Secondary 3 EOY Physics Notes

Physical Quantities and Units

SI Units

Unit	Symbol	Base Quantity
Meter	m	Length
Second	s	Time
Kilogram	kg	Mass
Ampere	A	Electric current
Kelvin	K	Temperature
Mole	-	Amount of substance, usually molecular scale
Candela	cd	Luminous intensity

Common Derived Units

Symbol	Base Quantity
m^2	Area
m^3	Volume
$m\ s^{-1}$	Speed or Velocity (velocity is vector)
$m\ s^{-2}$	Acceleration
$kg\ m^{-3}$	Density
$kg\ m^{-2}$	Pressure

Power of 10 prefixes

Multiples and Submultiples	Power	Prefixes	Symbols
1 000 000 000	9	giga	G
1 000 000	6	mega	M

1 000	3	kilo	k
1	0	-	-
0.1	-1	deci	d
0.01	-2	centi	c
0.001	-3	milli	m
0. 000 001	-6	micro	μ
0. 000 000 001	-9	nano	n

Converting Units

1. Take original fraction
2. Convert both to new units
3. Take new fraction and account for s.f.

1.0 km/h >> 1000m / 3600s >> 0.028m/s

Measurement Technique

Zero Error

- Reading when value should be 0 = Zero Error
- Accurate Measurement = Final Reading - Zero Error
- Especially in Vernier Calipers and Micrometer Screw Gauge

Types of Error

- Random error
  - Present in all measurements
  - May be due to human errors
  - Cannot be predicted, hence cannot be avoided
  - Reading can fall above or below actual value
  - Can be mitigated through taking repeated measurements OR reading multiple at once (random error is split among multiple objects)
- Systematic Error
  - Present in all measurements, an accurate reading has a small systematic error
  - May be due to human errors or faulty instruments
  - Causes a set of results to be displaced evenly from actual value
  - Minimised by method of difference / measuring known value and taking offset

Accuracy and Precision

- Accuracy = Hitting the target
- Precision = Having a compact set of hits

Significant Figures and Decimal Places

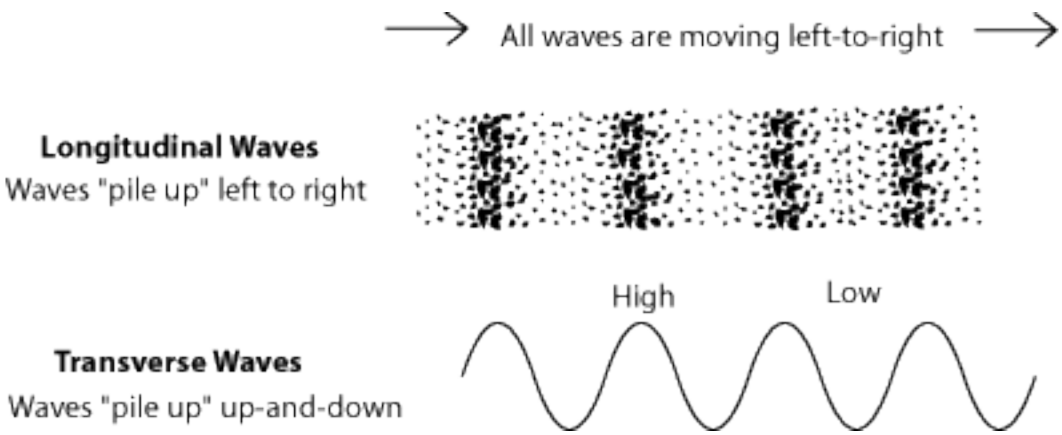
- s.f. is used during multiplication and division
- d.p. is used during addition and subtraction
- Generally keep all calculations to 3 s.f.

Waves

What is a wave?

- A phenomenon in which energy is transferred through vibrations
- Carries energy away from a source without transfer of matter
- Exist in transverse and longitudinal waves

Transverse vs Longitudinal waves



	Transverse	Longitudinal
Direction of oscillations	Up and down, perpendicular to direction of wave	Side to side, parallel to direction of wave
Characteristic observations	Crest and trough	Rarefactions and Compressions
Examples	Light	Sound

Structure of a wave

- Crest: High point
- Trough: Low point

- Amplitude A: Maximum displacement from rest position
- Wavelength λ: Distance between two successive crests, troughs, compressions or rarefactions
- Wavefront: Line that joins all crests/troughs, perpendicular to direction of wave
- Frequency f : Number of crests that pass through a point a second, number of waves made in a second or number of complete oscillations a particle makes in a second (Hz)
- Period T: Time taken to generate one wave or for a particle to complete one oscillation. (s)
- Speed v: Distance moved by a wave in one second, determined by medium of which wave passes through.

Wave Equations

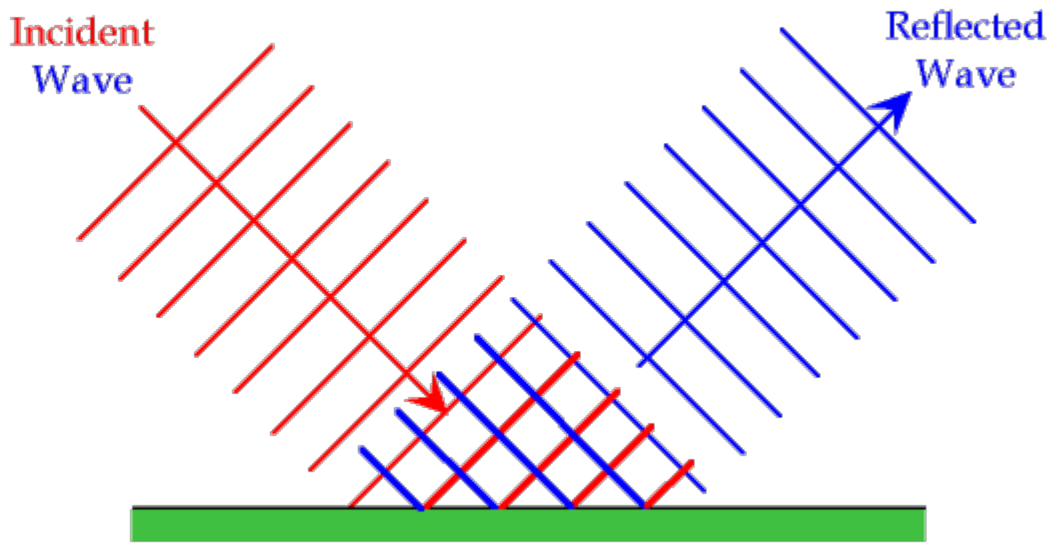
- Values in question are A λ f T v
- $fT = 1$
- $v = \lambda/T$
- $E \propto A^2$

Graphical Representation of Waves

- Remember: Wall against ground
- Displacement Position Graph
  - Y axis is Displacement
  - X axis is Position
  - Wavelength is wavelength
  - Amplitude is aptitude
- Displacement Time Graph
  - Y axis is Displacement
  - X axis is Time
  - Wavelength is period
  - Amplitude is amplitude

Wave Reflection and Refraction

- Reflection



- Refraction
    - Refractive index dependent on medium and depth
    - Waves are faster in deep water
    - Speed and wavelength modified, frequency is not
    - Faster wave refracted further from normal
    - Further apart wavelengths means faster wave.

EM Spectrum

Properties of EM waves

- All EM waves are produced by a fluctuation in electric and magnetic fields
- All travel at 3×10^8 m s^{-1} in vacuum (speed of light c)
- c = Fλ

Common EM waves

Wave type	Frequency	Wavelength	Applications
Radio waves	<300 MHz	> 1m	Radio communication Mobile phones
Microwaves	300 MHz - 300 GHz	1mm - 1m	Microwave oven Satellite television
Infra-red waves	300 GHz - 400 THz	760 nm - 1 mm	Remote controllers Night Vision
Visible light	400 THz -	380 nm -	Optical fibres

	800 THz	760 nm	Telecommunications
Ultraviolet waves	800 THz - 30 PHz	10 nm - 380 nm	Tanning beds Sterilisation
X-rays	30 PHz - 30 EHz	0.01 nm - 10 nm	Medical scans Baggage checks
Gamma rays	>30 EHz	< 0.01 nm	Sterilising medical equipment Cancer treatment

Sound

Structure of Sound waves

- Longitudinal waves
- Small but rapid changes in air pressure
- Human audible range from 20Hz to 20 000 Hz (20 kHz)
- Moves in air at 330 m s^{-1}
- Faster in denser medium (since it is a mechanical wave)
- Echoes occur when reflected sounds are heard at different times

Cathode Ray Oscilloscopes

- Y axis measures disturbance of air
- X axis measures frequency
- Amplitude of wave is amplitude of sound
- Period of wave shows period, and hence shows frequency.

Convex Lenses

Lens Terms

- Principal Axis: Line passing through the optical center and perpendicular to the plane of the lens.
- Optical Center C: Point midway between the lens on the principal axis
- Principal Focus: Point on the principal axis to which incident rays parallel to the axis converge
- Focal Length f: Distance between optical center and principal focus
- Focal plane: Vertical plane which passes through the principal focus and is perpendicular to the principal axis.

Drawing Ray Diagrams

- All real rays drawn with solid lines and arrows
- Virtual rays and objects are drawn with broken lines
- Rays are drawn from the tip of an object

- Bending only at the center of the lens
- Mark principal focuses, object and image
- Ray passing through center will not refract
- Ray entering parallel to principal axis will pass through principal focus on other side
- Ray passing through principal focus will exit parallel to principal axis on other side

6 Positions of Objects

Location of O	Location of I	Properties of I	Applications
at infinity	opposite side at f	Real Inverted Diminished	Objective lens of telescope
between 2f and infinity	opposite side between f and 2f	Real Inverted Diminished	Camera Human Eye
at 2f	opposite side at 2f	Real Inverted Same Size	Photocopier
between 2f and 1f	opposite side between 2f and infinity	Real Inverted Magnified	Projector Objective lens of microscope
f	real at opposite side at infinity virtual at same side at infinity	Depends on usage	Spotlight Eyepiece of telescope
between C and f	same side between f and infinity	Virtual Upright Magnified	Magnifying glass Spectacles for long-sightedness

Thin lens formula

$$u^{-1} + v^{-1} = f^{-1}$$

Where u = object distance, v = image distance and f = focal length

Real is positive, virtual is negative.

Kinematics

Units in Kinematics

- Speed = Distance / Time
- Velocity (V) = Displacement (V) / Time (v = s/T)

- Acceleration (V) = ΔVelocity (V) /Time (a = v/T)
    - Acceleration will change with a change in direction

Graphical Analysis of Motion

- Displacement Time Graph
    - Y axis is displacement
    - X axis is time
    - Gradient is velocity
- Velocity Time Graph
    - Y axis is velocity
    - X axis is time
    - Gradient is Acceleration
    - Area under graph gives displacement

Free Fall

- Object is in free fall if only force acting on it is gravity/weight
- Accelerating at a rate of 9.81 m s^{-2}

Equation of motions

Velocity from Initial and Acceleration	$v = u + at$
Velocity from combining Initial and Acceleration	$v^2 = u^2 + 2as$
Distance from sum of movement	$s = ut + at^2 / 2$
Acceleration from average of Speeds	$a = (v-u)/t$

Vectors

Scalars and vectors

- Scalars only account for magnitude
- Vectors account for direction and magnitude

Scalars	Vectors
Distance, speed, mass, time, pressure, energy, volume, density	Displacement, velocity, weight, acceleration, force, momentum

Vector addition and subtraction

- Graphical: Drawing the vectors end-to-end and measuring the distance and direction from the start point to the end point

- Calculative: Resolve into two-dimensional vectors and add independently (Horizontal and vertical vectors are independent)

Dynamics and Forces I

What is a force?

- Physical interaction in the form of a push or a pull
- Force is a vector
- Force = mass × acceleration
- SI unit is Newtons (N) or kg m s^{-2}
- Forces include:
  - Gravity
  - Electrostatic
  - Magnetic
  - Normal Contact
  - Frictional (-ve)
  - Tension
  - Drag (-ve)

Drawing forces

- Drawn with a straight line, from point of which force is acting towards direction of force
- Gravity is drawn from center of gravity
- Friction is drawn from contact point

Friction

- Force that opposes
  - Relative motion
  - Tendency towards motion
- Static friction > kinetic friction

Weight

- Weight = mass × gravity (9.81 m s^{-2})
- Mass is scalar, weight is vector

Free Body Diagrams

- Draw dot with all forces acting on it with arrows pointing outwards
- Compound force would be resultant motion of entire system
- Internal tension forces of strings cancel each other out
- Stationary system = all forces cancel each other out

Dynamics and Forces II

Rotational motion as Moments

- Dynamics and Forces I covered translational movement
- Rotational movement also needs to be considered
- Moment of a force = Force × Perpendicular distance from pivot
- SI unit is N m
- Categorised into clockwise and anticlockwise moments
- When object is in equilibrium, clockwise moment is equal to anticlockwise moment

Center of Gravity

- Center of gravity (CG) is the point where the entire weight of a body seems to act
- Regular objects have their CG at the center of the object.
- Objects are balanced when their CG is directly above or below a pivot or its base

Stability

- Stability is the measure of a body's ability to maintain its original position
- If a body returns to its original position after displacement and its CG returns to its original position, it is in a Stable Equilibrium
- If a body remains wherever it is displaced or the CG remains at the same height, it is in a Neutral Equilibrium
- If a body continues to move away from its original position after being displaced or its CG continues to move, it is in an Unstable Equilibrium
- Stability can be improved by having a heavier base to lower the CG or by having a broader base to shift the pivot further away from the CG

Energy, Work and Power

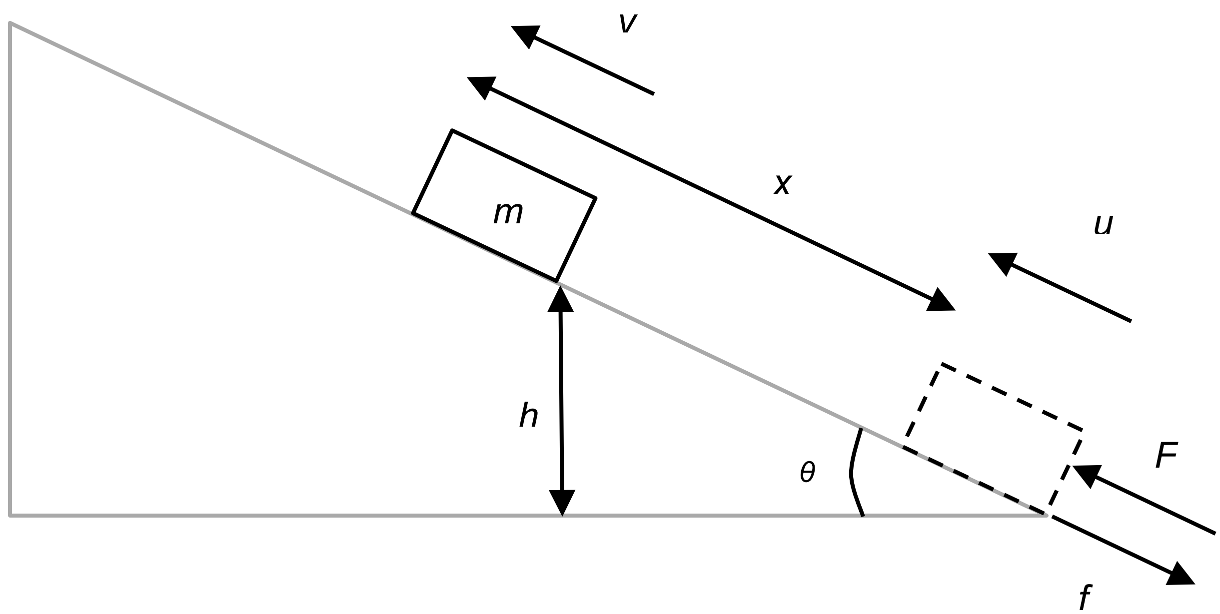
Energy and its Measurement

- Energy is measured in Joules (J)
- Energy exists as:
    - E_K or Kinetic Energy (external is movement AND internal is heat)
        - External Kinetic is calculated with $E_K = m v^2 / 2$
    - E_P or Potential Energy (chemical AND gravitational)
        - Gravitational Potential is calculated with $E_P = m g h$

Work

- Work is done when a force produces motion / When a force results in displacement
- Calculated with Work = force × distance moved in direction of force
- J = F d
- Work done is measured in Joules (J)

Work Energy Concept + Wedge Block Diagram



Force F is exerted on a mass m up a plane with frictional force f inclined at θ to the horizontal. The block then accelerates from initial velocity u to final velocity v after reaching distance x at height h.

A. Work done = F x
B. Increase in GPE = m g h
C. Increase in KE = m (v^2 - u^2) / 2
D. Work done against friction (to counter friction) = - f x (work done against sth is -ve)

According to the law of conservation of energy:

$$F x = m g h + m (v^2 - u^2) / 2 + f x$$

i.e.

$$A = B + C - D$$

Power

- Power is the rate of doing work
- SI Unit is Watt or J s^{-1}
- Power = Work Done / Time Taken = (Force * Distance) / Time Taken = Force * Velocity
- W = ΔE / t = (F d) / t = F v (if v is constant)

Efficiency

- Efficiency of a machine is how much useful energy is used or stored in a machine when compared to the amount of energy provided.

- Efficiency = Useful energy output / Total energy input × 100% = Useful power output / Total power output × 100%

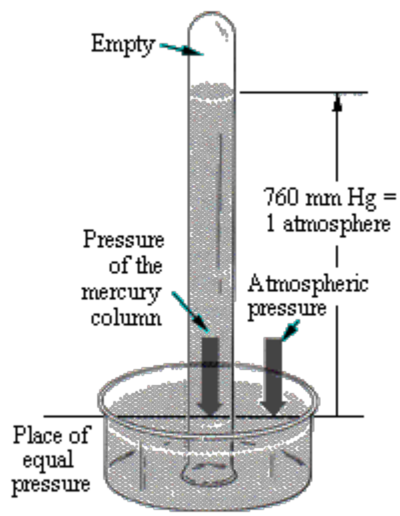
Pressure

Pressure and its Measurement

- Pressure P is the force F acting per unit surface area A
- Pressure P = Normal Force / Area in Contact
- P = F / A
- SI unit is Pa or N m^{-2}
- Other units include
    - Atm or Atmospheres, quantifying the pressure of a substance in comparison to atmospheric pressure at sea level. 1 atm = 10^5 Pa OR 100 kPa
    - mmHg or cmHg, quantifying the pressure of a substance in comparison to how tall a column of mercury it can support. 76 cmHg = 10^5 Pa OR 100 kPa

Pressure in Fluids

- Pressure due to a liquid column = height of column (m) × density of liquid (kg m^{-3})× strength of gravity (m s^{-2})
- P = h p g
- Pressure in liquids acts equally in all directions, in a direction perpendicular to the surface in question

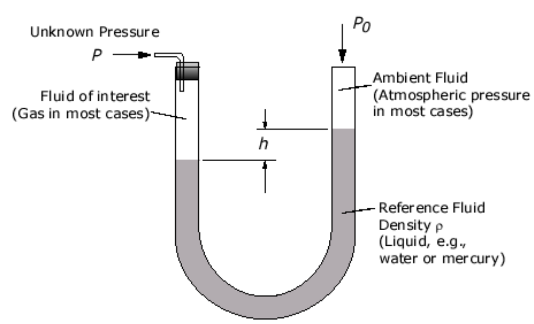


Measuring Pressure - Barometers

- Mercury is dense (13.401 kg m^{-3}) and liquid at RTP
- If water is used, column will be 10.9 meters tall
- Fill a glass with Hg
- Invert a tube such that the open end is submerged in a container of Hg
- Hg will fall to a level
- Atm pressure is supporting a column of Hg
- Measured in mmHg
- Readings are affected by:
    - Air/gas in enclosed area
    - Air/gas in supposed vacuum (especially if volatile substance)
    - Temperature

Measuring Pressure - Manometers

- Consists of U-tube containing incompressible liquid (preferably Hg or water)



- Both arms exposed to Atm or substance with modified pressure
- If water level on one side is higher than other, higher water level side + difference water level = pressure on lower water level side

Hydraulic Systems

- Uses incompressible liquid to transfer mechanical force, since pressure exerted on one part of liquid is transmitted evenly to all other parts of the liquid
- Use low pressure to press surface of low surface area, displacing small amount of force
- Liquid pushes on larger surface area which outputs high pressure force, despite moving a lesser distance due to larger surface area

Boyle's Law

Considering fixed mass and temperature

$$P_1 V_1 = P_2 V_2$$

Where P_1 and P_2 are the initial and final pressures, and V_1 and V_2 are the initial and final volumes.

Therefore:

$$P \propto V^{-1}$$

Kinetic Model of Matter

Matter and Internal Energy

- All matter exists in terms of particles
- Particles have "internal E_K" in the form of heat, usually causing particles to rotate and vibrate
- Certain levels of internal E_K causes changes in the behaviour of the matter
- Internal E_K may break IMFs, causing separation/contraction and hence a state change

The 3 States

- Solid
    - Strong IMF holds particles together
    - Molecules move in vibration in a fixed position
- Liquid
    - Lesser IMFs hold particles together
    - Molecules translate and vibrate, can freely move
    - Liquids will hence take the shape of its container
- Gas
    - Weak IMFs barely hold particles together
    - Molecules translate and vibrate
    - Additional heat causes thermal expansion

	Solid	Liquid	Gas
Volume / Compressibility / Density	Fixed	Fixed	Variable
Shape	Fixed	Variable	Variable

Kinetic Model and Pressure

- Randomly moving gas particles hit surfaces of objects
- Impact is called "Pressure"
- Determined by frequency and force of collisions

Ideal Gas Law

$$P V = N R T$$

Where:

- P is Pressure in pa
- V is Volume in m^3
- R is a constant 8.314 J K^{-1} mol^{-1}
- n is amount of particles in moles
- T is Temperature in K

When assuming that:

- Volume of particles is negligible
- IMF is negligible

Temperature

Temperature and Thermometry

- Heat or Internal E_K is measured in terms of its temperature
- Values of temperature express the degree of heat on a given scale
- General rule is to use any property of a substance that changes according to temperature in a predictable fashion and to measure it to obtain a value
  - e.g. Change in Volume, Change in Pressure, Variation in electromotive force or resistance, Change in colour etc
- Temperature is a relative measurement
- Scales of temperature are determined by upper fixed point and lower fixed point, using properties of linearity to predict values in between and out of range.

Common Temperature Scales

- Celsius:

- Upper bound is bp of water
  - Lower bound is mp of water
  - Divided into divisions of 100
- Kelvin:
  - Divisions of same size as Celsius
  - Lower bound is absolute zero (-273.15 □ or 0 K)

Linearity

- Lower bound determines X_1 and θ_1
- Upper bound determines X_2 and θ_2
- Calculated value is in X and θ

$$(\theta - \theta_1) / (\theta_2 - \theta_1) = (X - X_1) / (X_2 - X_1)$$

$$\theta = (X - X_1) / (X_2 - X_1) \times (\theta_2 - \theta_1) + \theta_1$$

$$X = (\theta - \theta_1) / (\theta_2 - \theta_1) \times (X_2 - X_1) + X_1$$

Properties of a Thermometer

- Sensitivity: Amount of change in volume per unit heat
- Responsiveness: Delay or lack thereof required to read accurate reading
- Range: Upper and Lower bounds of accurate range of a thermometer

Factor Increased	Bore Size	Thickness of bulb wall	Bulb size	Conductivity of glass	Conductivity of liquid	Length of column
Sensitivity	-		+			
Responsiveness		-	-	+	+	
Range	+		-			+

Thermal Properties of Matter

Basic Heat Capacity

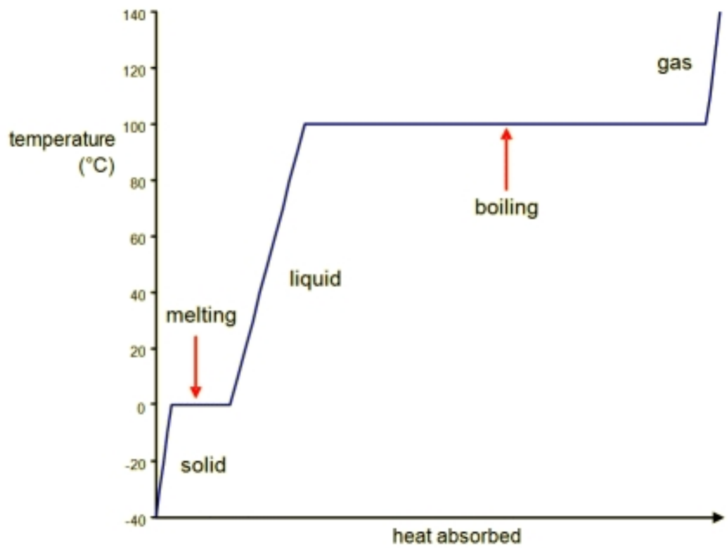
- Heat capacity of an object is the amount of energy required to increase a system by 1 K
- Written as C, measured in J K^{-1}
- Specific heat capacity is the amount of energy required to increase a unit mass of a certain material by 1K
- Written as c, measured in J K^{-1} kg^{-1}

Latent Heat

- Energy expended or released during a state change is its Latent Heat
- Boiling or Condensing is accounted by latent heat of vapourisation or L_V

- Melting or Freezing is accounted by latent heat of fusion or L_F
- Measured in J
- Specific latent heat is measured in J kg^{-1}, written with l

Heating curve of Water



Electric Fields

The Charge

- Atoms contain protons, neutrons and electrons
- Electrons are free-moving/mobile and can migrate from one nucleus to another
- Charged bodies have an unequal number of protons and electrons
    - Protons > electrons = Positively charged
    - Electrons > protons = Negatively charged
- Charges are neither created nor destroyed; net charges are constant
- Charge is quantified in coulombs written as Q, unit is C
    - One electron has a charge of 1.6×10^{-19} C
    - One coulomb contains 6.25×10^{18} electrons

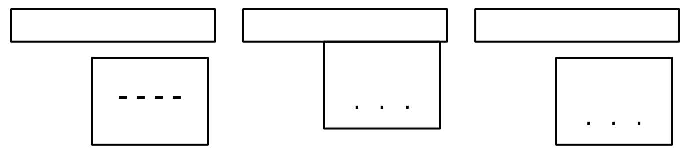
Forces between Charges

- Like charges repel, unlike charges attract
- Electric force between charges is
    - proportional to product of charge strength
    - inversely proportional to square of distance between charges

$$F = q_1q_2/4\pi\varepsilon_0r^2$$

Conductors and Insulators

Conductors	**Insulators**
Delocalised electrons flow thru body	Electrons bound to atoms and will not flow
Charges distribute evenly	Charges stay at point of attachment Induced charge create dipoles



Metals, graphite, salt solutions	Dry air, glass, ceramics, plastics

Charge Induction between conductors

- Consider positively charged conductor and neutral foil
- Positive conductor attracts electrons to top of foil, top negatively charged and bottom positively charged
- Positive charges further away than unlike charges -> Repulsion of positive charges is less than attraction of unlike charges -> net force upwards
- Rod and foil touch, electrons from foil move to rod, entire system positively charged
- Positive charges repel -> foil repelled downwards
- For charged conductor and neutral insulator: induction still occurs, electrons are distorted towards a certain direction to form charge poles, but cannot be net charged on contact

Tend to lose electrons ↑	(+)
	human hands (dry)
	glass
	human hair
	nylon
	cat fur
	silk
	cotton
	steel
	wood
	amber
	ebonite
	plastic wrap
↓ **Tend to gain electrons**	Teflon®
	(–)

Earthing and Discharge

- Providing a conducting path between object to earth
- Electrons can move freely between earth and object, neutralising all charges (earth is baseline neutral)
- Human body can cause earthing to occur
- To discharge conductors
    - Earth
    - Expose to air, ions in air due to UV/background radiation neutralise charge
- To discharge insulators

    - Pass over flame: Ions from flame (the colored flame) neutralise charge on rod

Methods of Charging

Contact

- Both are conductors
- Charged conductor contacts neutral conductor
- Net charge follows polarity of original charged conductor

Friction

- Two items in triboelectric series are rubbed together
- Electrons loosely attached to surface of one material removed by friction and deposited on other material
- Results in two differently charged bodies

Induction

- Induction and Separation of Conductors
- Force provided to keep charges apart, charges mechanically separated, induced charge causes object to be charged
- Charged object brought near object to be charged -> object to be charged has induced charge -> object to be charge earthed -> electrons flow to/from object and earth, gains net charge (induced charge has more dominant effect than earth, determines direction of electron flow) -> earth removed -> object charged
- Charged object brought near two objects to be charged -> objects touched, one object has more positive charge, other negative charge -> objects mechanically separated -> two oppositely charged objects

Applications of Electrostatic Charging

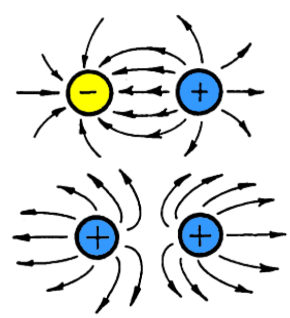
- Electrostatic precipitator
    - Removal of airborne particles without use of mechanical filter
    - Particles charged using wire mesh, attracted to oppositely charged collector plates
    - Collector plates shaken to remove particles
- Electrostatic painting
    - Paint droplets in aerosol/airbrush are negatively charged when passing thru nozzle
    - Readily adheres to positively charged/earthed painting surface e.g. cars
- Photocopier and laser printer
    - For photocopier: laser light reflected from page onto charged selenium rod -> lit areas conduct and lose charge
    - or printer: brush controlled by computer selectively charges rotating selenium rod
    - Charged areas of selenium rod attract black toner powder -> hot press to melt toner onto paper -> printed image

Electrostatic Hazards

- Accumulation of electric charges can pose dangers to humans
- Lightning
  - Clouds charged as friction charges water and air molecules
  - Excess charge can ionise air to create conducting path, discharges towards ground
  - Lightning conductors at top of buildings are charged positively by negative clouds, attract and remove electrons from surrounding air, positively charged air then passes into cloud to neutralise cloud
  - Lightning rods accept lightning strikes since they are grounded
- Fires
  - Buildup of static creates sparks which may ignite fuel
  - Trailing conductive strip behind fuel-carrying vehicles discharges all charge on the vehicle by earthing to prevent sparks from forming

Electric Fields

- Charged bodies create electric fields which attract and repel charges
- Direction of electric field is where a positive charge will move, positive to negative
- Direction of force is derived by obtaining tangent of electric field at the point
- Lines closer to each other indicate stronger field and vice versa
- Lines cannot cross each other
- Isolated charges
  - Positive charge has field lines directed outwards
  - Negative charge has field lines directed inwards
- Two Point charges
  - Like charges repel, have neutral point between two charges with no net electric field
  - Unlike charges attract, field lines diverge from positive and converge at negative
- Parallel charged plates
  - Field is of uniform strength and parallel
  - Field lines from positive plate to negative plate



Current Electricity

Electric Current

- Charges are by themselves static - they remain in place
- Electric currents involves the constant movement of electric charges when there is a potential difference between ends of an electric conductor or circuit
- Flow of electric current is measured in Amperes written I unit A, SI unit Q/t
  - 1 ampere of flow is when 1 coulomb of electrons pass through a point in 1 second
- Conventional flow is from positive to negative terminal of source

- Actual electron flow is in opposite direction, from negative to positive terminal

Volts and Ohms

- Electromotive force (e.m.f) is the amount of work done by an electric source by driving a unit of charge through a circuit
- Potential difference is the amount of work done to drive a charge through a circuit, usually across components which are not the electric source
- Ratio of work done to charge passed is measured in Volts written V unit V, SI unit W/Q
  - 1V of emf means that an electric source takes 1W of energy to create a constant flow of 1A
  - 1V of pd means that 1W of energy is expended to drive a constant 1A flow of charge
- Resistance is the degree of which an electrical component or circuit opposes the passage of electric current
- Amount of resistance is measured in Ohms written R unit Ω, SI unit V/I
  - A circuit which has an emf of 1V and resistance of 1Ω will have electric flow of 1A

Ohm's Law

- "The current passing through a conductor is directly proportional to the potential difference across it. The rate of proportion is determined by amount of resistance across a circuit."

$$V = R\ I$$

Where

- V is Volts
- R is Resistance
- I is current

Ohmic and Nonohmic Conductors

- Ohmic conductors have a constant resistance across all situations
- Nonohmic conductors have variable resistance in different situations, varying according to
  - Direction of electron flow (diodes and zener diodes)
  - Amount of potential difference/current (thermistors)
  - External factors (photoresistors, thermoresistors, transistors, rheostats)
- Ohmic conductors have linear V-I graphs, nonohmic have nonlinear
- Typical metallic conductors have increasing resistance the higher the power dissipated across them

<u>V-I graphs of conductors</u>

- Metallic conductors at constant temperature

    - Constant resistance
    - V-I graph linear and increasing, similar to y = mx where m > 0
- Filament lamps
    - Resistance increases as bulb heats up
    - V-I graph increases as V increases, then tapers off as V increases, similar to y = m ln(x+1) graph for x,m > 0
- Thermistor
    - Negative Temperature Coefficient thermistors resistance decreases as pd increases
    - V-I graph is similar to y = m/x graph where m > 0
    - Positive Temperature Coefficient thermistors resistance increases as current increases
    - Similar graph to filament lamp
- Semiconductor diode
    - Resistance is low with positive pd, high with negative pd
    - V-I graph similar to metallic conductor graph, but m is higher when x<0

Factors influencing Resistance

- Resistance of a wire is calculated as

$$R = p\, l / A$$

Where

- R is resistance in ohms
- p is the coefficient of resistivity according to the material in ohm meters
- l is the length of wire in meters
- A is the cross-sectional area of wire in meters squared
- Temperature also affects resistivity, where higher temperatures with faster-moving particles conduct electrons less readily

DC Circuits

Circuit Components

- Power sources are drawn with two parallel lines. Longer line indicates positive terminal, shorter line indicates negative terminal
- Resistors are drawn as hollow boxes or jagged lines
    - Variable resistors drawn with arrow pointing across resistor
        - Photoresistors (light ++ -> resistance --)
        - Rheostats
    - Thermistors drawn with flat then angled up line across resistor
- Ammeters and voltmeters are drawn as circles with A or V in center respectively
- Light bulbs are drawn as circles with cross in center
- Fuses are drawn as boxes with wire passing thru

Voltage and Current in Series and Parallel

- PD across branches of circuit in parallel is always the same
- Sum of PD across components in series is equal to emf from source
- Current in a series is always the same
- Sum of currents across branches of parallel circuits are equal to current at source

Resistors in Series and Parallel

- Resistance of resistors in series is sum of resistance $R = R_1 + R_2$
- Resistance of resistors in parallel is inverse of sum of inverse of resistors $R = 1 / (R_1^{-1} + R_2^{-1})$
    - Resistance of resistors in parallel is always lower than the least resistive resistor

Internal Resistance

- All batteries have a innate resistance due to battery structure
- EMF will be slightly larger than sum of PD because of internal resistance causing voltage drop

$$\mathcal{E} = IR + Ir$$

Where

- $\mathcal{E}$ is the emf of the battery
- I is the current
- R is the resistance of the circuit
- r is the internal resistance of the battery

Potential Divider Circuit

- Circuit to step down voltage for other use
- Two resistors placed in series.
- PD across each resistor calculated, one terminal joined to wire between resistors to obtain desired potential

Setups involving variable resistors

- Fire Alarm
    - Battery
    - NTC thermistor
    - Resistor and bell in parallel
    - High temperature -> NTC resistor has little resistance -> pd across resistor in parallel has high pd -> high pd across alarm -> alarm rings
- Night Light
    - Battery
    - Resistor
    - LDR and light in parallel
    - Lack of light -> LDR high resistance -> high pd across light -> light lights up

Practical Electricity

Electricity and Power

- Recall Voltage being amount of power expended to maintain current flow
- Power is converted to other forms of energy across electrical circuit
- Electrical energy written E units J -> other forms of energy (heat, light)
- Amount of energy is given by:

$$E = V I t$$

- Rate of energy conversion / power consumption is given by:

$$P = V I = I^2 R = V^2 / R$$

- Cost of electrical appliances is P ⨉ duration ⨉ rate of cost
- Typically calculated in kWh
- Due to conservation of energy, energy dissipated by source must equal to sum of energy dissipated by loads

Mains Electricity

- 3-pin power plug has 3 wires (looking into the socket)
  - Ground/Earth green/yellow wire at top
  - Live brown wire at right
  - Neutral blue wire at left
- Life and neutral wires complete circuit
- Earth wire used to ground all casings to dissipate electric charges
- Neutral and earth wires have 0 potential, hence safe to touch. Live wire hazardous to touch
- Switches placed along live wire to prevent appliances from having potential even when turned off
- Fuses placed along live wire for same reason as switch as well as to prevent all discharge, no matter if to neutral or to ground wire since all flow originates from live wire
  - Fuses break circuit when current passing through is too high and melts wire
  - Rated in round numbers, 1A, 2A, 5A, 10A and 13A
- Dangers of shock
  - Damaged insulation exposed wires
  - Overheated cables fuse connections and draw more current
  - Damp conditions create short circuits
  - Shock with 240V mains voltage is fatal
- Protection from shock
  - Circuit breakers switch off electrical supply when electrical fault is detected, breaking live wire circuit
    - Senses excessive current in live wire
    - Senses current in earth wire (hence lightning trips breakers)
  - Double insulation prevents connection between electrical parts and external body, reducing change of body becoming live if fault occurs

    - Earthed casing creates closed circuit to trip fuse before humans come into contact with faulty casing

Magnetic Fields

Magnets

- Materials which component atoms are ordered to exhibit properties of magnetism
- Only made of select materials: Iron, steel, nickel and cobalt
    - Iron or “soft iron” is easier to magnetise but loses magnetism easier (temporary)
    - Steel or “hard iron” is harder to magnetise but loses magnetism harder (permanent)
- Has two poles, north-seeking and south-seeking
- Pole of a magnet is where the magnetic force is strongest
- To test for magnetism: Place the item to be tested in a T shape, with the item to be tested on top. If the item slides to either pole, it is a magnet.
- Used in many areas
    - Permanent
        - Magnetic door locks
        - Compass
        - Motors
        - Speakers
    - Electromagnet
        - Magnetic Strip cards
        - Bells
        - Circuit Breakers

Magnetisation and Demagnetisation

- Induced Magnetism
    - Magnetic field of magnet aligns domains of magnetic object
    - Magnetic object is magnetised by induction
    - Process is repeated with further magnetic objects
    - When magnet is removed, domains are no longer aligned
    - Objects are demagnetised
- Magnetisation by Stroking
    - Bar is stroked several times in same direction across length
    - End of bar has opposite polarity of end of stroking magnet in contact
- Magnetisation by DC
    - Steel bar placed in solenoid
    - DC passed through
    - Magnetised when current is switched off
    - Polarities depends on direction of current
- Demagnetisation by AC
    - Low voltage AC passed through solenoid
    - Magnet inserted into solenoid

- Magnet slowly withdrawn in east-west direction away from solenoid while current is flowing
  - Magnet is magnetised in one way then opposite way quickly and repeatedly due to AC
  - Domains are scrambled
  - Magnetism becomes weaker until completely demagnetised
- Demagnetisation by Heating and Mechanical Shock
  - Magnet is hammed vigorously in east-west position
  - Magnetism becomes weaker and eventually demagnetised
  - Magnet also can be heated red-hot to cool in east-west position

Magnetic Fields

- Magnetic fields, similar to electric fields, involve visualising the forces induced by magnets
  - Field lines do not cross
  - Denser lines mean stronger field
  - Lines point from N to S
- Direction of magnetic fields involve the direction where a mobile north pole will proceed (towards south)
- Can be plotted by tracking the direction which a compass points
- Common field structures (single point, dual point, uniform parallel) share structure with electric fields

Magnetic effect of Current

- Flowing electric charges produce a magnetic field
- Magnitude of current ++ -> strength of field ++
- Magnetic field around a current carrying wire has a magnetic field
  - Field lines are concentric circles
  - Strength of field dissipates further from wire
  - Pole-less
- Direction of field is determined by right-hand grip rule
  - Imagine as if gripping wire with right hand, thumb pointing in direction of current
  - Fingers curl in direction of field
    - Into page = clockwise
    - Out of page = anticlockwise
- Direction of magnetic field of solenoid is also determined by right hand rule
  - Fingers curl in direction of conventional current flow
  - Thumb points in direction of north pole
  - Solenoid can be strengthened by placing soft iron core to concentrate magnetic field lines

Electromagnetism

Current in a magnetic field

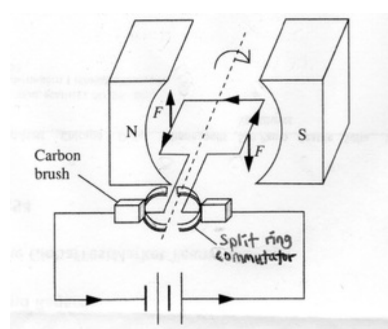
- A force is produced on a conductor in the presence of an external, uniform magnetic field when current is being passed through the conductor
- Current in conductor creates own magnetic field, magnetic field then interacts with external magnetic field
- Combination of fields creates a strong and weak field
- Magnetic force acts on conductor in direction from strong to weak field, setting conductor into motion
- Affected by (strength and direction of) external field, current and length of conductor
- Interaction can be summarised as Lorentz Force: the force experienced by a moving unit charge in an external magnetic field

Fleming's left hand rule

- Visual mnemonic to determine direction of lorentz force
- Thumb points upwards
- Forefinger points outwards
- Middle finger points perpendicular to both
- Hand rotated to fit situation, where thumb represents direction of magnetic field while forefinger represents conventional current flow
- Middle finger then shows direction of force

Current in parallel wires

- Parallel wires attract if current flowing in same direction
- Parallel wires repel if current flowing in different direction



Simple DC motor

- Converting electrical energy into kinetic energy using lorentz force
- Current carrying coil bound by pivot is placed in external magnetic field
- One end experiences upward force at arm, opposite end experiences downward force
- Net force results in rotation around the pivot but no translational movement
- Coil will eventually come to rest in vertical position
  - Net forces and moment is 0, no movement is made
- With a split-ring commutator, the coil's momentum brings it past the vertical
  - Split-ring commutator reverses polarity of coil every half-turn
- Force experienced by coil then enables it to rotate continuously
- Can be modified by

    - Adding soft iron core in coil to concentrate magnetic field lines
    - Increasing amount of current passing thru coil
    - Increasing strength of external magnetic field

Electromagnetic Induction

Movement in a magnetic field

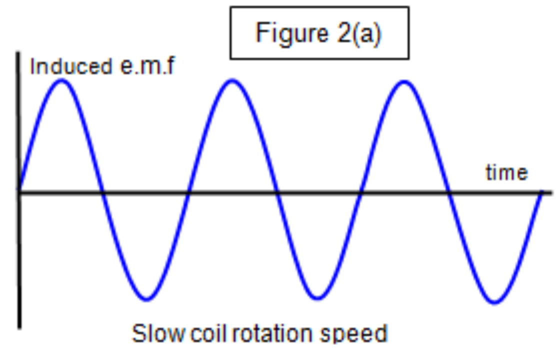
- A current is produced in a conductor whenever the magnetic field around it changes
- Faraday's law: the magnitude of the induced emf is proportional to the rate of change of magnetic flux linkage by a conductor
- Lenz's law: the induced current flows in a direction so as to oppose the change that produces it
- Resistance of mechanical movement results in the conversion of kinetic energy into electric energy
- Induced emf/current then can be increased by
    - Introducing soft iron core
    - Changing magnetic field faster
    - Increasing number of turns in the conductor coil

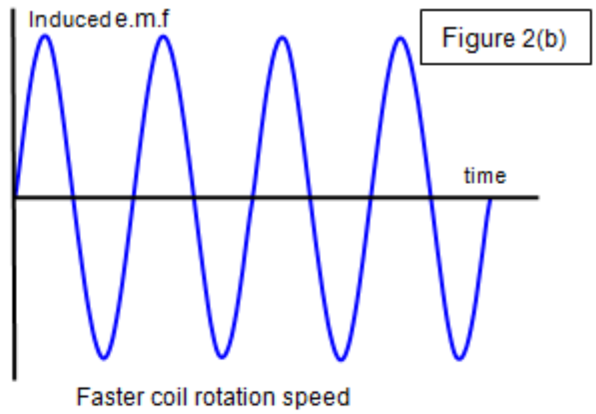
Lenz's law

- Induced current must produce an effect that opposes the [approaching/retreating] [north/south] pole
- One side of solenoid must then induce a [north/south] pole to [repel/attract] pole
- Use fleming's left hand rule with one vector reversed to determine direction of electric current flow given movement and magnetic field

AC Generator

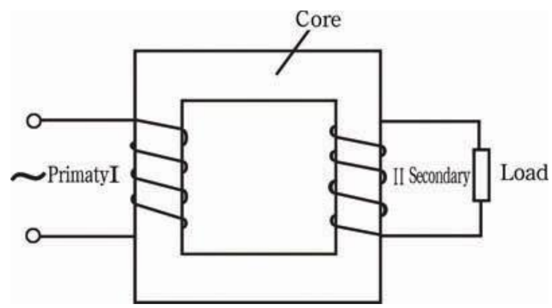
- Similar set up to DC motor, but split-ring commutator is replaced with slip-ring commutators
    - Ensures that coil is connected to same polarity no matter what point in rotation
- Coil rotates around pivot, movement perpendicular to external magnetic field induces emf across wire
- Current flows across circuit
- Electricity is produced in an alternating current
    - Just after vertical position, the motion of coil edges changes direction
    - emf will be in different direction
- Waveform is modified by
    - External magnet strength ++ -> amplitude ++
    - Coils ++ / soft iron core -> amplitude ++
    - Rotation speed ++ -> frequency ++ amplitude ++





Eddy Currents

- Induced current flowing thru a solid conductor
- Usually unwanted because leads to power wastage and undesirable heating
  - Change in flux linkage results in emf -> mechanical energy being wasted and converted into electric energy
- Rectified by cutting slots in solid conductor / using laminated blocks of iron to prevent eddy currents



Alternating Current

Transformers

- Changing current in primary coil results in changing magnetic field
- Primary coil is magnetically linked to secondary coil by iron core
  - No direct wire contact
- Secondary coil experiences changing flux linkage
- Induced emf in the secondary coil is created, current flows if circuit is closed
- Load will receive current if there is alternate current supplied
- Electrical energy is transferred from primary coil to secondary coil, at same frequency of primary circuit

Voltage in transformers

- Ratio of number of coils in primary and secondary coils = ratio of voltage in primary and secondary coils

$$V_P / V_S = N_P / N_S$$

Where

- V is voltage

- N is number of turns

Power in transformers

- Power in coils of transformers is equal in a perfect transformer (no energy wastage)

$$V_P I_P = V_S I_S = P_P = P_S$$

Where

- V is voltage
- I is current
- P is power

High voltage power transmission

- Recall $P = I^2 R$
- Resistance in transmission wires are constant
- In order to reduce power consumption over transmission wires, I needs to be minimised
- One method of minimising I is to dramatically step up voltage in transmission wiring
- Stepped up electricity -> high voltage low current -> lower $I^2 R$ -> less power dissipated in wires -> less power wastage

Voltage Rectification

- Most devices need DC to function and cannot use AC
- AC current can be rectified or “fixed” to produce DC by introducing a diode in series with power source
    - Electrical component which has very high reverse bias voltage, high resistance in one direction but low in the other
    - LED (light-emitting diode) produces light in addition to functioning as diode
- Half-wave rectifier is produced, where only the positive side of the wave is able to pass through the circuit