L}\ NH_3}{1\ \text{mol}\ NH_3} = \mathbf{0.0868\ L}$

25. (a) moles of $Ba(OH)_2$ (at start) $= 0.0538 \frac{\text{mol}}{\text{L}} \times 0.0250\ \text{L} = \mathbf{1.345 \times 10^{-3}\ mol}$

(b) moles of HCl $= 0.104 \frac{\text{mol}}{\text{L}} \times 0.0230\ \text{L} = 2.392 \times 10^{-3}\ \text{mol}$

moles of $Ba(OH)_2$ (remaining) $= 2.392 \times 10^{-3}\ \text{mol HCl} \times \frac{1\ \text{mol}\ Ba(OH)_2}{2\ \text{mol HCl}} = \mathbf{1.196 \times 10^{-3}\ mol}$

(c) moles of $Ba(OH)_2$ (reacted) = moles $Ba(OH)_2$ (at start) – moles $Ba(OH)_2$ (remaining)
$= 1.345 \times 10^{-3} - 1.196 \times 10^{-3} = \mathbf{1.49 \times 10^{-4}\ mol}$

(d) moles of $CO_2 = 1.49 \times 10^{-4}\ \text{mol}\ Ba(OH)_2 \times \frac{1\ \text{mol}\ CO_2}{1\ \text{mol}\ Ba(OH)_2} = \mathbf{1.49 \times 10^{-4}\ mol}$

(e) volume of $CO_2 = 1.49 \times 10^{-4}\ \text{mol} \times \frac{22.4\ \text{L}}{1\ \text{mol}} = 3.34 \times 10^{-3}\ \text{L}$

% CO_2 in air $= \frac{3.34 \times 10^{-3}\ \text{L}}{10.0\ \text{L}} \times 100\% = \mathbf{0.0334\%}$

26. mass of CS_2 (based on C) $= 17.5\ \text{g C} \times \frac{1\ \text{mol C}}{12.0\ \text{g C}} \times \frac{1\ \text{mol}\ CS_2}{5\ \text{mol C}} \times \frac{76.2\ \text{g}\ CS_2}{1\ \text{mol}\ CS_2} = 22.2\ \text{g}$

mass of CS_2 (based on SO_2) $= 39.5\ \text{g}\ SO_2 \times \frac{1\ \text{mol}\ SO_2}{64.1\ \text{g}\ SO_2} \times \frac{1\ \text{mol}\ CS_2}{2\ \text{mol}\ SO_2} \times \frac{76.2\ \text{g}\ CS_2}{1\ \text{mol}\ CS_2} = 23.5\ \text{g}$

Since C produces the least amount of CS_2, then the mass of CS_2 produced is **22.2 g.** The SO_2 is present in excess, so the mass of SO_2 used can be calculated arbitrarily based on the mass of C.

mass of SO_2 used $= 17.5\ \text{g C} \times \frac{1\ \text{mol C}}{12.0\ \text{g C}} \times \frac{2\ \text{mol}\ SO_2}{5\ \text{mol C}} \times \frac{64.1\ \text{g}\ SO_2}{1\ \text{mol}\ SO_2} = 37.4\ \text{g}$

mass of SO_2 in excess $= 39.5 - 37.4 = \mathbf{2.1\ g}$

27. $\text{mass of NO (based on Cu)} = 87.0\text{ g Cu} \times \frac{1\text{ mol Cu}}{63.5\text{ g Cu}} \times \frac{2\text{ mol NO}}{3\text{ mol Cu}} \times \frac{30.0\text{ g NO}}{1\text{ mol NO}} = 27.4\text{ g}$

$\text{mass of NO (based on HNO}_3) = 225\text{ g HNO}_3 \times \frac{1\text{ mol HNO}_3}{63.0\text{ g HNO}_3} \times \frac{2\text{ mol NO}}{8\text{ mol HNO}_3} \times \frac{30.0\text{ g NO}}{1\text{ mol NO}} = 26.8\text{ g}$

Since HNO_3 produces the least amount of NO, then the mass of NO produced is **26.8 g**.
Now find the mass of Cu in excess, based on the amount of HNO_3 used.

$\text{mass of Cu used} = 225\text{ g HNO}_3 \times \frac{1\text{ mol HNO}_3}{63.0\text{ g HNO}_3} \times \frac{3\text{ mol Cu}}{8\text{ mol HNO}_3} \times \frac{63.5\text{ g Cu}}{1\text{ mol Cu}} = 85.0\text{ g}$

mass of Cu in excess = 87.0 – 85.0 = **2.0 g**

28. $\text{mass of P}_4\text{ [based on Ca}_3\text{(PO}_4)_2] = 41.5\text{ g Ca}_3\text{(PO}_4)_2 \times \frac{1\text{ mol Ca}_3\text{(PO}_4)_2}{310.3\text{ g Ca}_3\text{(PO}_4)_2} \times \frac{1\text{ mol P}_4}{2\text{ mol Ca}_3\text{(PO}_4)_2}$

$\times \frac{124.0\text{ g P}_4}{1\text{ mol P}_4} = 8.29\text{ g}$

$\text{mass of P}_4\text{ (based on SiO}_2) = 26.5\text{ g SiO}_2 \times \frac{1\text{ mol SiO}_2}{60.1\text{ g SiO}_2} \times \frac{1\text{ mol P}_4}{6\text{ mol SiO}_2} \times \frac{124.0\text{ g P}_4}{1\text{ mol P}_4} = 9.11\text{ g}$

$\text{mass of P}_4\text{ (based on C)} = 7.80\text{ g C} \times \frac{1\text{ mol C}}{12.0\text{ g C}} \times \frac{1\text{ mol P}_4}{10\text{ mol C}} \times \frac{124.0\text{ g P}_4}{1\text{ mol P}_4} = 8.06\text{ g}$

Since C produces the least amount of P_4, then the mass of P_4 produced is **8.06 g.**
Next, calculate the masses of both $Ca_3(PO_4)_2$ and SiO_2 used by the C:

$\text{mass of Ca}_3\text{(PO}_4)_2\text{ used} = 7.80\text{ g C} \times \frac{1\text{ mol C}}{12.0\text{ g C}} \times \frac{2\text{ mol Ca}_3\text{(PO}_4)_2}{10\text{ mol C}} \times \frac{310.3\text{ g Ca}_3\text{(PO}_4)_2}{1\text{ mol Ca}_3\text{(PO}_4)_2} = 40.3\text{ g}$

mass of $Ca_3(PO_4)_2$ in excess = 41.5 – 40.3 = **1.2 g**

$\text{mass of SiO}_2\text{ used} = 7.80\text{ g C} \times \frac{1\text{ mol C}}{12.0\text{ g C}} \times \frac{6\text{ mol SiO}_2}{10\text{ mol C}} \times \frac{60.1\text{ g SiO}_2}{1\text{ mol SiO}_2} = 23.4\text{ g}$

mass of SiO_2 in excess = 26.5 – 23.4 = **3.1 g**

29. $\text{mass of Br}_2\text{ (based on K}_2\text{Cr}_2\text{O}_7) = 25.0\text{ g K}_2\text{Cr}_2\text{O}_7 \times \frac{1\text{ mol K}_2\text{Cr}_2\text{O}_7}{294.2\text{ g K}_2\text{Cr}_2\text{O}_7} \times \frac{3\text{ mol Br}_2}{1\text{ mol K}_2\text{Cr}_2\text{O}_7} \times \frac{159.8\text{ g Br}_2}{1\text{ mol Br}_2}$

$= 40.7\text{ g}$

$\text{mass of Br}_2\text{ (based on KBr)} = 55.0\text{ g KBr} \times \frac{1\text{ mol KBr}}{119.0\text{ g KBr}} \times \frac{3\text{ mol Br}_2}{6\text{ mol KBr}} \times \frac{159.8\text{ g Br}_2}{1\text{ mol Br}_2} = 36.9\text{ g}$

$\text{mass of Br}_2\text{ (based on H}_2\text{SO}_4) = 60.0\text{ g H}_2\text{SO}_4 \times \frac{1\text{ mol H}_2\text{SO}_4}{98.1\text{ g H}_2\text{SO}_4} \times \frac{3\text{ mol Br}_2}{7\text{ mol H}_2\text{SO}_4} \times \frac{159.8\text{ g Br}_2}{1\text{ mol Br}_2}$

$= 41.9\text{ g}$

KBr is the limiting reactant (it produces the least amount of Br_2). $K_2Cr_2O_7$ and H_2SO_4 are in excess.
Calculate the mass of $K_2Cr_2O_7$ and H_2SO_4 present in excess, arbitrarily based on the mass of KBr.

$\text{mass of K}_2\text{Cr}_2\text{O}_7\text{ used} = 55.0\text{ g KBr} \times \frac{1\text{ mol KBr}}{119.0\text{ g KBr}} \times \frac{1\text{ mol K}_2\text{Cr}_2\text{O}_7}{6\text{ mol KBr}} \times \frac{294.2\text{ g K}_2\text{Cr}_2\text{O}_7}{1\text{ mol K}_2\text{Cr}_2\text{O}_7} = 22.7\text{ g}$

mass of $K_2Cr_2O_7$ in excess = 25.0 – 22.7 = **2.3 g**

$\text{mass of H}_2\text{SO}_4\text{ used} = 55.0\text{ g KBr} \times \frac{1\text{ mol KBr}}{119.0\text{ g KBr}} \times \frac{7\text{ mol H}_2\text{SO}_4}{6\text{ mol KBr}} \times \frac{98.1\text{ g H}_2\text{SO}_4}{1\text{ mol H}_2\text{SO}_4} = 52.9\text{ g}$

mass of H_2SO_4 in excess = 60.0 – 52.9 = **7.1 g**

30. volume of CO_2 (based on C_5H_{12}) $= 0.0250 \text{ L } C_5H_{12} \times \frac{626.0 \text{ g } C_5H_{12}}{1 \text{ L } C_5H_{12}} \times \frac{1 \text{ mol } C_5H_{12}}{72.0 \text{ g } C_5H_{12}} \times \frac{5 \text{ mol } CO_2}{1 \text{ mol } C_5H_{12}}$

$$\times \frac{22.4 \text{ L } CO_2}{1 \text{ mol } CO_2} = 24.3 \text{ L}$$

volume of CO_2 (based on O_2) $= 40.0 \text{ L } O_2 \times \frac{1 \text{ mol } O_2}{22.4 \text{ L } O_2} \times \frac{5 \text{ mol } CO_2}{8 \text{ mol } O_2} \times \frac{22.4 \text{ L } CO_2}{1 \text{ mol } CO_2} = 25.0 \text{ L}$

Hence, the C_5H_{12} is the limiting reactant and **24.3 L** of $CO_2(g)$ will be produced.

31. moles of HCl $= 0.100 \frac{\text{mol}}{\text{L}} \times 0.0500 \text{ L} = 5.00 \times 10^{-3}$ mol

moles of NaCl (based on HCl) $= 5.00 \times 10^{-3} \text{ mol HCl} \times \frac{1 \text{ mol NaCl}}{1 \text{ mol HCl}} = 5.00 \times 10^{-3}$ mol

moles of NaOH $= 0.200 \frac{\text{mol}}{\text{L}} \times 0.0300 \text{ L} = 6.00 \times 10^{-3}$ mol

moles of NaCl (based on NaOH) $= 6.00 \times 10^{-3} \text{ mol NaOH} \times \frac{1 \text{ mol NaCl}}{1 \text{ mol NaOH}} = 6.00 \times 10^{-3}$ mol

Since the NaOH can produce more NaCl, the **NaOH** is in excess.

32. mass of $BaBr_2$ [based on $Ba(OH)_2$] $= 0.250 \text{ g } Ba(OH)_2 \times \frac{1 \text{ mol } Ba(OH)_2}{171.3 \text{ g } Ba(OH)_2} \times \frac{1 \text{ mol } BaBr_2}{1 \text{ mol } Ba(OH)_2}$

$$\times \frac{297.1 \text{ g } BaBr_2}{1 \text{ mol } BaBr_2} = 0.434 \text{ g}$$

moles of HBr $= 0.125 \frac{\text{mol}}{\text{L}} \times 0.0150 \text{ L} = 1.875 \times 10^{-3}$ mol

mass of $BaBr_2$ (based on HBr) $= 1.875 \times 10^{-3} \text{ mol HBr} \times \frac{1 \text{ mol } BaBr_2}{2 \text{ mol HBr}} \times \frac{297.1 \text{ g } BaBr_2}{1 \text{ mol } BaBr_2} = 0.279 \text{ g}$

Since HBr is the limiting reactant, **0.279 g** of $BaBr_2$ can be formed.

33. (a) First assume the $FeCO_3$ is 100 % pure.

mass of Fe_2O_3 $= 15.0 \text{ g } FeCO_3 \times \frac{1 \text{ mol } FeCO_3}{115.8 \text{ g } FeCO_3} \times \frac{2 \text{ mol } Fe_2O_3}{4 \text{ mol } FeCO_3} \times \frac{159.6 \text{ g } Fe_2O_3}{1 \text{ mol } Fe_2O_3} = 10.3 \text{ g}$

Since the $FeCO_3$ is only 42.0 % pure there will be less than 10.3 g.

mass of pure $FeCO_3$ = 0.420 x 10.3 g = **4.34 g**

(b) First calculate the mass of pure $FeCO_3$ required to produce 37.0 g of Fe_2O_3.

mass of $FeCO_3$ $= 37.0 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol } Fe_2O_3}{159.6 \text{ g } Fe_2O_3} \times \frac{4 \text{ mol } FeCO_3}{2 \text{ mol } Fe_2O_3} \times \frac{115.8 \text{ g } FeCO_3}{1 \text{ mol } FeCO_3} = 53.69 \text{ g}$

Then: % purity $= \frac{\text{mass of pure } FeCO_3}{\text{mass of impure } FeCO_3} \times 100\% = \frac{53.69 \text{ g}}{55.0 \text{ g}} \times 100\% =$ **97.6%**

(c) First calculate the mass of Fe_2O_3 EXPECTED from the reaction.

mass of Fe_2O_3 $= 35.0 \text{ g } FeCO_3 \times \frac{1 \text{ mol } FeCO_3}{115.8 \text{ g } FeCO_3} \times \frac{2 \text{ mol } Fe_2O_3}{4 \text{ mol } FeCO_3} \times \frac{159.6 \text{ g } Fe_2O_3}{1 \text{ mol } Fe_2O_3} = 24.12 \text{ g}$

Now: % yield $= \frac{\text{mass obtained}}{\text{mass expected}} \times 100\% = \frac{22.5 \text{ g}}{24.12 \text{ g}} \times 100\% =$ **93.3%**

(d) First find the mass of 100% pure $FeCO_3$ required to make 1.00×10^3 g of Fe_2O_3.

$$\text{mass of } FeCO_3 = 1.00 \times 10^3 \text{ g } Fe_2O_3 \times \frac{1 \text{ mol } Fe_2O_3}{159.6 \text{ g } Fe_2O_3} \times \frac{4 \text{ mol } FeCO_3}{2 \text{ mol } Fe_2O_3} \times \frac{115.8 \text{ g } FeCO_3}{1 \text{ mol } FeCO_3}$$

$$= 1451 \text{ g}$$

Since not all the ore was pure $FeCO_3$, dividing by the percentage purity will increase the amount of ore to be used and allow for losses in forming products.

$$\text{mass of ore} = \frac{1451 \text{ g}}{0.628} = \mathbf{2.31 \times 10^3 \text{ g}}$$

34. First calculate the mass of pure FeS_2 required to produce 4.50 L of SO_2.

$$\text{mass of } FeS_2 = 4.50 \text{ L } SO_2 \times \frac{1 \text{ mol } SO_2}{22.4 \text{ L } SO_2} \times \frac{4 \text{ mol } FeS_2}{8 \text{ mol } SO_2} \times \frac{120.0 \text{ g } FeS_2}{1 \text{ mol } FeS_2} = 12.05 \text{ g}$$

$$\% \text{ purity} = \frac{\text{mass of pure } FeS_2}{\text{mass of impure } FeS_2} \times 100\% = \frac{12.05 \text{ g}}{100.0 \text{ g}} \times 100\% = \mathbf{12.1\%}$$

35. (a)

$$\text{volume of } C_6H_5NO_2 \text{ EXPECTED} = 25.0 \text{ mL } C_6H_6 \times \frac{0.879 \text{ g } C_6H_6}{1 \text{ mL } C_6H_6} \times \frac{1 \text{ mol } C_6H_6}{78.0 \text{ g } C_6H_6} \times$$

$$\frac{1 \text{ mol } C_6H_5NO_2}{1 \text{ mol } C_6H_6} \times \frac{123.0 \text{ g } C_6H_5NO_2}{1 \text{ mol } C_6H_5NO_2} \times \frac{1 \text{ mL } C_6H_5NO_2}{1.204 \text{ g } C_6H_5NO_2} = 28.781 \text{ mL}$$

$$\% \text{ yield} = \frac{\text{volume obtained}}{\text{volume expected}} \times 100\% = \frac{18.0 \text{ mL}}{28.781 \text{ mL}} \times 100\% = 62.54\% \text{ (which rounds to } \mathbf{62.5\%}\text{)}$$

(b)

$$\text{mass of } C_6H_6 \text{ reacted} = 18.0 \text{ mL } C_6H_5NO_2 \times \frac{1.204 \text{ g } C_6H_5NO_2}{1 \text{ mL } C_6H_5NO_2} \times \frac{1 \text{ mol } C_6H_5NO_2}{123.0 \text{ g } C_6H_5NO_2}$$

$$\times \frac{1 \text{ mol } C_6H_6}{1 \text{ mol } C_6H_5NO_2} \times \frac{78.0 \text{ g } C_6H_6}{1 \text{ mol } C_6H_6} = 13.743 \text{ g}$$

$$\text{mass of } C_6H_6 \text{ (originally)} = 25.0 \text{ mL} \times \frac{0.879 \text{ g}}{1 \text{ mL}} = 21.975 \text{ g}$$

$$\text{mass of } C_6H_6 \text{ (unreacted)} = 21.975 \text{ g} - 13.743 \text{ g} = \mathbf{8.23 \text{ g}}$$

Alternately: if the reaction has a 62.54% yield, then 100.0 – 62.54 = 37.46% of the C_6H_6 is unreacted.

mass of C_6H_6 (originally) = 21.975 g (as calculated above)

and: mass of C_6H_6 (unreacted) = 21.975 g x 0.3746 = **8.23 g**

36. (a)

$$\text{mass of } SiF_4 \text{ formed} = 2.50 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.0 \text{ g } H_2O} \times \frac{1 \text{ mol } SiF_4}{2 \text{ mol } H_2O} \times \frac{104.1 \text{ g } SiF_4}{1 \text{ mol } SiF_4} = \mathbf{7.23 \text{ g}}$$

(b)

$$\text{mass of } SiO_2 \text{ used} = 2.50 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.0 \text{ g } H_2O} \times \frac{1 \text{ mol } SiO_2}{2 \text{ mol } H_2O} \times \frac{60.1 \text{ g } SiO_2}{1 \text{ mol } SiO_2} = 4.17 \text{ g}$$

mass of SiO_2 (unreacted) = 12.20 – 4.17 = **8.03 g**

(c)

$$\% \text{ yield} = \frac{\text{mass of } SiO_2 \text{ used}}{\text{mass of } SiO_2 \text{ available}} \times 100\% = \frac{4.17 \text{ g}}{12.20 \text{ g}} \times 100\% = \mathbf{34.2\%}$$

or:

$$\text{mass of } SiF_4 \text{ expected} = 12.20 \text{ g } SiO_2 \times \frac{1 \text{ mol } SiO_2}{60.1 \text{ g } SiO_2} \times \frac{1 \text{ mol } SiF_4}{1 \text{ mol } SiO_2} \times \frac{104.1 \text{ g } SiF_4}{1 \text{ mol } SiF_4} = 21.13 \text{ g}$$

$$\% \text{ yield} = \frac{\text{mass of } SiF_4 \text{ obtained}}{\text{mass of } SiF_4 \text{ expected}} \times 100\% = \frac{7.23 \text{ g}}{21.13 \text{ g}} \times 100\% = \mathbf{34.2\%}$$

37. (a) First find the mass of CuO produced if the purity and yield are both 100%.

$$\text{mass of CuO} = 5.00 \times 10^{3}\ \text{g malach} \times \frac{1\ \text{mol malach}}{221.0\ \text{g malach}} \times \frac{2\ \text{mol CuO}}{1\ \text{mol malach}} \times \frac{79.5\ \text{g CuO}}{1\ \text{mol CuO}} = 3597\ \text{g}$$

Next allow for a purity of 4.30 % and a yield of 84.0 % by decreasing the mass of products formed.

mass of CuO formed = 0.0430 x 0.840 x 3597 g = **1.30×10^2 g**

(b) First find the mass of pure malachite required to produce 100.0 g of CuO, assuming 100 % yield.

$$\text{mass of malachite} = 100.0\ \text{g CuO} \times \frac{1\ \text{mol CuO}}{79.5\ \text{g CuO}} \times \frac{1\ \text{mol malachite}}{2\ \text{mol CuO}} \times \frac{221.0\ \text{g malachite}}{1\ \text{mol malachite}} = 139.0\ \text{g}$$

Both percent purity and percentage yield decrease the mass of products so that the mass of malachite ore used must be increased to compensate for these losses. Dividing the mass of pure malachite by the percent purity and percent yield gives the required increased mass.

$$\text{mass of ore used} = \frac{139.0\ \text{g}}{0.870 \times 0.0370} = \mathbf{4.32 \times 10^{3}\ g}$$

38. (a) First find the mass of Ag produced if the ore is 100% pure Ag_2S.

$$\text{mass of Ag} = 250.0 \times 10^{3}\ \text{g Ag}_2\text{S} \times \frac{1\ \text{mol Ag}_2\text{S}}{247.9\ \text{g Ag}_2\text{S}} \times \frac{2\ \text{mol Ag}}{1\ \text{mol Ag}_2\text{S}} \times \frac{107.9\ \text{g Ag}}{1\ \text{mol Ag}} = 2.18 \times 10^{5}\ \text{g}$$

Now find the mass of silver if the ore is only 0.135% pure.

mass of Ag = 0.00135 x 2.18×10^5 g = **294 g**

(b) Find the mass of Ag_2S which produces 0.261 g of silver.

$$\text{mass of Ag}_2\text{S} = 0.261\ \text{g Ag} \times \frac{1\ \text{mol Ag}}{107.9\ \text{g Ag}} \times \frac{1\ \text{mol Ag}_2\text{S}}{2\ \text{mol Ag}} \times \frac{247.9\ \text{g Ag}_2\text{S}}{1\ \text{mol Ag}_2\text{S}} = 0.300\ \text{g}$$

$$\text{Hence: \% purity} = \frac{\text{mass of pure Ag}_2\text{S}}{\text{mass of impure ore}} \times 100\% = \frac{0.300\ \text{g}}{76.4\ \text{g}} \times 100\% = \mathbf{0.392\%}$$

c) First find the mass of pure Ag which is produced by 152.6 g of pure Ag_2S.

$$\text{mass of Ag} = 152.6\ \text{g Ag}_2\text{S} \times \frac{1\ \text{mol Ag}_2\text{S}}{247.9\ \text{g Ag}_2\text{S}} \times \frac{2\ \text{mol Ag}}{1\ \text{mol Ag}_2\text{S}} \times \frac{107.9\ \text{g Ag}}{1\ \text{mol Ag}} = 132.8\ \text{g}$$

$$\text{Hence: \% yield} = \frac{\text{actual mass of pure Ag}}{\text{expected mass of pure Ag}} \times 100\% = \frac{117.4\ \text{g}}{132.8\ \text{g}} \times 100\% = \mathbf{88.38\%}$$

(d) First find the mass of pure Ag_2S required to produce 50.0 kg of pure Ag.

$$\text{mass of pure Ag}_2\text{S} = 50.0 \times 10^{3}\text{g Ag} \times \frac{1\ \text{mol Ag}}{107.9\ \text{g Ag}} \times \frac{1\ \text{mol Ag}_2\text{S}}{2\ \text{mol Ag}} \times \frac{247.9\ \text{g Ag}_2\text{S}}{1\ \text{mol Ag}_2\text{S}}$$

$$= 5.744 \times 10^{4}\ \text{g}$$

Now find the mass of ore needed if the ore only contains 0.795% Ag_2S.

$$\text{mass of ore} = \frac{5.744 \times 10^{4}\ \text{g}}{0.00795} = \mathbf{7.22 \times 10^{6}\ g}$$

(e) First find the mass of Ag produced if the purity and yield are both 100%.

$$\text{mass of Ag expected} = 3.50 \times 10^{7}\ \text{g Ag}_2\text{S} \times \frac{1\ \text{mol Ag}_2\text{S}}{247.9\ \text{g Ag}_2\text{S}} \times \frac{2\ \text{mol Ag}}{1\ \text{mol Ag}_2\text{S}} \times \frac{107.9\ \text{g Ag}}{1\ \text{mol Ag}}$$

$$= 3.047 \times 10^{7}\ \text{g}$$

Now, the ore is only 1.86% pure Ag_2S and only 89.2% of the Ag_2S is extracted.

actual mass of Ag produced = 3.047×10^7 g x 0.0186 x 0.892 = **5.05×10^5 g**

ANSWERS TO UNIT VIII : ATOMS AND THE PERIODIC TABLE

1. Contradict. The Greek view of nature assumed that experimental work could be misleading and that philosophy should be used to reveal how nature worked.
2. Metals were immediately recognizable, valuable and useful in everyday life.
3. Dalton's work allowed the composition of chemicals to be known more accurately and compounds to be made efficiently without wasting reactants.
4. Thomson's work showed that atoms contained different particles having positive and negative charges.
5. The Law of Definite Proportions
6. The last column in the table below gives the result of dividing the mass of oxygen in each compound by the mass of oxygen in compound #1.

Compound #	Mass of N (g)	Mass of O (g)	Ratio
1	0.3160	0.0903	1
2	0.3160	0.3611	4
3	0.3160	0.7223	8
4	0.3160	0.5417	6

7. The "plum pudding" model assumed that the protons and electrons were uniformly distributed throughout the volume of the atom, such that the mass associated with the protons was distributed throughout the atom. When Rutherford found that most of the atom was empty space except for a tiny nucleus containing almost all the atom's mass, the even distribution of proton mass throughout the atom assumed by J.J. Thomson was seen to be incorrect.
8. Rutherford had found that the presence of protons in the nucleus could account for the charge on the nucleus but it could not account for all of the mass present in the nucleus.
9. Dalton's model is not in conflict with Rutherford's model because Rutherford accepted the idea that atoms exist and concerned himself with the internal structure of the atom. Dalton was concerned with the manner in which atoms had constant properties and were able to combine in specific ways.
10. Protons (but he suspected that some particle like the neutron existed in the nucleus).
11. (a) beta and gamma (alpha is stopped by a piece of paper) (b) gamma
12. Protons and neutrons exist in the nucleus and have a substantial mass while the region outside the nucleus consists only of electrons, which are almost massless. Therefore, most of the mass of the atom is concentrated in the nucleus.
13. (a) 4 (b) 92 (c) 25
14. (a) 6 (b) 26 (c) 18
15. (a) 10 (c) 20 (e) 18 (g) 54 (i) 2
    (b) 10 (d) 10 (f) 10 (h) 24 (j) 36
16. (a) S^{2-} (c) Cl^{-} (e) Cr^{2+} (g) V^{5+} (i) O^{-}
    (b) Ca^{2+} (d) Al^{3+} (f) Mn^{4+} (h) Sb^{3-}
17. (a) +12 (b) +10 (c) +19 (d) +16
18. Proton = ${}^{1}_{1}p$, neutron = ${}^{1}_{0}n$, electron = ${}^{0}_{-1}e$

19.

Particle	Atomic Number	Atomic Mass	Number of protons	Number of neutrons	Number of electrons
$^{52}_{24}Cr$	**24**	**52**	**24**	**28**	**24**
$^{222}_{86}Rn$	**86**	**222**	**86**	**136**	**86**
$^{70}_{31}Ga$	31	**70**	**31**	39	31
$^{27}_{13}Al$	**13**	**27**	13	14	13
$^{197}_{79}Au^{3+}$	**79**	197	**79**	118	76
$^{75}_{33}As^{3-}$	**33**	75	33	**42**	36
$^{209}_{83}Bi^{5+}$	**83**	**209**	83	126	78

20. (a) heavy water is $\frac{27.65}{25.00}$ = **1.106** times heavier than ordinary water

(b) molar mass of ordinary water = 18.0 g, so heavy water's molar mass = 1.106 x 18.0 g = **19.908 g.**

(c) heavy water = D_2O = 2 D + O = 19.908 g , so that: 2 D + 16.0 g = 19.908 g and: D = **1.95 g**

(d) $^{2}_{1}D$

(e) For D: # of e^- = 1, # of p = 1, # of n = 1 For H: # of e^- = 1, # of p = 1, # of n = 0
Since both H and D have one proton, they are both "hydrogen" but the extra neutron makes D a heavier version of hydrogen.

21. Sample 2 is $\frac{1.670}{1.539}$ = 1.085 times heavier than Sample 1
molar mass of Sample 1 = 2 x 1.008 + 32.066 = 34.082 g
molar mass of Sample 2 = 34.082 g x 1.085 = 36.983 g
mass of artificial S–isotope = 36.983 – 2 x 1.008 = **34.97 g**

22.

	Symbol	Atomic Mass	Atomic Number	Number of protons	Number of neutrons	Number of electrons
(a)	$^{84}_{36}Kr$	84	36	**36**	**48**	36
(b)	$^{80}_{35}Br$	**80**	**35**	35	45	35
(c)	$^{127}_{53}I^-$	127	53	**53**	**74**	54
(d)	$^{59}_{27}Co$	**59**	27	**27**	32	27
(e)	$^{66}_{30}Zn$	**66**	**30**	**30**	36	**30**
(f)	$^{112}_{48}Cd^{2+}$	112	**48**	**48**	**64**	**46**
(g)	$^{88}_{38}Sr^{2+}$	**88**	**38**	38	50	36
(h)	X^{2-} = $^{127}_{52}Te^{2-}$	**127**	**52**	**52**	75	54
(i)	X^{3+} = $^{103}_{45}Rh^{3+}$	103	**45**	**45**	**58**	42
(j)	X^{3-} = $^{75}_{33}As^{3-}$	**75**	33	**33**	42	**36**

23. (a) 10.8 g
(b) 69.8 g
(c) 108.0 g
(d) 72.7 g
(e) 65.4 g
(f) 91.3 g
(g) 95.9 g

24. Average mass = 0.9890 x 12.000 000 + 0.0110 x 13.003 355 = **12.011 g**

25. Average mass = 0.9223 x 27.976 927 + 0.0467 x 28.976 495 + 0.0310 x 29.973 770 = **28.0855 g**

26. (a) P ($1s^2 2s^2 2p^6 3s^2 3p^3$)
(b) Ti ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$)
(c) Co ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^7$)
(d) Br ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$)
(e) Sr ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$)
(f) Ar ($1s^2 2s^2 2p^6 3s^2 3p^6$)
(g) K ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$)
(h) Cd ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10}$)
(i) Ca ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$)
(j) Xe ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6$)
(k) Cs ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^1$)
(l) Pb ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^2$)
(m) Ga ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^1$)
(n) Mn ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$)
(o) Zr ($1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^2$)

27. (a) P ([Ne] $3s^2 3p^3$)
(b) Ti ([Ar] $4s^2 3d^2$)
(c) Co ([Ar] $4s^2 3d^7$)
(d) Br ([Ar] $4s^2 3d^{10} 4p^5$)
(e) Sr ([Kr] $5s^2$)
(f) Ar ([Ne] $3s^2 3p^6$)
(g) K ([Ar] $4s^1$)
(h) Cd ([Kr] $5s^2 4d^{10}$)
(i) Ca ([Ar] $4s^2$)
(j) Xe ([Kr] $5s^2 4d^{10} 5p^6$)
(k) Cs ([Xe] $6s^1$)
(l) Pb ([Xe] $6s^2 4f^{14} 5d^{10} 6p^2$)
(m) Ga ([Ar] $4s^2 3d^{10} 4p^1$)
(n) Mn ([Ar] $4s^2 3d^5$)
(o) Zr ([Kr] $5s^2 4d^2$)

28. (a) H^- ($1s^2$)
(b) Sr^{2+} ([Ar] $4s^2 3d^{10} 4p^6$)
(c) Br^- ([Ar] $4s^2 3d^{10} 4p^6$)
(d) N^{3+} ([He] $2s^2$)
(e) Ti^{2+} ([Ar] $3d^2$)
(f) N^{2-} ([He] $2s^2 2p^5$)
(g) Mn^{2+} ([Ar] $3d^5$)
(h) Ge^{4+} ([Ar] $3d^{10}$)
(i) Fe^{3+} ([Ar] $3d^5$)
(j) Ge^{2+} ([Ar] $4s^2 3d^{10}$)
(k) Ru^{3+} ([Kr] $4d^5$)
(l) Sb^{3+} ([Kr] $5s^2 4d^{10}$)

29. (a) 6
(b) 5
(c) 5
(d) 2
(e) 0
(f) 2
(g) 6
(h) 0
(i) 2
(j) 6
(k) 0
(l) 0
(m) 3
(n) 2
(o) 7
(p) 2

30. The actual properties of Germanium are as follows. How close were your estimates?
atomic mass = 72.6 ; density = 5.35 ; density of oxide = 4.23 ; formula of chloride = $GeCl_4$; density of chloride = 1.84 ; color = greyish white ; lustre = metallic

31. (a) noble gases
(b) alkaline earth metals
(c) transition metals
(d) alkali metals
(e) halogens
(f) transitions metals
(g) alkali metals
(h) halogens

32. (a) two of Li, K, Rb, Cs and Fr
(b) two of He, Ne, Kr, Xe and Rn
(c) two of Be, Ca, Sr, Ba and Ra
(d) two of F, Cl, I and At

33. (a) two of Li, Be, B, N, O, F and Ne
(b) two of Na, Mg, Al, Si, P, Cl and Ar

34.

SAMPLE	PROPERTIES	CLASSIFICATION
A	pale yellow gas, non–conductor	NONMETAL
B	conductor, shiny, hard, silvery, malleable	METAL
C	non–conductor, yellow, looks waxy, soft, brittle	NONMETAL
D	hard, silvery–grey, brittle, somewhat shiny, fair conductor	MIXTURE
E	liquid, shiny, silvery, conductor	METAL
F	dark red, liquid, non–conductor	NONMETAL
G	fair conductor, brittle, dull grey	MIXTURE

35. On the right side.

36. (a) Ga (b) Ge (c) Sn (d) Mg (e) Bi

37. Ca, Ge, Si, P, F

38. (a) Sb (b) K (c) Ge (d) Al (e) Tl (f) Sb

39. P = iii, Ba = ii, Sb = iv, Ar = v, As = i

40. The atomic radius increases. The more electrons around the nucleus, the greater the volume needed to contain them (since electrons repel each other and can't easily be "compacted"). Therefore, going down a group the atomic radius of the elements in the group should increase.

41. Going across a row, the positive charge on the nucleus increases, and each electron experiences a greater attraction to the nucleus. This results in a smaller distance between the individual electrons and the nucleus, which causes the atomic radius to decrease going across each period of the table.

42.

If an atom has:	Then its outermost shell is:	If an atom has:	Then its outermost shell is:
1 electron	**OPEN**	10 electrons	**CLOSED**
2 electrons	**CLOSED**	11 electrons	**OPEN**
3 electrons	**OPEN**	16 electrons	**OPEN**
8 electrons	**OPEN**	18 electrons	**CLOSED**

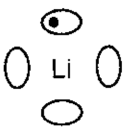
43. The NOBLE GASES have CLOSED SHELLS. All other elements have OPEN SHELLS.

44. (a) Cl : open (c) Mg : open (e) Na^+ : closed (g) O^- : open (i) I : open
(b) Ne : closed (d) Si : open (f) Cl^- : closed (h) Ca^{2+} : closed (j) Al^+ : open

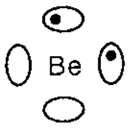
45.

atom	# of valence electrons	atom	# of valence electrons
F	7	Pb	4
Ne	0	Pb^{2+}	2
Na	1	S^-	7
Ne^+	7	S^{2-}	0

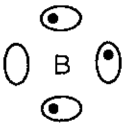
46. (a, b)



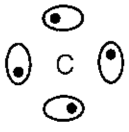
1



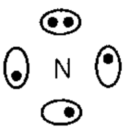
2



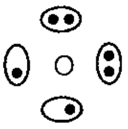
3



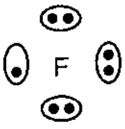
4



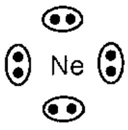
3



2



1



0

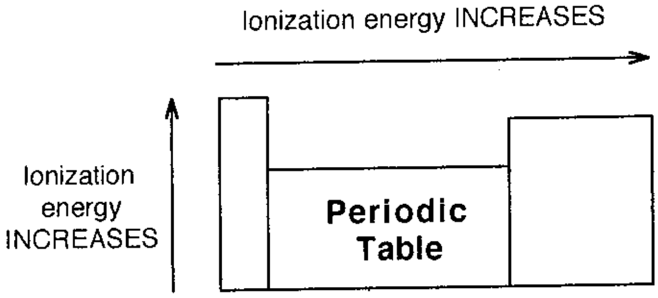
47.

atom	H	He						
valence	1	0						
atom	Li	Be	B	C	N	O	F	Ne
valence	1	2	3	4	3	2	1	0
atom	Na	Mg	Al	Si	P	S	Cl	Ar
valence	1	2	3	4	3	2	1	0

48. (a) The distance between the nucleus and the outermost electrons increases. The greater the number of electrons, the larger the atomic radius.
    (b) The nucleus has a decreasing hold on the outer electrons because of the increasing nucleus–electron distance.
    (c) The ionization energy will decrease going down a family. The less hold the nucleus has on the outer electrons, the easier it is to remove one of them.

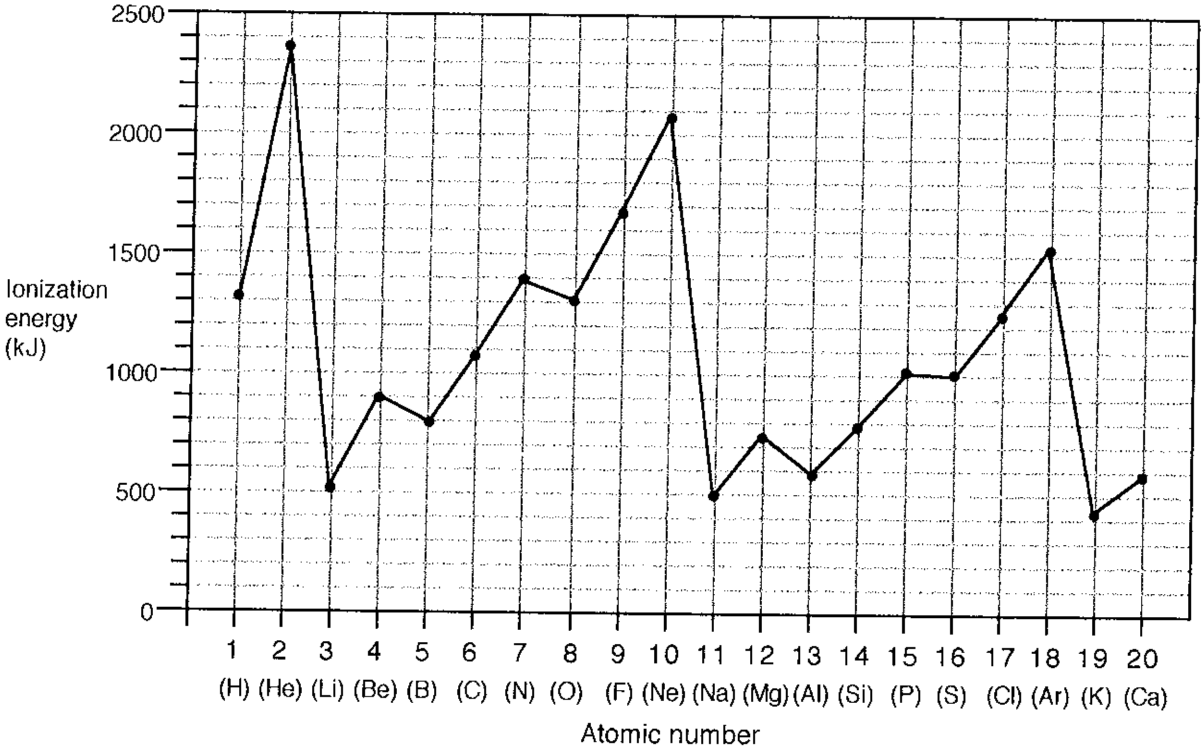
49. (a) The distance decreases as the increasing nuclear charge pulls the electrons in closer.
    (b) increases
    (c) The nucleus can hold more strongly to a given outer electron because of the greater charge and the smaller electron–nucleus distance.
    (d) The ionization energy (energy required to remove an outer electron) will therefore increase going across a period.

50.



51. (a) Cl (b) Cl (c) Ne (d) Mg (e) Ne (f) I

52.



(a) Electrons are being removed from full shells, which is very difficult to do.
(b) The outermost electrons are farther from the nucleus, so that the attraction between the nucleus and outer electrons is decreased and less energy is required for electron removal.
(c) The outer electrons are drawn closer to the nucleus (recall exercise 40), causing an increased attraction between the larger nuclear charge and the outermost electrons. The increased attraction requires a greater energy to be applied before an electron can be removed.
(d) Be and Mg have filled s–subshells, so that their ionization energies are higher than those of the elements immediately before and after them. Similarly, N and P have half–filled p–subshells and their ionization energies are higher than those of the elements immediately before and after them. The filling of the p–subshells (Ne and Ar) is a special case of increased stability leading to increased ionization energy.

53. (a) Te (b) O (c) Te (d) 6 (e) 2 (f) O

54. Li^+ and F^- (smaller ions are closer together)

55. (a) Ga (b) Br (c) same (d) Ga = 3, Br = 7 (e) Ga = 3, Br = 1 (f) Br

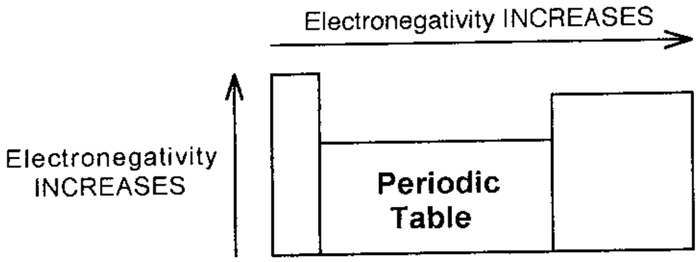
56. Se, Sr^+, Kr^+ and Ge

57. (a) Ba and S = ionic
(b) P and Cl = non–ionic
(c) Ca and O = ionic
(d) Rb and I = ionic
(e) O and H = non–ionic
(f) S and O = non–ionic

58. (a) Li (b) F (c) F (d) F
(e) IN GENERAL, going from left to right across the periodic table the electronegativity of the atoms will INCREASE.

59. (a) I (more electron shells) (b) F
(c) IN GENERAL, going down a family of the periodic table the electronegativity of the atoms will DECREASE.

60.



61. (a) F (b) Fr (c) Be (d) S

62. (a) NaCl
   (b) The smaller the ions, the smaller the distance between the + and – charges and the greater the force of attraction between the ions.
   (c) The smaller the ions involved, the greater the ionic bond strength and the higher the melting temperature. This is confirmed by the fact that the melting temperatures of NaCl and KBr are 801°C and 734°C respectively.

63. Although the ions are about the same size, there is more charge on both O^{2-} and Mg^{2+}. Recall that the greater the charge, the greater the force of attraction. The increased attraction between O^{2-} and Mg^{2+} requires a greater energy to separate the ions and therefore a higher melting point. This is confirmed by the fact that the melting temperatures of MgO and NaF are 2852°C and 993°C respectively.

64. (a) CaO (b) BN (c) LiF (d) BaS (e) KCl (f) BeO

65. (a) amount of repulsion INCREASES
   (b) volume INCREASES
   (c) Negative ions are LARGER than the corresponding neutral atom.

66. (a) amount of repulsion DECREASES
   (b) volume DECREASES
   (c) Positive ions are SMALLER than the corresponding neutral atom.

67. Na^+ = smaller circles

68. (a) SO = covalent (c) FeCl = (ionic) (e) HS = covalent
   (b) BaO = (ionic) (d) NO = covalent (f) CH = covalent

69. (a) As the size of the atoms increases, the distance between the nuclei and the shared electrons increases, and the electrostatic attraction between the nuclei and the shared electrons decreases.
   (b) Going down the halogens, the distance between the nuclei and the shared electrons increases and the strength of the covalent bond should decrease. (F_2 actually doesn't follow the trend.)

70. The more electrons shared in a bond, the greater the electrostatic attraction between the nuclei and the shared electrons and the stronger the bond.

71. The more electrons shared between two atoms, the greater the electrostatic attraction between the nuclei and the electrons (pulling the electrons closer to the nucleus) and the shorter the bond length.

72. (a) PCl_3 (c) CS_2 (e) H_2Se (g) H_2O (i) B_4C_3 (k) Si_3P_4
   (b) B_2O_3 (d) P_2O_3 (f) F_2O (h) NI_3 (j) CCl_4 (l) SiS_2

73. (a) increases (b) increases

74. intermolecular

75. The London forces between F_2 molecules are broken because London forces are much weaker than the covalent bonds involved.

76. Both melting and boiling points increase

77. (a) Ar (b) Br_2 (c) CF_4 (d) CBr_4

78. The student's answer incorrectly implies that covalent bonds are broken when melting occurs and that London forces are absent.

79. (a) covalent (b) ionic (c) ionic (d) covalent (e) ionic (f) covalent (g) covalent

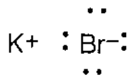
80. (a) F (b) Li (c) Cl (d) Si (e) S (f) N

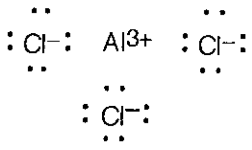
81. (a) Na^+Cl^- (b) C–O (c) $Ca^{2+}O^{2-}$ (d) $Mg^{2+}O^{2-}$ (e) C–C (f) $N\equiv N$

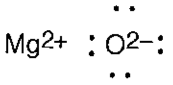
82. ionic bonding and London forces

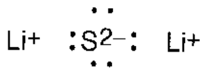
83. (a) Na^- (b) I (c) As^{3-} (d) Cs^+ (e) Se^- (f) S^{2-} (g) Se^{2-} (h) S^{2-} (i) Cl^-

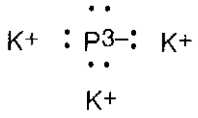
84. (a) London (b) ionic (c) London (d) covalent (e) ionic (f) London

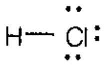
85. (a)


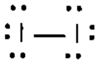
(b)


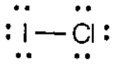
(c)


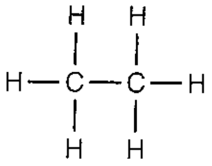
(d)


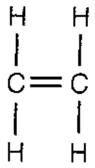
(e)


86. (a)


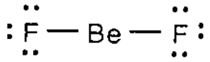
(b)


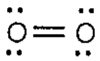
(c)


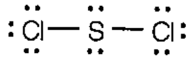
(d)


(e)


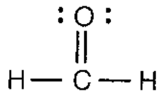
(f)

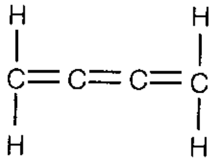

(g)


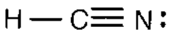
(h)


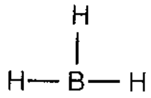
(i)


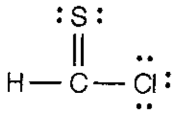
(j)

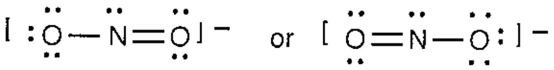

(k)


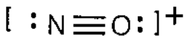
(l)


(m)


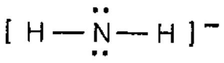
(n)


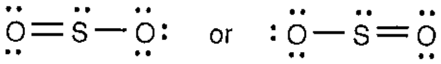
(o)


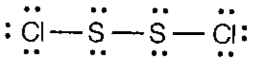
(p)


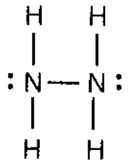
(q)


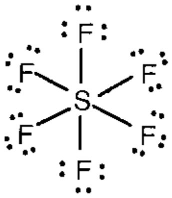
(r)


(s)


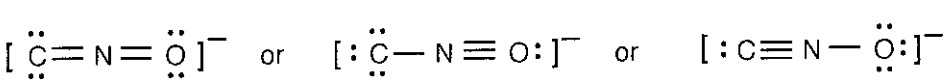
(t)


(u)


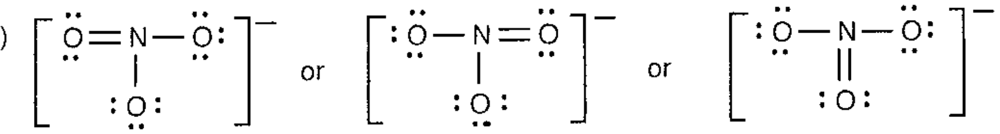
(v)


(w)


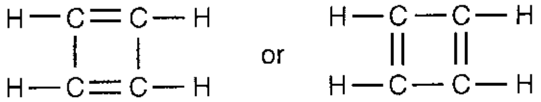
(x)



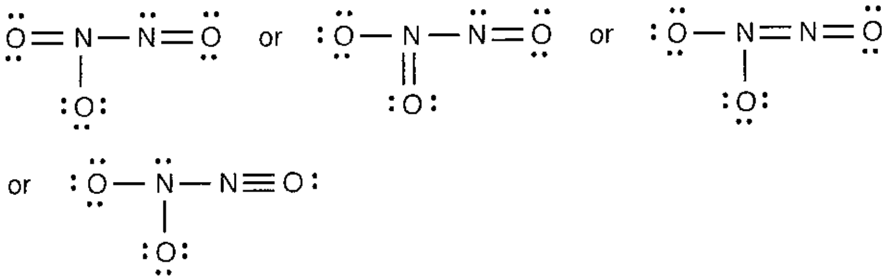
(y)



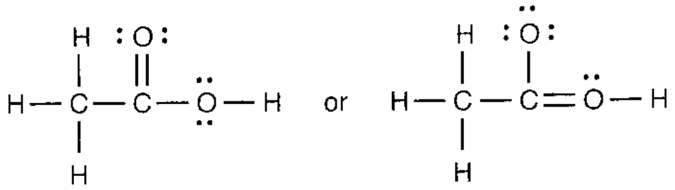
(z)



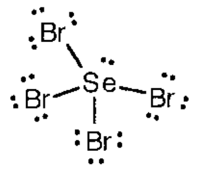
(aa)



(bb)



(cc)



87. He($1s^2$) ; Ne([He] $2s^2 2p^6$) ; Ar([Ne] $3s^2 3p^6$) ; Kr ([Ar] $4s^2 3d^{10} 4p^6$) ; Xe ([Kr] $5s^2 4d^{10} 5p^6$)

88. The full valence shells of the inert gases make them unreactive.

89. Since no other type of bond is possible, due to the full valence shells, the inert gases are held next to one another by London forces. The melting/boiling temperatures will be very low because London forces are very weak.

90. The more electrons on an atom or molecule, the greater the London forces involved. Hence, the London forces should increase going down a family in the periodic table and the melting/boiling temperatures should increase.

91. The farther down a family in the periodic table, the larger the atoms and the farther the outermost electrons are from the nucleus. As a result, the farther down the table the easier to remove an electron (the lower the ionization energy).

92. The reaction of a noble gas will involve the removal of an electron from the outer shell (since it would have no tendency to gain an extra electron), so the question is really asking about the ionization energy. As seen earlier, the lower the atom on the table the lower the ionization energy and the easier for the atom to react. Rn will be more reactive.

93. The noble gases form no naturally–occurring compounds from which they can be extracted. Also, the gases are relatively rare and do not liquify easily so the noble gases were only found when samples of air were liquified and different portions of the sample were boiled off and analyzed.

94. Li ([He] $2s^1$) ; Na ([Ne] $3s^1$) ; K ([Ar] $4s^1$) ; Rb ([Kr] $5s^1$) ; Cs ([Xe] $6s^1$) ; Fr ([Rn] $7s^1$)

95. All families show the same trend : going down the periodic table the outermost electrons are farther from the nucleus, less strongly held by electrostatic forces and easier to remove.

96. Li^+ is produced when Li reacts. The ease of removing an outer electron (tendency to react) increases going down the periodic table.

97. This is essentially the same as the previous exercise: the ionization energy decreases going down the periodic table because the electrons being removed are farther from the nucleus and less strongly held by electrostatic forces.

98. The alkali metals are good electrical conductors because they have a single valence electron which is easily removed and able to move freely from atom to atom. (Recall from exercise 52 that the ionization energies of the alkali metals are very low, indicating loosely–held valence electrons.)

99. Going down the alkali metals in the periodic table, the outer electrons are farther from the nuclei and adjacent nuclei are not as tightly held together, causing a lowered melting/boiling temperature.

100. Electrons are removed when both the alkali metals and alkaline earth metals react. Since it is easier to remove one electron from an atom (alkali metals) than to remove two electrons (alkaline earth metals), the alkaline earth metals should be less reactive. (This is experimentally observed to be true.)

101. (a) The melting/boiling temperature decreases. (The larger distances between valence electrons and nuclei decrease the attractions holding metal atoms together in solid and liquid phases.)
 (b) The reactivity increases. (Larger atoms have decreased attractions between valence electrons and nuclei, allowing easier removal of electrons. Since the reaction of the alkaline earth metals involves the removal of electrons, the reactivity should increase.)
 (c) The ionization energy decreases. (see reasons for part b)

 Mg is an exception to the MP/BP trend; Ba is also an exception to the BP trend.

102. Since Cl_2 is a gas, bromine is a liquid and iodine is a solid, the melting/boiling temperatures must increase going down the table.

103. Only London forces can explain such low melting/boiling temperatures.

104. Halogen molecules form halide ions having a –1 charge. Since the halogens must attract or gain an extra electron, the electronegativity (electron-attracting tendency) must dictate the ease with which the halogens gain an electron. Since the electronegativity decreases going down the periodic table, the halogens will have less tendency to react by gaining an electron.

105. As with all families, the halogen atoms are larger going down the periodic table, the outer electrons are less tightly held and the ionization energy decreases.

106. (a) A valence electron is an electron in an open shell.
 (b) An open shell is an electron shell which contains less than its maximum number of electrons.
 (c) An intermolecular bond is a bond which occurs between adjacent molecules.
 (d) Electronegativity is the tendency of an atom to attract an extra electron.
 (e) A covalent bond is a bond in which electrons are shared equally by the atoms being joined.
 (f) An intramolecular bond is a bond which occurs within a given molecule.
 (g) The valence of an atom is the number of unpaired electrons in an atom.
 (h) An ionic bond is a bond resulting from a positive ion being held next to a negative ion by the electrostatic attraction of the negative electrical charge for the positive charge.
 (i) The London force is a force of attraction which exists between species having closed shells and which exists as a result of a temporary dipolar attraction between the species.

107. Pb is bigger than Si since Pb has more electron shells.

108. Halogen molecules are held next to one another by London forces, which increase in strength as the number of electrons increases going down the periodic table. The alkali metals are held together by bonds which decrease in strength as the size of the atoms (and distance between the valence electrons and nuclei) increases going down the periodic table.

109. Both N_2 and O_2 are held together in the solid phase by London forces. Since London forces increase as the number of electrons increases, and since O_2 has more electrons than N_2, O_2 should have the higher melting temperature.

110. Both O_2 and S_2 are held together with covalent bonds. Since S is larger than O, the shared electrons in S_2 are farther from the nuclei so that it is easier to separate the nuclei and break the bond in S_2.

111. Both S and Te have the same number of valence electrons, but S is a smaller atom than Te and therefore more electronegative.

112. An ion is an atom which has more or less electrons than its atomic number.

113. AlN has a greater electrostatic attraction between the ions (+3 and –3 charge) than does NaF (+1 and –1), so a greater melting temperature is required to separate the ions.

114. Molecules of F_2 and I_2 are held next to one another in the solid phase by London forces. Since I_2 has more electrons than F_2, and since London forces increase as the number of electrons increases, F_2 will melt at a lower temperature than I_2.

115. # of valence electrons: Se = 6, K^- = 2, Sn = 4, Ge^{2+} = 2, Br = 7

116. Both substances have the same number of charges attracting each other but the ions in RbI are larger than the atoms in KBr, so the greater separation of the ions in RbI lowers the electrostatic attraction between the ions and lowers the melting temperature.

117. the valences are: S = 2, B = 3, Ca = 2, Xe = 0, Ga = 3, Bi = 3

118. total numbers of electrons:
Cl_2 = 2 x 17 (Cl) = 34
O_2 = 2 x 8 (O) = 16
CH_4 = 6 (C) + 4 x 1 (H) = 10
S_4 = 4 x 16 (S) = 64
H_2SO_4 = 2 x 1 (H) + 16 (S) + 4 x 8 (O) = 50

119. # of shells:
Rn = 6 (closed) = 6 (total) ; Sb = 4 (closed) + 1 (open) = 5 (total)
Sr^{2+} = 4 (closed) = 4 (total) ; Na^- = 2 (closed) + 1 (open) = 3 (total)
P = 2 (closed) + 1 (open) = 3 (total) ; Ga^{2+} = 3 (closed) + 1 (open) = 4 (total)
I^+ = 4 (closed) + 1 (open) = 5 (total)

120. O_2 has the stronger bond because the greater number of shared electrons in O_2 holds the nuclei together more strongly.

121. London forces increase in strength going down the periodic table.

122. Ionic and covalent bonds decrease in strength going down the periodic table.

123. (a) The noble gases are held together by London forces. Going down the periodic table, the number of electrons in the atoms increases and the strength of the London forces increases, leading to an increased melting temperature.
(b) When alkali metals react, they lose an electron. As the alkali metal atoms increase in size, their valence electrons are farther from the nuclei, less tightly held, and easier to remove.
(c) Since the noble gases have no tendency to attract extra electrons, the only way they can react is to lose an electron or allow one or more of the outer electrons to be attracted to another atom and engage in covalent bonding. Going down the periodic table, the outermost electrons are further from the nucleus and the electrostatic attraction between the electrons and nucleus decreases, increasing the reactivity of the noble gases.
(d) As the alkali metals increase in size, their valence electrons are farther from the nuclei and therefore are not able to hold the nuclei together as strongly, resulting in a lowered melting temperature.
(e) Going down the periodic table, the size of the ions involved in the ionic bond increases and the distance between the charges increases. As a result, the electrostatic attraction between the charges decreases and the melting temperature decreases.
(f) The halogens react by attracting an electron to form a negative charge. This tendency to attract extra electrons is just the electronegativity and electronegativity decreases going down the periodic table due to the increased distance between the nucleus and electrons outside the atom.

124. The number of unpaired electrons is just the valence, so:
H = 1, C = 4, O = 2, He = 0, S = 2, N = 3, F = 1, Kr = 0.

125. Rn is the largest noble gas atom, so its outermost electrons are farther from its nucleus than is the case with the other noble gases. This increased distance makes it easier to remove an outer electron and form a +1 charge.

126. O = 2, P = 3, Al = 3, Xe = 0, Cl = 1, Na = 1, Ba = 2, Ga = 3, Se = 2, He = 0

127. The molecules are held in the solid phase by London forces. Since S_8 has more electrons than S_4 , S_8 should have stronger London forces and a higher melting temperature.

128. The number of covalent bonds will be the same as the valence of the atom, so:
Xe = 0, I = 1, N = 3, Se = 2, B = 3, P = 3, C = 4, O = 2

129. London forces

130. (a) PbI_4 (b) InAs (c) Al_4Si_3 (d) NF_3 (e) SiC (f) PH_3

ANSWERS TO UNIT IX : SOLUTION CHEMISTRY

1. The solution is saturated if a visible amount of solid NaCl is present. The solution is NOT saturated if the NaCl was added only a few seconds before, because the salt hasn't had enough time to completely dissolve. If the newly–made salt water mixture is constantly stirred the resulting solution might or might not be saturated – only the eventual observation of undissolved NaCl allows you to say the solution is saturated.
2. Normally, the hotter a solvent is the more solute it can dissolve. Therefore, you would expect warming of a saturated solution to allow the solution to dissolve more solute and become "unsaturated".
3. Some solutions found in nature are: sea, lake and river waters, the air (oxygen and nitrogen), rocks (solid solutions of minerals), water lying in puddles on soil (contains dissolved minerals from the soil), fruit juices, tree sap (such as maple syrup) and various biological fluids.
4. Glass is not soluble in water.
5. i) Only the smallest bulb glows so there is very little conductivity and very low ion concentration.
   ii) Compounds 3, 4, 5, 7, 8, 10
   iii) It has the same conductivity as pure water and therefore the same concentration of ions. This can be interpreted to mean glucose does not produce ions.
   iv) The non–conducting compounds start with a carbon atom (are organic).
   v) HCl and H_2SO_4 are acids; KOH and NaOH are bases.
   vi) NaCl and NH_4NO_3 are salts.
   vii) NaSCN, NaOH, Na_3PO_4
   viii) Substances in the solid phase do not conduct electricity.
   ix) The phase must be a liquid (melted substance or aqueous solution).
   x) The greater the concentration of ions, the greater the conductivity.
   xi) A reaction occurs between water and acetic acid to produce ions.
   xii) The acetic acid solution, and its ions, are being diluted in concentration.
6. Conducting = a, c, d, f, g, i ; Non–conducting = b, e, h, j
7. Organic compounds and nonpolar compounds (which can be the same compound in some cases)
8. c, d, f, i, k, l, o, q, s, t, u, v, x
9. (a) nonpolar (b) polar (c) polar (d) nonpolar
10. (a) polar (c) polar (e) polar (g) nonpolar
    (b) nonpolar (d) nonpolar (f) polar (h) polar
11. HCl is expected to have a higher boiling temperature than F_2 because HCl is a polar molecule and experiences dipole–dipole forces in addition to London forces. F_2 experiences only London forces.
12. The low boiling temperature of CF_4 is expected because only London forces are involved. The higher boiling temperature of CHF_3 is explained by the fact that the molecule is polar. The dipole–dipole forces in CHF_3 hold the molecules together to a greater degree and raise the boiling temperature.
13. (a) Going up column 15 of the periodic table, the atoms Sb, As and P have fewer and fewer electrons and therefore smaller London forces hold molecules to their neighbours. As a result, it is easier to melt the compounds. (Although the molecules are all polar, the dipole–dipole forces are almost the same for each molecule because the electronegativity of Sb, As and P are almost identical.)
    (b) NH_3 contains the N–H bond, which means that hydrogen bonding is present in NH_3 but not in the others. Since hydrogen bonds are much stronger than London forces, the melting temperature is higher than otherwise expected.
14. c, e, g, h

15. Propane molecules are held next to neighbouring molecules in the liquid phase by weak London forces. Such forces are not very "sticky" and freely allow one molecule to "slide" or "flow" past one another, leading to a low viscosity (low resistance to flow). Glycerine has three O–H groups which can hydrogen bond strongly to neighbouring molecules, preventing the molecules from sliding freely past each other and leading to a high viscosity.

16. The molecule with the higher boiling temperature is the one with hydrogen bonding in addition to London forces. Hence, molecules with N, O or F bonded to H have higher boiling temperatures.
(a) CH_3–CH_2–OH (b) H_2O (c) CH_3NH_2

17.

Solvent	Polar or nonpolar?	Solvent	Polar or nonpolar?
water	Polar	acetic acid	Polar
methanol	Polar	chloroform	Polar
ethanol	Polar	carbon tetrachloride	Nonpolar
benzene	Nonpolar	heptane	Nonpolar
ethoxyethane	Polar	liquid ammonia	Polar
acetone	Polar		

18. Both hexane and Br_2 are nonpolar; "like dissolves like". Water is polar and does not dissolve nonpolar Br_2 to a great extent.

19. The long carbon chain can help dissolve nonpolar solutes, while the ionic end helps to dissolve polar solutes.

20. Nonpolar solvents can only attach to solutes using weak London forces; these forces are unable to overcome the strong bonds holding an ionic compound together so that nonpolar solvents are unable to dissolve ionic compounds.

21. Pentane is held together in the liquid phase by weak London forces. Pentane is not affected by the polar character of water, or its potential for hydrogen bonding, but water **does** exert weak London forces which to a certain extent are able to overcome the London forces holding $C_5H_{12}(l)$ together.

22. (a) Only the highly polar water can dissolve appreciable amounts of ionic KCl(s).
(b) The large "nonpolar" part of $CH_3CH_2CH_2CH_2Br$ is dissolved to the greatest extent by the greater London forces available with CH_3CH_2OH.
(c) The large nonpolar octane molecule is dissolved to the greatest extent by the greater London forces available with CH_3CH_2OH.

23. (a) London force
(b) London force
(c) Dipole–dipole and London forces
(d) Hydrogen bonding
(e) Covalent bond
(f) London force
(g) Dipole–dipole and London forces
(h) London force
(i) Dipole–dipole and London forces
(j) Ionic bond
(k) Hydrogen bond
(l) London force

24. (a) Xe
(b) HBr
(c) HO-CH_2CH_2-OH
(d) Br_2
(e) CCl_4
(f) H_2O
(g) CH_3F
(h) HI

25. a, d

26. For $I_2(s)$ try any of ethanol, acetone, heptane or carbon tetrachloride.
For $NaNO_3$ try water
For carbon disulphide try any of ethanol, acetone, heptane or carbon tetrachloride
For $H_2C{=}O$ try any of water, ethanol, acetone, heptane or carbon tetrachloride
For sulphur try any of ethanol, acetone, heptane or carbon tetrachloride

27. X is water (polar). A is sodium chloride (soluble in water). Liquids Y and Z must be nonpolar solvents (do not dissolve NaCl). Nonpolar naphthalene must be C (insoluble in polar water). Polar benzoic acid must be B (slightly soluble in polar water; fairly soluble to soluble in the nonpolar solvents).

28. (a) $KBr(s) \longrightarrow K^+(aq) + Br^-(aq)$
(b) $HCl(g) \longrightarrow H^+(aq) + Cl^-(aq)$
(c) $Na_2SO_4(s) \longrightarrow 2Na^+(aq) + SO_4^{2-}(aq)$
(d) $Ca(OH)_2(s) \longrightarrow Ca^{2+}(aq) + 2\,OH^-(aq)$
(e) $Al_2(SO_4)_3(s) \longrightarrow 2\,Al^{3+}(aq) + 3\,SO_4^{2-}(aq)$
(f) $K_3PO_4(s) \longrightarrow 3\,K^+(aq) + PO_4^{3-}(aq)$
(g) $AlCl_3(s) \longrightarrow Al^{3+}(aq) + 3Cl^-(aq)$
(h) $(NH_4)_2S(s) \longrightarrow 2\,NH_4^+(aq) + S^{2-}(aq)$

29. Water is plentiful, cheap, nontoxic/nonpolluting and an excellent solvent for many ionic and polar solutes.

30. $[SO_4^{2-}] = 3 \times 0.135\text{ M} = \mathbf{0.405\ M}$

31. $[BaCl_2] = \dfrac{10.0\text{ g}}{0.600\text{ L}} \times \dfrac{1\text{ mol BaCl}_2}{208.3\text{ g}} = 0.0800\text{ M}\ ;\ [Cl^-] = 2 \times [BaCl_2] = 2 \times 0.0800\text{ M} = \mathbf{0.160\ M}$

32. $[HCl] = 0.300\text{ M} \times \dfrac{55.0\text{ mL}}{135.0\text{ mL}} = 0.1222\text{ M}\ ;\ [Cl^-] = [HCl] = 0.1222\text{ M}$

$[CaCl_2] = 0.550\text{ M} \times \dfrac{80.0\text{ mL}}{135.0\text{ mL}} = 0.3259\text{ M}\ ;\ [Cl^-] = 2 \times [CaCl_2] = 2 \times 0.3259\text{ M} = 0.6519\text{ M}$

total $[Cl^-] = 0.1222\text{ M} + 0.6519\text{ M} = \mathbf{0.774\ M}$

33. $[MgCl_2] = 0.250\text{ M} \times \dfrac{350.0\text{ mL}}{275.0\text{ mL}} = 0.3182\text{ M}\ ;\ [Cl^-] = 2 \times [MgCl_2] = 2 \times 0.3182\text{ M} = \mathbf{0.636\ M}$

34. (a) moles $K_2SO_4 = 0.20\ \dfrac{\text{mol}}{\text{L}} \times 0.60\text{ L} = 0.12\text{ mol}$

so that: # of moles K^+ = 2 x moles K_2SO_4 = **0.24 mol**,
and: # of moles SO_4^{2-} = moles K_2SO_4 = **0.12 mol**

(b) moles $Na_3PO_4 = 0.300\ \dfrac{\text{mol}}{\text{L}} \times 0.450\text{ L} = 0.135\text{ mol}$

so that: # of moles Na^+ = 3 x moles Na_3PO_4 = **0.405 mol**,
and: # of moles PO_4^{3-} = moles Na_3PO_4 = **0.135 mol**

(c) moles $MnCl_2 = 0.160\ \dfrac{\text{mol}}{\text{L}} \times 0.0750\text{ L} = 0.0120\text{ mol}$

so that: # of moles Mn^{2+} = moles $MnCl_2$ = **0.0120 mol**,
and: # of moles Cl^- = 2 x moles $MnCl_2$ = **0.0240 mol**

(d) moles $Al_2(SO_4)_3 = 0.235\ \dfrac{\text{mol}}{\text{L}} \times 0.0950\text{ L} = 0.022\,33\text{ mol}$

so that: # of moles Al^{3+} = 2 x moles $Al_2(SO_4)_3$ = 2 x 0.022 33 mol = **0.0447 mol**,
and: # of moles SO_4^{2-} = 3 x moles $Al_2(SO_4)_3$ = 3 x 0.022 33 mol = **0.0670 mol**

35. $[BaCl_2] = 0.200\ M \times \frac{100.0\ mL}{250.0\ mL} = 0.0800\ M$; $[Ba^{2+}] = [BaCl_2] =$ **0.0800 M**

$[Cl^-] = 2 \times [BaCl_2] = 2 \times 0.0800\ M = 0.160\ M$

$[NaCl] = 0.400\ M \times \frac{150.0\ mL}{250.0\ mL} = 0.240\ M$; $[Na^+] = [NaCl] =$ **0.240 M** ; $[Cl^-] = [NaCl] = 0.240\ M$

total $[Cl^-] = 0.160\ M + 0.240\ M =$ **0.400 M**

36. $[Na_3PO_4] = 0.200\ M \times \frac{75.0\ mL}{100.0\ mL} = 0.150\ M$; $[Na^+] = 3 \times [Na_3PO_4] = 3 \times 0.150\ M =$ **0.450 M**

$[PO_4^{3-}] = [Na_3PO_4] = 0.150\ M$

$[K_3PO_4] = 0.800\ M \times \frac{25.0\ mL}{100.0\ mL} = 0.200\ M$; $[K^+] = 3 \times [K_3PO_4] = 3 \times 0.200\ M =$ **0.600 M**

$[PO_4^{3-}] = [Na_3PO_4] = 0.200\ M$

$[PO_4^{3-}]$ (total) $= 0.150\ M + 0.200\ M =$ **0.350 M**

37. $[Na_3PO_4] = 0.325\ M \times \frac{15.0\ mL}{50.0\ mL} = 0.0975\ M$; $[Na^+] = 3 \times [Na_3PO_4] = 3 \times 0.0975\ M =$ **0.293 M**

$[PO_4^{3-}] = [Na_3PO_4] =$ **0.0975 M**

$[K_2SO_4] = 0.225\ M \times \frac{35.0\ mL}{50.0\ mL} = 0.1575\ M$; $[K^+] = 2 \times [K_2SO_4] = 2 \times 0.1575\ M =$ **0.315 M**

$[SO_4^{2-}] = [K_2SO_4] =$ **0.158 M**

38. $[K_2CrO_4] = \frac{3.25\ g}{0.1000\ L} \times \frac{1\ mol}{194.0\ g} = 0.1675\ M$; $[K^+] = 2 \times [K_2CrO_4] = 2 \times 0.1675\ M = 0.3351\ M$

$[CrO_4^{2-}] = [K_2CrO_4] =$ **0.168 M**

$[K_2Cr_2O_7] = \frac{1.75\ g}{0.1000\ L} \times \frac{1\ mol}{294.0\ g} = 0.059\ 52\ M$; $[K^+] = 2 \times [K_2Cr_2O_7] = 2 \times 0.059\ 52\ M = 0.1190\ M$

$[Cr_2O_7^{2-}] = [K_2Cr_2O_7] =$ **0.0595 M**

total $[K^+] = 0.3351 + 0.1190 =$ **0.454 M**

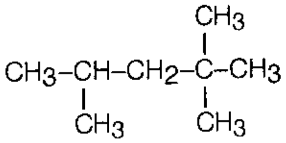
ANSWERS TO UNIT X : ORGANIC CHEMISTRY

1. C_NH_{2N+2}

2. (a) 7 carbons; heptane
   (b) 7 carbons; heptane
   (c) 8 carbons; octane
   (d) 10 carbons; decane

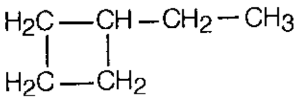
3. (a) 3–methylhexane
   (b) 4-ethylheptane
   (c) 3-ethyloctane
   (d) 2–methylhexane
   (e) 4–methylnonane
   (f) 3–methylheptane

4. (a)

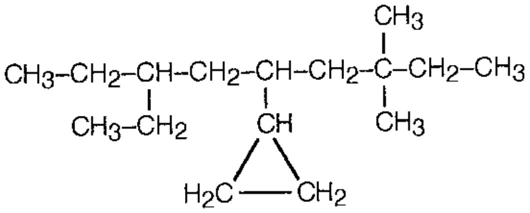


$$CH_3-\underset{\substack{|\\CH_3}}{CH}-CH_2-\overset{\substack{CH_3\\|}}{\underset{\substack{|\\CH_3}}{C}}-CH_3$$

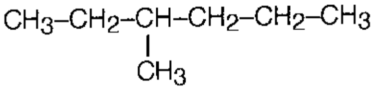
(b)



(c)

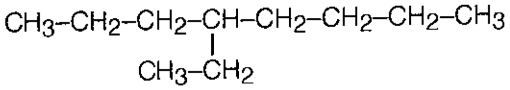


5. (a)



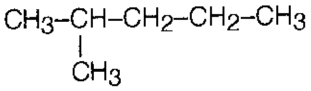
$$CH_3-CH_2-\underset{\substack{|\\CH_3}}{CH}-CH_2-CH_2-CH_3$$

(b)



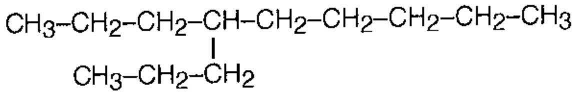
$$CH_3-CH_2-CH_2-\underset{\substack{|\\CH_3-CH_2}}{CH}-CH_2-CH_2-CH_2-CH_3$$

(c)



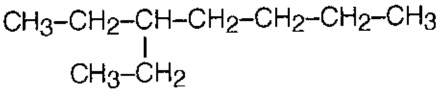
$$CH_3-\underset{\substack{|\\CH_3}}{CH}-CH_2-CH_2-CH_3$$

(d)



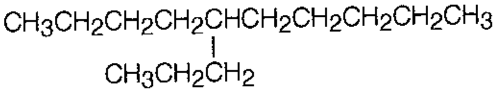
$$CH_3-CH_2-CH_2-\underset{\substack{|\\CH_3-CH_2-CH_2}}{CH}-CH_2-CH_2-CH_2-CH_2-CH_3$$

(e)



$$CH_3-CH_2-\underset{\substack{|\\CH_3-CH_2}}{CH}-CH_2-CH_2-CH_2-CH_3$$

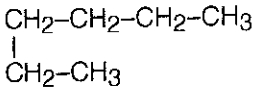
(f)



$$CH_3CH_2CH_2CH_2\underset{\substack{|\\CH_3CH_2CH_2}}{CH}CH_2CH_2CH_2CH_2CH_3$$

6. (a) the molecule is numbered from the wrong end; it should be 2–methylheptane

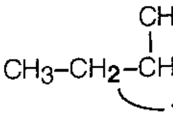
   (b) 1–ethylbutane is



$$\underset{\substack{|\\CH_2-CH_3}}{CH_2}-CH_2-CH_2-CH_3$$

which is just hexane

   (c)



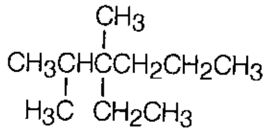
$$CH_3-CH_2-\overset{\substack{CH_3\\|}}{CH}-CH_3$$

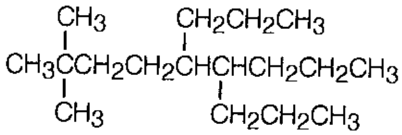
this carbon has the subscript "2"

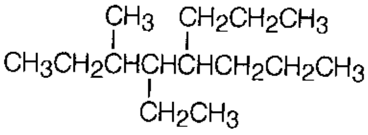
   (d) the carbon at the 2–position of the propane chain should have NO hydrogens

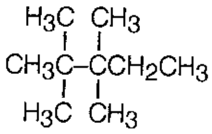
7. C_NH_{2N+2} (unchanged from straight–chain alkanes)

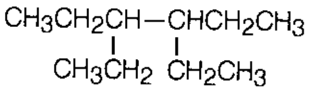
8. (a) 3,4–dimethylheptane
   (b) 3,4,4,5–tetraethylheptane
   (c) 2,2,7,7–tetramethyloctane
   (d) 5–ethyl–3,4–dimethylheptane
       or 3–ethyl–4,5–dimethylheptane
   (e) 4–methyl–4–ethyloctane
   (f) 2,2,5–trimethyloctane
   (g) 4,6–dimethylnonane
   (h) decane
   (i) 4,5–diethyl–3,7–dimethylnonane
   (j) 3,3,4,5–tetramethyloctane
   (k) 4–ethyl–3–methyl–5–propyloctane
   (l) 3,6–diethyl–5,8–dimethyldecane
       or 5,8–diethyl–3,6–dimethyldecane

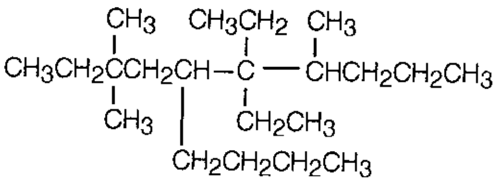
9. (a) 
$CH_3\underset{H_3C}{CH}\overset{CH_3}{\underset{CH_2CH_3}{C}}CH_2CH_2CH_3$

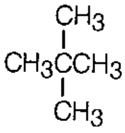
(b) 
$CH_3\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_2\overset{CH_2CH_2CH_3}{CH}\underset{CH_2CH_2CH_3}{CH}CH_2CH_2CH_3$

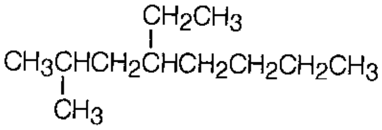
(c) 
$CH_3CH_2\overset{CH_3}{CH}\underset{CH_2CH_3}{CH}\overset{CH_2CH_2CH_3}{CH}CH_2CH_2CH_3$

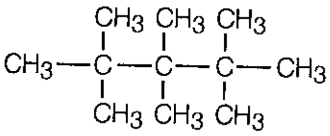
(d) 
$CH_3\overset{H_3C}{\underset{H_3C}{C}}-\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_3$

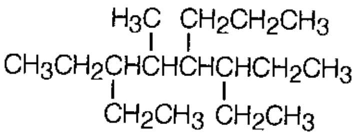
(e) 
$CH_3CH_2\underset{CH_3CH_2}{CH}-\underset{CH_2CH_3}{CH}CH_2CH_3$

(f) 
$CH_3CH_2\overset{CH_3}{\underset{CH_3}{C}}CH_2\underset{CH_2CH_2CH_2CH_3}{CH}-\overset{CH_3CH_2}{\underset{CH_2CH_3}{C}}-\overset{CH_3}{CH}CH_2CH_2CH_3$

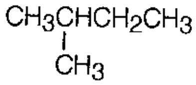
(g) 
$CH_3\overset{CH_3}{\underset{CH_3}{C}}CH_3$

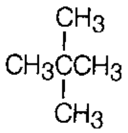
(h) 
$CH_3\underset{CH_3}{CH}CH_2\overset{CH_2CH_3}{CH}CH_2CH_2CH_2CH_3$

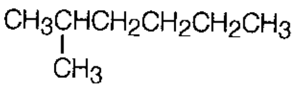
(i) 
$CH_3-\overset{CH_3}{\underset{CH_3}{C}}-\overset{CH_3}{\underset{CH_3}{C}}-\overset{CH_3}{\underset{CH_3}{C}}-CH_3$

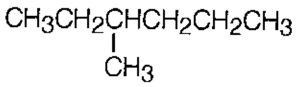
(j) 
$CH_3CH_2\underset{CH_2CH_3}{CH}\overset{H_3C}{CH}\overset{CH_2CH_2CH_3}{CH}\underset{CH_2CH_3}{CH}CH_2CH_3$

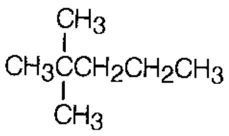
10. pentane = $CH_3CH_2CH_2CH_2CH_3$

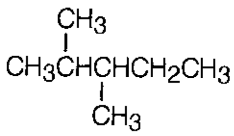
methylbutane = 
$CH_3\underset{CH_3}{CH}CH_2CH_3$

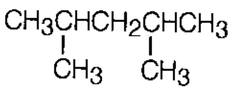
dimethylpropane = 
$CH_3\overset{CH_3}{\underset{CH_3}{C}}CH_3$

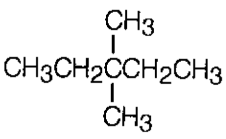
11. 2–methylhexane = 
$CH_3\underset{CH_3}{CH}CH_2CH_2CH_2CH_3$

3–methylhexane = 
$CH_3CH_2\underset{CH_3}{CH}CH_2CH_2CH_3$

12. 2,2–dimethylpentane = 
$CH_3\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_2CH_3$

2,3–dimethylpentane = 
$CH_3\overset{CH_3}{CH}\underset{CH_3}{CH}CH_2CH_3$

2,4–dimethylpentane = 
$CH_3\underset{CH_3}{CH}CH_2\underset{CH_3}{CH}CH_3$

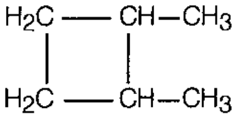
3,3–dimethylpentane = 
$CH_3CH_2\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_3$

13. 3 – having methyl groups at the 2, 3 or 4 position

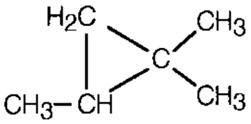
14. C_NH_{2N}

15. (a) ethylcyclohexane
(b) 1,3–dimethylcyclobutane
(c) methylcyclopropane
(d) 1–ethyl–1,3–dimethylcyclopentane
(e) 2–ethyl–1,3–dimethylcyclooctane

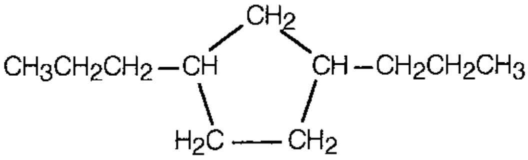
16. (a)



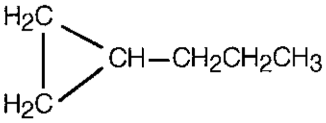
(b)



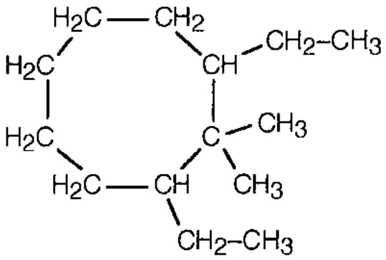
(c)



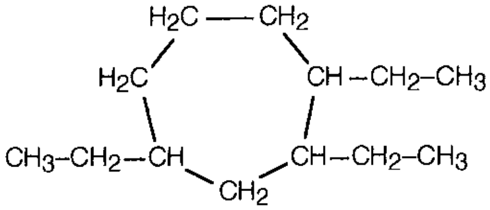
(d)



(e)



(f)

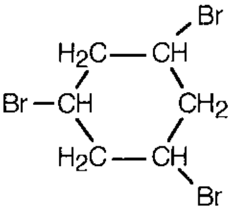


17. (a) chloroethane
(b) 1,3-dibromopropane
(c) 1-iodo-4-methylpentane
(d) 1,1-dichloro-2-fluoroethane
(e) 1,1-dichloro-2-ethylcyclohexane

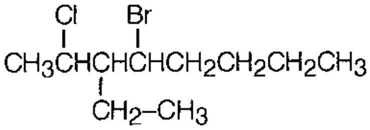
18. (a) $CHCl_3$

(b) $ClCH_2CH_2Cl$

(c)

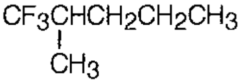


(d)



$CH_3\overset{Cl}{C}H\underset{CH_2-CH_3}{C}H\overset{Br}{C}HCH_2CH_2CH_2CH_3$

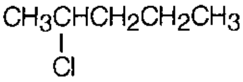
(e)



$CF_3\underset{CH_3}{C}HCH_2CH_2CH_3$

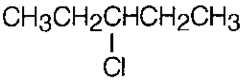
19. 1-chloropentane = $C lCH_2CH_2CH_2CH_2CH_3$

2-chloropentane =



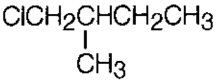
$CH_3\underset{Cl}{C}HCH_2CH_2CH_3$

3-chloropentane =



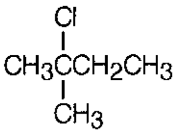
$CH_3CH_2\underset{Cl}{C}HCH_2CH_3$

1-chloro-2-methylbutane =



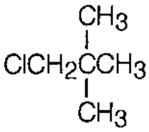
$ClCH_2\underset{CH_3}{C}HCH_2CH_3$

2-chloro-2-methylbutane =



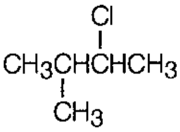
$CH_3\overset{Cl}{\underset{CH_3}{C}}CH_2CH_3$

chlorodimethylpropane =



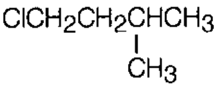
$ClCH_2\overset{CH_3}{\underset{CH_3}{C}}CH_3$

3-chloro-2-methylbutane =
(or 2-chloro-3-methylbutane)



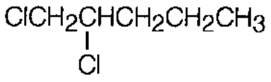
$CH_3\underset{CH_3}{C}H\overset{Cl}{C}HCH_3$

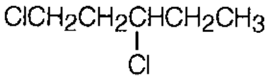
1-chloro-3-methylbutane =

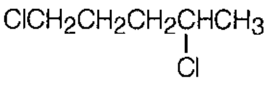


$ClCH_2CH_2\underset{CH_3}{C}HCH_3$

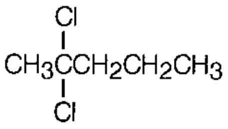
20\. 1,1–dichloropentane = $Cl_2CHCH_2CH_2CH_2CH_3$

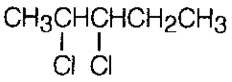
1,2–dichloropentane =

$ClCH_2\underset{\displaystyle Cl}{\underset{|}{C}}HCH_2CH_2CH_3$

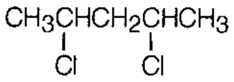
1,3–dichloropentane =

$ClCH_2CH_2\underset{\displaystyle Cl}{\underset{|}{C}}HCH_2CH_3$

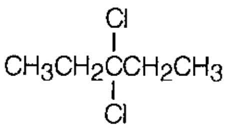
1,4–dichloropentane =

$ClCH_2CH_2CH_2\underset{\displaystyle Cl}{\underset{|}{C}}HCH_3$

1,5–dichloropentane = $ClCH_2CH_2CH_2CH_2CH_2Cl$

2,2–dichloropentane =

$CH_3\overset{\displaystyle Cl}{\overset{|}{\underset{\displaystyle Cl}{\underset{|}{C}}}}CH_2CH_2CH_3$

2,3–dichloropentane =

$CH_3\underset{\displaystyle Cl}{\underset{|}{C}}H\underset{\displaystyle Cl}{\underset{|}{C}}HCH_2CH_3$

2,4–dichloropentane =

$CH_3\underset{\displaystyle Cl}{\underset{|}{C}}HCH_2\underset{\displaystyle Cl}{\underset{|}{C}}HCH_3$

3,3–dichloropentane =

$CH_3CH_2\overset{\displaystyle Cl}{\overset{|}{\underset{\displaystyle Cl}{\underset{|}{C}}}}CH_2CH_3$

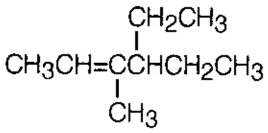
21\. (a) alkene = C_NH_{2N} (same as cycloalkane) (b) alkyne = C_NH_{2N-2}

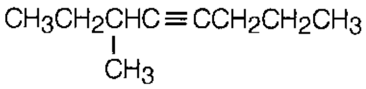
22\. (a) $CH_2{=}CHCH_2CH_2CH_2CH_3$ (b) $CH_3CH_2CH_2C{\equiv}CCH_2CH_2CH_2CH_3$

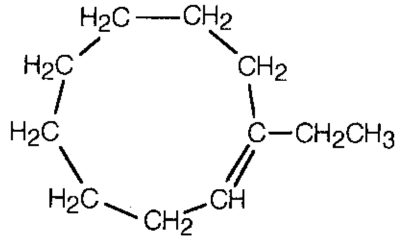
(c) $CH_3CH_2CH{=}CHCH_2CH_2CH_2CH_2CH_2CH_3$ (d) $CH_3C{\equiv}CCH_2CH_2CH_2CH_3$

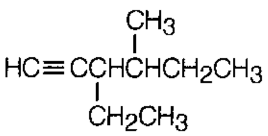
(e) $CH_3CH{=}CHCH_2CH_2CH_2CH_2CH_3$ (f) $HC{\equiv}CCH_2CH_2CH_2CH_2CH_2CH_3$

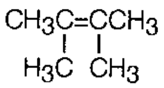
23\. (a) 3–hexene (b) 1–heptyne (c) 4–decyne (d) 3–heptene

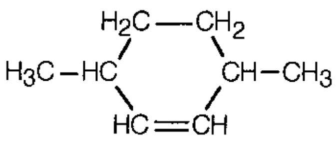
24\. (a)

$CH_3CH{=}\underset{\displaystyle CH_3}{\underset{|}{C}}\overset{\displaystyle CH_2CH_3}{\overset{|}{C}}HCH_2CH_3$

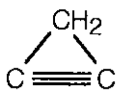
(b)

$CH_3CH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HC{\equiv}CCH_2CH_2CH_3$

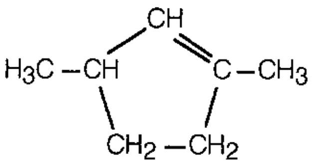
(c)


(d)

$HC{\equiv}C\underset{\displaystyle CH_2CH_3}{\underset{|}{C}}H\overset{\displaystyle CH_3}{\overset{|}{C}}HCH_2CH_3$

(e)

$CH_3\underset{\displaystyle H_3C}{\underset{|}{C}}{=}\underset{\displaystyle CH_3}{\underset{|}{C}}CH_3$

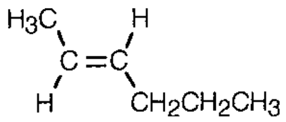
(f)


(g)


(h)


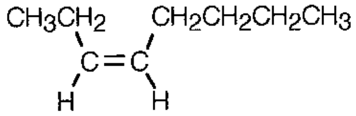
25\. (a) 5–ethyl–6,6–dimethyl–3–heptene
(b) 3,6–diethyl–2–methyl–4–octyne
(c) 1,3,4–trimethyl–1–cyclobutene
(d) 5,6–dimethyl–1–cyclooctyne
(e) 3–methyl–3–hexene
(f) 3–methyl–1–cyclohexene

26. (a)

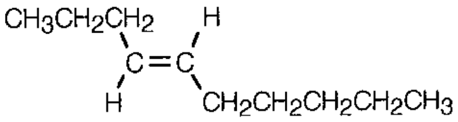


(b) $CH_3CH_2C \equiv CCH_2CH_3$

(c)

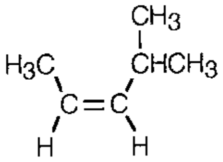


(d)



(e) $CH_3C \equiv CCH_3$

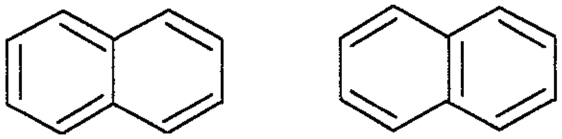
(f)



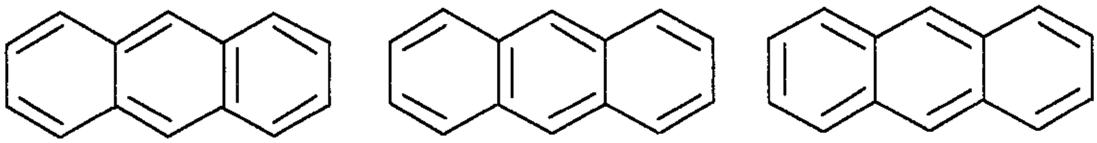
27. (a) no (b) yes (c) no (d) yes (e) no (f) no

28. (a) cis–3–hexene (b) trans–3–octene (c) trans–2–heptene (d) cis–4–octene

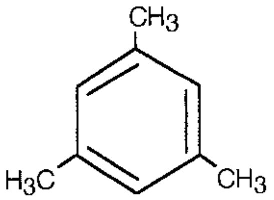
29. (a)



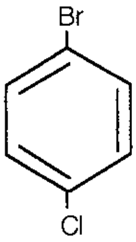
(b)



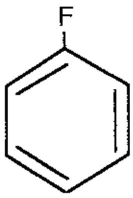
30. (a)



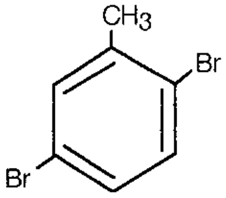
(b)



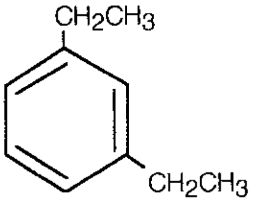
(c)



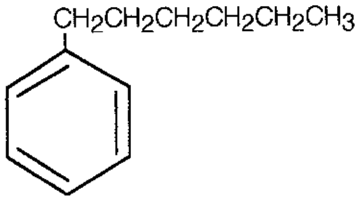
(d)



(e)



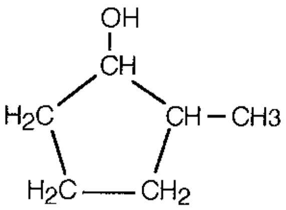
(f)



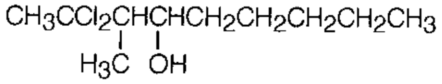
31. (a) ethylbenzene
   (b) 1–bromo–4–methylbenzene
      or 4–bromo–1–methylbenzene
   (c) hexachlorobenzene
   (d) 1,2–dimethylbenzene
   (e) 1–ethyl–3,5–dimethylbenzene
      or 3–ethyl–1,5–dimethylbenzene
      or 5–ethyl–1,3–dimethylbenzene
   (f) 1–ethyl–4–methylbenzene
      or 4–ethyl–1–methylbenzene

32. (a) $CH_3CH_2CH_2CH_2OH$

(b)

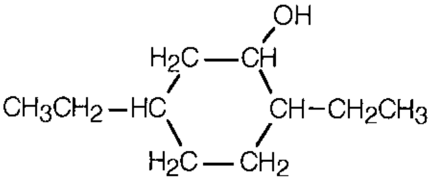


(c)

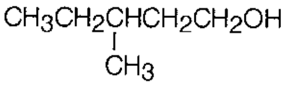


$CH_3CCl_2\underset{H_3C}{\underset{|}{C}}H\underset{OH}{\underset{|}{C}}HCH_2CH_2CH_2CH_2CH_3$

(d)

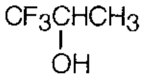


(e)



$CH_3CH_2\underset{CH_3}{\underset{|}{C}}HCH_2CH_2OH$

(f)



$CF_3\underset{OH}{\underset{|}{C}}HCH_3$

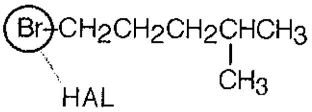
33. (a) 2–propanol
(b) 4,4,4–trifluoro–2–butanol
(c) 3–methyl–1–butanol
(d) 2–methyl–2–propanol
(e) 2–chloro–1–cyclobutanol
(f) 2,3–dimethyl–1–cyclopropanol

34. (a) methyl propanoate
(b) propyl methanoate
(c) ethyl butanoate
(d) hexyl ethanoate
(e) butyl pentanoate

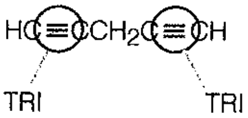
35. (a) $CH_3CH_2CH_2CH_2COOCH_2CH_2CH_3$
(b) $CH_3CH_2CH_2CH_2CH_2COOCH_3$
(c) $CH_3CH_2COOCH_2CH_3$
(d) $CH_3CH_2CH_2COOCH_2CH_2CH_2CH_3$
(e) $HCOOCH_2CH_2CH_2CH_2CH_2CH_3$

36. (a) CH_3OH and CH_3CH_2COOH
(b) $CH_3CH_2CH_2OH$ and $HCOOH$
(c) CH_3CH_2OH and $CH_3CH_2CH_2COOH$
(d) $CH_3CH_2CH_2CH_2CH_2CH_2OH$ and CH_3COOH
(e) $CH_3CH_2CH_2CH_2OH$ and $CH_3CH_2CH_2CH_2COOH$

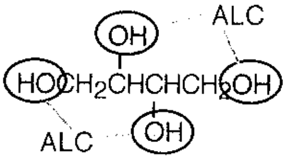
37. (a)



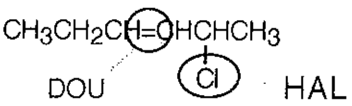
(b)



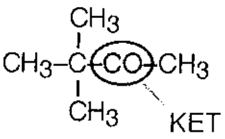
(c)



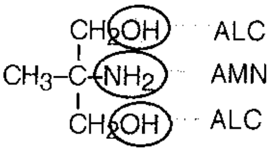
(d)



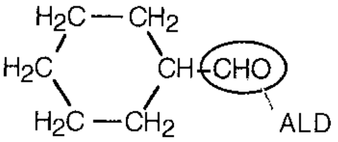
(e)



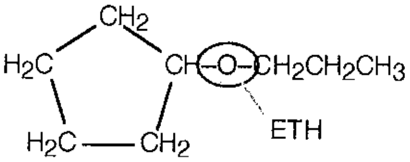
(f)

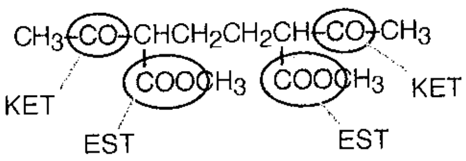


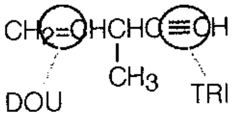
(g)

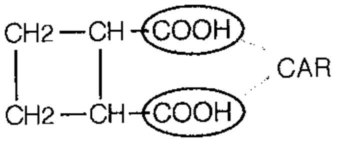


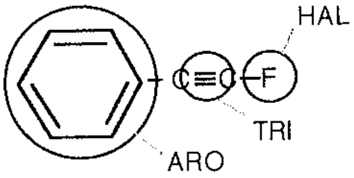
(h)

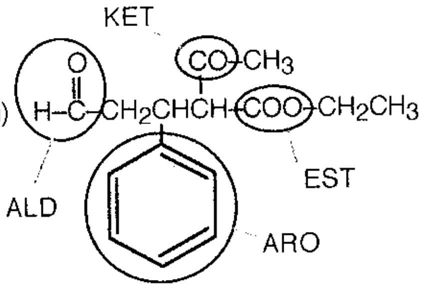


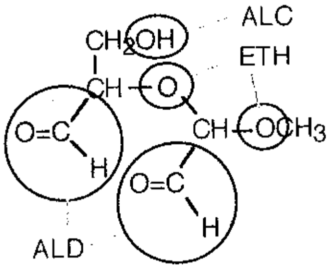
(i)


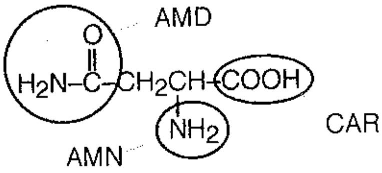
(j)


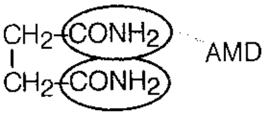
(k)


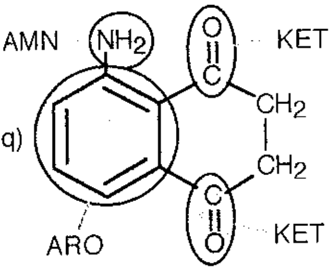
(l)


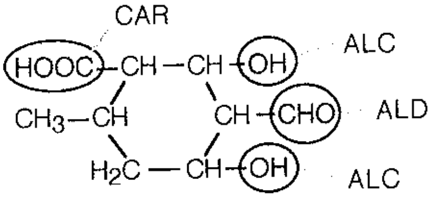
(m)


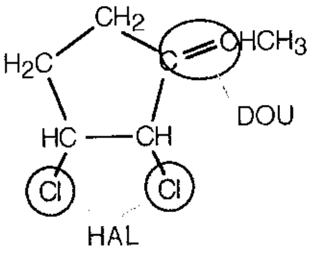
(n)


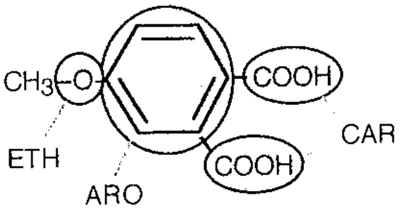
(o)


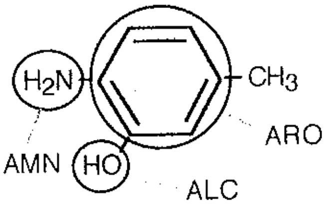
(p)


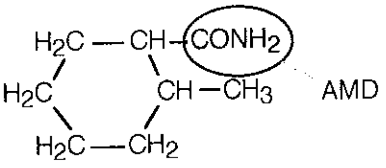
(q)


(r)


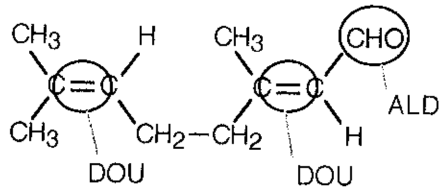
(s)


(t)


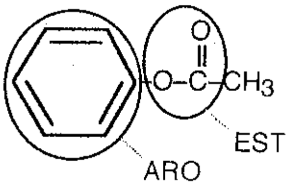
(u)


(v)


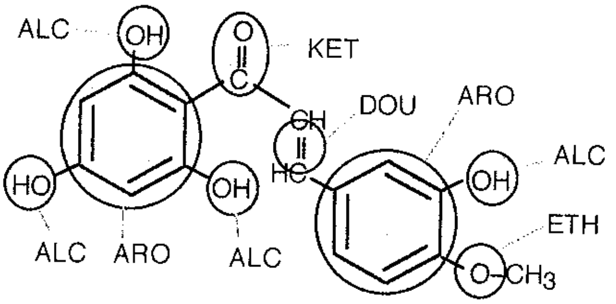
(w)



(x)

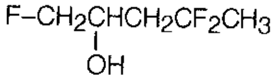


(y)



38. (a) 2–fluoropentane
(b) 3–chloro–3–hexene
(c) 1,4–diiodo–2–butyne
(d) pentyl methanoate
(e) 3–bromo–3,5,5–trimethyloctane
(f) 1,3–dichlorocyclobutane
(g) 1–fluoro–4–propylbenzene
or 4–fluoro–1–propylbenzene
(h) 2,6–dimethyloctane
(i) 4–bromo–5–chloro–1–iodo–2–pentyne
(j) 4–iodo–2–butanol
(k) 3–methyl–1–cyclopentanol
(l) 1,3,5–triethylbenzene
(m) 3–bromo–1–propene
(n) pentyl ethanoate
(o) 2,4–dibromo–1–methylbenzene
(p) 1,2,3–trimethylcyclopropane
(q) cyclopropanol
(r) 1–chloro–2–ethylbenzene
or 2–chloro–1–ethylbenzene

39. (a)

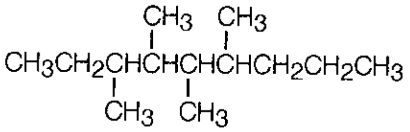


$F\text{-}CH_2\underset{OH}{C}HCH_2CF_2CH_3$

(b) $CH_3C\equiv CCHClCH_2CH_3$

(c) $CH_3CH_2CH_2CH_2COOCH_2CH_3$

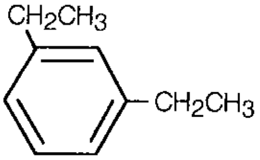
(d)



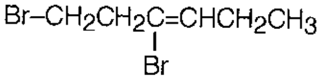
$CH_3CH_2\underset{CH_3}{C}H\overset{CH_3}{C}H\underset{CH_3}{C}H\overset{CH_3}{C}HCH_2CH_2CH_3$

(e) $CH_3CH_2C\equiv CCH_2CH_2CH_2CH_3$

(f)

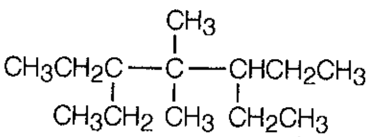


(g)



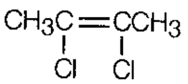
$Br\text{-}CH_2CH_2\underset{Br}{C}=CHCH_2CH_3$

(h)



$CH_3CH_2\underset{CH_3CH_2}{C}-\overset{CH_3}{\underset{CH_3}{C}}-\underset{CH_2CH_3}{C}HCH_2CH_3$

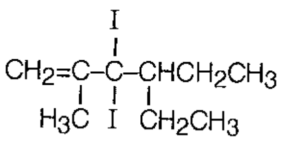
(i)



$CH_3\underset{Cl}{C}=\underset{Cl}{C}CH_3$

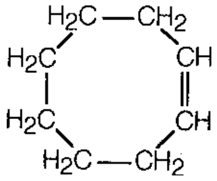
(j) $CH_3CH_2CH_2CH_2CH_2CH_2CH_2COOCH_3$

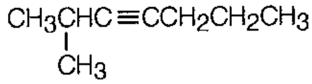
(k)

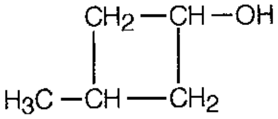


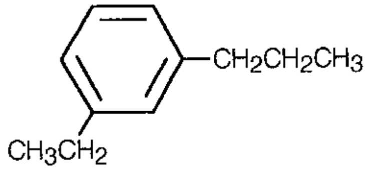
$CH_2=\underset{H_3C}{C}-\overset{I}{\underset{I}{C}}-\underset{CH_2CH_3}{C}HCH_2CH_3$

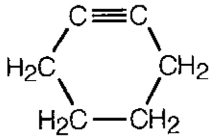
(l)

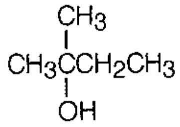


(m) 
$CH_3\underset{\displaystyle CH_3}{CH}C\equiv CCH_2CH_2CH_3$

(n) 

(o) 

(p) 

(q) 
$CH_3\overset{\displaystyle CH_3}{\underset{\displaystyle OH}{C}}CH_2CH_3$

(r) $CH_3CBr_2CBr_2CH_3$

40. C_NH_{2N+2} implies no loss of H's (no multiple bonds; no ring present which joins one end of a chain back onto itself).

C_NH_{2N} implies the loss of 2 H's due to either a ring present **OR** a double bond.

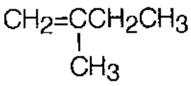
C_NH_{2N-2} implies the loss of 4 H's due to either a triple bond **OR** two double bonds **OR** two rings present **OR** a double bond AND a ring present.

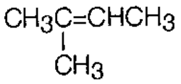
Answers: c, e, g, i

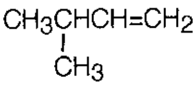
41. Structures involving a double bond:

$CH_2{=}CH{-}CH_2{-}CH_2{-}CH_3$ = 1–pentene

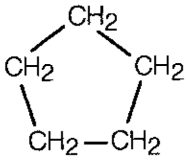
$CH_3{-}CH{=}CH{-}CH_2{-}CH_3$ = 2–pentene

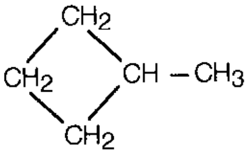

$CH_2{=}\underset{\displaystyle CH_3}{C}CH_2CH_3$ = 2–methyl–1–butene

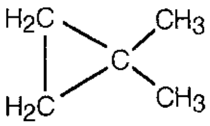

$CH_3\underset{\displaystyle CH_3}{C}{=}CHCH_3$ = 2–methyl–2–butene

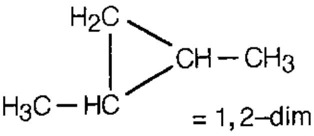

$CH_3\underset{\displaystyle CH_3}{C}HCH{=}CH_2$ = 3–methyl–1–butene

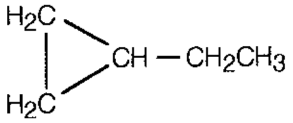
Structures involving a ring:


= cyclopentane


= methylcyclobutane

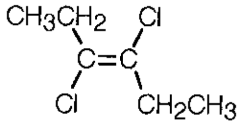

= 1, 1–dimethylcyclopropane


= 1, 2–dimethylcyclopropane

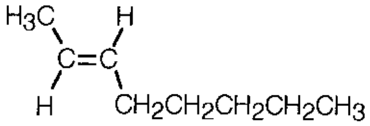

= ethylcyclopropane

42. (a) carboxylic acids, amino acids
(b) amines
(c) esters
(d) alkanes
(e) amino acids
(f) esters

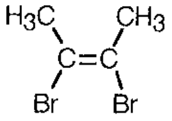
43. (a)



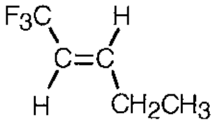
(b)



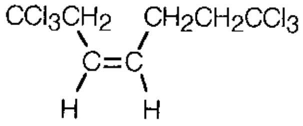
(c)



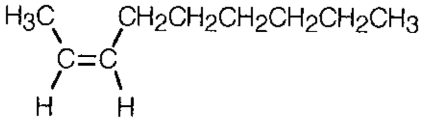
(d)



(e)

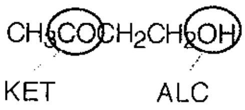


(f)

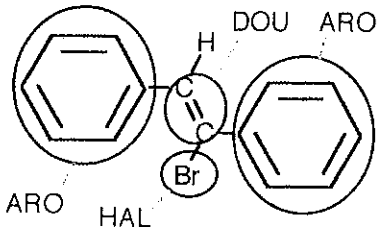


44. (a)

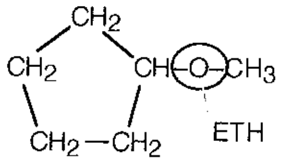
(b)



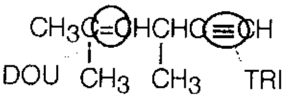
(c)



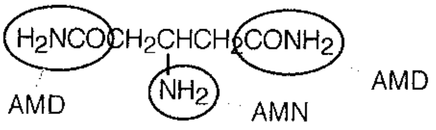
(d)



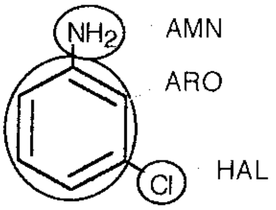
(e)



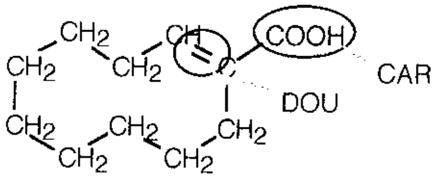
(f)



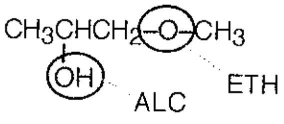
(g)



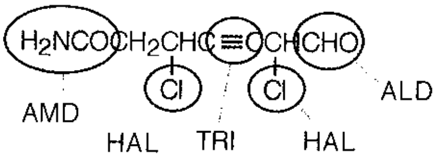
(h)



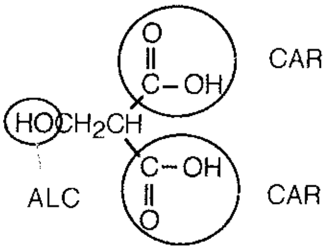
(i)



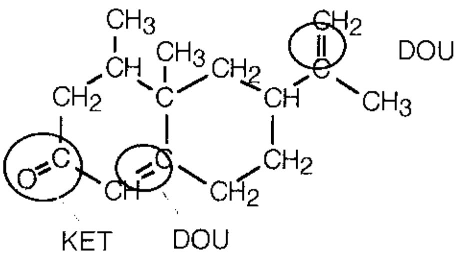
(j)



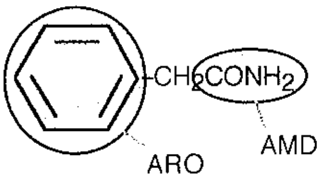
(k)



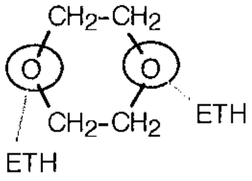
(l)



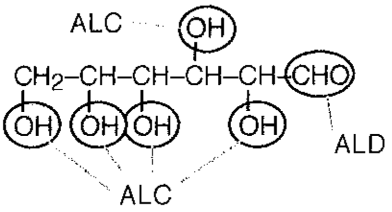
(m)


CH2CONH2
ARO
AMD

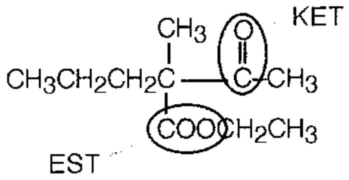
(n)


CH2-CH2
O
O
CH2-CH2
ETH
ETH

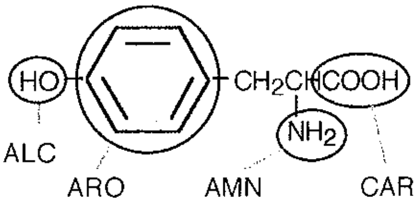
(o)


ALC
OH
CH2-CH-CH-CH-CH-CHO
OH
OH
OH
OH
ALD
ALC

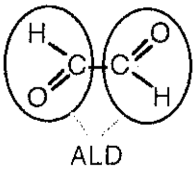
(p)


CH3
O
KET
CH3CH2CH2C
C
CH3
COOCH2CH3
EST

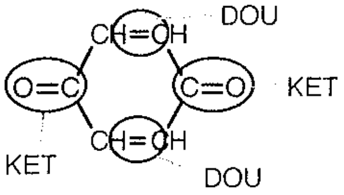
(q)


HO
CH2CHCOOH
NH2
ALC
ARO
AMN
CAR

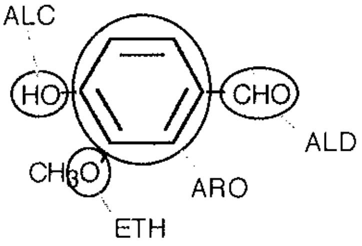
(r)


H
C
C
O
O
H
ALD

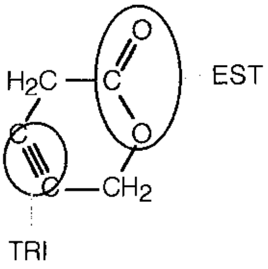
(s)


CH=CH
DOU
O=C
C=O
KET
CH=CH
KET
DOU

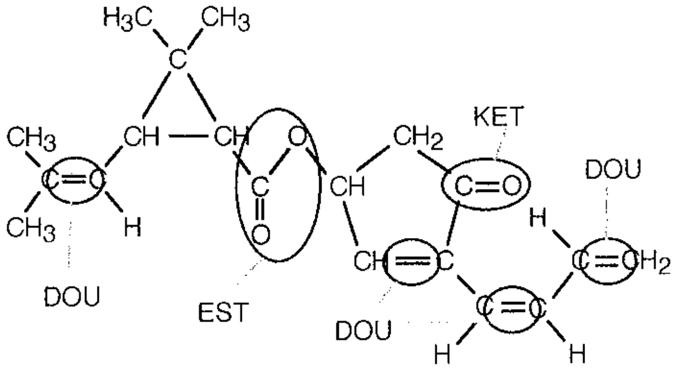
(t)


ALC
HO
CHO
ALD
CH3O
ARO
ETH

(u)


O
H2C
C
EST
C
O
C
CH2
TRI

(v)


H3C
CH3
C
CH3
CH
CH
O
CH2
KET
C=C
C
CH
C=O
DOU
CH3
H
O
H
DOU
CH=C
C=CH2
EST
DOU
C=C
H
H

GLOSSARY

The number following each entry is the page number where the term is defined or first mentioned.

ACCURATE MEASUREMENT – a measurement that is close to the CORRECT or ACCEPTED value (28)

ACID – a compound whose formula starts with "H" (74)

ACTINIDE – an element in the row underneath the main part of the table, starting with actinium (161)

ALCOHOL– an organic compound containing an OH group (233)

ALDEHYDE – an organic compound containing a CHO group at the end of a hydrocarbon chain (234)

ALKALI METAL – an element in the first column of the periodic table (except hydrogen) (161)

ALKALINE EARTH METAL – an element in the second column of the periodic table (161)

ALKANE – a hydrocarbon in which all the carbon atoms are connected by single bonds (215)

ALKENE – an organic compound containing a carbon–carbon double bond (226)

ALKYL GROUP – an alkane which has lost one hydrogen atom (217)

ALKYL HALIDE – an alkane having a halogen attached (224)

ALKYNE – an organic compound containing a carbon–carbon triple bond (226)

ALPHA PARTICLE – a He^{2+} ion which is given off by a radioactive atom (142, 143)

AMIDE – an organic compound containing a $CONH_2$ group (236)

AMINE – an organic compound containing an NH_2 group (236)

AMINO ACID – a carboxylic acid with an amine group at the 2–position (237)

ANION – an ion with a NEGATIVE charge (68)

AQUEOUS SOLUTION – a solution in which the solvent is WATER (51)

AROMATIC MOLECULE – a molecule containing one or more benzene rings (231)

ASYMMETRICAL MOLECULE – a molecule in which one end is different than the other (200)

ATOM – the smallest possible unit of an element which retains the fundamental properties of the element (49)

ATOMIC MASS – the total number of protons and neutrons in an atom (146)

ATOMIC NUMBER – the number of protons in the nucleus of an atom; also, the charge on the nucleus (145)

AVOGADRO'S HYPOTHESIS – equal volumes of gases, at the same temperature and pressure, contain the same number of particles (77)

AVOGADRO'S NUMBER – the number of particles in 1 mol of a substance = 6.02×10^{23} (83)

BALANCED EQUATION – a chemical reaction equation in which mass, atoms, and electrical charge are conserved (107)

BASE – a compound that has a chemical formula ending with OH (116)

BASE UNIT – one of the basic units in SI measurement (such as gram, metre, second and mole) (16)

BETA PARTICLE – a high energy electron emitted directly from an atomic nucleus (142)

BINARY COMPOUND – a compound made of two different types of atom (73)

BOHR MODEL (OF THE ATOM) – a model in which the electrons in an atom are restricted to having certain specific energies and are restricted to following specific paths at a fixed distance from the nucleus (144)

BOILING TEMPERATURE– the temperature at which a liquid changes into the gas phase. At the boiling temperature the liquid and gas phases co–exist. (60)

CARBOXYLIC ACID – an organic compound which contains a COOH group (236)

CATION – an ion with a POSITIVE charge (68)

CHEMICAL CHANGE – a change in which new substances are formed (59)

CHEMICAL PROPERTY – the ability of a substance to undergo chemical reactions and change into new substances, either by itself or with other substances (44)

CHEMICAL REACTION EQUATION – an equation that shows the chemicals used up and produced during a chemical reaction (105)

CHEMICAL WORD EQUATION – uses words to describe the REACTANTS and PRODUCTS (105)

CHEMISTRY – the science concerned with the properties, composition and behaviour of matter (44)

CHROMATOGRAPHY – a separation process in which different dissolved substances in a solution (the mobile phase) preferentially move through an absorbent material (the stationary phase) and are separated according to the relative attractions of the dissolved solids to the mobile phase or stationary phase (57)

CIS ISOMER – an isomer in which attached groups are on the same side of a double bond (230)

CLOSED SHELL – an electron shell which contains its maximum number of electrons (154)

CLOSED SYSTEM – a system is closed if nothing can enter or leave it (105)

COEFFICIENT – the number shown in front of each species involved in a chemical reaction (105)

COMBINATION REACTION – see SYNTHESIS

COMBINING CAPACITY – see VALENCE (as a noun)

COMBUSTION – a general term referring to the rapid reaction of a substance with oxygen to produce substantial amounts of heat, and usually a flame (116)

COMPOUND – a pure substance made of two or more types of atoms (51)

CONCENTRATED SOLUTION – a solution with a relatively high concentration of a particular substance (96)

CONCENTRATION (of a substance in solution) – the amount of the substance which exists in a given volume of the solution (96)

CONDENSATION TEMPERATURE – the temperature at which a gas changes into the liquid phase. At the condensation temperature the liquid and gas phases co–exist. (60)

CONSERVATION LAW – an experimentally observed law which states what is CONSERVED (unchanged) in a special set of circumstances (106)

CONSERVED QUANTITY – a quantity which does not change during a closed system reaction (106)

CONTROLLED FIRE – a fire which is contained in a beaker, flask or test tube, such that the fire can be put out by placing a watch glass or inverted beaker over the top of the container and smothering the fire (5)

CONVERSION FACTOR – is a fractional expression relating or connecting two different units (9)

CORE – the set of electrons with the configuration of the nearest noble gas having an atomic number LESS than that of the atom being considered (155)

COVALENT BOND – a bond which involves the equal sharing of electrons (176)

CRYSTAL LATTICE – the orderly arrangement of particles which exists within a crystal (209)

CYCLOALKANE – a hydrocarbon chain which is connected in a head–to–tail "circle"; also called a cyclic hydrocarbon (222)

DATA – quantitative information which is experimentally–determined or obtained from references (41)

DECOMPOSITION REACTION – involves breaking down a molecule into simpler substances (114)

DENSITY – the mass contained in a given volume of a substance, calculated from the formula $d = \frac{m}{V}$ (24)

DERIVED QUANTITY – a number made by combining two or more other values (23)

DERIVED UNIT – a unit which is made by combining two or more other units (23)

DESCRIPTION – a list of the properties of something (41)

DEUTERIUM – an isotope of hydrogen having an atomic mass of 2; sometimes call "heavy hydrogen" (148)

DIATOMIC SPECIES – a chemical species that is made up of two atoms (which may be the same or different types) (68)

DIFFUSION – the intermingling of fluids as a result of motion within the fluid (this applies to both gases and liquids) (46)

DILUTE SOLUTION – a solution with a relatively low concentration of a particular substance (96)

DIPOLE – a partial charge separation existing when one end of a molecule (or bond) has a slight excess of positive charge and the other end of the molecule (or bond) has a slight excess of negative charge (179)

DIPOLE–DIPOLE FORCE – a bonding force which exists as a result of an electrostatic attraction between molecules having permanent dipoles (199)

DISSOCIATION REACTION – a reaction involving separating previously–existing ions in an ionic solid (210)

DISTILLATION – a separation process in which a liquid is boiled and the resulting vapour is condensed to a liquid by being passed through a condenser. Since different liquids boil at different temperatures, mixtures of liquids can be separated by the distillation process. (53)

DOUBLE REPLACEMENT or **METATHESIS REACTION** – a reaction which involves an exchange of atoms or groups between two different compounds (115)

DUCTILITY – the ability of a substance to be stretched or drawn into wires (46)

ELECTRON CONFIGURATION – a description of which orbitals in an atom contain electrons and how many electrons are in each orbital (154)

ELECTRON–DEFICIENT MOLECULE – a molecule in which one or more atoms (other than hydrogen) does not possess a full octet of electrons (186)

ELECTRON DOT DIAGRAM – see LEWIS STRUCTURE

ELECTRONEGATIVITY – the tendency of the atom to attract electrons from a neighbouring atom (173)

ELECTROSTATIC FORCE – a force existing as a result of the attraction or repulsion between two charged particles (165)

ELEMENT – a substance which cannot be separated into simpler substances as a result of any chemical process (49)

EMERGENCY EQUIPMENT – equipment which is intended to be used only in the event of an emergency (1)

EMPIRICAL FORMULA (sometimes called the **SIMPLEST FORMULA**) – the smallest whole–number ratio of atoms which represents the molecular composition of a species (91)

ENDOTHERMIC REACTION – a reaction which absorbs heat from its surroundings (120)

ENERGY LEVEL – a specific amount of energy which an electron in an atom can possess (151)

ENTHALPY – the heat contained in a system (121)

EQUIVALENCE POINT or **STOICHIOMETRIC POINT** – the point in a titration where the mole ratio of the reacting species equals the ratio of the coefficients of the species in the balanced reaction equation (130)

ESTER – an organic compound in which a COO group connects two hydrocarbon chains (238)

ETHER – a compound in which an oxygen joins two hydrocarbon groups (235)

EVAPORATION (as a method of physical separation) – the process of allowing the liquid in a solid–in–liquid solution to evaporate or to be boiled away, leaving the solid (53)

EXCESS REACTANT – a reactant which is not completely used up in a reaction (132)

EXOTHERMIC REACTION – a reaction which gives off heat to its surroundings (119)

EXPERIMENT – a test or a procedure that is carried out in order to discover a result (41)

EXPERIMENTAL UNCERTAINTY – the estimated amount by which a measurement might be in error (34)

EXPONENTIAL EQUIVALENT – an exponential number which can replace an SI prefix symbol (for example, "10^3" is the exponential equivalent of "k") (17)

EXTENSIVE PROPERTY – a physical property which depends on the amount of the substance present (44)

FAMILY – see GROUP

FILTRATE – the liquid which passes through a filter paper (53)

FILTRATION – the separation of an undissolved solid from a liquid by passing the liquid through a filter paper, so as to leave the solid behind (53)

FREEZING TEMPERATURE – the temperature at which a liquid changes into the solid phase. At the freezing temperature the solid and liquid phases co–exist. (60)

FUNCTIONAL GROUP – a specific group of atoms which exists in a molecule and gives a molecule an ability to react in a specific manner or gives it special properties (233)

GAMMA PARTICLE – high energy radiation given off by the nucleus (142)

GRAVITY SEPARATION – any of several separation methods which separate the components of a mechanical mixture according to their densities. The methods include gold panning, mechanical shaking, froth flotation and centrifugation. (56)

GROUP or **FAMILY** – the set of all the elements in a given column going down the table (161)

HALOGEN – an element in the 17th column of the periodic table (headed by fluorine) (161)

HAND SEPARATION – the separation of a mechanical mixture by bare hand, sieve or magnet (53)

HARDNESS – the ability of a solid to resist abrasion or scratching (46)

HETEROGENEOUS SUBSTANCE – a substance consisting of more than one phase (50)

HOMOGENEOUS SUBSTANCE – a substance consisting of only one phase (50)

HYDRATE – a molecule which includes one or more water molecules in its crystal structures (72)

HYDROCARBON – a compound made of carbon and hydrogen (116)

HYDROGEN BOND – a bond which exists as a result of a strong dipole–dipole attraction between molecules having H–F, H–O or H–N bonds (202)

HYPOTHESIS – a SINGLE, UNPROVEN assumption or idea which attempts to explain why nature behaves in a specific manner. When initially put forward, hypotheses are tentative but, if they survive testing, eventually gain general acceptance. (41)

IMMISCIBLE LIQUIDS – liquids which are insoluble in each other (54)

INDICATOR – a coloured dye which changes colour when an acidic solution has been exactly neutralized by a basic solution, or vice versa (130)

INORGANIC NOMENCLATURE – the naming of elements and inorganic compounds (65)

INTENSIVE PROPERTY – a physical property which depends solely on the nature of a substance, and NOT on how much of a substance is present (44)

INTERMOLECULAR FORCE – a force which holds complete, neutral molecules next to one another (179)

INTERPRETATION (or "inference") – an attempt to put meaning into an observation (41)

INTRAMOLECULAR FORCE – a force which holds atoms together to make a molecule (179)

ION – an atom or molecule which possesses an electrical charge (49)

IONIC BOND – a bond formed by the attraction of positive ions to negative ions (172)

IONIC COMPOUND – a compound made up of ions (70)

IONIC SOLID – a solid whose crystal structure is made up of ions (209)

IONIZATION ENERGY – the energy required to remove an electron from a neutral atom (168)

IONIZATION REACTION – a reaction which involves the breaking up of a neutral molecule into ions (210)

ISOTOPES – atomic species having the same atomic number but different atomic masses (148)

KETONE – an organic compound containing a C=O group at a position other than at the end of a hydrocarbon chain (235)

KINETIC ENERGY – the energy that molecules possess as a result of their motion (62)

LANTHANIDE – an element in the row underneath the main part of the table, starting with lanthanum (161)

LAW – a broad generalization or summary statement which describes a large amount of experimental evidence stating how nature behaves when a particular situation occurs (41)

LAW OF CONSERVATION OF ATOMS – the total number and type of atoms in a closed system does not change during a chemical reaction (106)

LAW OF CONSERVATION OF ELECTRICAL CHARGE – the total electrical charge in a closed system does not change during a chemical reaction (106)

LAW OF CONSERVATION OF ENERGY – the total energy in a closed system does not change during a chemical reaction (106)

LAW OF CONSERVATION OF MASS – the total mass in a closed system does not change during a chemical reaction; that is, the mass of the reactants equals the mass of the products (106)

LAW OF CONSTANT COMPOSITION – see LAW OF DEFINITE PROPORTIONS

LAW OF DEFINITE PROPORTIONS (or LAW OF CONSTANT COMPOSITION) – every pure sample of a particular compound always contains the same proportion by mass of the elements in the compound (140)

LAW OF MULTIPLE PROPORTIONS – when different masses of one element combine with a specific mass of a second element, the mass ratios of the first element are small whole number ratios (141)

LEADING ZERO – a zero digit which is not significant and only serves to hold the place value of the following digits (37)

LEWIS STRUCTURE – a diagram showing how the valence electrons are distributed in an atom, ion or molecule; also called an electron dot diagram (172)

LIMITING REACTANT – a reactant which sets a limit on the amount of product which can be formed (132)

LONDON FORCES – weak attractive forces which arise as a result of temporary dipolar attractions between neighbouring atoms (179)

LUSTRE – the manner in which a solid surface reflects light (46)

MALLEABILITY – the ability of a substance to be rolled or hammered into thin sheets (46)

MASS – the quantity of matter in an object (24)

MATTER – anything that has mass and occupies space (44)

MECHANICAL MIXTURE – a heterogeneous mixture of two or more substances (50)

MELTING TEMPERATURE – the temperature at which a solid changes into the liquid phase. At the melting temperature the solid and liquid phases co–exist. (60)

METALLOID – see semiconductor

METATHESIS REACTION – see DOUBLE REPLACEMENT REACTION

METRIC CONVERSION – a unit conversion between a prefix symbol and its exponential equivalent (19)

MISCIBLE LIQUIDS – liquids that are mutually soluble in each other in all proportions (54)

MIXTURE – a system made up of two or more substances, such that the relative amounts of each substance can be varied (50)

MOLAR CONCENTRATION or **MOLARITY** (of a substance in solution) – the number of moles of the substance contained in 1 L of solution (96)

MOLARITY – see MOLAR CONCENTRATION

MOLAR MASS – the mass of ONE MOLE of particles. The molar mass of an element is the mass shown on the periodic table, expressed in grams (79)

MOLAR VOLUME (of a substance) – the volume occupied by one mole of the substance. The molar volume of any gas at STP is 22.4 L. (82)

MOLE – the fundamental unit used for measuring amount. One mole of particles is 6.02×10^{23} particles. (Strictly speaking, one mole is the number of carbon atoms in exactly 12 g of carbon–12.) (79, 83)

MOLECULAR SOLID – a solid whose crystal structure is made of neutral molecules (209)

MOLECULE – a cluster of two or more atoms, held together strongly by electrical forces (49)

MONATOMIC SPECIES – a chemical species that is made up of only ONE atom (68)

NEUTRALIZATION REACTION – the reaction between **H** in an acid and **OH** in a base to make $\mathbf{H_2O}$ (116)

NEUTRAL SOLUTION – a solution which has no excess of either an acid or a base (116)

NOBLE GAS– an element in the 18th column of the periodic table (headed by helium) (161)

OBSERVATION – ***qualitative*** information collected through the direct use of our senses (41)

OCTET RULE – states that atoms in columns 14 to 17 of the periodic table tend to form covalent bonds so as to have eight electrons in their valence shells (176)

OPEN SHELL – a shell containing less than its maximum number of electrons (166)

OPEN SYSTEM – a system is OPEN if things can enter and leave it (105)

ORBITAL – the actual region of space occupied by an electron in a particular energy level (152)

ORGANIC CHEMISTRY – the chemistry of carbon compounds (213)

OUTER ELECTRON– see VALENCE ELECTRON

PARTICLE – a general term used to describe a small bit of matter such as an atom, molecule or ion (49)

PERCENTAGE COMPOSITION – the percentage (by mass) of the species in a chemical formula (90)

PERCENTAGE PURITY – the amount of pure chemical actually present in a sample as a percentage of the amount of the impure chemical present; calculated from the expression:
Percentage Purity = (mass of pure chemical / mass of impure chemical) x 100% (134)

PERCENTAGE YIELD – the amount of a product actually produced as a percentage of the expected amount; calculated from the expression:
Percentage Yield = (mass of product obtained / mass of product expected) x 100% (134)

PERIOD – the set of all the elements in a given row going across the table (161)

PERIODIC LAW – the properties of the chemical elements recur periodically when the elements are arranged from lowest to highest atomic numbers (160)

PHASE – any part of a system which is uniform in both its composition and properties (49)

PHYSICAL CHANGE – a change in a substance's phase, such that no new substances are formed (59)

PHYSICAL PROPERTY – a property that can be found without creating a new substance (44)

POLARIZATION – the repulsion of the electrons on one atom by the electrons on a second atom, combined with the simultaneous attraction of the electrons on one atom for the nucleus of a second atom (180)

POLAR MOLECULE – a molecule which has a partial positive charge at one end and a partial negative charge at the other end (199)

POLYATOMIC SPECIES – a general term for a chemical species made up of many atoms (68)

POLYELECTRONIC ATOM – an atom having more than one electron (153)

PRECIPITATE – a solid formed when two liquids or aqueous solutions react (113)

PRECISE MEASUREMENT – a reproducible measurement. In general, the more precise a measurement, the more SIGNIFICANT DIGITS it possesses. (28)

PREFIX-NAMING SYSTEM – a method of naming binary compounds made of nonmetals in which the number of each type of atom in the molecule is indicated by a prefix such as mono, di, tri, tetra, etc. (73)

PREFIX SYMBOL – a symbol which stands for a power of 10 (for example "c" stands for "10^{-2}") (17)

PRODUCT – a chemical which is formed as a result of a chemical reaction (105)

PROTECTIVE EQUIPMENT – equipment which is used to protect you from the effects of hazardous chemicals or material BEFORE any problems arise (5)

PURE SUBSTANCE – a substance that is homogeneous and has an unchangeable composition (50)

QUALITATIVE INFORMATION – NON-NUMERICAL information (41)

QUANTITATIVE INFORMATION – NUMERICAL information (41)

QUANTUM OF ENERGY – the energy difference between two particular energy levels in an atom (151)

RADIOACTIVITY – the ability of an atom to give off energy and nuclear particles (142)

REACTANT – a chemical which is present at the start of a chemical reaction (105)

RECRYSTALLIZATION – a purification and separation process in which a solid is dissolved in a suitable solvent and the mixture is allowed to cool or evaporate until purified crystals of the solid are deposited in the mixture (55)

REPRESENTATIVE ELEMENTS – the groups of elements which includes columns 1, 2 and 13 to 18 of the periodic table (161)

RESIDUE – the solid which remains behind on a filter paper after a filtration (53)

RESONANCE STRUCTURES – structures differing only in the placement of alternating double bonds (231)

ROTATIONAL ENERGY – kinetic energy which a molecule possesses as a result of rotation about one of its molecular axes (62)

RUTHERFORD MODEL (OF THE ATOM) – a model in which the atom consists of a tiny, positively–charged nucleus surrounded by a cloud of negatively–charged electrons (143)

SALT – an ionic compound that is neither an acid nor a base (116)

SATURATED HYDROCARBON – a hydrocarbon in which the carbon atoms are connected by single bonds; in other words, an alkane (215)

SATURATED SOLUTION – a solution which has dissolved as much of a particular solute as possible (193)

SEMICONDUCTOR – a nonmetal having an electrical conductivity which increases with temperature. Semiconductors were formerly called metalloids or semimetals. (163)

SEMIMETAL – see semiconductor

SHELL – the set of all orbitals having the same n–value. For example, the four orbitals consisting of the 2 s and three 2 p orbitals is a shell. (152)

SIGNIFICANT FIGURE – a measured or meaningful digit (27)

SINGLE REPLACEMENT REACTION – involves replacing **one** atom in a compound by another atom (114)

SOLUBILITY (of a solute) – the maximum amount of a solute which can dissolve in a given amount of solvent at a given temperature (193)

SOLUTE – the component in a solution which exists in the smaller quantity (51)

SOLUTION – a homogeneous mixture of two or more substances (50)

SOLUTION CHEMISTRY– the study of chemical reactions that occur in solutions (193)

SOLVATION – the interaction between a solute and a solvent (209)

SOLVENT – the component in a solution which exists in the greater quantity (51)

SOLVENT EXTRACTION – a separation process in which one of more components of a mixture are preferentially dissolved by the addition of a solvent. The added solvent and the dissolved substances are then removed, leaving the remainder of the original mixture behind. (54)

STOCK SYSTEM (of naming ions) – a method of naming metal ions in which the charge is indicated by a Roman numeral, in parentheses, immediately following the name (69)

STOICHIOMETRIC POINT – see EQUIVALENCE POINT

STOICHIOMETRY – the relationship between the amounts of reactants used in a chemical reaction and the amounts of products produced by the reaction (123)

STP – Standard Temperature and Pressure = $0^{o}C$ and 101.3 kPa (82)

STRUCTURAL ISOMERS – compounds which have the same molecular formula but a different arrangement of atoms (222)

SUBSHELL – a set of orbitals of the same type. For example, the set of three 2 p orbitals is a subshell. (152)

SUBSTANCE – something with a unique and identifiable set of properties (44)

SYNTHESIS or **COMBINATION REACTION** – involves the combination of two or more substances to form (or "synthesize") a compound (114)

SYSTEM – the part of the universe being studied in a given situation (49)

TERNARY COMPOUND – a compound made of three different types of atoms (73)

THEORY – a set of hypotheses that ties together a large number of observations of the real world into a logically consistent and understandable pattern. In other words, a theory is a TESTED, REFINED and EXPANDED explanation of why nature behaves in a given way. (41)

THOMSON MODEL (OF THE ATOM) – a model which proposed that an atom consisted of a ball of positive charge having negative charges distributed through the ball (141)

TITRATION – a process by which a measured amount of a solution is reacted with a known volume of another solution (one of the solutions has an unknown concentration) until a desired equivalence point is reached (130)

TRAILING ZERO – a zero digit which is significant (37)

TRANSLATIONAL ENERGY – kinetic energy which a molecule or atom possesses as a result of motion in a straight line (62)

TRANS ISOMER – an isomer in which attached groups are on opposite sides of a double bond (230)

TRANSITION METAL – an element in columns 3 to 12 of the periodic table (161)

TRIATOMIC SPECIES – a chemical species that is made up of three atoms (which may be the same or different types) (68)

TRITIUM – an isotope of hydrogen with an atomic mass of 3; sometimes called "radioactive hydrogen" (148)

UNCONTROLLED FIRE – a fire which is not minor and will possibly continue to spread (6)

UNIT CONVERSION – a calculation method which uses conversion factors to change the units associated with an expression to a different set of units (10)

UNIT SYMBOL – a symbol which stands for one of the SI base units (for example, **g** stands for grams) (16)

UNSATURATED HYDROCARBON – a general term for alkenes and alkynes (226)

VALENCE (as a noun) – the number of unpaired electrons on the atom; also called combining capacity (168)

VALENCE ELECTRON – an electron which can take part in a chemical reaction; also, any electron in an atom except those in the core, or in filled d– or f–subshells. In other words, electrons in OPEN shells. (157)

VAN DER WAALS FORCE – a general term referring to any of three types of weak intermolecular force, including the London force, dipole–dipole force and hydrogen bonding (179)

VAPOUR – the gaseous material formed by the evaporation of a substance which boils above room temperature (47)

VAPOUR PRESSURE – the pressure created by the vapour evaporating from a liquid (47)

VIBRATIONAL ENERGY – kinetic energy which a molecule possesses as a result of changes in its bond lengths and/or angles (62)

VISCOSITY – the *resistance* of a fluid to flow (46)

VOLUMETRIC FLASK – a special flask used to make up an exact volume of a solution. The flask has a narrow neck with a line etched around the neck. When filled to the etched line, the flask holds its exact rated volume. (97)

PERIODIC TABLE OF THE ELEMENTS

14 — Atomic number
Si — Symbol
Silicon — Name
28.1 — Atomic mass

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.0																	2 He Helium 4.0
3 Li Lithium 6.9	4 Be Beryllium 9.0											5 B Boron 10.8	6 C Carbon 12.0	7 N Nitrogen 14.0	8 O Oxygen 16.0	9 F Fluorine 19.0	10 Ne Neon 20.2
11 Na Sodium 23.0	12 Mg Magnesium 24.3											13 Al Aluminum 27.0	14 Si Silicon 28.1	15 P Phosphorus 31.0	16 S Sulphur 32.1	17 Cl Chlorine 35.5	18 Ar Argon 39.9
19 K Potassium 39.1	20 Ca Calcium 40.1	21 Sc Scandium 45.0	22 Ti Titanium 47.9	23 V Vanadium 50.9	24 Cr Chromium 52.0	25 Mn Manganese 54.9	26 Fe Iron 55.8	27 Co Cobalt 58.9	28 Ni Nickel 58.7	29 Cu Copper 63.5	30 Zn Zinc 65.4	31 Ga Gallium 69.7	32 Ge Germanium 72.6	33 As Arsenic 74.9	34 Se Selenium 79.0	35 Br Bromine 79.9	36 Kr Krypton 83.8
37 Rb Rubidium 85.5	38 Sr Strontium 87.6	39 Y Yttrium 88.9	40 Zr Zirconium 91.2	41 Nb Niobium 92.9	42 Mo Molybdenum 95.9	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Ha Hahnium (262)	106 Sg Seaborgium (263)	107 Uns Unnilseptium (262)	108 Uno Unniloctium (265)	109 Une Unnilennium (266)									

58 Ce Cerium 140.1	59 Pr Prasodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Based on mass of C^{12} at 12.00

Values in parenthesis are the masses of the most stable or best known isotopes for elements which do not occur naturally.

ATOMIC MASSES OF THE ELEMENTS

Based on mass of C^{12} at 12.00. Values in parentheses are the mass of the most stable or best known isotopes for elements which do not occur naturally.

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	(227)	Mercury	Hg	80	200.6
Aluminum	Al	13	27.0	Molybdenum	Mo	42	95.9
Americium	Am	95	(243)	Neodymium	Nd	60	144.2
Antimony	Sb	51	121.8	Neon	Ne	10	20.2
Argon	Ar	18	39.9	Neptunium	Np	93	(237)
Arsenic	As	33	74.9	Nickel	Ni	28	58.7
Astatine	At	85	(210)	Niobium	Nb	41	92.9
Barium	Ba	56	137.3	Nitrogen	N	7	14.0
Berkelium	Bk	97	(247)	Nobelium	No	102	(259)
Beryllium	Be	4	9.0	Osmium	Os	76	190.2
Bismuth	Bi	83	209.0	Oxygen	O	8	16.0
Boron	B	5	10.8	Palladium	Pd	46	106.4
Bromine	Br	35	79.9	Phosphorus	P	15	31.0
Cadmium	Cd	48	112.4	Platinum	Pt	78	195.1
Calcium	Ca	20	40.1	Plutonium	Pu	94	(244)
Californium	Cf	98	(251)	Polonium	Po	84	(209)
Carbon	C	6	12.0	Potassium	K	19	39.1
Cerium	Ce	58	140.1	Praseodymium	Pr	59	140.9
Cesium	Cs	55	132.9	Promethium	Pm	61	(145)
Chlorine	Cl	17	35.5	Protactinium	Pa	91	231.0
Chromium	Cr	24	52.0	Radium	Ra	88	(226)
Cobalt	Co	27	58.9	Radon	Rn	86	(222)
Copper	Cu	29	63.5	Rhenium	Re	75	186.2
Curium	Cm	96	(247)	Rhodium	Rh	45	102.9
Dysprosium	Dy	66	162.5	Rubidium	Rb	37	85.5
Einsteinium	Es	99	(252)	Ruthenium	Ru	44	101.1
Erbium	Er	68	167.3	Rutherfordium	Rf	104	(261)
Europium	Eu	63	152.0	Samarium	Sm	62	150.4
Fermium	Fm	100	(257)	Scandium	Sc	21	45.0
Fluorine	F	9	19.0	Selenium	Se	34	79.0
Francium	Fr	87	(223)	Silicon	Si	14	28.1
Gadolinium	Gd	64	157.3	Silver	Ag	47	107.9
Gallium	Ga	31	69.7	Sodium	Na	11	23.0
Germanium	Ge	32	72.6	Strontium	Sr	38	87.6
Gold	Au	79	197.0	Sulphur	S	16	32.1
Hafnium	Hf	72	178.5	Tantalum	Ta	73	180.9
Hahnium	Ha	105	(262)	Technetium	Tc	43	(98)
Helium	He	2	4.0	Tellurium	Te	52	127.6
Holmium	Ho	67	164.9	Terbium	Tb	65	158.9
Hydrogen	H	1	1.0	Thallium	Tl	81	204.4
Indium	In	49	114.8	Thorium	Th	90	232.0
Iodine	I	53	126.9	Thulium	Tm	69	168.9
Iridium	Ir	77	192.2	Tin	Sn	50	118.7
Iron	Fe	26	55.8	Titanium	Ti	22	47.9
Krypton	Kr	36	83.8	Tungsten	W	74	183.8
Lanthanum	La	57	138.9	Uranium	U	92	238.0
Lawrencium	Lr	103	(262)	Vanadium	V	23	50.9
Lead	Pb	82	207.2	Xenon	Xe	54	131.3
Lithium	Li	3	6.9	Ytterbium	Yb	70	173.0
Lutetium	Lu	71	175.0	Yttrium	Y	39	88.9
Magnesium	Mg	12	24.3	Zinc	Zn	30	65.4
Manganese	Mn	25	54.9	Zirconium	Zr	40	91.2
Mendelevium	Md	101	(258)				

NAMES, FORMULAE AND CHARGES OF SOME COMMON IONS

Positive ions (cations)	
Aluminum	Al^{3+}
Ammonium	NH_4^+
Barium	Ba^{2+}
Calcium	Ca^{2+}
Chromium(II), chromous	Cr^{2+}
Chromium(III), chromic	Cr^{3+}
Copper(I)*, cuprous	Cu^+
Copper(II), cupric	Cu^{2+}
Hydrogen	H^+
Hydronium	H_3O^+
Iron(II)*, ferrous	Fe^{2+}
Iron(III), ferric	Fe^{3+}
Lead(II), plumbous	Pb^{2+}
Lead(IV), plumbic	Pb^{4+}
Lithium	Li^+
Magnesium	Mg^{2+}
Manganese(II), manganous	Mn^{2+}
Manganese(IV)	Mn^{4+}
Mercury(I)*, mercurous	Hg_2^{2+}
Mercury(II), mercuric	Hg^{2+}
Potassium	K^+
Silver	Ag^+
Sodium	Na^+
Tin(II)*, stannous	Sn^{2+}
Tin(IV), stannic	Sn^{4+}
Zinc	Zn^{2+}

Negative ions (anions)	
Bromide	Br^-
Carbonate	CO_3^{2-}
Chlorate	ClO_3^-
Chloride	Cl^-
Chlorite	ClO_2^-
Chromate	CrO_4^{2-}
Cyanide	CN^-
Dichromate	$Cr_2O_7^{2-}$
Dihydrogen phosphate	$H_2PO_4^-$
Ethanoate, acetate	CH_3COO^-
Fluoride	F^-
Hydrogen carbonate, bicarbonate	HCO_3^-
Hydrogen oxalate, binoxalate	$HC_2O_4^-$
Hydrogen sulphate, bisulphate	HSO_4^-
Hydrogen sulphide, bisulphide	HS^-
Hydrogen sulphite, bisulphite	HSO_3^-
Hydroxide	OH^-
Hypochlorite	ClO^-
Iodide	I^-
Monohydrogen phosphate	HPO_4^{2-}
Nitrate	NO_3^-
Nitrite	NO_2^-
Oxalate	$C_2O_4^{2-}$
Oxide †	O^{2-}
Perchlorate	ClO_4^-
Permanganate	MnO_4^-
Phosphate	PO_4^{3-}
Sulphate	SO_4^{2-}
Sulphide	S^{2-}
Sulphite	SO_3^{2-}
Thiocyanate	SCN^-

* Aqueous solutions are readily oxidized by air.

† Not stable in aqueous solutions.