H2 Physics
Formulae & Definitions
This list is NOT exhaustive! This is meant to supplement your own summary notes.

Chapter 1 : Measurement

- Base quantities (units): *mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol), luminous intensity (candela, cd)*

- **Base quantities** are physical quantities that are the most *fundamental* and they are independent of each other.

- The **base units** are a choice of seven well-defined units which by convention are regarded as the most fundamental and dimensionally independent.

- **Factors :**

Factor (Multiples)	Prefix	Symbol
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T

Factor (Sub-Multiples)	Prefix	Symbol
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

- if $X = nA \pm mB$, where n and m are constants then $\Delta X = n\Delta A + m\Delta B$

- If $Y = a \times b$ or $Y = a \div b$, then the consequential uncertainty of Y is given by

$$\frac{\Delta Y}{Y} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$$

- If $Y = a^n = a \times a \times a \ldots$, then

$$\frac{\Delta Y}{Y} = n\frac{\Delta a}{a}$$

- Fractional Uncertainty = $\dfrac{\Delta R}{R}$

- Percentage Uncertainty = $\dfrac{\Delta R}{R} \times 100\%$

- Random errors are errors of measurements in which the measured quantities differ from the mean value with different magnitudes and directions.

- Systematic errors are errors of measurements in which the measured quantities are displaced from the true value by fixed magnitude and in the same direction.

- Accuracy is a measure of how close the results of an experiment agree with the true value.

- Precision is a measure of how close the results of an experiment agree with each other. It is a measure of how reproducible the results are.

Chapter 2 : Kinematics

- **Distance** is the total length covered by a moving object irrespective of the direction of motion.
- **Displacement** is the shortest linear distance of the position of a moving object from a given reference point.
- The **speed** of an object is defined as the rate of change of **distance travelled** with respect to time.
- The **velocity** of an object is defined as the rate of change of its **displacement** with respect to time.
- The **acceleration** of an object is defined as the rate of change of its **velocity** with respect to time.

- $v = u + a t$
  $s = ut + \frac{1}{2} at^2$
  $v^2 = u^2 + 2as$
  $s = \frac{1}{2} (v+u) t$
- Gradient of the displacement – time graph at any point, $\frac{ds}{dt}$ = instantaneous velocity
- Gradient of the $v - t$ graph at any point, $\frac{dv}{dt}$ = instantaneous acceleration
- Area under a velocity-time curve gives the change in displacement.
- In solving Projectile motion, resolve velocity in the vertical and horizontal direction (refer to lect, tut for examples)

Chapter 3 & 4 : Forces & Dynamics

- **Hooke's Law** states that within the **limit of proportionality**, the **extension** produced in a material is **directly proportional to the load applied.**
- elastic potential energy stored in a material $= \frac{1}{2} ke^2$

  = area under the Force-extension graph

- pressure due to a column of liquid of depth h is then given by $p = h\rho g$
- w = mg
- **Centre of gravity** is the point on an object through which the entire weight of the object may be considered to act.

- *Conditions for Equilibrium :*

(i) The resultant force on the object must be zero *(translational equilibrium)*

(ii) The resultant torque on the object about any axis must be zero *(rotational equilibrium)*

- Area under the force-time graph **equals to the change in momentum or its impulse.**

- The **principle of conservation of momentum** states that the **total momentum** of a system of objects remains **constant** provided **no resultant external force** acts on the system.

❖ **Elastic Collision** in which both *total momentum* and *total kinetic energy* are **conserved.**

❖ **Inelastic Collision** in which *total momentum is conserved* but *total kinetic energy* is **not conserved.**

❖ **Completely Inelastic Collision** in which *total momentum is conserved* and **the particles stick together after collision** so that their final velocities are the same. *Total Kinetic energy is not conserved.*

- For an **elastic collision**, it can be shown that the ***relative speed of approach*** of the bodies before collision is equal to the ***relative speed of separation*** of the bodies after collisions. $(u_2 - u_1 = v_1 - v_2)$

Newton's first law of motion states that a body will continue in its **state of rest** or **uniform motion** in a straight line unless an external **resultant** force acts on it.

Newton's second law of motion states that the **rate of change of momentum** of a body is **proportional to the resultant force** acting on it and the change takes place **in the direction of the force.**

$$F = \frac{d(mv)}{dt} = m\frac{dv}{dt} + v\frac{dm}{dt} = ma + v\frac{dm}{dt}$$

Newton's third law of motion states that if body A exerts a force (action) on body B, then body B exerts a **force of equal magnitude but in the opposite direction** on body A.

The **linear momentum**, p, of a body is defined as the product of its mass, m, and its velocity, v of a moving body.

Impulse = change in momentum

Force : rate of change of momentum

Newton (N) is defined as the force required to effect a change in momentum at the rate of one kg m s^{-2}.

The **moment** of a force is the *product* of the *force* and the *perpendicular distance between the axis of rotation* and the *line of action of the force.*

The **torque or moment of a couple** is the *product of one of the forces* and the *perpendicular distance between their lines of action of the forces.*

- A **couple** is a pair of forces, equal in magnitude but opposite in direction, whose lines of action do not coincide.
- Pressure is defined as force acting per unit area Pressure, $P = \dfrac{\text{Force}}{\text{Area}}$
- For a fluid, $p = h\rho g$ (derivation ref lect notes)
- **Upthrust** or **buoyancy force** is an **upward force** on a body immersed in a fluid due to the **pressure difference** in the fluid. **(Archimedes' Principle** states that the) **upthrust** experienced by an object partially or entirely immersed in a fluid is **equal to the weight of the fluid displaced by the object**.
- For an object floating in equilibrium, the upthrust is equal to the weight of the object

Chapter 5 : Work, Energy and Power

- **Work done** by a force on a body is defined as the ***product*** of that force and the displacement of that body ***in the direction of the force***.
- ***Energy*** is defined to be the stored ability to do work.
- ***Kinetic energy*** is the energy possessed by a body due to its motion.
- ***Potential energy*** is the energy possessed by a body due to its position relative to something else.
- ***Elastic energy*** is the energy possessed by an elastic body when it is subjected to deformation.
- The ***principle of conservation of energy*** states that energy may be transformed from one form to another or transferred from one body to another but it cannot be created or destroyed, i.e. the total energy of is constant.
- ***Power*** is defined as the rate at which work is done (work done per unit time) **OR** the rate at which energy is transformed.
- ***Efficiency*** of an engine is an indication of how good the engine is at converting input energy into useful output energy.
- KE = ½ mv^2 (need to know how to derive: refer lect notes)
- gPE = mgh (need to know how to derive: refer lect notes)
- Work done by a gas which is expanding against ext pressure : $W = p\,\Delta V$
  (p: pressure; ΔV :change in volume)

Chapter 6 : Motion in a Circle

- **angular displacement** (in radian) $\theta = \dfrac{s}{r}$
  where s : arc length ; r : radius of the circle
- Angular velocity is the rate of change of angular displacement with respect to time $\omega = \dfrac{d\theta}{dt}$ (unit: **rad s^{-1}**)
- The frequency f of an object in circular motion is the number of complete revolutions made by the object per unit time. (Unit: **s^{-1}** OR **Hz** (hertz)
- The period T of an object in circular motion is the time taken for the object to make one complete revolution. (unit: **s** (seconds)

- $T = \frac{1}{f}$
- angular velocity $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T} = 2\pi f$
- $v = r\omega$
- **centripetal acceleration** $a = \frac{v^2}{r} = r\omega^2$
- **centripetal force** $F = ma = mv^2/r = mr\omega^2$
- practice solving different problems relating to circular motion: ref lect / tut

Chapter 7 : Gravitational Field

- **Newton's Law of Universal Gravitation** states that: every particle in the Universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. ($F = \frac{Gm_1m_2}{r^2}$)
- **Gravitational field strength** at a point is defined as the gravitational force per unit mass acting on a mass placed at that point. ($g = \frac{F}{m}$) S.I. Unit of g **:** N kg^{-1} or m s^{-2}
- $g = G\frac{M}{r^2}$
- The **weight** of an object is the gravitational force exerted on the object by the Earth's gravitational field.
- The **gravitational potential energy,** U, of a point mass m, in a gravitational field, is the work done by an external force in bringing that point mass from infinity to that point. ($U = -G\frac{Mm}{r}$)
- The **gravitational potential,** ϕ**,** at a point in a gravitational field is the work done per unit mass, by an external force, in bringing the mass from infinity to that point. ($\phi = -G\frac{M}{r}$)
- $F = -\frac{dU}{dr}$ **and** $g = -\frac{d\phi}{dr}$
- A satellite in geostationary orbit (GEO) orbits the Earth in exactly 1 day and is placed above the equator.
- The minimum speed with which a mass should be projected from the Earth's surface in order to escape Earth's gravitation field is known as the **escape speed** of the body from the Earth.
- **Kepler's 3rd Law :** $T^2 \propto r^3$ (can be derived from circular motion and gravitational law – ref lect notes; use this expression if the same planet in the question changes from one orbit to another around the same source)

Chapter 8 : Oscillations

- The period T of a periodic motion is the time to make *one complete* cycle. SI unit is ***second (s).***
- The frequency f of a periodic motion is the *number* of cycles per unit time. SI unit is ***hertz (Hz).***

- The angular frequency ω of a periodic motion is the *rate of change* of angular displacement with respect to time. It is also known as angular velocity. SI unit is ***radians per second (rad s^{-1}).***

  $T = \dfrac{1}{f}$ $\qquad\qquad$ $\omega = 2\pi f = \dfrac{2\pi}{T}$

- The displacement x of an object is the distance of the oscillating particle from its *equilibrium position* at any instant.

- The amplitude x_o of a periodic motion is the magnitude of the *maximum* displacement of the oscillating particle from the *equilibrium position.*

- **Simple harmonic motion** (SHM) is defined as the oscillatory motion of a particle whose acceleration a is always directed towards a fixed point and is directly proportional to its displacement x from that fixed point. ($a = -\omega^2 x$)
- Oscillation can be represented by:

$$x = x_o \sin \omega t = x_o \sin (2\pi f)t = x_o \sin (\frac{2\pi}{T})t$$

OR

$$x = x_o \cos \omega t = x_o \cos (2\pi f)t = x_o \cos (\frac{2\pi}{T})t$$

- $v = \pm \omega \sqrt{x_o^2 - x^2}$
- Phase difference : $\Delta\phi = \left(\dfrac{t}{T}\right) \times 2\pi$ OR $\Delta\phi = \left(\dfrac{\Delta x}{\lambda}\right) \times 2\pi$
- KE of SHM : $E_k = \dfrac{1}{2} m\omega^2 (x_o^2 - x^2)$
- PE of SHM : $E_p = \dfrac{1}{2} m\omega^2 x^2$ (this expression includes all PE, eg. gPE and elastic PE)
- Total energy of SHM : $E_T = \dfrac{1}{2} m\omega^2 x_o^2$
- When the amplitude and mechanical energy of a system gradually decreases to zero as a result of dissipative forces, the oscillation is said to be ***damped.***
- **Light Damping :** Defined oscillations are observed, but the amplitude of oscillation is ***reduced gradually*** with time
- **Critical Damping:** The system returns to its equilibrium position in the ***shortest possible time without any oscillation.***
- **Heavy Damping :** The system returns to the equilibrium position ***very slowly, without any oscillation.*** Heavy damping occurs when the resistive forces exceed those of critical damping.
- Every system has a frequency at which it will vibrate freely and this frequency is called the ***natural frequency, f_o*** of the system.
- If an external periodic force (***driving force***) is applied to an oscillating system, the system will oscillate with a frequency equal to the frequency of the periodic force (***driving frequency***). This is known as a ***forced oscillation.***

- For a ***forced oscillation***, when the driving frequency is ***equal*** to the natural frequency of the oscillating system, ***maximum energy transfer*** occurs from the periodic force to the system which will vibrate with ***maximum amplitude*** This phenomenon is called ***resonance***.

Chapter 9 : Thermal Physics

- The internal energy is the sum of a random distribution of the microscopic kinetic and potential energies associated with the molecules of a system.
- Microscopic **potential energy**, E_p comes from the forces of interaction between the particles due to the relative positions (especially in solids and liquids).
- Microscopic **kinetic energy**, E_k comes from the continuous random motion of the particles.
- **Thermal Contact**: Two objects are said to be in thermal contact if energy can be exchanged between them.

- **Thermal Equilibrium**: Two objects are in thermal equilibrium if there is no net exchange of energy when they are placed in thermal contact.

- **Heat**: It is the energy exchanged between two objects due to a temperature difference between them.
- When thermal equilibrium is reached, there is no net transfer of energy from one body to another; the two bodies are said to be in ***thermal equilibrium***.
- **Thermodynamic Scale of Temperature (or Kelvin / Ideal Gas Scale)** : $T/K = T/°C + 273.15$
- **Absolute zero**: at this temperature, all particles' motion will cease (no particles will hit the walls of the container, resulting in zero pressure). The substance will therefore have minimum internal energy at this temperature.

- ***specific heat capacity*** of a substance is the quantity of heat required to produce a unit change in temperature per unit mass of that substance. $c = \frac{Q}{m\Delta T}$
- Determination of the Specific Heat Capacity of a substance using an Electrical Method (ref lect notes)

- The ***specific latent heat of fusion*** L_f is defined as the quantity of heat required to change a unit mass of a substance from the solid phase to the liquid phase without any change in temperature.
- The ***specific latent heat of vaporisation*** L_v is defined as the quantity of heat required to change a unit mass of a substance from the liquid phase to the vapour phase without any change in temperature.

- Explain using Kinetic Theory why melting and boiling take place w/o a change in temp; and why specific latent heat of vapourisation is higher than specific latent heat of fusion – ref lect notes

- One ***mole*** of a substance contains as many elementary units as there are atoms in 0.012 kg of carbon-12. This number is called the ***Avogadro constant*** N_A, where $N_A = 6.02 \times 10^{23}$ mol^{-1}

- Ideal gas equation : $pV = nRT$ or $pV = NkT$
- average (translational) kinetic energy E_k of a gas molecule is given by:

$$E_k = \frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT \text{ hence } E_k \propto T$$

- for ideal monatomic gas : $U = E_k = \frac{3}{2}nRT = \frac{3}{2}NkT$
- **first law of thermodynamics** : the increase in internal energy is equal to the sum of heat transferred into the system and work done on the system.

Word equation of first law:

Increase in internal energy of a system	=	***Heat supplied to*** the system	+	***Work done on*** the system

- pV graphs and examples : ref lect / tutorial

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Types of process	Characteristics
Isochoric	Volume is kept constant throughout
Isobaric	Pressure is kept constant throughout
Isothermal	Temperature is kept constant throughout
Adiabatic	No heat gain or loss throughout

Chapter 10 : Waves

- The **crest** is the highest point on a wave while the **trough** is the lowest point.
- **Displacement** is the distance moved by the particle from its equilibrium position (i.e. undisturbed position).
- **Amplitude** of a wave is the **maximum displacement** of the particle from its equilibrium position.
- **wavelength (λ)** is the distance between 2 successive points on a wave which are in phase (at the same stage of oscillation) with one another.
- **period (T)** is the time taken for a particle on the wave to complete one oscillation.
- **frequency (f)** of a wave is the number of complete oscillations that pass through a given point in 1 second. The unit of frequency is the Hertz (Hz) or s^{-1}.

Frequency and period are related by

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

- velocity of the wave is, $v = \frac{\lambda}{T} = f\lambda \quad \therefore v = f\lambda$

- **phase difference (ϕ)** between two particles or two waves tells us how much a particle (or wave) is in front of or behind another particle (or wave). The value ranges from 0 to 2π radians.

$$\Delta\phi = \left(\frac{\Delta x}{\lambda}\right)\times 2\pi \qquad\qquad \phi = \left(\frac{t}{T}\right)\times 2\pi$$

- wave equation $y = y_0 \sin(\frac{2\pi}{\lambda}x)$ OR $y = y_0 \sin(\frac{2\pi}{T}t)$

(note: it can be cosine function, depending whether displacement is 0 or max when t = 0)

- ***intensity*** of a wave : $I = \frac{energy}{time \times area, S} = \frac{power, P}{area, S}$ unit is **W m^{-2}**
- **Intensity vs. Amplitude**

$$I \propto (Amplitude)^2$$

- Polarization is said to occur when a wave vibrates in a **single plane**. It is a phenomenon associated with **transverse waves** only.
- Determine freq using CRO : ref lecture notes
- Diff between longitudinal vs transverse waves : ref lecture notes

Chapter 11 : Superposition

- **Diffraction** is a phenomenon of waves. It refers to the bending or spreading out of waves when they travel through a small opening or when they pass round a small obstacle.

- The **Principle of Superposition** states that when two waves of the ***same kind*** meet at a point in space, the resultant displacement at that point is the ***vector sum*** of the displacements that the two waves would separately produce at that point.

- **Coherence :** phase difference between two oscillations must be constant in order to be coherent (and hence the frequencies of the two oscillations must be the same).

- **Interference** refers to the superposing of two or more coherent waves to produce regions of maxima and minima in space, according to the principle of superposition.

- **constructive interference** occurs when two or more waves arrive in phase with each other, such that the amplitude of the resultant wave is the sum of the amplitudes of the individual waves.
- **Destructive interference** occurs when the two or more waves arrive π out of phase with each other and the resultant wave has minimum amplitude.

- **Conditions for interference:**

	Path Difference	
	2 sources in phase	2 sources π out of phase
Constructive Interference at screen	$n\lambda$	$(n + \frac{1}{2})\lambda = n\lambda + \frac{1}{2}\lambda$
Destructive Interference at screen	$(n + \frac{1}{2})\lambda = n\lambda + \frac{1}{2}\lambda$	$n\lambda$

- Double slit equation : $x = \frac{\lambda D}{a}$ where fringe separation x; λ is the wavelength of the monochromatic light, D is the distance from the double slits to the screen, a is the separation of the two slits (measure from centre to centre of slits)

- **Conditions for Observable Interference**

	Condition	Explanation
1	Coherent Sources	This is necessary so that a constant interference pattern can be obtained.
2	Equal or approximately equal amplitudes	This is necessary so that complete or almost complete cancellation is achieved at points of destructive interference.
3	Polarised in the same plane (or unpolarised)	If the waves are not polarised in the same plane, then complete cancellation is not possible even at points where the two waves are completely out of phase.

Note:
Conditions 2 and 3 are needed so as to provide **good contrast** between the maxima and minima, so that they are observable.

- Conditions for stationary wave:
  - waves are of the same type
  - of the same amplitude
  - of the same frequency
  - traveling in opposite directions
- **Resonant Stationary Waves in Stretched Strings :** ref lecture notes
- **Resonant Stationary Waves in Air Column** : ref lecture notes
- Diffraction equation : $d \sin\theta = m\lambda$

  where d = line spacing (i.e. slit separation) of the diffraction grating

  θ = angle the diffracted beam makes with the normal to the diffraction grating,

  m = order of the diffracted line

  λ = wavelength of the incident light.

- Max order is when $m < \frac{d}{\lambda}$

Chapter 12 : E-field

- An **electric field** is a region of space in which an electric force acts on a charged particle due to the presence of some source charge that creates the field.
- **Coulomb's Law :** The electrostatic force between two point charges is ***proportional to the product of their charges*** and inversely ***proportional to the square of the distance between them*** $(F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2})$
- Electric Field Strength E at a point in an electric field is defined as the ***electrostatic force per unit charge*** experienced by a small ***positive test charge*** placed at that point.
- **For point charge :** $E = \frac{Q_1}{4\pi\varepsilon_0 r^2}$
- **Electric Potential** at *a point in an electric field* is defined as the **work done per unit charge** by an external agent in bringing **a positive test charge from infinity to that particular point without acceleration**. $(V = \frac{W}{q})$
- **For point charge :** $V = \frac{Q}{4\pi\varepsilon_0 r}$
- **E-field = potential gradient** $E = -\frac{dV}{dr}$
- **Force on charge q given by F = qE**
- **For parallel plate :** $E = -\frac{\Delta V}{\Delta d}$
- The **electron volt** is defined as energy that an electron (or proton) gains (or loses) when it is accelerated (or decelerated) through a potential difference of 1 volt. (1 eV = 1.6×10^{-19} J)
- **For two point charges : electric PE** $U_{EPE} = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$

Chapter 13 : Current of Electricity

- **Electric current** is defined as the rate of flow of charge through a particular cross sectional area with respect to time.
- *steady current I* due to flow of charges is given by $I = \frac{Q}{t}$
- If the current *changes with time*, we define the ***instantaneous*** current, I as $I = \frac{dQ}{dt}$
- *current direction* is the *direction* in which ***positive*** *charges effectively move.*

The ***charge*** that passes through a given point is the *product* of the *steady current flowing* past the point and the *time during which the current flows.* $Q = I \times t$

- One ***coulomb*** is defined as the *quantity of charge* that flows through a point when a *steady current* of *one ampere* flows for *one second.*

- total charges Q, that flow between time t_1 and t_2 is *given by the* area under the *I-t* curve.

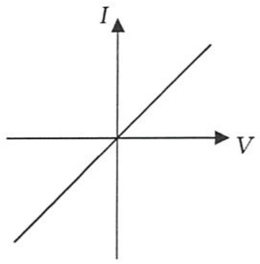
- The ***potential difference*** between two points in an electrical circuit is defined as the *electrical energy converted* into *other forms of energy per unit charge* passing from one point to the other. $V = W / Q$

- One ***volt*** is the *potential difference* between two points in an electrical circuit when *one joule of electrical energy* is *converted* to *other forms of energy* as *one coulomb of charge* passes from one point to the other.

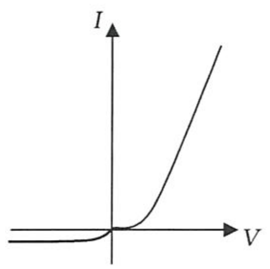
- ***Ohm's law*** states that the *ratio* of the *potential difference* across a conductor to the *current* flowing through it, is a *constant* (i.e. V/I = constant), provided that its *physical conditions* such as temperature *remain constant.*

- The ***resistance*** of a device is defined as the *ratio* of the *potential difference* across it to the *current* flowing through it. $R = V/I$

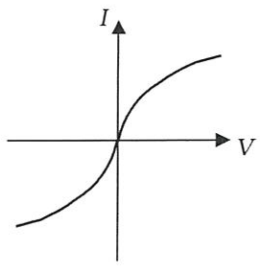
- **Ohm** : A resistor has a *resistance* of one ***ohm*** if there is a *current of one ampere* through it when the *potential difference* across it is *one volt*.
- Electrical Power $P = VI$ **or** $P = I^2R$ **or** $P = V^2/R$
- I-V graphs:



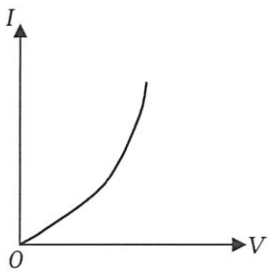
(a) metallic conductor at constant temperature



(b) semi-conductor diode



(c) filament lamp



(d) thermistor

- The gradient of the *I-V* curve is ***not equal*** to the resistance of the component. Resistance is the ratio of potential difference to current i.e. $R = \frac{V}{I}$, and not $\frac{dV}{dI}$!
- The **resistivity** (ρ) of any object is a property of the *material* or *substance* it is made of; it is constant at steady physical conditions, regardless of the shape or size of the object. Resistance on the other hand, is a property of the *object*. $R = \frac{\rho l}{A}$
- *The* ***electromotive force*** of a source is the *energy converted from other forms* to *electrical energy per unit charge* delivered round a complete circuit. $\varepsilon = W/Q$

where ε = e.m.f. of the source in **volts** (V)
W = energy supplied by the source
Q = charge that passes through the source

- Diff between emf and pd : refer lecture notes
- Internal resistance of a source : refer lect notes

Chapter 14 : DC circuit

- resistors placed in series, its effective resistance $R_{eff} = R_1 + R_2 + \ldots + R_n$
- resistors placed in parallel, its effective resistance

$$\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$$

$$R_{eff} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n} \right)^{-1}$$

- circuit calculations : ref lect and tutorial
- potential divider application; use of thermistor, LDR and potentiometer problems – ref lecture notes and tut.

Chapter 15 : Electromagnetism

- **Force on conductor** of length l carrying a current I placed at an angle of θ in a region of magnetic field B, $F = B I l \sin \theta$
- **Magnetic flux density** is defined as the force acting per unit current per unit length on a wire placed at right angles to the field. $B = \frac{F}{I l}$

where F is the total force acting on the wire,
l is the length of the wire and
I is the current flowing through the wire.

- 1 **Tesla** is defined as the magnetic flux density of a uniform magnetic field when a wire of length 1m, carrying a current of 1A, placed perpendicular to the field, experiences a force of 1N in a direction at right angles to both the field and the current.

- **Force on charged particle** : $F = Bqv\sin\theta$
- Application of rules : **Left-hand rule**; **right hand grip**: refer examples in notes
- Example involving **Current Balance** : ref lecture notes
- Flux patterns due to wire, coil and solenoid: ref lecture notes
- Like currents attract; unlike currents repel. (different from like magnetic poles repel; unlike attract)

Chapter 16 : Electromagnetic Induction

- Use Left-hand rule: when current-carrying conductor placed in B-field, it experiences a magnetic force
- Use Right-hand rule: when there is no electric source (ie no battery), but conductor when cuts magnetic field, an induced emf (or current) is created.
- Magnetic flux ϕ through a plane surface is the **product** of the **magnetic flux density normal to the surface, B_N** and the **area A** of the surface.

$\phi = AB_N = AB\cos\theta$ where θ is the angle between the B-field and the normal to the area A.

S.I. unit for ϕ: weber (Wb) or tesla metre squared (T m^2)

- The **weber** is defined as the **magnetic flux** through a surface if a magnetic field of flux density **1 T** exists perpendicularly to an area of **1 m^2**.
- **Magnetic flux linkage Φ** is defined as the **product** of the **number of turns N** of the coil and the **magnetic flux ϕ** linking each turn.

$$\Phi = N\phi = NAB_N = NAB\cos\theta$$

S.I. unit for Φ : weber (Wb)

- **Faraday's law:** The induced e.m.f. ε is **directly proportional** to the **rate of change of magnetic flux linkage Φ** (or rate of cutting of magnetic flux linkage Φ).

$$\varepsilon = -\frac{d\Phi}{dt}$$

- Lenz's law state that the **induced e.m.f.** will be directed such that the **current** which it causes to flow **opposes the change that is producing it**.

Chapter 17 : Alternating Current

- The **root-mean-square (r.m.s.)** value of an **alternating current** is **equivalent to the steady direct current** that converts **electrical energy to other forms of energy** at the **same average rate** as the alternating current in a given resistance.
- Calculation of rms value: ref lecture notes
- Only for sinusoidal function : $I_{rms} = \frac{I_0}{\sqrt{2}}$; $V_{rms} = \frac{V_0}{\sqrt{2}}$ (does NOT apply for other functions)
- for sinusoidal function: $P_0 = V_0 I_0 = I_0^2 R$;

$$\langle P \rangle = I^2_{rms} R = I_{rms} V_{rms} = \frac{V^2_{rms}}{R}$$

turns ratio of transformer: $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$

- use of diode for rectification: ref lecture notes

Chapter 18 : Quantum Physics

- Photoelectric experiment : ref lecture notes
- **Observations of the photoelectric experiment :**
    - *The existence of the threshold frequency*
    - *The almost immediate emission of photoelectrons*
    - *The independence of KE on intensity and the dependence on frequency*
    - *The rate of emission of photoelectrons is proportional to the intensity of the incident radiation* (i.e. the light energy per unit time per unit area falling on the surface).

- energy E of a single photon is proportional to its frequency f :

$$E = hf = \frac{hc}{\lambda} \quad \text{(since } c = f\lambda\text{)} \quad \text{, where Planck constant } h = 6.63 \times 10^{-34} \text{ J s}$$

- **Einstein's Photoelectric Equation** $hf = \Phi + E_{k\,max}$ OR $hf = \Phi + \frac{1}{2}mv_{max}^{\ 2}$
- The **work function** Φ of a material is defined as *minimum* amount of the work necessary to remove a *free* electron from the *surface* of the material.

- Threshold frequency, f_0 : For photoelectric effect to take place, frequency of incident radiation $f > f_o$ and $f_o = \frac{\Phi}{h}$

- $\frac{1}{2}m^2_{max} = eV_s$, where V_s is the stopping potential.

- Hence $V_s = \frac{h}{e}f - \frac{\Phi}{e}$

- Why the maximum photoelectric energy is independent of intensity :

  An electron is emitted if it gains enough energy from the photon. Since all the photon energy is delivered immediately to the electron in a single collision, there is no time delay and is independent on the intensity of the incident radiation.

- Why the photoelectric current is proportional to intensity :

  Since intensity I of a beam of photons is the energy transmitted per unit area per unit time,

$$I = \frac{E}{tA} = nhf$$

where n is the number of photons passing a unit area per unit time.

An increase in intensity I means a greater number of photons striking the metal surface per second and therefore greater number of electrons can be emitted.

hf	$=$	ϕ	$+$	$E_{k\ max}$
॥		॥		॥
$\frac{hc}{\lambda}$		hf_0		$\frac{1}{2}mv^2_{max}$
		॥		॥
		$\frac{hc}{\lambda_{max}}$		eV_S

- de Broglie wavelength $\lambda = \frac{h}{p}$, where h = the Planck constant.

	Evidence
Light behaves as a wave	Interference / Diffraction of light
Light behaves as particles	Photoelectric effect
Electrons behave as particles	Electrons undergo collision, has mass and charge
Electrons behave as a wave	Electron diffraction

- Line emission and absorption spectrum : ref lecture notes
- recall and solve problems using the relation $hf = E_1 - E_2$.
- **X-rays**: highly energetic electromagnetic radiation
- Explain features of **X-rays**: ref lect notes
- **Heisenberg position-momentum Uncertainty Principle** $\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$ where $\hbar = \frac{h}{2\pi}$
- **Heisenberg time-energy Uncertainty Principle** $\Delta E \cdot \Delta t \geq \frac{\hbar}{2}$ where $\hbar = \frac{h}{2\pi}$
- An electron can be described by a wave function Ψ where the square of the amplitude of wave function $|\Psi|^2$ gives the probability of finding the electron at a point.
- Describe how quantum tunneling is applied to Scanning Tunneling microscope: ref lecture notes

transmission coefficient $T = e^{-2kd}$ where d = barrier thickness / width

where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$

m = mass of particle
U = potential energy of the electron in tunnelling through the barrier
E = initial mechanical energy of the electron
h = Planck's constant

- **reflection coefficient** R is such that $R + T = 1$

Chapter 19 : Lasers and Semiconductors

- **LASERS** (an acronym for Light Amplification by Stimulated Emission of Radiation)

1. **Stimulated Absorption** – An atom can be 'excited' from a lower energy state (or *ground state*) E_1 to a higher energy state E_2 when one of its electron absorbs a photon of energy corresponding to $hf = E_2 - E_1$.

2. **Spontaneous Emission** – An atom in an excited state E_2 can go to a lower energy state (or ground state) E_1 by the spontaneous emission of a photon and the energy of the photon emitted is equal to $hf = E_2 - E_1$.

3. **Stimulated Emission** – An atom in an excited state can be stimulated by an incident photon to emit another photon of the same *frequency, phase, momentum* and in the *same direction of travel* as the incident photon. In other words, stimulated emission produces a second photon that is an exact clone of the incident photon.

Principle of lasers:

1. The system must be in a state of **population inversion** – there must be more atoms in an excited state than in the ground state. This is to ensure that the number of atoms emitting photons is more than the number absorbed.

2. A two-level system is difficult and insufficient for steady-state lasing to occur, e.g., for a stand-alone He system. We must at have least a three-level system, i.e., HeNe system. A system with more energy levels is likely to contain excited states that are **metastable state**, with lifetimes that are much longer than normal excited states (10^{-3} s as compared to 10^{-8} s). This would thus allow enough time for population inversion to take place before the atoms de-excite.

3. The emitted photons must be confined in the system long enough to enable them to **stimulate** further **emissions** from other excited atoms, i.e., *light amplification*. This can be achieved simply enough with the use of reflecting cavity mirrors.

- Semiconductor: Materials that fall within the category of ***semiconductors*** have a narrow energy gap (~1-3 eV) between the valence and conduction bands.
- When an electron leaves the lower filled ***valence band*** to enter the upper empty ***conduction band***, it leaves behind a vacant site known as a ***hole*** in the lower valence band. This ***hole*** acts as a positive charge carrier in the valence band.
- A pure semiconductor crystal containing only one element or one compound is called an **intrinsic** semiconductor
- By adding impurities, called **dopants**, the conductivity (inverse of resistivity) of the semiconductor is greatly increased. **Doped** semiconductors are known as **extrinsic semiconductors.**
- Extrinsic semiconductors doped with donor impurities are called **n-type** because they donate an excess of **negative** charge carriers.
- Extrinsic semiconductors doped with acceptor impurities are called **p-type** because they donate an excess of **positive** charge carriers.
- **P-N junction** and its use as a rectifier: ref lecture notes

Chapter 20 : Nuclear Physics

- **The α-particle Scattering Experiment :** results
    - Most of the particles were scattered through very small angles.
    - BUT a very small fraction (less than 1%) of the particles were scattered through very large angles, some of which were close to 180°.

- The **proton number (atomic number)**, **Z**, gives the number of protons in a nucleus.
- The **nucleon number (mass number)**, **A**, gives the total number of nucleons (i.e. protons + neutrons) in the nucleus
- **A = Z + N**

  where **N** is the number of neutrons in the nucleus

- Isotopes are atoms that have the same number of protons but different number of neutrons.
- **One unified atomic mass unit is one-twelfth the mass of the carbon-12 atom.**

- **Einstein's mass-energy relation: $E = mc^2$**

- One electron-volt is the energy gained by a charge equal to that on an electron in moving through a potential difference of one volt. 1 eV = 1.602 × 10^{-19} J; 1 MeV = 1.602 × 10^{-13} J
- 1 u ≡ 931.5 MeV
- The mass defect of a nucleus is defined as the difference between the mass of the separated nucleons and the combined mass of the nucleus. $\Delta M = Zm_p + Nm_n - M_n$
- The **nuclear binding energy** of a nucleus is defined as the work done on the nucleus to separate it into its constituent neutrons and protons. $\Delta E = (\Delta M)c^2$
- The binding energy (B.E.) per nucleon of a nucleus is the binding energy divided by the total number of nucleons. It is a measure of the stability of the nucleus – the larger the binding energy per nucleon, the more stable the nucleus
- Energy released in reactions = $(m_{reactants} - m_{products})c^2 = (BE_{products} - BE_{reactants})$.
- Induced nuclear reactions occur when a nucleus changes as a result of being struck by a particle.
- If the products have greater mass than the reactants (i.e. nucleus & incident particle) before the reaction, then the incident particle must supply enough kinetic energy to make up for the increase in mass of the products to allow a reaction to take place.
- Nuclear fission is the disintegration of a heavy nucleus into two lighter nuclei of approximately equal masses.
- Nuclear fusion is the combining of two light nuclei to produce a heavier nucleus.
- Radioactive decay is the spontaneous disintegration of the nucleus of an atom which results in the emission of particles and/or radiation.
- **Spontaneous Process**:
  - ⇒ Radioactive decay occurs *spontaneously*; the process cannot be speeded up or slowed down by physical means such as changes in pressure or temperature.
  - ⇒ The decay of a radioactive atom is *not affected* by any chemical condition or the chemical compound that it exists in and is independent of physical conditions such as temperature, pressure and most importantly the decay of other atoms.
- **Random Process:**
  - Radiation is emitted at random. By random, we mean that it is impossible to predict *which nucleus* and *when any particular nucleus* will disintegrate.
- α-particles are helium-4 nuclei, $^{4}_{2}He$.
- Beta particles are electrons $^{0}_{-1}e$
- Gamma rays are electromagnetic waves of wavelengths shorter than those of X-rays.
-

- The activity of a radioactive substance is defined as the average number of atoms disintegrating per unit time. $\mathbf{A} = -\frac{d\mathbf{N}}{d\mathbf{t}}$ where **N** is the number of parent nuclei and **t** is the time.
- An activity of one decay per second is one Becquerel (1 Bq).

- The decay constant λ of a nucleus is defined as its probability of decay per unit time.
- $A = -\frac{dN}{dt} = \lambda N$
- $\mathbf{N} = \mathbf{N_o} e^{-\lambda \mathbf{t}}$

- Half-life is defined as the time taken for half the original number of radioactive nuclei to decay.
- $\mathbf{t}_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$
- The radiation hazards to human beings arise from
    i) exposure of the body to external radiation
    ii) ingestion or inhalation of radioactive matter. (ref lect notes for details)