General Chemistry I

NAC 1101

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Chemistry New Building - 1st Floor

Ahmad Alakraa

Ahmad Alakraa

- B.Sc. 1995 (CU) (Major Chem.)
- M.Sc. 1999 (CU) (Phy. Chem./Surf. Chem.)
- Ph.D. 2004 (PennState + CU) (Physical Chem./Nanotech.)

- Post Doc. 2005-2007, TiTech/Sanyo Electric Co., Ltd., Japan.
- Assistant Professor 2007-2009, QU/KSA.
- Associate Professor 2011-2015, BUE/EG
- Professor 2019, Physics/AUC- Nanotech.
- Professor 2020, HTI.
- Professor 2024-Current, FoE/CU
- Professor 2016-Current, FoS/CU

Research Nanomaterials; Water Treatment, Energy Conversions.

Publications 96 articles in Scopus + 2150 Citations

Editor J. Chem, Wiley & Discover Electrochem, Springer Nature.

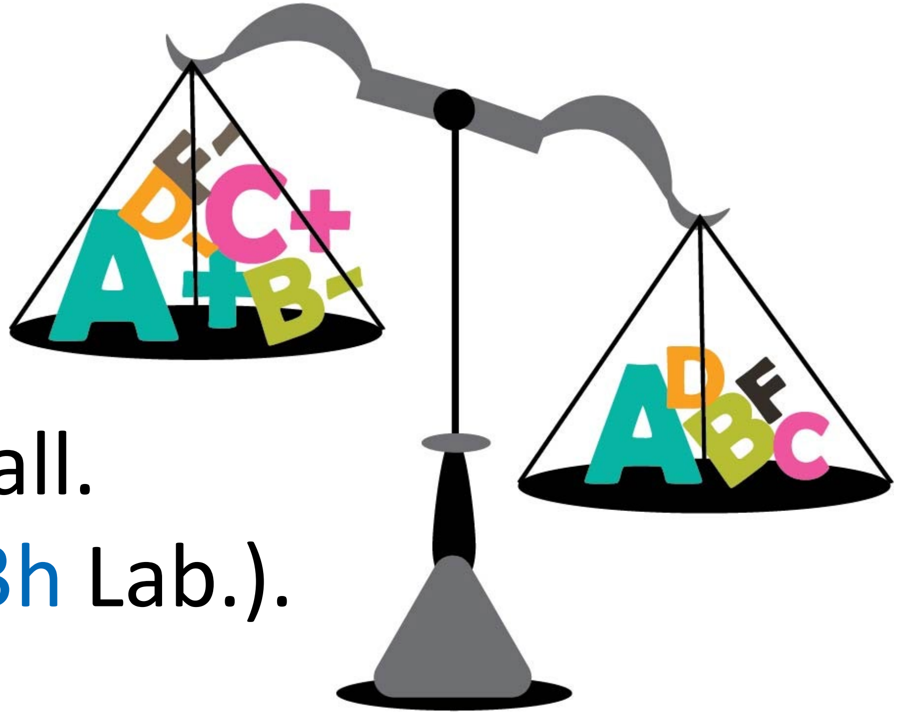
Reference

- Theodore L. Brown, Eugene H. LeMay, Bruce E. Bursten, Catherine – Chemistry: The Central Science, 15th Global Edition in SI Units (2022, PearSon)

Content

- **Introduction**: Matter, Energy & Measurements **(Ch. 1)**.
- **Atoms, Molecules & Ions**: Atomic Theory of Matter Periodic Table, Molecular & Ionic Cpds., Naming Inorganic Cpds. **(Ch. 2).**
- **Electronic Structure of Atoms**: Quantization of Energy, Orbitals, Electron Configuration **(Ch. 6)**.
- **Periodic Properties of the Elements**: Size, Ionization Energy, Electron Affinity, etc. **(Ch. 7).**
- **Chemical Bonding**: Ionic, Covalent, etc. **(Ch. 8).**
- **Molecular Geometry**: VSEPR Model, Molecular Orbitals etc. **(Ch. 9).**

Credit & Grading



- Compulsory
- Offered in regularly in Fall.
- (2 cr. 2h Lecture + 1 cr. 3h Lab.).
- **Prerequisites**: None

- 20% Evaluation & HomeWorks
- 10% Midterm Exam
- 20% Lab. Coursework (Final Lab. Exam)
- 10% Final Oral
- 40% Final Exam

Lecture 1

Introduction

Matter, Energy & Measurements

Chemistry

is the study of **matter**, its **properties**, and the **changes** that matter undergoes.

Matter — the physical **material** of the universe; it is anything that has mass and occupies space.

Property — any **characteristic** that allows us to recognize a particular type of matter and to distinguish it from other types.

- The tremendous variety of existing matter in our world is comprised of combinations of only about 100 substances called **ELEMENTS**.

Properties of Matter depend on

Composition

kinds of constituting **atoms**
(*almost infinitesimally small building blocks of matter*)

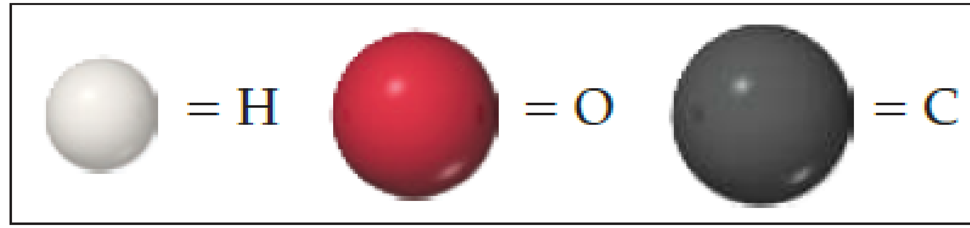
Structure

arrangements of atoms

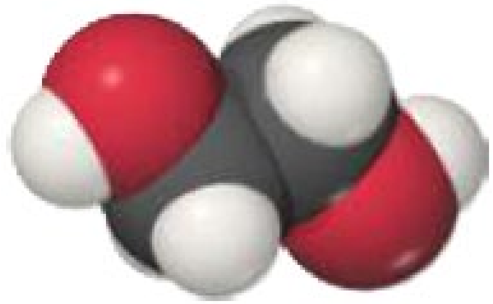
Minor differences in the composition or structure of molecules can cause profound **differences** in properties

Altering Composition/Structure

New Substances



Oxygen

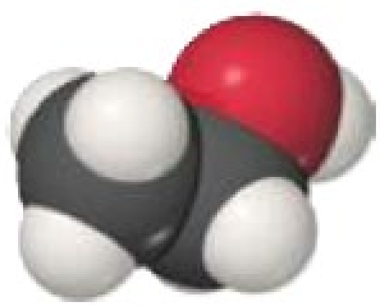


Ethylene Glycol

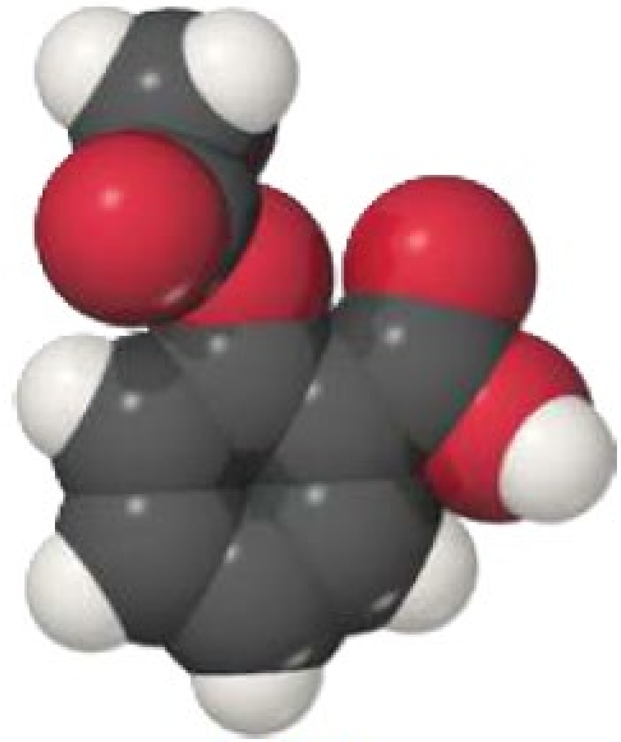
$C_2H_6O_2$

Water

Carbon dioxide



ethanol C_2H_6O



Aspirin

$C_9H_8O_4$

Energy: Solar panels (Si-based)

Biotechnology: Flash of the firefly results from a chemical reaction in the insect.

Chemistry

Cellphones,
Tablets,
TV displays

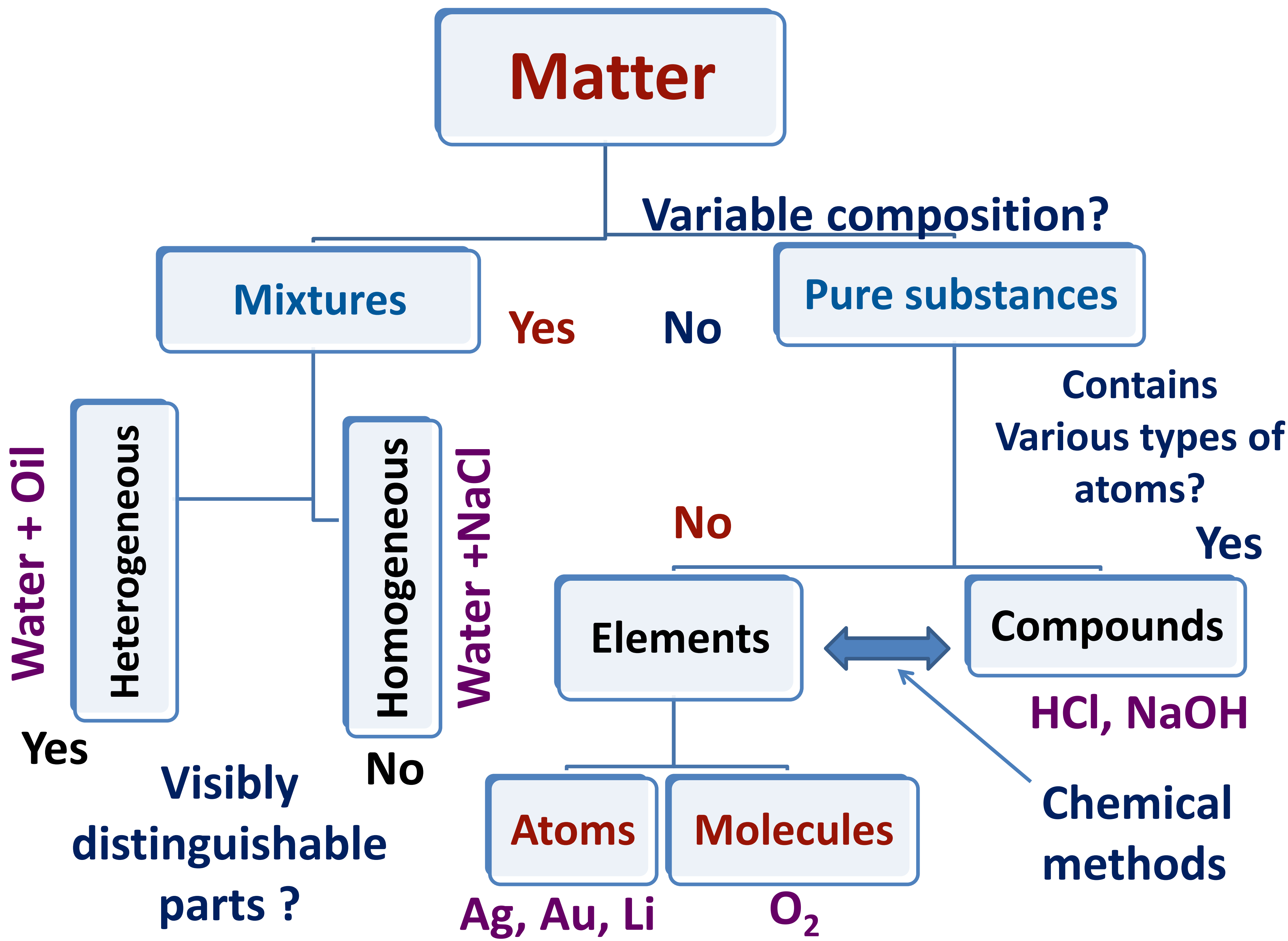
Technology: OLEDs (organic light-emitting diodes)

Medicine: Drugs

Exercise

Which of the following groups of substances involve the use of **chemicals**? Indicate all that apply..

(a) Paints, printer toner, food coloring
(b) Computer displays, LED lights, barcode readers
(c) Antiseptic cream, pain killers, energy drinks
(d) A light-weight bicycle frame, food packaging, a car exhaust catalytic converter
(e) Soap, shampoo, washing powder



Matter
Variable composition?
Mixtures
Yes
No
Pure substances
Heterogeneous
Homogeneous
Water + Oil
Water +NaCl
Yes
No
Visibly distinguishable parts ?
Contains Various types of atoms?
No
Yes
Elements
Compounds
HCl, NaOH
Chemical methods
Atoms
Molecules
Ag, Au, Li
O_2

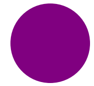
Densities at 20°C & 1 atm

Substance	Physical State	Density (g/cm^3)
Oxygen	Gas	0.00133
Hydrogen	Gas	0.000084
Ethanol	Liquid	0.789
Benzene	Liquid	0.880
Water	Liquid	0.9982
Magnesium	Solid	1.74
Salt (sodium chloride)	Solid	2.16
Aluminum	Solid	2.70
Iron	Solid	7.87
Copper	Solid	8.96
Silver	Solid	10.5
Lead	Solid	11.34
Mercury	Liquid	13.6
Gold	Solid	19.32

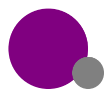
Interatomic distance & Volume

Density & Intermolecular force

Types of motion

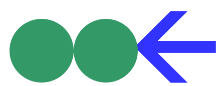
- **Translational** 

whole atom or molecule changes its location in three dimensional space

- **Rotational** 

whole molecule spins around an axis in three dimensional space

Motion of whole molecule

- **Vibrational**  Motion within a molecule

motion that changes the shape of the molecule – stretching, bending, and rotation of bonds

Properties "Characteristics" of Matter

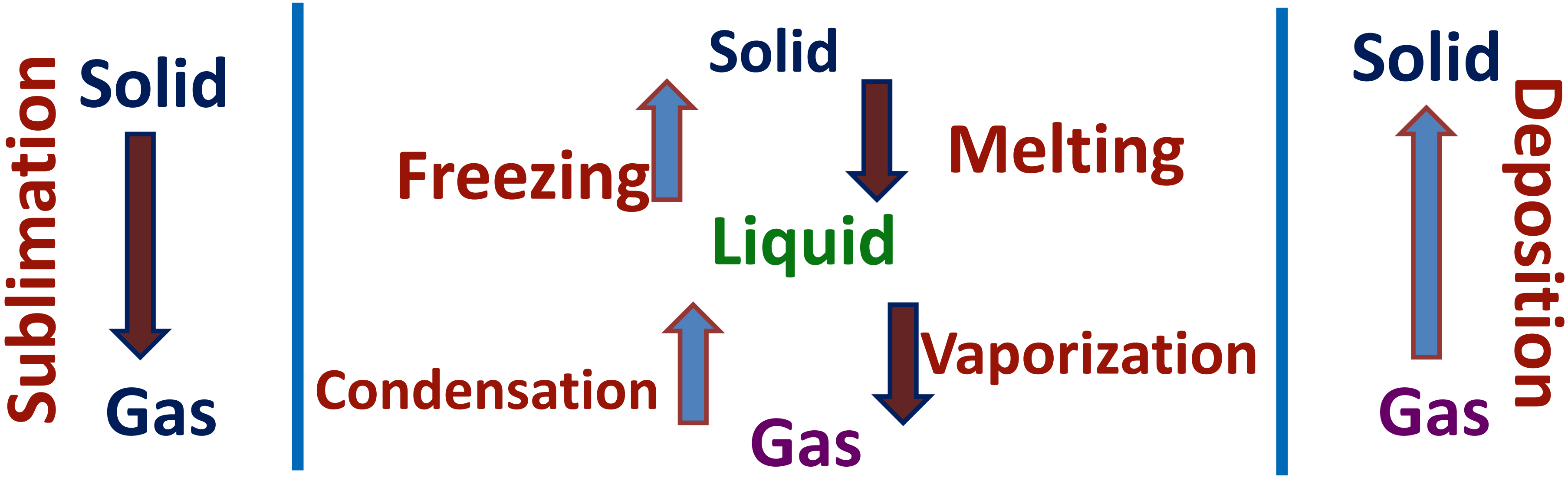
Character	Solid	Liquid	Gas
Attraction	Strong	Intermediate	Very weak
Shape	Fixed	Not fixed	Not fixed
Volume	Fixed	Fixed	Not fixed, Highly dependent of P, T
Motion (Translation, Rotational, Vibrational)	V- Only vibrating	TR - Move around past each other	TRV Freely – randomly
Compressibility	No	little	high

KE **Lowest** **Intermediate** **Highest**

Liquids and Solids: **Condensed phases**
Liquids and Gases: **Fluids**

Gas	Liquid	Solid
Particles are far apart, run in rapid random motion (translation, rotational, vibrational)	Particles lies in-between, intermediate motion (translation, rotational)	Particles are very close together, vibrate only in place
High volumes and Low densities	Intermediate volumes and densities	Small volumes and high densities
Very weak attraction forces	Intermediate forces	Strong forces
assumes the shape and volume of its container	assumes the shape of the part of the container which it occupies – has a fixed volume	retains a fixed volume and shape rigid - particles locked into place
compressible lots of free space between particles	not easily compressible little free space between particles	not easily compressible little free space between particles
flows easily particles can move past one another	flows easily particles can move/slide past one another	does not flow easily rigid - particles cannot move/slide past one another

State's Conversion: Physical not chemical



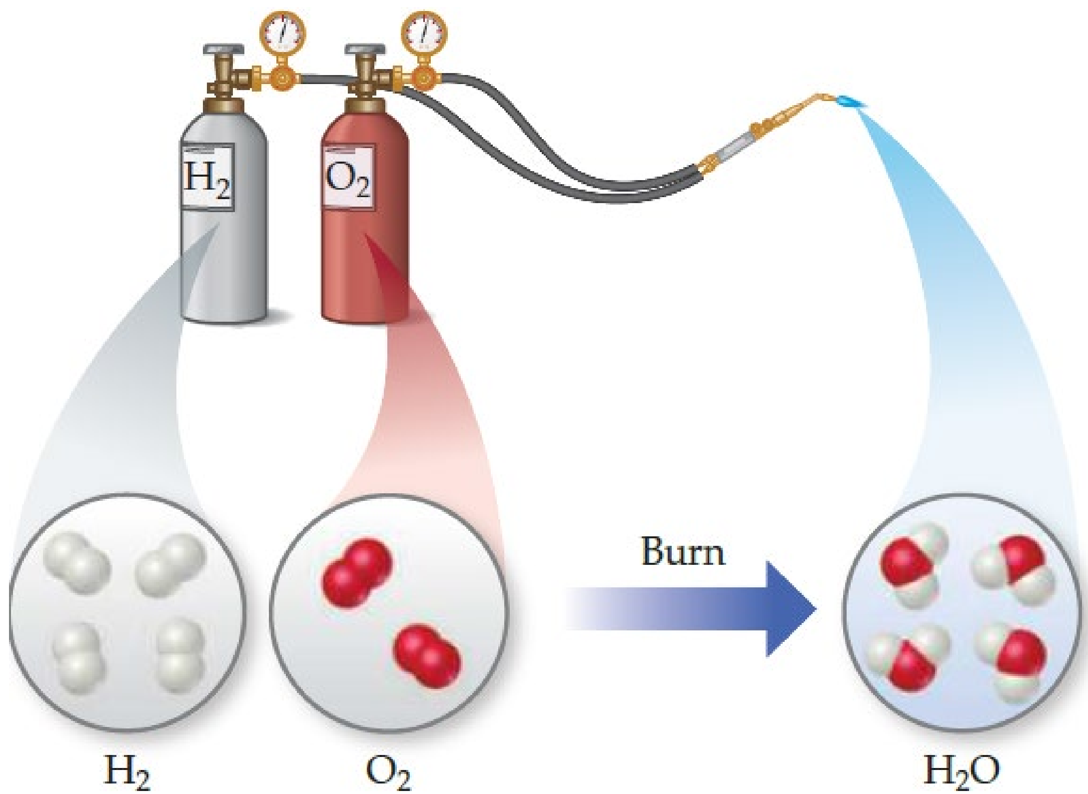
- **Sublimation:** is the **direct** conversion of a state from a solid phase to a gas phase, without passing by the liquid state.

- **Deposition** is the **direct** conversion from the gaseous to the solid state, without passing by the liquid phase.

Physical & Chemical Changes

- A **physical** change involves a change(s) in the physical appearance of a substance not its composition. (e.g., **evaporation**)

- A **chemical** change involves a transformation of a substance into a chemically different substance. (e.g., burning hydrogen in air).



Boiling Point

Temperature at which the vapor pressure of the liquid equal the **external atmospheric pressure**

Normal Boiling Point

Temperature at which the vapor pressure of the liquid equal **1 atm**

Normal Melting/Freezing Point

Temperature at which the vapor pressure of a liquid **equals** the vapor pressure of its solid at **1 atm**

Chemical Reactions/Balancing

- Mass is **conserved** & atoms are neither created nor destroyed in chemical reactions.
- involves **reorganization** of atoms in one or more substances.

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

Unbalanced

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Balanced

Reading Chemical Equations

	Reactants				Products		
	$CH_4(g)$	+	$2O_2(g)$	$\rightarrow$	$CO_2(g)$	+	$2H_2O(g)$
Molecules	1		2		1		2
Moles	1		2		1		2
Molecules	6.022×10^{23}		$2\ (6.022 \times 10^{23})$		6.022×10^{23}		$2\ (6.022 \times 10^{23})$
g	16		2 (32)		44		2 (18)
Total mass	80				80		

Mass is conserved

Chemical equation

- gives important information:
  - ✓ Nature
  - ✓ Relative numbers
  - ✓ Physical states

} Reactants & Products

State	Symbol
Solid	**(s)**
Liquid	**(l)**
Gas	**(g)**
Dissolved in Water (aqueous)	**(aq)**

$$HCl\ (aq) + NaHCO_3\ (s) \rightarrow CO_2\ (g) + H_2O\ (l) + NaCl\ (aq)$$

Stoichiometric Calculations

Reaction of propane with oxygen: (Combustion)

What mass of oxygen will react with 96.1 g of propane?

Balance equation

$$C_3H_8\ (g) + 5O_2\ (g) \rightarrow 3CO_2\ (g) + 4H_2O\ (g)$$

g → 1×44 5×32=160 3×44=132 4×18=72

204 g 204 g

Convert masses to moles:

$$96.1\ g\ C_3H_8 \times \frac{1\ mol\ C_3H_8}{44.1\ g\ C_3H_8} = 2.18\ mol\ C_3H_8$$

- Number of moles of O_2 necessary to react with 2.18 mole C_3H_8

$$2.18 \text{ mol } C_3H_8 \times \frac{5 \text{ mol } O_2}{1 \text{ mol } C_3H_8} = 10.9 \text{ mol } O_2$$

- **Convert** from moles to grams O_2

$$10.9 \text{ mol } O_2 \times \frac{32 \text{ g } O_2}{1 \text{ mol } O_2} = 349 \text{ g } O_2$$

- Therefore, 349 g O_2 is required to burn 96.1 g propane.

- What mass of carbon dioxide is produced when 96.1 grams of propane is combusted with oxygen? (Homework)

Nature of Energy

- Energy is the capacity to do work or transfer heat.
- Work ($w = F \times d$) is the energy transferred when a force (F) exerted on an object causes a displacement (d) of that object.

Basic forms of Energy

Potential Energy

energy due to position or composition. e.g., attractive and repulsive forces

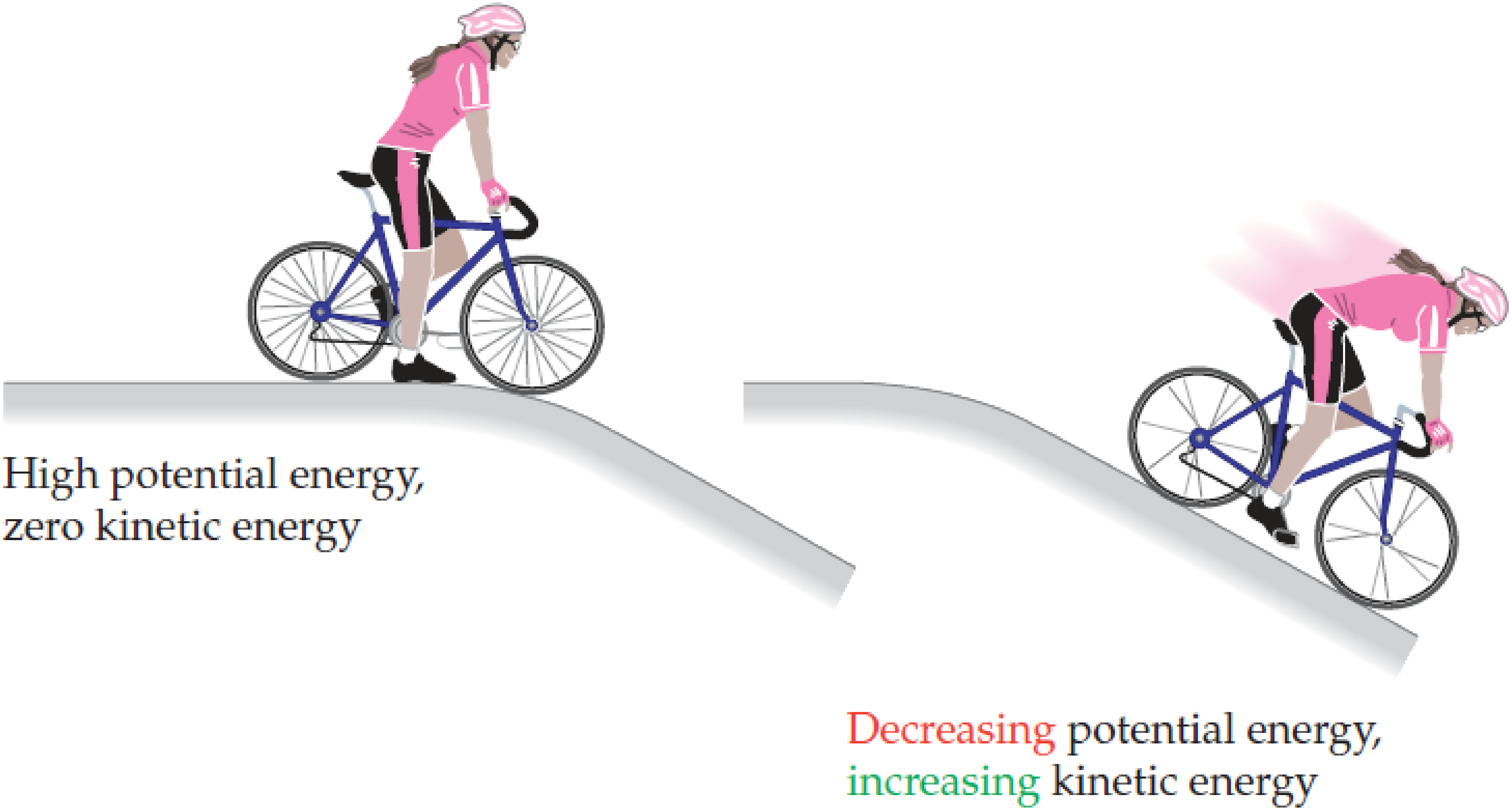
$$PE(kJ) = mgz$$

Kinetic Energy

energy due motion of an object of a mass m and a velocity υ.

$$K.E. = \frac{1}{2} m \upsilon^2$$

Conversion of Energy



Electrostatic potential energy arises from the interactions between charged particles.

Units of measurements

SI: French Système International d'Unités

Dimension	Unit	Unit Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Electrical Current	ampere	A
Amount of light	candela	cd
Amount of matter	mole	mol

7 SI Base UNITS

Recognize the **capital** and **small** letters

Standard prefixes in SI Base units

Multiple	Prefix
10^{24}	yotta, Y
10^{21}	zetta, Z
10^{18}	exa, E
10^{15}	peta, P
10^{12}	tera, T
10^{9}	giga, G
10^{6}	mega, M
10^{3}	kilo, k
10^{2}	hecto, h
10^{1}	deka, da
10^{-1}	deci, d
10^{-2}	centi, c
10^{-3}	milli, m
10^{-6}	micro, μ
10^{-9}	nano, n
10^{-12}	pico, p
10^{-15}	femto, f
10^{-18}	atto, a
10^{-21}	zepto, z
10^{-24}	yocto, y

Exercises

- Which is the smallest: 1 mg, 1 μg, or 1 pg? 1 pg
- What is the name of the unit that equals to (a) 10^{-9} g , (b) 10^{-6} s, (c) 10^{-3} m? ng, μs, mm
- How many picometers are there in 1 m? 10^{12} pm
- Express 6.0×10^{3} m using a prefix to replace the power of ten? 6.0 km
- Use exponential notation to express 4.22 mg in grams? 4.22×10^{-3} g
- Use decimal notation to express 4.22 mg in grams?

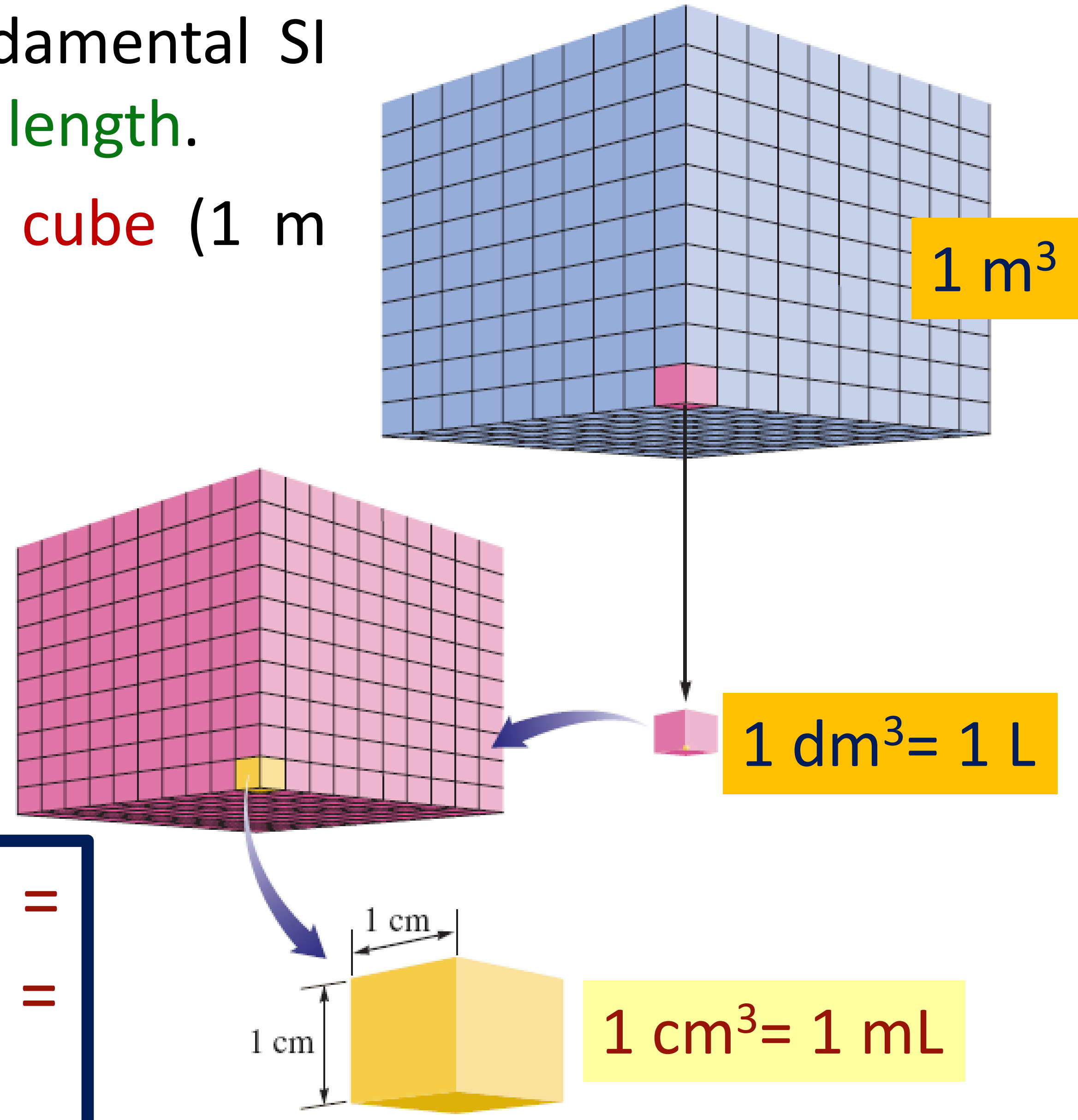
  0.00422 g

Derived SI Units

- **Volume** is not a fundamental SI unit but derived from length.
- The volume (V) of a cube (1 m edge) = $(1\ m)^3 = 1\ m^3$.

$1\ m^3 = 1000\ dm^3$

$1\ dm^3 = 1000\ cm^3$



$1L = (1\ dm)^3 = 1\ dm^3 = (10\ cm)^3 = 1000\ cm^3 = 1000\ mL = 1L$

Other Derived SI Units

Physical quantity	Symbol (s)	Name of SI unit	Derived Unit	Definition
Frequency	v, f	Hertz	Hz	s^{-1}
Force	F	Newton	N	$kg\ m\ s^{-2} = J\ m^{-1}$
Energy	E, H,V, etc	Joule	J	$N\ m = kg\ m^2\ s^{-2}$
Pressure	P	Pascal	Pa	$N\ m^{-2} = kg\ m^{-1}s^{-2}$
Power	p	Watt	W	$J\ s^{-1} = kg\ m^2\ s^{-3}$
Charge	Q	Coulomb	C	A s
Potential	E,…etc	Volt	V	$J\ A\ s^{-1}$
Resistance	R	Ohm	Ω	$V\ A^{-1}$
Conductance	G	Siemens	S	Ω^{-1}
Capacitance	C	Farad	F	$C\ V^{-1}$

Other Units

Physical quantity	Symbol	SI unit
Area	A	m^2
Volume	V	m^3
Velocity	U, V, c	$m\ s^{-1}$
Acceleration	a, g	$m\ s^{-2}$
Weight	G,W	N
Density	p	$kg\ m^{-3}$
Volume	liter (l)	dm^3
Force	dyne (dyn)	10^{-5} N
Concentration	Molar (M)	$mol\ dm^{-3}$
Energy	Calorie (Cal)	4.18 J
Energy	Erg (erg)	10^{-7} J
Pressure	Atmosphere (atm)	1.013×10^5 Pa
Pressure	(mm Hg)	133.322 Pa
Pressure	Torr (torr)	133.322 Pa
Pressure	Bar	10^5 Pa
Pressure	Atmosphere	760 mm Hg = 76 cm Hg

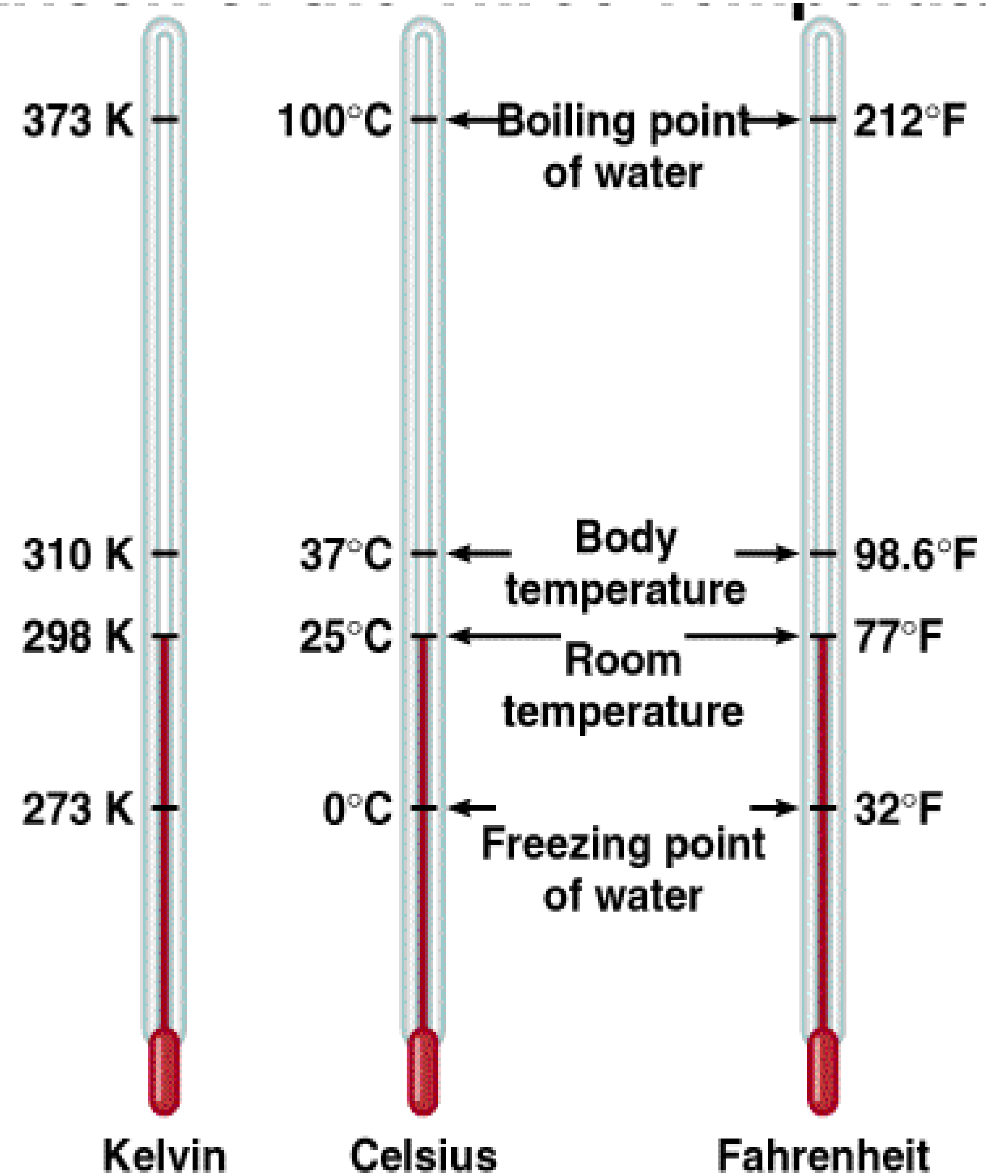
Temperature

T is a physical property for the **hotness** or **coldness** of an object. It determines "direction of heat flow" & reflects the **random motions** of particles in a substance.

$$T(°F) = \frac{9}{5}(°C) + 32$$

$$T(K) = T(°C) + 273.15$$

$$T(°C) = \frac{5}{9}[T(°F) - 32]$$



Exercises

Normal body temperature is 98.6°F. Convert this temperature to the Celsius and Kelvin scales?

$$T(°C) = \frac{5}{9}(98.6 - 32.0) = 37.0°C$$

Convert to the Kelvin scale:

$$\mathrm{T} = 37.0°C + 273.15 = 310.2\ \mathrm{K}$$

Pressure

- is the normal force exerted by a fluid (gas or liquid) per unit area.
- It has the unit (N/m^2), which is called a Pascal (Pa).
- Pressure is also used on solid surfaces as synonymous to normal stress.

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$1 \text{ atm} = 101{,}325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars} = 760 \text{ mm Hg} = 760 \text{ torr}$$

Exercise

- The pressure of a gas is measured as 49 torr. Represent this pressure in both atmospheres and pascals?

Solution

$$P = 49 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 6.4 \times 10^{-2} \text{ atm}$$

$$P = 6.4 \times 10^{-2} \text{ atm} \times \frac{101{,}325 \text{ Pa}}{1 \text{ atm}}$$
$$= 6.5 \times 10^{3} \text{ Pa}$$

Errors

♣ Systematic or Determinate Errors

- exist in **every** reading of a series of repeated measurements. (like a speck of dust on a pan).
- occur always in the same direction with the same magnitude (high or low).
- in experimental observations, it usually comes from the measuring instruments.
- are difficult to detect even for experts

Ex.

- there is something wrong with the instrument or its data handling system.
- instrument is wrongly used by the experimenter.

- https://www.physics.umd.edu/courses/Phys276/Hill/Information/Notes/ErrorAnalysis.html
- https://chemistnotes.com/analytical_chemistry/errors-in-chemical-analysis-determinate-and-indeterminate-errors/

Types of Systematic Errors

Offset or zero setting error

- instrument does not read zero when the quantity to be measured is zero

Multiplier or scale factor error

- instrument consistently reads changes in the quantity to be measured greater or less than the actual changes.

Ex.

- errors in measurements of temperature due to poor thermal contact between the thermometer and the substance whose temperature is to be found.
- errors in measurements of solar radiation because trees or buildings shade the radiometer.

Accuracy of measurements is often reduced by SE

Errors

♣ Random, non-Systematic or Indeterminate Errors

- caused by **unknown** and **unpredictable** changes in the measuring instruments or in the environmental conditions.
- vary **randomly** in a series of repeated measurements and can average to zero.
- have an equal probability of being **high** or **low**.
- occurs in estimating the value of the last digit of a measurement

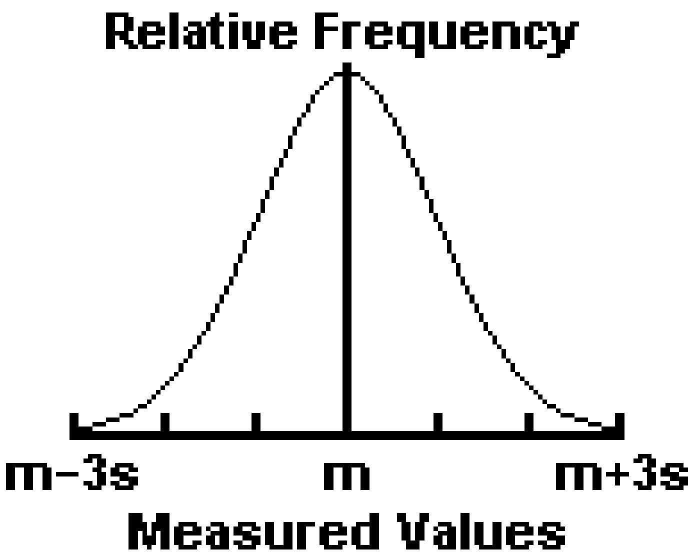
Ex.

- electronic noise in the circuit of an electrical instrument,
- irregular changes in the heat loss rate from a solar collector due to changes in the wind.

https://www.physics.umd.edu/courses/Phys276/Hill/Information/Notes/ErrorAnalysis.html

Handling Random Errors

- RE often have a **Gaussian normal** distribution.
- Statistical methods may be used to analyze the data.



- The **mean** ***m*** of a number ***n*** of measurements of the same quantity is the best estimate of that quantity, and the **standard deviation** ***s*** of the measurements shows the accuracy of the estimate. The **standard error** of the estimate ***m*** is ***s*/sqrt(*n*)**.

Random Errors/Precision

- The **precision** of a measurement is how close a number of measurements of the same quantity **agree** with each other.

- The **precision** is limited by the **random errors**. It may usually be determined by repeating the measurements.

Accuracy & Precision

♣ Accuracy

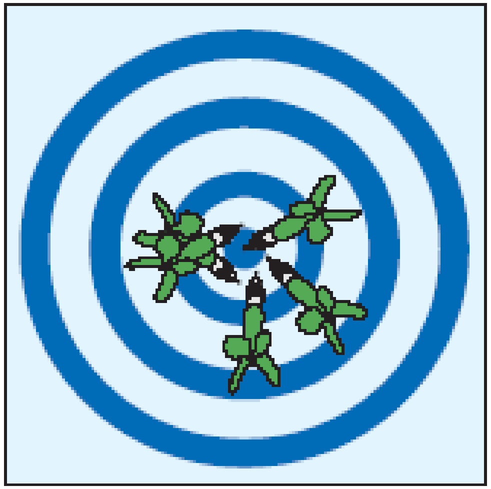
- refers to the agreement of a particular value with the **true** value.

♣ Precision

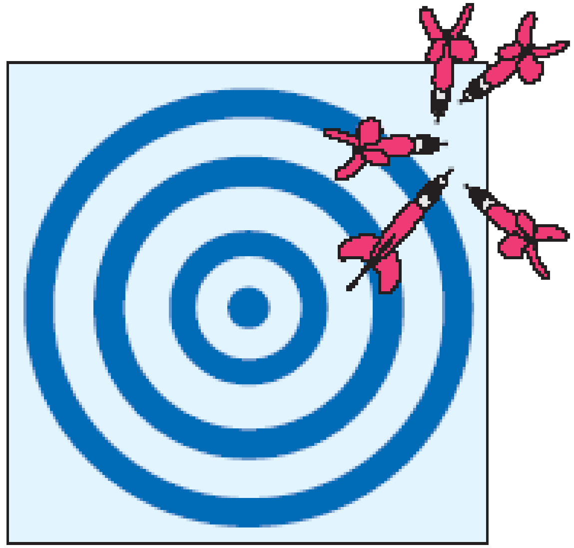
- refers to the degree of agreement among several measurements of the same quantity.
- reflects the **reproducibility** of a given type of measurement.

Throwing Darts

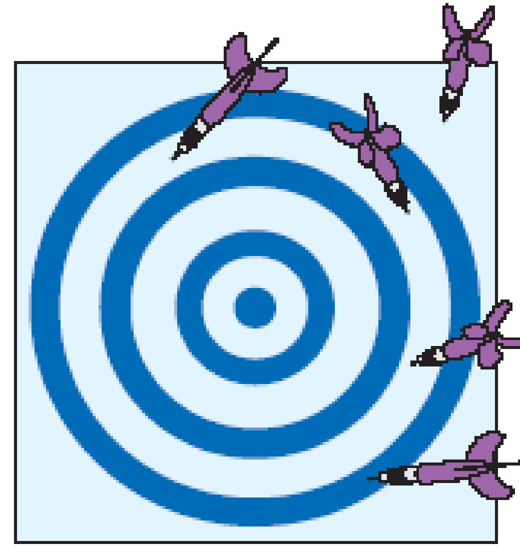
رمي السهام



Both **precise** and **accurate** (small random errors, no systematic error)



Precise but **not accurate** (small random errors, large systematic error)



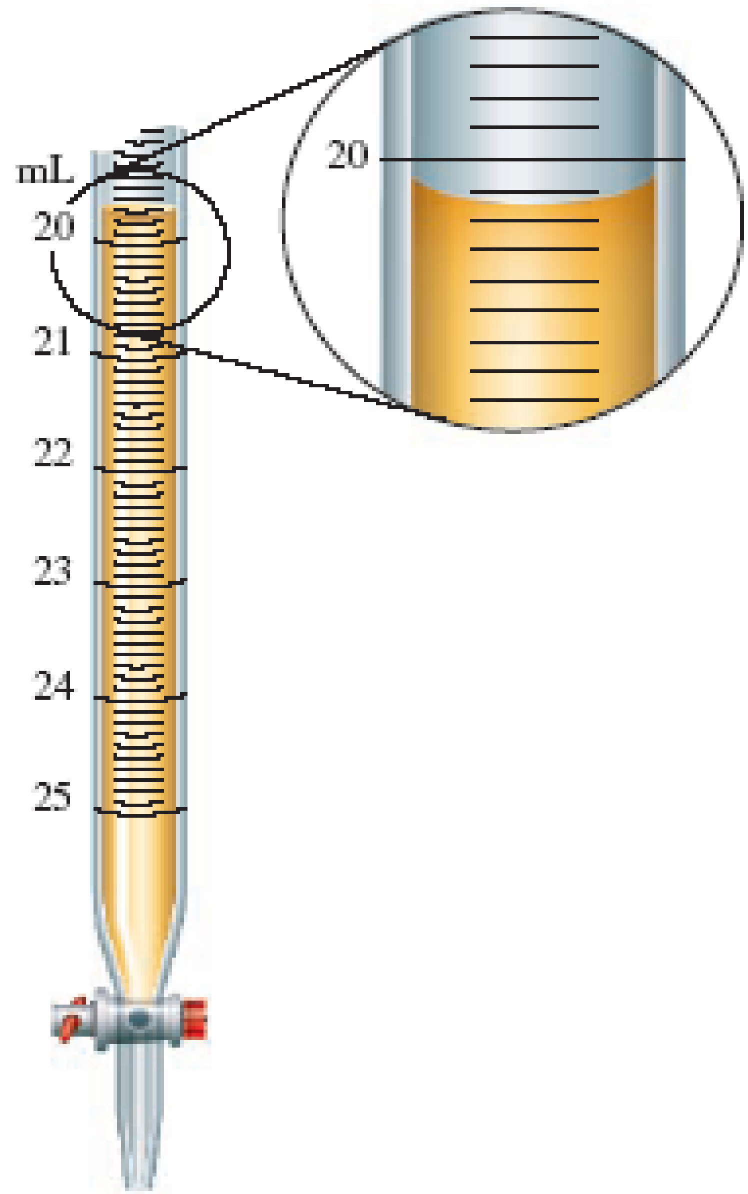
Neither accurate nor precise (large random errors).

Uncertainty in Measurement

- If five different people read same volume, the results **in mL** might be

20.16, 20.14, 20.16, 20.17, 20.15

- 20.1 are <u>certain digits</u> <u>but</u> the last digit is estimated (**<u>uncertain, doubtful</u>**) digit

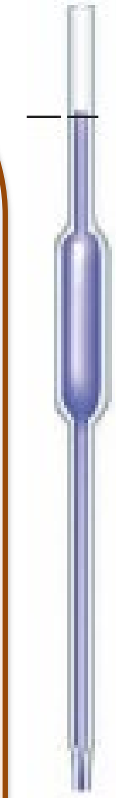


Significant Figures, SF

- Any measurement is reported by recording only **SF** (all certain digits + 1st uncertain digit).

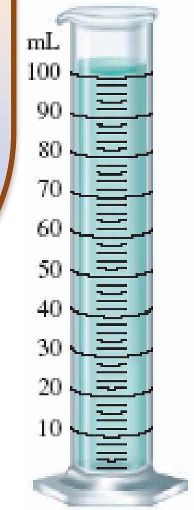
- For a burette, it would not make any sense to record the volume of thousandths of a milliliter (0.004) (insignificant) because the value for hundredths of a milliliter must be estimated.

- In analyzing a sample of polluted water, a chemist measured out a 25.00 mL water sample with a pipette. Another chemist used a graduated cylinder to measure 25 mL of a solution. What is the difference between the measurements?



Solution

- The quantity 25 mL means that the volume is between 24 mL and 26 mL, whereas the quantity 25.00 mL means that the volume is between 24.99 mL and 25.01 mL.



A pipette measures volume with much greater precision

Counting SF: Rules

- **Nonzero** → always SF
- **Zeros**: three types

A- **Leading zeros** (zeros precede nonzero digits)

→ do not count as SF

0.0025 → has only two SF

B- **Captive zeros** (zeros between nonzero digits)

→ always count as SF

1.008 → has four SF

C- **Trailing zeros** (zeros at the right end of the number)

→ are SF only if the number contains a decimal point.

100 → has only one SF

1.00×10^2 → has three SF

Exact numbers: numbers obtained by **counting** or **definitions** & not measured by devices.

These have an **infinite number** of SF.

Examples

- 10 experiments, 3 apples, 8 molecules.
- 2 in $2\pi r$ (circumference of a circle) and 4/3 in 4/3 r^3 (volume of a sphere).
- **1 inch = 2.54 cm**.

$\Rightarrow$ Neither 2.54 nor 1 limits the number of SF when used in a calculation.

Exercise

Counting No. of SF

- A student's extraction on tea yields 0.0105 g of caffeine.

  2 leading zeros **(not SF)**, 1 captive zero **(SF)**, 2 nonzeros **(SF)**.

  → Overall: 3 SF

- 0.050080 g in a measurement.

  2 leading zeros **(not SF)**, 2 captive zero **(SF)**, 1 trailing zero **(SF)**, 2 nonzeros **(SF)**.

  → Overall: 5 SF

- 8.050×10^{-3} s → Overall: 4 SF

Rules in calculations

Multiplication and division

- Count No. of **SF** in each No. being multiplied or divided and limit the answer to the least of them

$$4.56 \times 1.4 = 6.38 \xrightarrow{\textit{Corrected}} 6.4$$

Limiting: 2 SF → 2 SF

Addition and subtraction

- The result should have the same number of decimal places as the least precise measurement in the calculation.

No. of **SF**, is not considered

12.11 +

18.0 +

1.013

______

31.123 —*Corrected*→ 31.1

Rounding

- Carry extra digits through to the final result, then round.
- If the digit to be removed
  - < 5, preceding digit stays the same.

    1.33 → 1.3

  - ≥ 5, preceding digit is increased by 1.

    1.36 → 1.4

- Use only the first number to the right of the last significant figure.
  - Do not round **sequentially**. Rounding 6.834 to 3 SF

    6.8347 → 6.83 √ 6.84 ×

Calculate and count SF

$$1.05 \times 10^{-3} \div 6.135 = 1.711491 \times 10^{-4}$$

$$\xrightarrow{\text{Corrected to 3 SF}} 1.71 \times 10^{-4}$$

$$\mathbf{21 - 13.8 = 7} \quad \textit{no DP} \ \mathbf{1\ SF}$$

Dimensional Analysis

Apples and oranges do not add

- Calculate in inches the length of a 2.85 cm pen knowing that 2.54 cm = 1 in?

$$1 = \frac{1\ in}{2.54\ cm}$$

is called a **unit factor** which does not affect SF

$$2.85\ cm \times \frac{1\ in}{2.54\ cm} = \frac{2.85}{2.54}\ in = 1.12\ in$$

3 SF

Exercises

- How many mL are in 1.63 L?

$$1.63\ L \times \frac{1000\ mL}{1\ L} = 1630\ mL = 1.63 \times 10^3\ mL$$

- The speed of sound in air is about 343 m/s. What is this speed in miles per hour?

$$343\ \frac{m}{s} \times \frac{3600\ s}{1\ h} \times \frac{1\ mi}{1609\ m} = 767\ \frac{mi}{h}$$