Physics Unit 4 Summary Sheets

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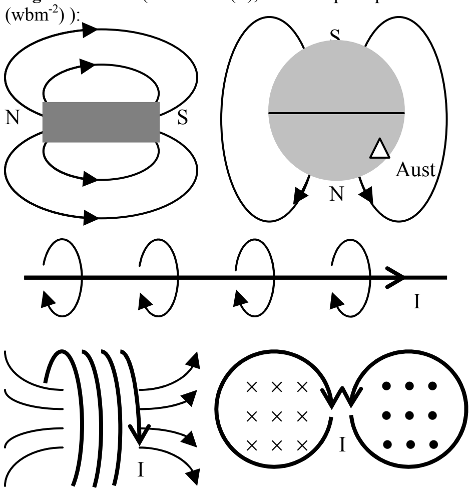
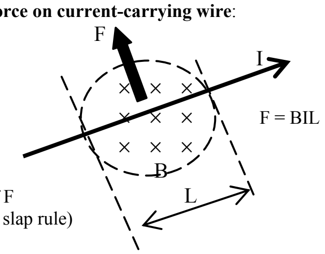
Magnetic field B (Unit: tesla (T); or weber per square metre (wbm^{-2})):



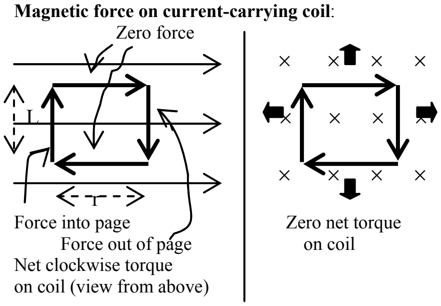
Use right-hand grip rule to find direction of B.

Magnetic force on current-carrying wire:



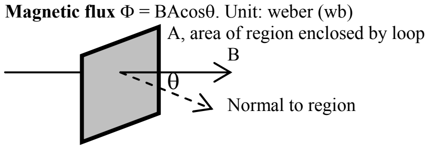
Direction of F
(Right-hand slap rule)

Magnetic force on current-carrying coil:



Refer to above diagrams, the two forces (each F = BIL in and out of the page) exert a turning effect called torque (τ = rF) on the coil causing it to speed up its rotation in the first quarter turn. In the second quarter turn the torque is in the opposite direction causing the coil to slow down. In a **simple DC motor**, the direction of the coil current is reversed with a **split-ring commutator** at 90° turn when the net torque is zero. Hence the torque on the coil remains in the same direction in the second quarter turn. The next reversal of current occurs at 270° turn to ensure the same torque direction and the process repeats after a complete revolution.

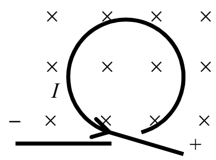
Magnetic flux Φ = BAcosθ. Unit: weber (wb)



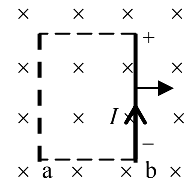
Electromagnetic induction: is the generation of electricity by changing magnetic flux. The generated current is called **induced current** I; the generated voltage is called **induced emf** ξ.

Magnitude of $\xi_{av} = \frac{\Delta\Phi}{\Delta t}$, $I = \frac{\xi}{R}$ where Δt time taken for the change, R resistance of the loop.

Ways to induce emf or current: Since Φ = BAcosθ, emf can be induced **(1)** by changing A to change Φ

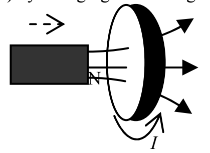


when the area of the loop inside B increases, the induced current is as shown



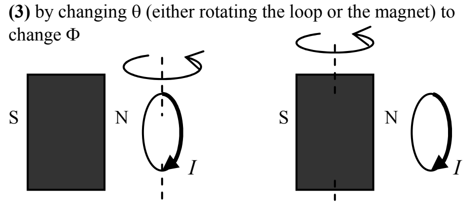
when a conductor moves across the magnetic field lines from a to b (change in area enclosed by dotted lines), induced emf is shown as + –.

(2) by changing B to change Φ



when magnet moves closer to the loop, magnetic field increases and the induced current is as shown

(3) by changing θ (either rotating the loop or the magnet) to change Φ

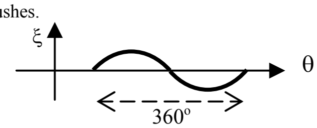


Direction of induced current and polarity of output terminals of a generator are determined by **Lenz's Law**: an induced current in a conducting loop flows in a direction such that the magnetic field of the induced current *opposes* the change in magnetic flux that produces it. The terminal that the induced current flows to is +, the other –.

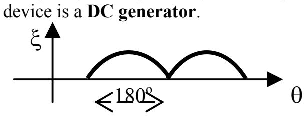
Faraday's Law: $\left|\xi_{av}\right| = n\frac{\Delta\Phi}{\Delta t}$ where *n* is the number of loops in the coil through which the flux passes.

$\xi_{av} \propto n$, $\xi_{av} \propto \Delta\Phi$, $\xi_{av} \propto \frac{1}{\Delta t}$.

AC generator: Alternating emf induced by a rotating conducting coil (loop area A) in a magnetic field B is made accessible with **slip-rings** connected to the terminals of the coil, and the external circuit is connected to the rings via conducting brushes.



If the slip-rings are replaced by a set of **split-ring** commutators, the device is a **DC generator**.

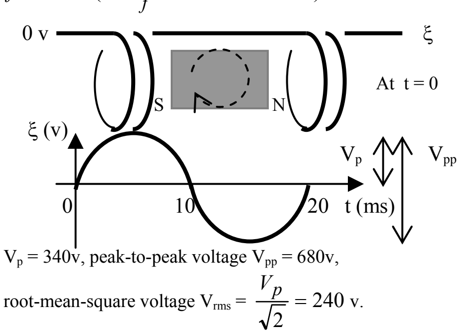


The amplitude of the AC emf is called the peak voltage V_p .

$V_p \propto n$, $V_p \propto B$, $V_p \propto A$, $V_p \propto f$.

***DC motor** has the same construction, and can be used as a **DC generator** by turning the coil mechanically.*

AC power supply delivered to homes and offices are generated by rotating an electromagnet between two connected coils at $f = 50\text{Hz}$ ($T = \frac{1}{f} = 0.02$ s $= 20$ ms).



V_p = 340v, peak-to-peak voltage V_{pp} = 680v,

root-mean-square voltage $V_{rms} = \frac{V_p}{\sqrt{2}} = 240$ v.

Alternator: Alternating emf is induced by rotating a permanent magnet (or electromagnet) beside a coil. External circuit is connected directly to the terminals of the coil and no slip rings are required.

An AC supply of V_{rms} = 240v provides the same power as a DC supply of constant V = 240v.

$I_p = \frac{V_p}{R}$, $I_{pp} = \frac{V_{pp}}{R}$, $I_{rms} = \frac{V_{rms}}{R}$, $I_{rms} = \frac{I_p}{\sqrt{2}}$

$P = P_{av} = \frac{V_p^2}{2R} = \frac{1}{2}I_p^2R = \frac{V_pI_p}{2}$ or

$P = P_{av} = \frac{V_{rms}^2}{R} = I_{rms}^2R = V_{rms}I_{rms}$.

In a power station the generator **always rotates at the same rate**. If the power consumption by homes and offices is higher (lower), more (less) energy is required to maintain the same rotation rate.

Transformer: An electrical device that is used to change the voltage of an AC power supply without changing the power to be delivered.

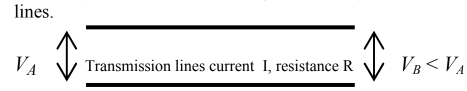
Working of a transformer: Alternating current at the primary (input) coil produces an alternating B inside the soft iron core. The secondary (output) coil is linked to the primary through the core, a changing B in the core results in a changing Φ in the secondary coil. According to Faraday's Law an emf is induced in the secondary coil (output).

Step-up transformer $N_S > N_P$; step-down $N_S < N_P$.

For an ideal (100% efficiency) transformer, $P_S = P_P$,

$V_SI_S = V_PI_P$, $\frac{N_S}{N_P} = \frac{V_S}{V_P} = \frac{I_P}{I_S}$.

Power loss P_{loss} and **voltage drop** V_{drop} occur when electricity is transmitted over long distances by transmission lines.



$V_{drop} = V_A - V_B = IR$;

$P_{loss} = I^2R = V_{drop}I = \frac{V_{drop}^2}{R}$. $P_{loss} \propto I^2$,

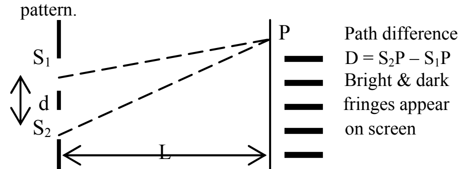
power loss is greatly reduced by lowering *I* in the lines and hence increasing the voltage for transmission in order to deliver the same energy, ∴step-up transformer at power station.

Load curve is a graph showing the demand of electric power over a time period. Area under the curve represents the total consumption of electrical energy during the period.

$E = P\Delta t$.

Kilowatt-hour (kwh) is a unit of electrical energy.
1 kwh = 3.6 MJ

Thermal oscillations of electrons in atoms give off electromagnetic radiation (visible light). In an incandescent light bulb, the atoms in the filament are excited by heating, and they give off their excess energy as wave trains (with **wide spectrum** of wavelengths) of light, each lasts about 10^{-8}s. The emitted light is the sum of such wave trains that bear a **random phase** relation to each other and they are **incoherent**. Two light bulbs are thus incoherent, hence no **interference pattern**. Thomas Young demonstrated the **wave nature** of light with his **double-slit experiment** to obtain an interference pattern. He used sunlight through a narrow slit as the light source and then through the double slits. Lights through the double slits are **coherent** because they are split from the same wave trains, ∴ there is an interference pattern. **Laser** is a very coherent source because it is **monochromatic** (single wavelength) and wave trains are emitted simultaneously, hence a very clear interference pattern.

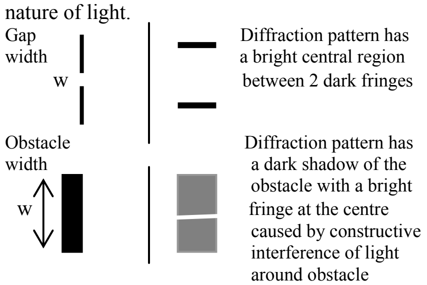


Constructive interference (bright): D = 0λ, 1λ, 2λ, ...
Destructive interference (dark): D = 0.5λ, 1.5λ, 2.5λ, ...

Spacing between fringes increases when wavelength λ increases, screen distance L increases and/or slits separation d decreases.

$\lambda_{red} > \lambda_{green} > \lambda_{blue} > \lambda_{violet}$. $f = \frac{c}{\lambda}$.

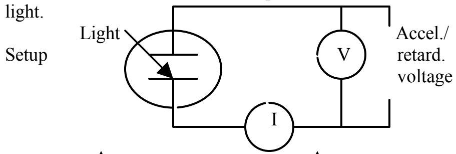
Diffraction of light also demonstrates the wave nature of light.

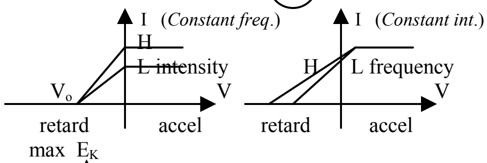


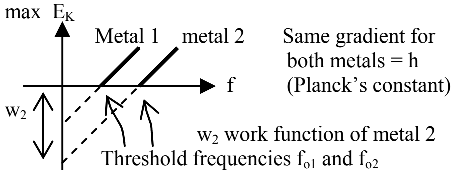
Extent of diffraction $\propto \frac{\lambda}{w}$. Significant effect when $\frac{\lambda}{w} \approx 1$.

Greater diffraction when λ is longer and/or w is smaller.

Photoelectric effect demonstrates particle-like nature of light.







$w = hf_o$, max $E_K = qV_o$

Einstein's interpretation of photoelectric effect-the photon model: A beam of light is a beam of particles called **photons**. Light of a single frequency f consists of photons of the same energy E = hf.

There are more photons in a more intense beam, hence higher current. When photons strike a metal, some will be absorbed by the electrons in the metal. To have photoelectrons emitted, the energy of each photon must be high enough for the electrons to overcome the bonding energy (i.e. the **work function** w). As the photons penetrate into the metal they collide with other electrons before they are absorbed. Each collision lowers the photon frequency (energy) slightly, the **Compton effect**. ∴ electrons at the surface escape with higher (max) kinetic energy than those inside metal, max $E_K = hf - w$ for surface electrons.

The Compton effect and photon momentum: The particle nature of light was further supported by the Compton effect.

Photon momentum $p = \frac{E}{c} = \frac{h}{\lambda}$.

The two models (wave and particle) of light appear to be inconsistent with each other but both have been shown to be valid depending on the circumstances. This dual nature of light is known as **wave-particle duality**.

Wave nature of matter: de Broglie proposed that a moving material particle also has wave-particle duality. Wavelength of particle is related to its momentum (like a photon).

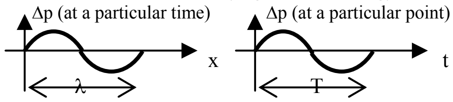
de Broglie $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE_k}}$. These equations are valid when λ in m, m in kg, v in ms^{-1}, E_K in J, h in Js.

The **diffraction of electrons** from the surface of a metal crystal confirmed the wave nature of matter.

An electron with the same λ as a photon has the same momentum as the photon.

When a gas or metal vapour is heated, the gas or vapour glows and emits a characteristic diffraction pattern (obtained with a **diffraction grating**) called an **emission spectrum**. When sunlight passes through a gas/vapour, some dark lines appear in its spectrum called **absorption spectrum**, caused by the absorption of certain wavelengths of sunlight by the atoms or molecules in the gas/vapour. These spectra are evidence for **quantised atomic energy levels**. Electrons move around a nucleus with **discrete** energies. When an electron jumps from high to low energy level, itloses energy in discrete amount equal to the difference between the two levels and results in the emission of a photon of the same energy. $hf = E_H - E_L$. de Broglie used the idea of **standing matter waves** to explain the quantised energy levels of the atom. The only matter waves that persist are those for which the circumference of the orbit is an integral multiple of λ.

Travelling sound wave through air is **longitudinal** because the air molecules oscillate parallel to the direction of propagation of the sound wave. A sequence of high (**compression**) and low (**rarefaction**) air pressure is generated and it propagates outwards from the source carrying the sound energy with it.



$f = \frac{1}{T}$, speed of sound $v = \frac{\lambda}{T} = f\lambda$.

$v(solid) > v(water) > v(hotair) > v(coolair)$. ***v* is constant** when sound travels in the same medium, ∴

$\lambda \propto \frac{1}{f}$ and $\frac{\lambda_2}{\lambda_1} = \frac{f_1}{f_2}$. ***f* is constant** when it travels from a medium into another, $\therefore v \propto \lambda$ and $\frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}$.

Sound intensity *I* measures the amount of energy (J) arriving at a square metre of surface in a second. It is defined as

$I = \frac{E}{A\Delta t} = \frac{P}{A}$, *E* energy received, *A* area exposed, *Δt* time exposed. Unit: Js^{-1}m^{-2} or wm^{-2}. For a small sound source in the open, the sound energy spreads outwards spherically,

$I = \frac{P}{4\pi r^2}$, *P* is the **acoustic power** of source, $\therefore I \propto \frac{1}{r^2}$,

$\frac{I_b}{I_a} = \frac{r_a^2}{r_b^2}$. When the distance *r* from the source is doubled, intensity *I* is a quarter of the original.

Sound intensity level $L = 10 \times \log_{10} \frac{I}{10^{-12}}$, in dB.

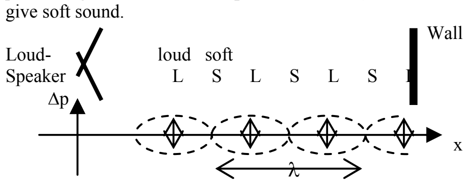
$I = 10^{\frac{L}{10} - 12}$. $\Delta L = 10 \times \log_{10} \frac{I_f}{I_i}$, $\frac{I_f}{I_i} = 10^{\frac{\Delta L}{10}}$.

When *I* is doubled, i.e. $\frac{I_f}{I_i} = 2$, $\Delta L = +3$ dB.

When *r* is doubled, $\frac{I_f}{I_i} = \frac{1}{4}$, $\Delta L = -6$ dB.

Threshold of hearing	10^{-12} wm^{-2}	0 dB
Normal conversation	10^{-6}	60
Car alarm 1 m away	10^{-2}	100
Threshold of pain	1	120
Jet engine 30 m away	10^{2}	140

After **reflection**, *f*, *λ* and *v* remain the same. When the forward and the reflected travelling waves superpose each other, a **standing wave** (a sequence of loud and soft sound at fixed positions quarter of a wavelength apart) is formed between the source and the wall. **Pressure antinodes** (max fluctuation in air pressure) give loud sound and **pressure nodes** (min fluctuation) give soft sound.



Every object has its own natural frequencies of vibration. If an energy source at one of these frequencies interacts with the object, the latter will be set into vibration, i.e. a standing wave is formed. The object is in **resonance**. The natural frequencies of vibration are called **resonant frequencies**.

Standing waves in **stretched string** of length L:

Overtones	Harmonics	λ	f = v/λ
Fundamental	first	2L/1	1(v/2L)
First	second	2L/2	2(v/2L)
Second	third	2L/3	3(v/2L)

Note: v is the speed of travelling wave in string.

Standing waves in **open resonant tube** of length L: The vibration of the air column in the tube forms a standing wave. Same pattern of harmonics as strings but v is the speed of travelling sound wave in a tube.

Standing waves in **closed resonant** tube of length L:

Overtones	Harmonics	λ	f = v/λ
Fundamental	first	4L/1	1(v/4L)
First	third	4L/3	3(v/4L)
Second	fifth	4L/5	5(v/4L)

For closed tubes only odd harmonics exist.

Dynamic microphone: Sound moves the cone and the attached coil of wire in magnetic field to and fro. Electromagnetic induction produces an emf (signal) at the terminals of the coil. **Ribbon (or velocity) microphone**: Air movement due to sound waves moves the metallic ribbon in a magnetic field. Electromagnetic induction generates emf between the ends of the ribbon. **Condenser microphone**: The back plate and the front metallic membrane form a capacitor (charged with a battery). Sound waves cause the membrane to vibrate and change the spacing between the plate and the membrane. This causes the output voltage (signal) to change. In **electret-condenser microphone** a permanently charged electret material is used for the membrane, thus eliminating the need of a charging battery. **Crystal microphone**: uses a thin strip of piezoelectric crystal attached to a diaphragm that is sent into vibration by sound waves, causing the crystal to deform and produce a voltage (signal).

A **dynamic loudspeaker** has the same basic construction as a dynamic microphone. The input signal changes the current in the coil and results in a varying magnetic force on the coil that is attached to the cone.

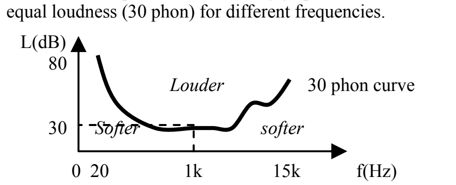
Enclosure formed by baffles: to prevent the sound from the back of the speaker cone cancelling the sound from the front due to interference. Usually the enclosure has an acoustic resonant frequency lower than that of the loudspeaker. This effectively lowers the low cutoff frequency of the system.

Directional spread of sound waves (diffraction): Sound diffracts when it passes by the edge of a barrier. Refer to diffraction of light. **Extent of diffraction** $\propto \frac{\lambda}{w}$. w is the width of obstacle or opening. High pitch (high f, short λ) sound diffracts less than low pitch.

A loudspeaker is **omni-directional**, (i.e. it radiates sound energy spherically in all directions) when $\frac{\lambda}{w} > 4$, w is the diameter of speaker cone. The higher the frequency the less omni-directional it becomes.

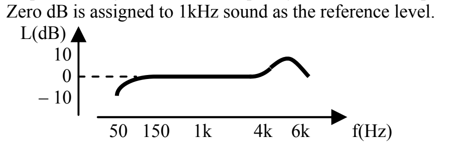
Frequency response of human ear: is most sensitive to sound of frequency 4000Hz, e.g. of the three sounds, 100Hz, 4kHz and 10kHz, at the same dB level at the ear, the 4kHz will sound the loudest to the listener. To make 100Hz and 10kHz the same loudness as 4kHz, increase their dB level.

Loudness is measured in **phon**. The loudness of a sound is compared with the loudness of 1kHz sound. The loudness of a *x* dB 1kHz sound is *x* phon. Sounds at different frequencies, which are as loud as the *x* dB 1kHz sound have a loudness of *x* phon. The following graph shows a curve of equal loudness (30 phon) for different frequencies.



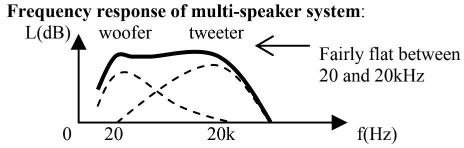
A point above/below the curve is louder/softer than 30 phon.

Frequency response curve of a microphone: is a graph of output intensity level versus frequency for a constant input. Zero dB is assigned to 1kHz sound as the reference level.



This graph indicates that the microphone responds equally well to frequencies between 150 and 4kHz, more sensitive to over 4kHz, less sensitive to below 150Hz.

Frequency response of multi-speaker system:



A single loudspeaker on its own (e.g. the woofer or tweeter) tends to '**colour**' the sound it produces, i.e. some frequencies are louder than others due to resonance. An ideal loudspeaker system would need to have the same loudness at all frequencies, i.e. a fairly **flat** response curve. Some loudspeaker enclosures have tubes (called **ports**) put in them. Size and depth of ports can be changed to absorb sound of particular frequencies to produce a flat response.