Physics Notes (RP) - EOY

Topics

Measurements

1.1 Accuracy vs. Precision

ACCURACY	PRECISION
Closeness to the actual value	Reproducibility
Based on a measurement's true value	Not based on a measurement's true value
Can be derived from one reading	Has to be derived from multiple readings

- Measurement is usually recorded to smallest half division of smallest scale of instrument (e.g. thermometer, measuring cylinder)

- When measurements involve intervals, record to smallest division (e.g. metre rule, protractor)

1.2 Units

SI DERIVED UNITS		
Quantity	**Common units**	**Derived unit**
Volume	m^3	m^3
Density	$kg\ m^{-3}$	$kg\ m^{-3}$
Acceleration	$m\ s^{-2}$	$m\ s^{-2}$
Force	$kg\ m\ s^{-2}$	Newton (N)
Work done	$kg\ m^2\ s^{-2}$	Joule (J)

SI PREFIXES		
Prefix	**Symbol**	**Multiply by**
giga-	G	x1,000,000,000
mega-	M	x1,000,000
kilo-	k	x1,000
deci-	d	÷10
centi-	c	÷100
milli-	m	÷1,000
micro-	u	÷1,000,000
nano-	n	÷1,000,000,000

1.3 S.F & D.P

Addition & Subtraction – least decimal place of a term

e.g. 0.04529 + 0.0028 = 0.0481 (actual: 0.04809)
5 d.p + 4 d.p = 4 dp

Multiplication & Division – least significant figure of a term

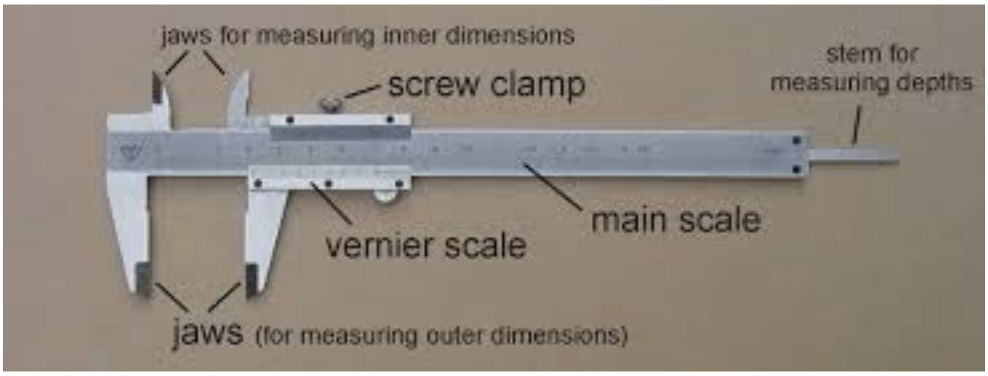
e.g. 0.93 ÷ 0.07837 = 12 (actual: 11.86678576)
2 s.f ÷ 4 s.f = 2 s.f

Combined – find d.p first, then overall s.f

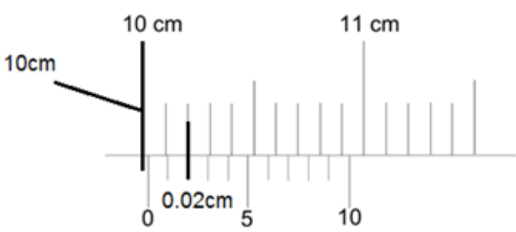
e.g. $\frac{14.991-14.98}{14.991} = \frac{0.01}{14.991} = 0.0007\ (1.s.f)$

1.4 Measuring Instruments

Vernier Calipers



- Correct to 0.01cm

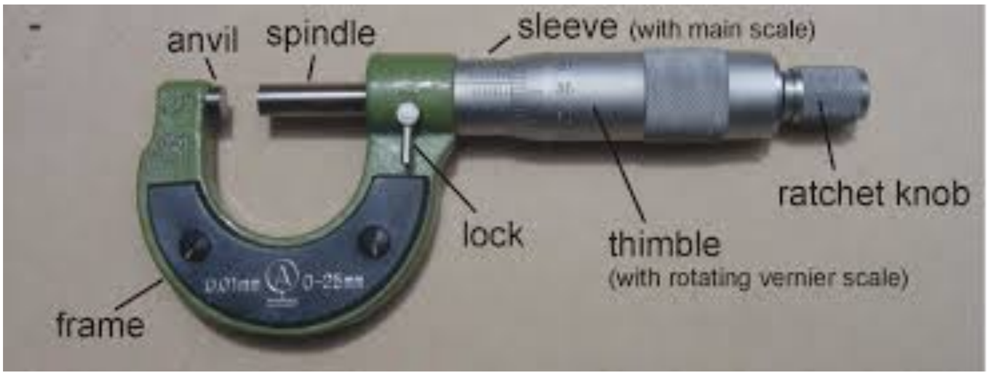


10cm + 0.02cm = 10.02cm

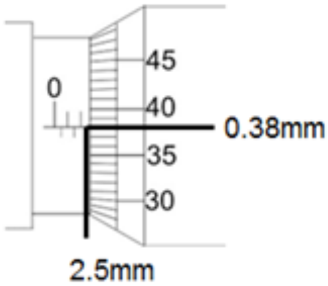
- When no object is being measured
    - Lower jaw slightly to left – negative zero error
    - Lower jaw slightly to right – positive zero error

Observed reading – Zero error = Corrected reading
e.g. 2.64cm – (-0.02cm) = 2.66cm

Micrometer Screw Gauge



- Place object between anvil & spindle
- Turn ratchet until 2-3 clicks heard
  - correct pressure
  - any further turning results in inaccurate reading
- Smallest division = 0.01mm
- Every horizontal interval is 0.5mm



2.5mm + 0.38mm = 2.88mm

- When no object is being measured
  - Reading < 0 or 0 cannot be seen – Negative zero error
  - Reading > 0 – Positive zero error
- Same method to obtain corrected reading as vernier calipers

1.5 Types of measurement errors

Systematic	Random
> or < true value by fixed amount	readings scattered about a mean value; equal chance of (+) & (-)
e.g. not accounting for zero error, not accounting for background radiation when measuring activity of radioactive source	e.g. fluctuation in count-rate of radioactive decay, variation in diameter of a piece of wire
can be eliminated	can only be reduced
eliminated only if source of error is known, not by repeating measurements & averaging	reduced by repeating measurement & averaging, plotting graph & line of best fit

Kinematics

2.1 Definitions & Equations

$$v=u+at$$

v = final velocity **a** = acceleration
u = initial velocity **t** = time taken

$$v^2=u^2+2as$$

v = final velocity **a** = acceleration
u = initial speed **s** = displacement

$$s=ut+\frac{1}{2}at^2$$

s = displacement **t** = time taken
u = initial speed **a** = acceleration

$$s=\frac{1}{2}(u+v)t$$

s = displacement **v** = final velocity
u = initial speed **t** = time taken

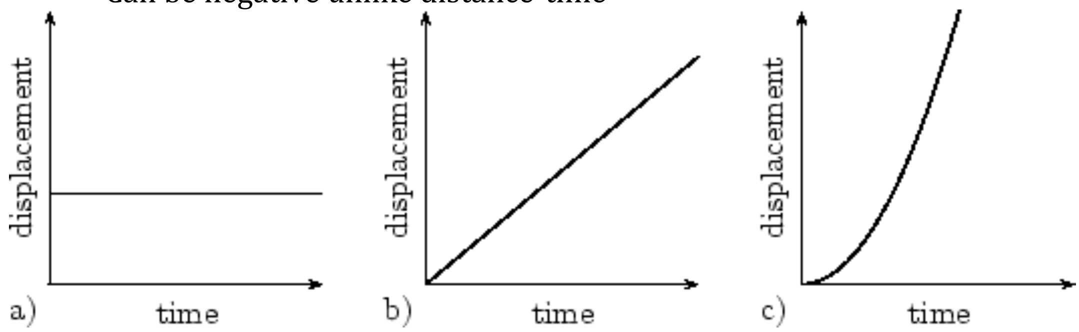
(aka trapezium area under v-t graph)

QUANTITY		DEFINITION	SYMBOL
Displacement		Distance moved in a specified direction from a reference point	s
Speed		Distance travelled / time taken	v
Velocity	Instantaneous	Rate of change of displacement with respect to time (found by drawing tangent on s-t graphs)	
	Average	Change in displacement / time taken	v_{ave}
Acceleration	Instantaneous	Rate of change of velocity with respect to time	
	Average	Total change in velocity / total time taken	a_{ave}

2.2 Graphs

Displacement-time graphs

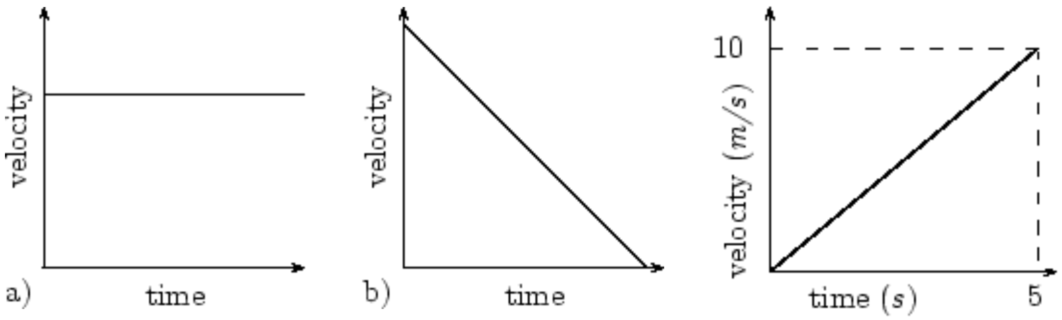
- Gradient = velocity
- Can be negative unlike distance-time



a) Velocity = 0 ***b) Velocity = constant*** ***c) Constant acceleration***

Velocity-time graphs

- Gradient = acceleration
- Area = change in displacement
- Can be negative unlike speed-time

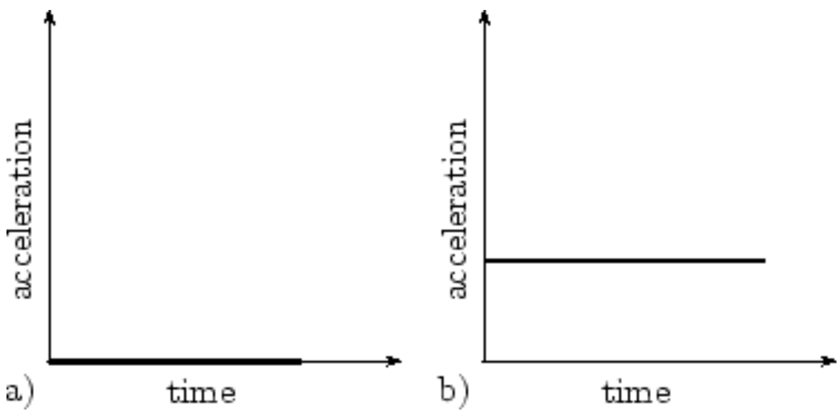


a) Acceleration = 0 b) Acceleration = negative c) Acceleration = positive

In all cases, because gradient = constant, acceleration = constant

Acceleration-time graphs

- Area = change in velocity
- Can be negative



a) velocity = constant b) acceleration = constant

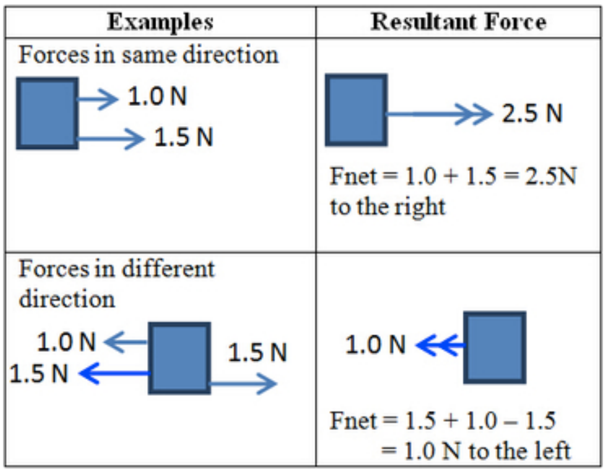
2.3 Sign conventions

- For displacement
    - taken with respect to a reference point
        - e.g. starting point of motion
    - if, e.g., displacement to right is positive, then to left is negative
- For velocity
    - Fix a direction of motion as positive
        - e.g. in vertical motion
        - if downward motion is fixed as positive, then up is negative
    - Same case for acceleration

Scalars & Vectors

SCALARS	VECTORS
quantities that are fully described by a magnitude alone	quantities that are fully described by both a magnitude and a direction (remember using the letters V&S)
e.g. distance, speed, time mass, area, volume, energy, work done, and power	e.g. displacement, velocity, acceleration, force, weight and momentum

3.1 Addition of Vectors

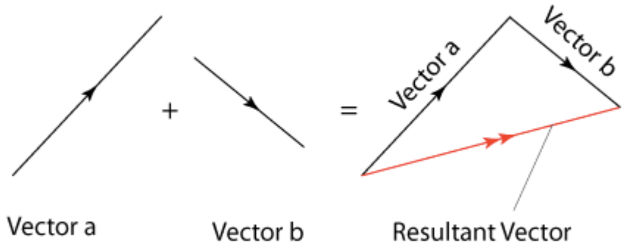


- If both forces in same direction, then $F_r = F_1 + F_2$
- If two forces in opposite direction, then $F_r = F_1 - F_2$ or $F_2 - F_1$, depending on the direction
- Hence the addition of two forces ($F_1 > F_2$) is:

$$F_1 - F_2 \le F_r \le F_1 + F_2$$

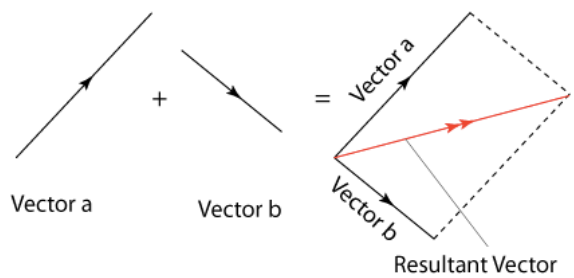
1. Vector Triangle Method

- Connect the tail of V2 to the head of V1
- Everything is to scale (i.e. angles, lengths)
- Resultant V joins tail of 1 to head of 2



2. Parallelogram Method

- 2 V's represented by sides of a parallelogram
- Resultant V is diagonal

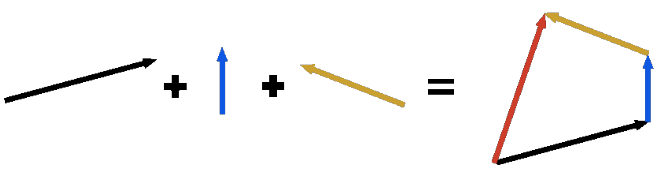


Subtraction of vectors

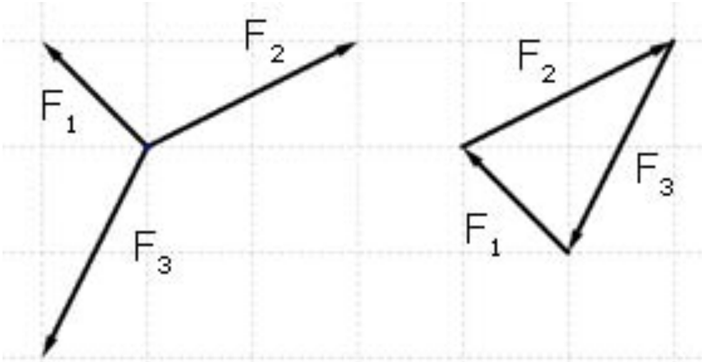
- Flip the head & tail of the vector being subtracted

Addition of more than 2 vectors

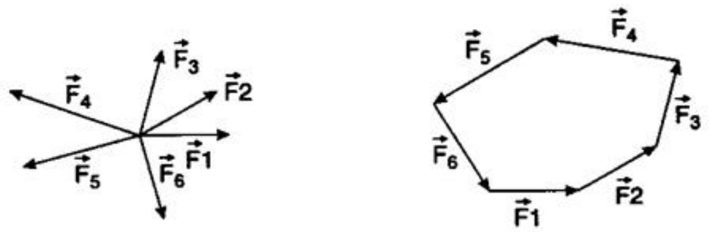
- Use a vector polygon
- Similar to vector triangle



Forces in Equilibrium



- When 3 coplanar forces acting on a point are in equilibrium
  - can be represented in by adjacent sides of triangle
  - when drawn in a vector triangle, the forces form a closed triangle



(a) Concurrent coplanar forces (b) Polygon of force vectors

- Same for polygon of forces

3.3 Vector Resolution

- Any vector can be resolved into any two perpendicular directions
  - Perpendicular components
  - e.g. horizontal & vertical components
- Component of vector = influence of vector in a given direction
- Perpendicular components are independent of each other
- e.g.

Using trigonometry,

$\sin 37° = F_y / 5$
$F_y = 5 \sin 37° = 3.01N$

$\cos 37° = F_x / 5$
$F_x = 5 \cos 37° = 3.99N$

- When object is in equilibrium
  - Sum of all vertical components of forces = 0
  - Sum of all horizontal components of forces = 0

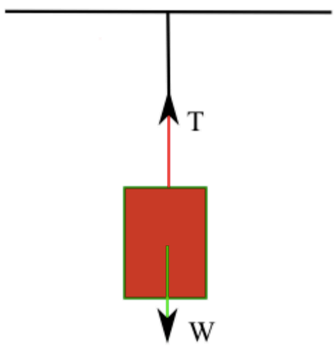
Dynamics 1

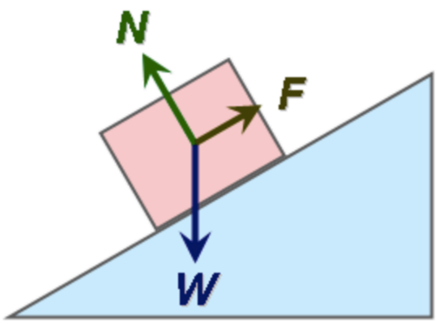
4.1 Different Types of Forces

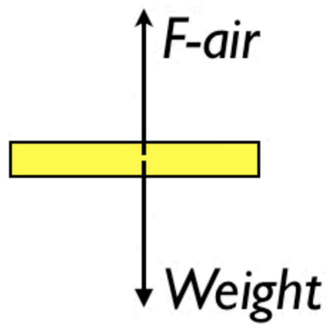
FORCE	DESCRIPTION
Weight (W)	• Gravitational force exerted by Earth on an object
Friction (F)	• When 2 surfaces in contact, exert force on each other • Component parallel to surfaces is friction • Acts in a direction so as to resist relative / tendency of motion between the surfaces
Normal Contact Force (N)	• Perpendicular component of contact force • Acts outwards from surfaces
Air resistance	• Resistive force exerted by air on object moving through it • Increases as speed increases • 0 when object at rest
Tension (T)	• Pulling force acting in a string / rod
Magnetic Force (F_B)	• Forces exerted by magnets on magnetic materials ○ Like iron or nickel • Originates from moving charges
Electric Force (F_E)	• Forces exerted by electric charges on each other

4.2 Free Body Diagrams

- Forces acting on an object usually drawn as arrows
- Originate from point of action
- Length of arrows represents magnitude of force







4.3 Resultant Force

- Resultant force (F_r) = Vector sum of all forces acting on object

4.4 Newton's Laws of Motion

Newton's First Law

An object at rest will remain at rest, while an object in motion will continue in motion at constant velocity when without resultant force acting on it.

- Known as Law of Inertia
    - Implies that every body has inertia
    - A measure of its resistance to change in state of motion
    - Measure by mass (kg)

Newton's Second Law

The rate of change of momentum (mass · v) of a body is directly proportional to resultant force acting on it.

The direction of resultant force is in the direction of the change in momentum.

$$\text{Resultant Force} = \frac{\textit{Change in (mass x v)}}{\textit{time}}$$

$$= \text{mass x } \frac{\text{change in velocity}}{\text{time}}$$

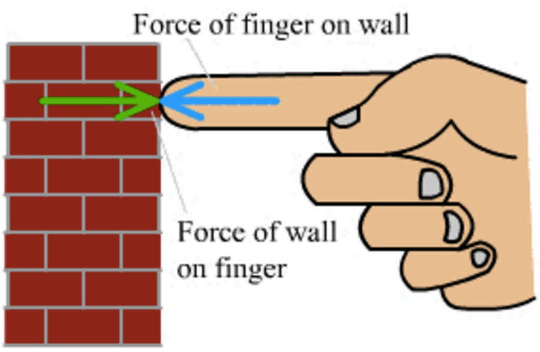
$$= \text{mass x acceleration}$$

Hence, $F_{resultant} = ma$

Newton's Third Law

If object A exerts a force on object B, then object B exerts an equal but opposite force on object A.

To every action there is an equal and opposite reaction.



- Force exerted by finger on wall is equal and opposite in direction to force exerted by wall on finger

- However, not all equal and opposite forces are an action-reaction pair (e.g. Weight & NCF)
- Action-reaction pair must satisfy these conditions
    - equal in magnitude
    - act in opposite directions
    - act on different bodies
    - same type / nature

4.5 Static & Kinetic Friction

- Friction can occur even when the objects are not moving relative to each other
- e.g. exerting a small force on a heavy box
  - Initially, when force applied is small, box still stationary
  - Static friction = applied force
  - When increase applied force
  - Static friction is overcome, box moves
  - Hence static friction is a limiting value
- Kinetic friction = when objects are moving relative to each other
  - Constant regardless the object's velocity
- Factors that affect friction:
  - Nature of surfaces in contact
  - How tightly the surfaces are pressed together
- However, not affected by area of surfaces in contact
- Friction as useful force (e.g. walking, holding an object, braking)
- Friction as nuisance (e.g. loss in useful energy, generate heat, wear & tear)
- To reduce friction → 1. Ball Bearings 2. Lubricants 3. Air layer

4.6 Air Resistance & Terminal Velocity

- Higher velocity of object = More air resistance
- Air resistance also affected by shape & size of object

- When air resistance not negligible
  - Terminal velocity reached when air resistance increases to equal weight of object and velocity stops increasing

4.7 Mass & Weight

$$W = mg$$

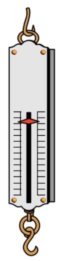
where g = 9.81 N kg^{-1} is the gravitational field strength on Earth (1.6 on Moon)

By extension, gravitational field strength, $g = \frac{weight}{mass}$

- acceleration of free-fall = gravitational field strength

Devices to Measure Mass & Weight

- Mass → Balance scale
  - Any change in gravitational field strength affects both pans equally
  - When balance achieved, unknown & standard masses equal
- Weight → Spring balance
  - Extension of spring proportional to gravitational pull on object
  - i.e. weight



Dynamics 2

5.1 Moment of a Force

- Moment = turning effect of a force, e.g. NCF or applied force
- Direction = clockwise or anticlockwise

Moment = Magnitude of force x Perpendicular distance

- Perpendicular distance is from the point to the line of action of the force
- Forces without a perpendicular distance passing through the pivot / point do not contribute to any moment

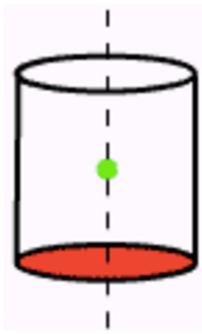
- Differences between moment & work
  - Moment is a very different physical quantity from work / energy even though same units (N m)
  - Moment is a vector, work & energy are scalars

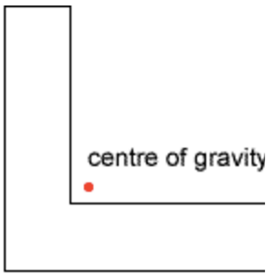
5.2 Principle of Moments

- For a body in equilibrium
  - Sum of all moments of all external forces about any axis / pivot = 0

Sum of clockwise moments = Sum of anticlockwise moments

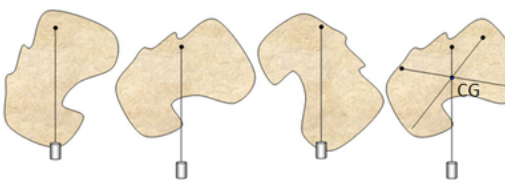
5.3 Centre of Gravity

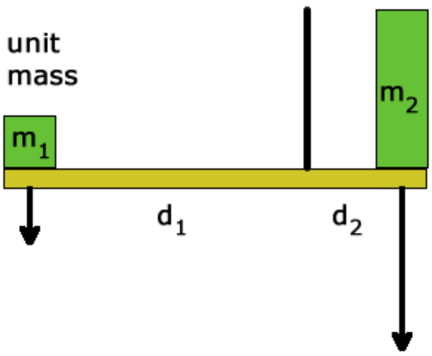




- Centre of gravity = Point at which the whole weight of object appears to act
- In uniform gravitational field, centre of gravity = centre of mass
- However, CG need not be located on object

- To determine CG of a laminar
  - Hang laminar on one end and draw vertical line
  - Repeat for another end
  - Intersection of 2 lines = CG





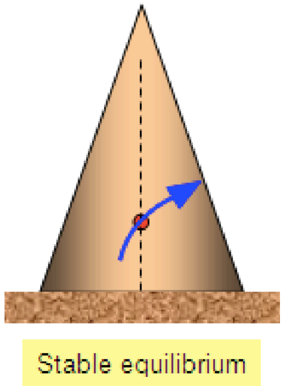
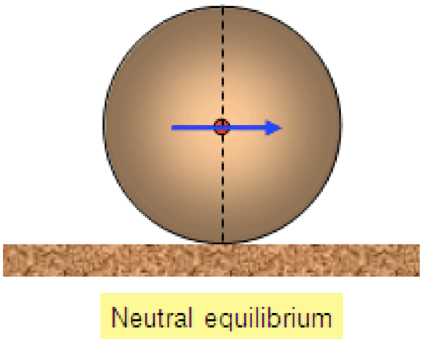
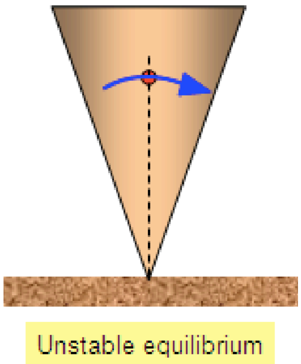
- Determining CG of 2 unknown objects
- In uniform gravitational field g
- CW moment about pivot due to M_2 = Anti-CW moment about pivot due to M_1

$$M_2 \ g \ d_2 = M_1 \ g \ d_1$$
$$M_2 \, d_2 = M_1 \, d_1$$

5.4 Equilibrium & Stability

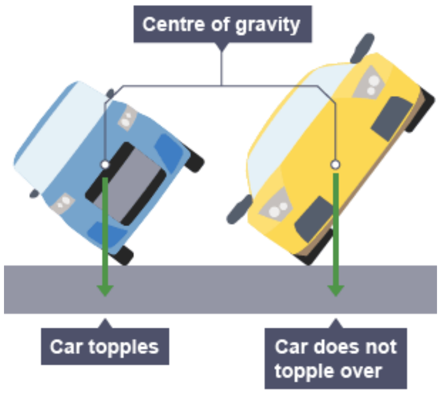
An object is in equilibrium if it is in

1. Translational equilibrium, i.e. resultant force = 0
2. Rotational equilibrium, i.e. resultant moment = 0

Stable Equilibrium	• When tilted by very small angle from original position and released • Returns to original position	
Neutral Equilibrium	• When tilted by any angle from original position and released • Stays at new position • Only for round objects e.g. spheres & cylinders	
Unstable Equilibrium	• When tilted by arbitrarily small angle from original position and released • Topples to new position	

Stability & CG

- Types of equilibrium can also be seen from movement of CG
- For stable & unstable equilibrium, when CG is outside pivot point, topple

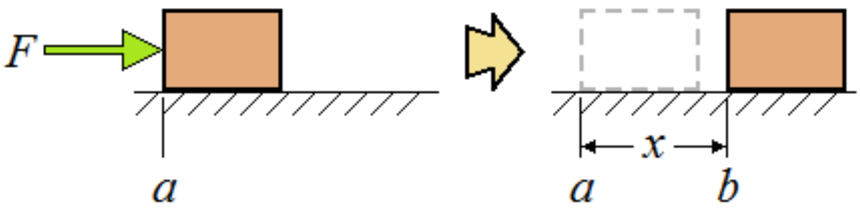


Work, Energy & Power

6.1 Work

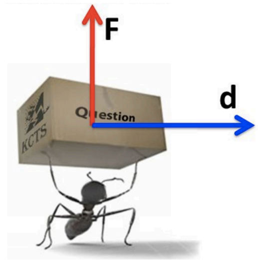
- Work is only done if an object displaces while a force is applied
    - With some component of the applied force along direction of displacement

$$W = Fs$$

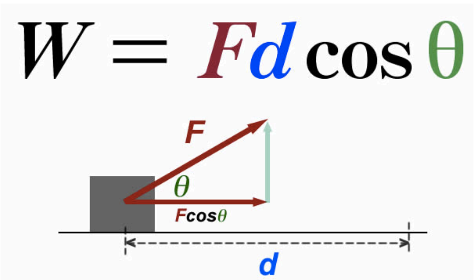


In this case, W= Fs

For friction *f*, W = -*fs*



For displacement ⊥ direction of applied force,
$W = Fs = F(0) = 0$



For displacement at an angle,
$W = Fs = F\cos\theta \, s = Fs\cos\theta$

6.2 Energy

FORM OF ENERGY	EXAMPLES
Chemical Energy (a form of potential E related to the structural arrangement of atoms / molecules)	• Fuels, e.g. oil, wood, coal • Electric cells, food & explosives
Nuclear Energy (Energy released from atomic nucleus)	• Radioactive decay • Nuclear reaction (fusion, fission) • Nuclear weapons, nuclear reactors
Radiant Energy (Energy of electro-magnetic waves)	• Radiometry – measurement of EM radiation – visible light, radio waves, X-rays, γ-rays • Solar energy • Heating & lighting
Electrical Energy	• Energy associated with current in circuits & electric appliances • Power station

FORM OF ENERGY	EXAMPLES
Internal / Thermal Energy (Sum of kinetic & potential energy of molecules)	• Thermal energy of a system, e.g. a gas in container, a solution in test tube
Mechanical Energy (PE & KE present in components of mechanical system) 1. Kinetic (E_k) 2. Potential (E_p) a. Gravitational E_p b. Electric E_p c. Elastic E_p	1. E_k – all objects in motion 2. E_p – a. Waterfall, raised object b. Charged capacitors c. Compressed or stretched springs, bent springboard

Kinetic Energy

$$E_k = \frac{1}{2} mv^2$$

Gravitational Potential Energy

$$E_p = mgh$$

- Depends on zero potential energy level
- h = Height over 0-PEL

6.3 Energy Conversion & Conservation

Principle of Conservation of Energy

Energy cannot be created or destroyed. It can be transformed or transferred but the total amount in any isolated system must remain constant.

Hence, $(PE + KE)_{initial} = (PE + KE)_{final}$

6.4 Power

- Power = rate of doing work / rate of energy converted

$$P = \frac{W}{t}$$

and hence

$$P = \frac{Fs}{t} = F\frac{s}{t}$$

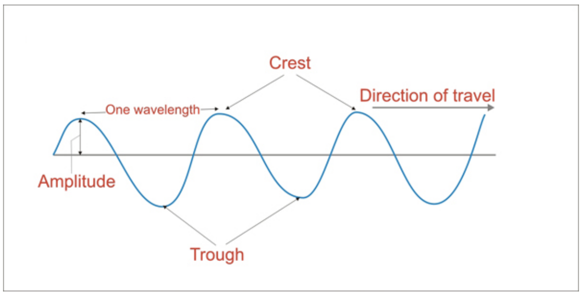
$$P = Fv$$

Efficiency

$$\text{Efficiency} = \frac{Energy\ converted\ to\ useful\ output}{Total\ energy\ input}$$

EM Spectrum

7.1 Properties of Electromagnetic Waves



- Transverse
- Transfer energy from one place to another
- Travel through vacuum at same speed
    - 3×10^8 m s^{-1}
    - Speed of light
- All follow the wave equation of:

$$v = f\lambda$$
$$v = \frac{\lambda}{T}$$

&

$$f = \frac{1}{T}$$

in which

v = speed f = frequency
λ = wavelength T = period

7.2 Effects of Absorbing Electromagnetic Waves

- All EM waves carry energy
- An object that absorbs EM waves will increase in energy, e.g.
    - By becoming hotter (microwave), or
    - By getting ionized (produce free electrons)
- If a body absorbs high-energy EM waves (e.g. UV, X-ray, gamma ray)
    - Electrons may damage living cells & tissues
    - This effect is used in cancer treatment

7.3 The Electromagnetic Spectrum

Increasing frequency →

Radio waves | **Microwaves** | **Infra-red waves** | **Visible light** | **Ultra-violet** | **X-rays** | **Gamma rays**

← ***Increasing wavelengths***

EM WAVE	Wavelength/m	Sources	Detectors	Uses
Radio wave	10^{-1} to 10^{5}	• Electronic devices	• Aerials of TV & radio transmitters	• Radio telescope • Radar communication
Microwave	10^{-3} to 10^{-1}	• Electronic devices	• Valve circuit arranged as microwave receiver	• Radar communication • Microwave oven • Analysis of molecular structures
Infra-red	10^{-7} to 10^{-3}	• Warm bodies • The Sun	• Blackened thermometer • Thermo-couples • Special photographic film	• TV remote control • Household electrical appliances • Intruder alarms • Night vision • Satellite footage of weather
Visible Light	10^{-7}	• Hot bodies • The Sun • Lasers	• Eyes • Photographic film	• Optical fibres • Medical uses (e.g.endoscopy) • Telecommunications
Ultra-violet	10^{-8} to 10^{-7}	• Lamps • The Sun	• Dyes • Photocells	• Sun beds • Fluorescent tubes • Sterilisation • Forensics
X-ray	10^{-13} to 10^{-8}	• X-ray tubes	• Photographic film • Fluorescent screens	• Hospital use • Fault detection • Airport security • Crystallography
Gamma ray	10^{-14} to 10^{-10}	• Cosmic rays • Radioactive substances	• Geiger-Müller counters • Photographic film	• Sterilisation of medical equipment • Cancer treatment • Checking of welds

Waves

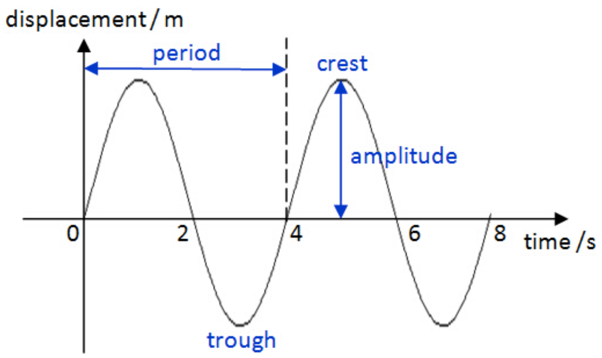
8.1 Progressive Waves

- Wave is a disturbance through a medium from one location to another
  - Transfers energy from one point to another without transporting matter
  - Mechanical waves require medium through which they propagate
  - Electromagnetic waves do not require any medium
- Particles of a wave do not move with the propagation of the wave
  - Only vibrate about their equilibrium positions with different phases within 1 wavelength

8.2 Definitions

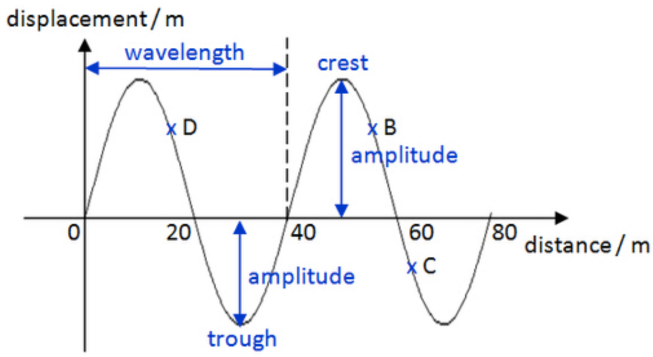
TERM	*DEFINITION*	*UNIT*
Displacement	Distance of the oscillating particle in a wave from its equilibrium position	m
Amplitude	Maximum displacement of oscillating particle from equilibrium position	m
Period	Time taken to complete 1 oscillation	T / s
Frequency	No. of oscillations made by wave per unit time	f / Hz (s^{-1})
Wavelength	Distance between corresponding points in successive wavefronts	λ / m

8.3 Graphs



Vertical displacement against time graph

Shows variation of vertical displacement of one particle over time



Vertical displacement against distance graph

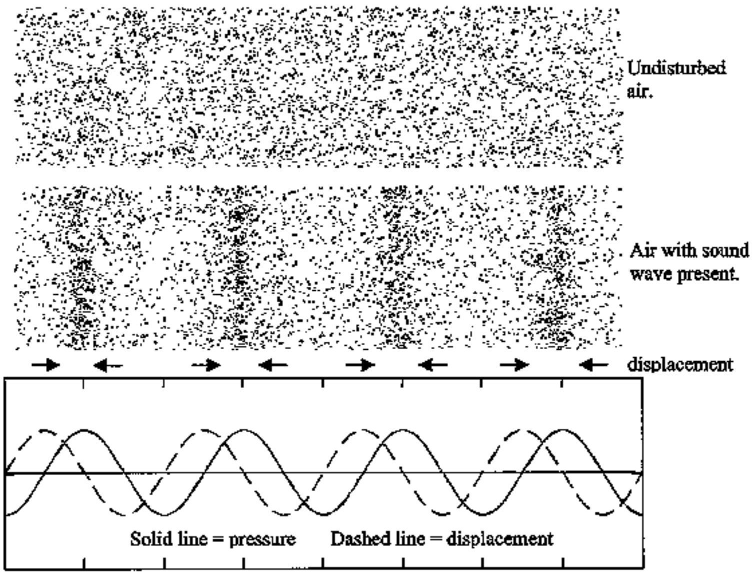
Shows position of all the particles in a wave at a particular instant of time

8.4 Transverse & Longitudinal Waves

- Transverse wave
    - Wave in which particles of the medium move perpendicularly to the direction of travel of the wave
    - e.g. EM waves, pulses in ropes & springs
- Longitudinal wave
    - Wave in which particles of the medium move parallel to the direction of travel of the wave
    - e.g. Sound, longitudinal pulses in springs

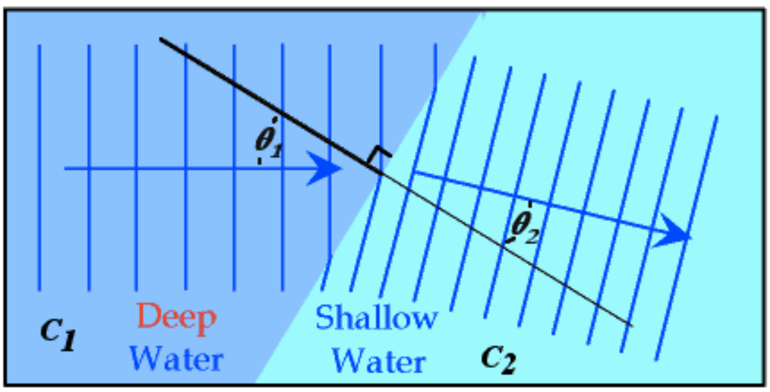
8.5 Sound Waves

- Particles of a sound wave oscillate about their equilibrium positions in a direction parallel to direction o motion of the wave
- Produce a series of high and low pressure regions known as compressions and rarefactions
- Point where displacement = 0
    - Is the point of compression / rarefaction
    - Point where arrows meet → C
    - Point where arrows go away → R
- Point where pressure = highest → C
- Point where pressure = lowest → R



8.6 Water Waves

- Water waves undergo refraction when its speed changes
- When refraction occurs,
    - Speed changes
    - Wavelength changes
    - Frequency stays constant
- Water waves travel fast in deep water than shallow water
- From deep to shallow
    - Speed decreases
    - Wavelength decreases
    - Frequency stays constant
- Vice versa

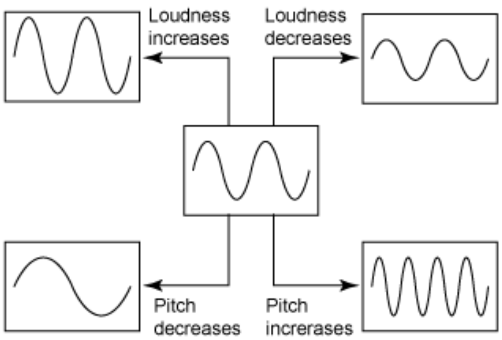


Sound

9.1 Medium

- Wave speed depends only on the medium
- Wave travels faster in denser mediums
    - i.e. $V_{solid} > V_{liquid} > V_{gas}$

9.2 Pitch & Loudness



- Loudness depends on amplitude
    - 🡅 amplitude = 🡅 volume

- Pitch depends on frequency
    - 🡅 frequency = 🡅 pitch

9.3 Range of audible frequencies

- Range of audible frequencies for an average human
    - 20 Hz – 20 kHz
- Range decreases as one gets older
    - Ears lose sensitivity to extreme ends of frequency range

9.4 Ultrasound

- Ultrasound = sounds above upper hearing limit of 20 kHz
- Infrasound = sounds below upper hearing limit of 20 Hz
- Applications of ultrasound
    - Ultrasonic cleaning
        - Can reach internal areas which are inaccessibly using other cleaning means
        - Provides "push" required to break the mechanical bonds that hold minute particles to surfaces

Pressure

10.1 Fundamentals

$$p = \frac{F}{A}$$

where p = pressure, F = force & A = area

- SI unit: N m^{-2}
  - aka the Pascal (Pa)

For a gas,

Pressure x Volume = Constant
pV = constant

(Boyle's Law)

10.2 Pressure in Fluids

- Fluid = liquid / gas
- The greater the depth in a fluid, the more pressure exerted

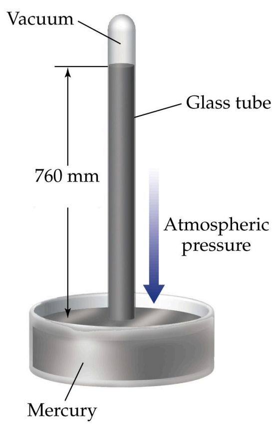
Pressure due to a liquid column, $p = h\rho g$

h = height ρ = density
g = gravitational field strength

- Pressure at one depth in a liquid acts equally in all directions
  - When water bag poked, water squirts out from all directions at not just downwards
- Liquids find their own level
  - To achieve pressure equilibrium
  - Cancels any resultant force created by a pressure difference

10.3 Atmospheric Pressure

- Atmosphere exerts a pressure caused by the weight of the thick layer of air above the Earth's surface
- At sea level, around 10^5 Pa
- Measured with a barometer
- Total pressure acting at a depth (h) below the liquid's surface = atmospheric pressure + $h\rho g$



10.4 Pressure Measurement

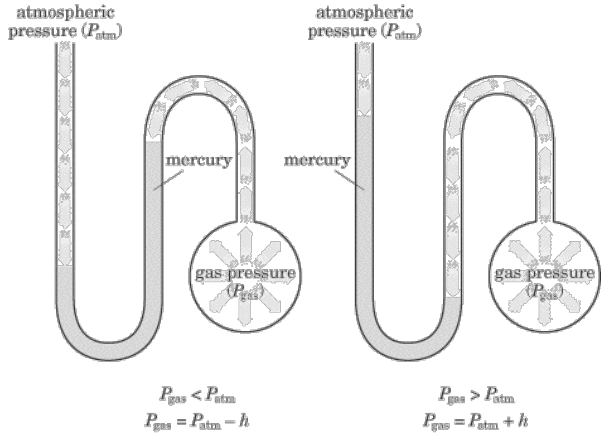
Mercury Barometer

- Makes use of the height of a liquid column
- Made with a glass tube which is filled to the top with mercury
- Inverted in a trough of mercury
- Mercury level drop until 760mm above mercury level in trough
- ATP = 760 mm Hg (at sea level) ≈ 100 kPa
- Height of mercury column does not depend on diameter / angle of tube

Water Barometer

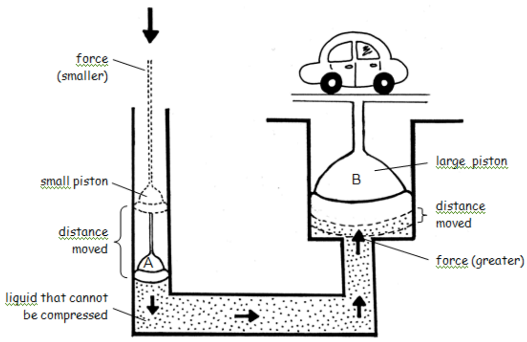
- Works on the same principle
- However, needs a much longer glass tube
  - Water has much lower density than mercury
- ATP >10m of water

Manometer



- Consists of a U-tube filled with liquid
  - Usually mercury, water or oil
- Measures gas pressure through pressure difference between atmosphere and the gas
- One arm of U-tube connected to gas supply, the other arm exposed to atmosphere
- Either Gas Pressure + Liquid Pressure = ATP
- Or Gas Pressure = Liquid Pressure + ATP
- Oil is often used
  - As it is less dense, it makes manometer more sensitive (for same pressure difference, oil registers greatest height)
- Manometer can be used in cleanrooms
  - To ensure pressure inside a room is slightly higher than outside to repel dust from outside

10.5 Hydraulic Systems



- Work by using liquids under pressure
- Uses the properties of liquids which are:
  - Incompressible
  - If pressure applied to enclosed liquid, the pressure is transmitted uniformly to all parts of liquid
- Hydraulic system must not contain any air bubbles to maintain efficiency of system as no applied force will be used to compress air bubbles

$p_A = p_B$

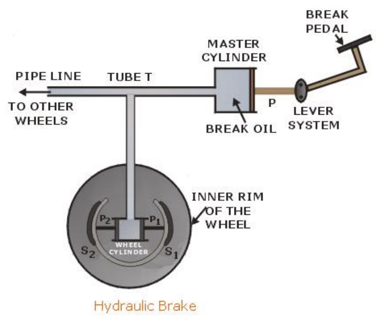
$F_A/A_A = F_B/A_B$

$F_B = F_A(A_B/A_A)$

Since $A_B > A_A$, it follows that $F_B > F_A$.

Hydraulic Brakes

- Brake pedal pressed → piston of master cylinder applies pressure on brake fluid and this pressure is transmitted via a system of pipes to each cylinder at the wheels
- Cylinder at wheels cause pair of pistons to push outwards onto a pair of friction pads (brake shoe) which in turn press against the surface of the brake discs or brake drums
- Frictional forces between these brake components cause the vehicle to slow down and stop
- When brake pedal released, spring restores the brake shoes to their original positions



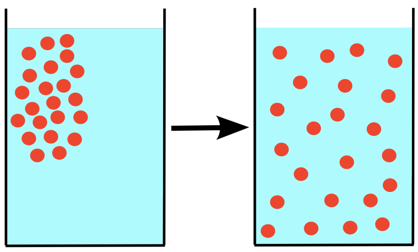
Kinetic Model of Matter

- Kinetic Model of Matter states that
  - All matter made up of very large number of particles
  - That are in a state of continuous random motion
  - Higher temperature = Greater average KE of particles

11.1 States of Matter

	Solid	**Liquid**	**Gas**
Arrangements of particles	Regular	Less regular	No fixed position
Distance between particles	Very small	Slightly larger than in solid	Very large
Intermolecular forces	Very strong	Slightly weaker than in solid	Negligible
Motion of molecules	Vibrate about fixed position	Vibrations & random movements throughout but particles cling along together	On top of vibrational motion, particles can move about freely.
Shape	Fixed shape	No fixed shape; takes shape of container	No fixed shape; takes shape of container
Volume	Fixed volume	Fixed volume	No fixed volume as gases are compressible

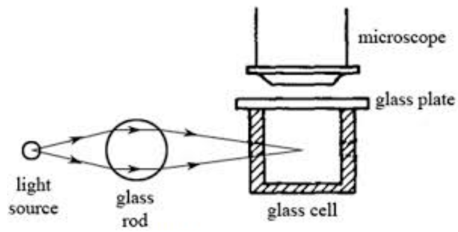
11.2 Evidence of Kinetic Model



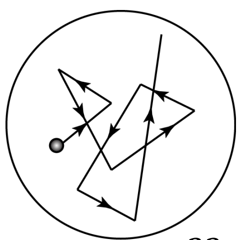
Diffusion

- Movement of particles from a region of higher concentration to a region of lower concentration

Brownian Motion



- Smoke enclosed in illuminated transparent container
- Microscope focused on smoke particles
- Smoke particles barely visible, appear as minute specks of light moving around in random & erratic motion
- Smoke particles are bombarded by air molecules
- Smaller smoke particles = More rapid movement
- **Brownian Motion** = haphazard movement of microscopic particles suspended in a fluid due to the uneven bombardment of suspended particles by the fluid's molecules


Brownian Movement

11.3 Gas Laws

Boyle's Law

$$P \propto \frac{1}{V}$$

Volume ↓

↓

Number of molecules per unit volume ↑

↓

Frequency of collisions with surface of container ↑

↓

Pressure of gas ↑

Pressure Law

$$P \propto T$$

Temperature ↑

↓

Average speed of air molecules ↑

↓

Frequency & force of collisions with surface of container ↑

↓

Pressure of gas ↑

Charle's Law

$$V \propto T$$

Temperature ↑

↓

Average speed of air molecules ↑

↓

Frequency & force of collisions with surface of container ↑

↓

Pressure of gas ↑

↓

To keep pressure constant, gas expands

Temperature

12.1 Temperature & Heat

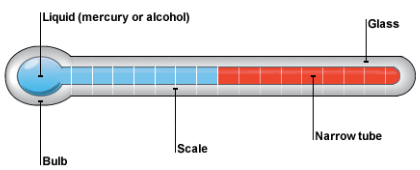
- Temperature = measure of how hot / cold an object is
- Heat = amount of thermal energy transferred from a hotter to a colder region
    - Describes the process of energy transfer
    - Once transferred, energy ceases to be heat
        - Energy becomes part of total energy of the molecules of the molecules / system (internal energy)
- Matter contains molecular KE & PE, but not heat
- Internal Energy = Combination of total KE & PE of the molecules
    - Includes translational KE of jostling atoms
    - Rotational & vibrational KE of molecules
    - KE due to internal movement of atoms within molecules
    - PE due to forces between molecules
- Rise in temperature = Increase in average KE of particles

12.2 Thermometers

- Thermometric property = Physical property of a thermometric substance that varies continuously

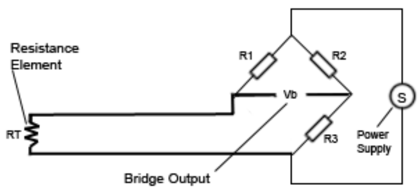
THERMOMETRIC PROPERTY	THERMOMETER
Volume of fixed mass of liquid	Liquid-in-glass
Resistance of piece of metal	Resistance thermometer
Colour of hot object	Thermostrips / liquid crystal thermometer
Length of solid	Bimetallic thermometer
Electromotive force	Thermocouple
Gas pressure	Constant volume gas thermometer

- Good thermometers are
    - Responsive to temperature changes
    - Sensitive to small temperature changes
    - Able to measure a wide range of temperatures



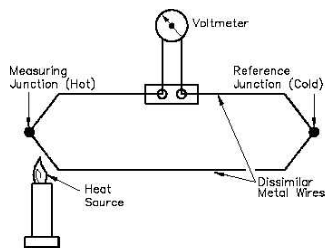
Liquid-in-Glass Thermometer

- Thin glass bulb to conduct heat
- Portable & cheap
- Independent of other equipment



Resistance Thermometer

- Usually made of platinum due to linear resistance-temperature relationship
- Highly accurate & sensitive
- Wide range of temps (-200°C– 1000°C)



Thermocouple

- Measures electromotive force based on temp difference of 2 junctions
  Wide range of temps (-200°C– 1700°C)
- Can be use in precise places

12.3 Calculating Temperature

Celsius Scale

- In general, for a thermometric substance with physical property X (e.g. height of mercury) which changes linearly with temperature rise:

$$\theta°C = (X_\theta - X_L / X_H - X_L) \times (\theta_H - \theta_L) + \theta_L$$

X_L = Physical property at lower fixed point
X_H = Physical property at higher fixed point
X_θ = Physical property at θ°C

Kelvin Scale

- At absolute zero, all possible thermal energy transferred away from body
- Unit = Kelvin (K) → SI unit for temperature
- Temperature in Kelvin = Temperature in Celsius + 273.15°C

Thermal Properties of Matter

13.1 Heat Capacity

Heat Capacity

- Heat capacity of a substance = amount of energy required to raise the temperature of substance by 1°C

$$Q = C\Delta\theta$$

Q = amount of energy transferred (J)
C = heat capacity (J K^{-1})
Δ = change in temperature (K)

Specific Heat Capacity

- SHC = amount of energy required to raise temperature of a ***unit mass*** of the substance by 1°C

$$Q = mc\Delta\theta$$

Q = amount of energy transferred (J)
m = mass (kg)
c = specific heat capacity (J kg^{-1} K^{-1})
Δ = change in temperature (K)

Heat Transfer without Change in State

- When 2 bodies of different temperatures finally reach thermal equilibrium,
- Energy lost by hot body = Energy gained by cold body

$$m_1c_1\Delta\theta_1 = m_2c_2\Delta\theta_2$$

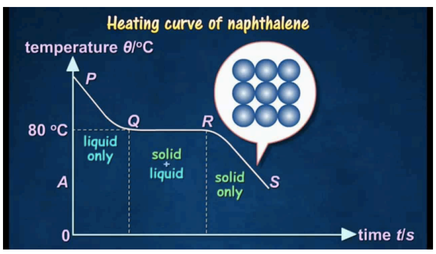
13.2 Specific Latent Heat

$$Q = P \times t$$

Q = amount of energy transferred (J)
P = power of heater (W)
t = time taken (s)

Cooling Curve of Napthalene

- From P to Q:
  - Temp ↓ due to loss of average KE of particles
- From Q to R:
  - Temp constant
  - Heat loss comes from loss of PE of particles as bonds form to hold particles in more stable configurations
- From R to S:
  - Temp ↓ due to loss of average KE of particles



Latent Heat

= the energy that is absorbed / released by substance when there is a change in state of substance without change in temp

- required to overcome the IMF between the particles
- 2 types: LH of fusion & LH of vaporization

Specific Latent Heat

- SLH of fusion (l_f) = amount of energy needed to change a unit mass of the substance from solid to liquid (or vice versa), without a change in temp

- SLH of vaporization (l_v) = amount of energy needed to change a unit mass of the substance from liquid to gas (or vice versa), without a change in temp

$$l_f = \frac{Q}{m}$$

Q = amount of energy transferred (J)
m = mass (kg)

$$l_v = \frac{Q}{m}$$

Q = amount of energy transferred (J)
m = mass (kg)

- In general, if there is a change in state: **Q = ml**

- SLH of F of ice = 33600 J kg^{-1}
- SLH of V of water = 2268000 J kg^{-1}

13.3 Boiling & Evaporation

Evaporation

- Molecules in liquids are in constant motion
- More energetic molecules at surface can break free from surface, while less energetic molecules left behind
- Hence, average KE of liquid molecules decreases
- Less average KE = Lower temp
- Hence, evaporation cools down a liquid
- Factors affecting: temp, surface area, wind, humidity, pressure of surrounding air

EVAPORATION	**BOILING**
Occurs only at surface of liquid	Occurs throughout liquid
Occurs at all temps	Occurs at b.p. only
Slow process	Quick process
Energy source not required	Energy source e.g. heater required