Laws and Definitions in AL Physics

Newton's laws of motion

1st law:	If a body is at rest it remains at rest or if it is in motion it moves with uniform velocity until it is acted on by a resultant force.
2nd law:	The rate of change of momentum of a body is proportional to the resultant force and occurs in the direction of the force.
3rd law:	If body A exerts a force on body B, then body B exerts an equal but opposite force on body A.

Conservation of linear momentum

When bodies in a system interact, the total momentum remains constant provided no external force acts on the system.

Conservation of energy

Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes

Conservation of mechanical energy

In a system in which there is no work done by forces other than those associated with potential energy (e.g. gravitational and elastic forces) the sum of the kinetic and potential energies is constant.

Elastic collision and Inelastic collision

An elastic collision is one in which the total kinetic energy of the colliding objects remains constant. In other words, no energy is converted into internal energy (or other forms). Besides, the total momentum of the colliding objects is also conserved.

In an inelastic collision, kinetic energy is converted into internal energy. The total amount of energy is conserved, but the total amount of kinetic energy is not. Nevertheless, the total momentum is conserved.

Circular motion

Circular motion is a kind of acceleration because the direction of velocity changes continuously. According to Newton's second law, a force is required to produce an acceleration. The resultant force needed for circular motion is called centripetal force

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Force resolution in "conical pendulum" and "simple pendulum"

Conical pendulum:	Centripetal force is provided by the horizontal component of the tension $T \sin\theta = m\omega^2 r$.
Simple pendulum :	Centripetal force is provided by the difference between the tension and the radial component of the bob's weight. $T - mg\cos\theta = m\omega^2 r$

Looping a loop

Just complete a whole loop: At the top , the whole weight is used for centripetal force .

Centrifuge

The liquid inside a centrifuge undergoes a circular motion. A pressure gradient exists along the tube. For any part of the liquid the force due to the pressure gradient supplies exactly the centripetal force required. If this part of the liquid is replaced by matter of smaller density (and thus of smaller mass), the force is too large and the matter moves inwards.

Moment of inertia

Moment of inertia of a body is the sum of the mr^2 values for all the particles of the body, where r is the distance from the axis of rotation. It depends on the mass and its distribution and is taken as a measure of the inertia of rotational motion about the axis.

Moment of inertia in rotational motion is analogous to the mass in linear motion

(1) The mass in linear motion represent the factor determining the linear acceleration associated with a particular force. The moment of inertia represents the factor determining the angular acceleration associated with a particular torque.
(2) Both are factors representing the 'inertia' of the system, which give resistance to the respective motion.

Conservation of angular momentum

The total angular momentum of a system remains constant provided no external torque acts on the system

Simple harmonic motion

A SHM is an oscillating motion about a fixed point such that

1. the acceleration is always directed towards the fixed point, and
2. the acceleration is proportional to the displacement from the fixed point.

Isochronous motion

The period is independent of the amplitude of oscillation.

Relationships among a, v and x

a leads v by $\pi/2$, v leads x by $\pi/2$
x and a are anti-phase
$a = -\omega^2 x$
amplitude of x = A; amplitude of v = ωA, amplitude of a = $\omega^2 A$
$x^2 + (v/\omega)^2 = A^2$

Damped oscillation

1. Lightly damped SHM : There is an oscillation but the amplitude decreases exponentially with time.
2. Heavily damped SHM: There is no real oscillation. There is only a very slow return of the object to the initial equilibrium position.
3. Critical damped SHM: There is no real oscillation. It returns to the equilibrium position in the shortest time

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Forced oscillations and resonance

Natural frequency:	The frequency at which a system would oscillate by itself if displaced.
Forced oscillation:	A periodic force at a given frequency is applied to an oscillating system. Eventually the system settles down with oscillation at the frequency of the driving force.
Resonance:	When the driving frequency is at the same frequency as the natural frequency of the oscillator, the amplitude of oscillation is at its greatest. When this happens the energy of the oscillator becomes a maximum.

Kepler's laws

1. Each planet moves in an ellipse which has the sun at one focus.
2. The line joining the sun to the moving planet sweeps out equal areas in equal times.
3. The squares of the periods are proportional to the cubes of the average distances of the planets from the sun. (r^3/T^2 = constant)

Gravitational Field

The strength of a gravitational field is defined as the force acting on unit mass placed in the field

Gravitational potential difference and potential

The gravitational potential difference between A and B is defined as the work done by the external force balancing the gravitational force in moving unit mass from B to A.
The gravitational potential at point A is defined as the work done by the external force balancing the gravitational force in moving unit mass from infinity to point A.

To an orbiting satellite, KE : PE: E = 1 : -2 : -1

Weightlessness

An astronaut in an orbiting spacecraft is in a state of free fall. His acceleration towards the Earth is exactly the same as that of the spacecraft, so the floor of the spacecraft exerts no force on him. As a result, he experiences exactly the same sensation of weightlessness as he would in zero gravity. However, he is not really weightless

Weight and mass

Mass	Weight
Mass is a quantitative measure of the inertia in linear motion. It is a scalar. The unit of mass is kg.	Weight of an object is the gravitational force acting on it. It is a vector. The unit of weight is N.
Inertia is an inherent property which is the same no matter where the object is placed.	Weight is position-dependent. It is proportional to the strength of the g-field and the mass of the object.

Electric field strength

The electric field strength is defined as the electric force per unit charge.

Electric field lines

Electric field lines are drawn to aid the visualization of an electric field.

1. Tangent to a field line gives the direction of the electric field.
2. The number of field lines drawn per unit perpendicular cross-sectional area is proportional to the magnitude of the electric field.
3. The field lines starts from positive charges and end on equal negative charges. They do not start or end in empty space.
4. The field lines cannot cross

.

Electric field strength due to a point charge $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$

Electric field strength due to a parallel-plate $E = \dfrac{Q}{\varepsilon_0 A}$

Electric potential difference and potential

The electric potential difference between A and B in an E-field is defined as the work done by an external force balancing the electric force in moving unit positive charge from B to A.
The electric potential at a point A in an E-field is defined as the work done by an external force balancing the electric force in moving unit positive charge from infinity to point A.

Capacitance

The capacitance C of a capacitor is defined as the charge stored per unit p.d. applied to the capacitor.

Current in conductor

When a battery is connected across the ends of a conductor, an electric field is set up inside. On each free electrons there is an electric force acting (F = -eE). The free electrons accelerate but only for successive short time intervals because they are continually colliding with the thermally jiggling ion cores that make up the lattice. Therefore, the electrons can only drift from one end of the conductor to the other with a very slow speed (~ 10^{-4} ms^{-1}). On the other hand, the effect of the collisions is to transfer kinetic energy from the accelerating free electrons into vibrationl energy of the lattice. Hence the conductor is heated up.

Electromotive and potential difference in a circuit

The <u>electromotive force</u> of a source (a battery, generator, etc.) is the energy (chemical, mechanical, etc.) converted into electrical energy when unit charge passes through it.

The <u>potential difference between two points in a circuit</u> is the amount of electrical energy changed to other forms of energy when unit charge passes from one point to the other.

Power and Energy in resistor

Power = VI = I^2R = V^2/R , Energy = Power x time

Potentiometer

In null deflection, the "two circuits" are independent (no current flows between them).

Magnetic field

The magnetic induction, or called magnetic flux density, B, is defined as the force acting per unit current length, i.e. the force acting per unit length on a conductor which carries unit current and is at right angles to the direction of the magnetic field.

Ampere

The ampere is that current which, if maintained in two straight parallel conductors of infinite length and negligible circular cross-sectional placed 1 metre apart in a vacuum, will produce between these conductors a force equal to 2×10^{7} N per metre length.

Electromagnetic induction

Induced EMF will be produced in a conductor placed in a magnetic field only when either

1. there is a relative motion between the magnetic field and the conductor which cuts the magnetic field lines, or
2. the magnetic field itself changes with time.

Faraday's law of induction

The induced EMF in a coil of N turns encircling a region of changing magnetic field is equal to the rate of change of total flux linkage. Mathematically, it is written as
induced emf $\varepsilon = -d(N\Phi)/dt$.

Lenz's law

The induced EMF must be in such a direction as to oppose the change which is causing the induced EMF.
Lenz's law is a consequence of the conservation of energy.

Self-induction

A coil through which a current is flowing has an associated magnetic field. If the current changes with time, then so does the magnetic flux and an EMF is induced in the coil. Since this EMF has been induced in the coil by a change in the current through the same coil, the process is known as self-induction.

Self-inductance

$$\text{Self-inductance} = \frac{\textit{back emf induced in a coil by a changing current}}{\textit{rate of change of current through coil}}$$

Series resonance in a.c. circuit

1. V and I are in phase ($\phi = 0$)
2. $V = V_R = IR$
3. $X_L = X_C$
4. Z is the smallest and equal to R.
5. The current is the largest
6. It happens when freq = $\dfrac{1}{2\pi\sqrt{LC}}$

Power in an a.c. circuit

$$\text{Power} = V_{RMS} I_{RMS} \cos\phi = I^2_{RMS} R$$

Tuning in radio receivers

Radio signals from different transmitting stations induce e.m.f.s of various frequencies in the aerial which cause currents to flow in the aerial coil. These induce currents of the same frequencies in coil L by mutual induction. If the capacitance C is adjusted (tuned) so that the resonant frequency of circuit LC equals the frequency of the wanted station, a large p.d. at that frequency (and no other) is developed across C. This p.d. is then applied to the next stage of the receiver.

Transformer

Transformers increase or decrease alternating voltage. Provided there is no flux leakage from the core: $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

In an ideal transformer, the power output is equal to the power input. In practice, a transformer wastes some power. Two main reasons for this are

1. coil resistance
2. the changing flux induces eddy currents in the core. The core is laminated (layered) to reduce these.

Properties of Op-amp

1. An op-amp has a very high open-loop voltage gain A_0. This means the p.d. across the two inputs is negligible.
2. An op-amp has a very high input resistance. This means the current flowing into the op-amp is very insignificant.

Negative feedback

Negative feedback is applied to a situation where the output of a device is fed back to the input and added to it in such a way as to reduce the effect of the input signal on the device.

Advantages of applying negative feedback

1. The voltage gain is set by the user.
2. The use of negative feedback improves the range of frequencies that the amplifier will amplify and improves stability.

Difference between a linear amplifier and a comparator using an op-amp

Amplifier:
The gain should be constant and frequency-independent. It utilizes the linear amplifying region. A too large input may cause distortion. Negative feedback is usuall employed to reduce the gain

Comparator:
It utilizes the saturation region. No negative-feedback is needed. High sensitivity because of the huge open-loop gain.

Wave motion

Wave motion can be defined as that mechanism by which energy is transported from a source to a distant receiver without the transfer of matter between the two points.

Huygen's principle

Every point on a wavefront may be regarded as a source of secondary spherical wavelets spreading out from the point. The new wavefront is the common envelope of these secondary wavelets

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Constructive and destructive interference

Constructive interference will occur at point P if the (two) waves arriving there are exactly in phase. Hence, the waves are added up to form a big wave at P.
Destructive interference will occur at point P if the (two) waves arriving there are exactly out of phase. Hence, the waves are cancelled and no signal is detected at P.

Conditions for observable interference

1. The two waves must have the same frequency.
2. The two waves should have approximately equal amplitude.
3. The sources of the two waves must have a constant phase difference over time. If so, the two sources are said to be coherent.
4. If one wave is polarized the second should be polarized in the same sense.

Energy and interference

In superposition of two waves, energy is still conserved. There is only a re-distribution of energy.

Number of slits is increased keeping d and a constant

The effect is to narrow the peaks of the Young's double slits pattern and to make them more intense, but the separation of the maxima does not change.

Polarization

Light is a transverse wave motion. Light is unpolarized if the plane of vibration is continually and randomly changing. Plane-polarized light contains only one, fixed plane of vibration

Two pieces of Polaroid be used to demonstrate the transverse nature of light

When light is viewed through just one piece of Polaroid, though there is some general reduction in intensity there is no apparent effect on rotating the sheet. However, if the light is viewed through two pieces of Polaroid and one is rotated relative to the other, the light intensity transmitted varies and is virtually zero at one particular orientation. These effects can only be explained on the basis of light being a transverse wave motion. With a transverse wave motion, more than one plane of vibration is possible. The first Polaroid only permits light of one particular polarization to transmit. If the transmission axis of the second Polaroid is perpendicular to that polarization, no light is therefore transmitted.

Methods producing plane-polarized light

1. using a polaroid 2.by reflection 3. by scattering

Comparison of stationary and travelling waves

Travelling waves	Stationary waves
If there is no absorption, amplitude is the same for particles along a 1-dimensional travelling wave.	Amplitude varies from zero at the nodes (permanently at rest) to a maximum at the antinodes.
Waveform advances with the velocity of the wave	Waveform does not advance. The curved string becomes straight twice in each period.
Particles separated by λ are in phase. Particles separated by $\lambda/2$ are antiphase	All particles in a 'loop' are in phase. Any two particles in adjacent 'loops' are antiphase
All particles vibrate in SHM with the frequency of the wave	All particles vibrate in SHM with the frequency of the wave (except for those at the nodes which are at rest)
Energy transfer in the direction of travel of the wave.	No transfer of energy, but there is energy associated with the wave.

Near point

The position of the nearest object that can be focused clearly and without strain by the unaided eye. For normal eye, the near point is about 25 cm from the eye and is called the least distance of distinct vision.

Visual angle

The size of the image formed by the eye is determined by the visual angle subtended at the eye by the object.
This explains why a small object situated close to the eye may seem to be the same or bigger than a much larger object situated a long way off

.

Angular magnification

It is defined as the ratio of the angle subtended at the eye by the image seen through an optical instrument to the angle subtended by the object at the unaided eye when the object is placed at some stated distance. For a magnifier or a microscope, the "stated distance" refers to the least distance of distinct vision, but for a telescope, it refers to infinity.

Internal energy

Internal energy of a substance is the grand total of all microscopic energies inside it. This include kinetic energy due to random movements of the molecules and potential energy due to the intermolecular forces.

Internal energy of an ideal gas

In an ideal gas, the molecules are well separated and so they are treated as independent particles. The internal energy of an ideal gas is therefore the grand total of molecular kinetic energy only.
according to the kinetic theory, molecular kinetic energy is directly proportional to the absolute temperature.
Internal energy per mole of an ideal gas = $3RT/2$

Work and heat

Work is the energy transferred from one system to another by a force moving through a distance.
Heat is the energy transferred by means of conduction, convection or radiation, from a body at a higher temperature to one at a lower temperature.

First law of thermodynamics

It is a statement of the conservation of energy and states that when a quantity of heat ΔQ is transferred to a system, the effect is to increase the internal energy of the system by an amount ΔU and generate work of an amount ΔW. $\Delta Q = \Delta U + \Delta W$

Work done by a gas = area under P-V graph

Macroscopic definition of an ideal gas

An ideal gas is a gas for which Boyle's law is exactly true, for all temperature and pressure

Basic assumptions of ideal gas (microscopic definition)

1. A gas consists of a vast number of molecules in random motion.
2. The volume occupied by the molecules is negligible compared with the volume of the gas.
3. The intermolecular forces are negligible except during collisions.
4. The time spent by a molecules in collision with another is negligible compared with the time during collisions.
5. Between collisions molecules move with uniform velocity.
6. All collisions are elastic.

Isothermal change (i.e. a change at the same temperature) (P.108)

For isothermal change in volume of an ideal gas, there is no change in internal energy (**$\Delta U = 0$**). So $\Delta Q = \Delta W$. In expansion, heat ΔQ must be supplied to provide energy to enable the gas to do work ΔW. Slow process = isothermal process

Quick process

$\Delta Q = 0$, $\Delta U = - \Delta W$

Real gas and ideal gas

A gas or vapour does not behave like an ideal gas at high pressures or low temperatures because if so,
1. the volume of molecules is not negligible compared with the volume of the container.
2. the attractive forces between the molecules are no longer negligible, since the molecules are much closer.

Liquefaction

An ideal gas cannot be liquefied, by cooling or by increasing the pressure. According to one assumption of an ideal gas, there is no attractive force between molecules. Molecules in an ideal gas are incapable to stick together to form a liquid.
A real gas can be liquefied by increasing the pressure only when the temperature is lower than the critical temperature. At a temperature higher than the critical temperature, the molecules always have enough KE to escape from liquid bonding forces, however closely they are crowded.

Electron-volt

1 eV = 1.6×10^{-19} J

Observations and explanations of photoelectric effect

1. A strong light beam emits more photoelectrons than a weak one of the same frequency.
   A strong beam consists of more photons. Under the assumption that one photon is totally absorbed by an electron, the number of photoelectrons ejected is thus proportional to the number of incoming photons.
2. No time lag between the arrival of light on a surface and the emission of electrons even though the light is very weak. This is because the energy are localized at 'bursts' (photons), not spread uniformly over a large surface area.
3. The photoelectrons' KE varies from zero to a maximum value, which increases linearly with frequency. This is fully explained by Einstein's equation, $KE_{max} = hf - \phi$
4. There is a threshold frequency f_0 below which no electron can be ejected regardless of the intensity of the incident light. If $hf < \phi$, no individual photon imparts enough energy to an individual electron to cause ejection.

X-rays

X-rays from an X-tube show a line spectrum superimposed on a continuous spectrum. The continuous spectrum is produced by the deceleration of the electrons in collision with the atoms of the target. The minimum wavelength of the continuous spectrum is produced when an electron gives up all its kinetic energy to the production of a single X-ray photon, i.e. $hf = 1/2\ mv^2$. The line spectrum is produced when the energetic incident electrons cause the removal of the inner-shell atomic electrons and electrons from higher levels subsequently fall into the vacancies, with the emission of X-ray photon

Optical spectra

Line spectra: they are produced only by low-density monoatomic gases and vapours. The atoms are well separated so that they are not interacting with each other. Low-pressure discharge tubes (e.g. sodium lamps, mercury lamps) are the common sources for producing line spectra. Every element displays a unique line spectrum.

Continuous spectra: they are produced by hot solids and liquids, and by high-density gases such as the sun. The atoms are close together that they interact with each other. As a result, some of the electrons have a continuous range of energies. A continuous spectrum is not characteristic of the substance which produces it. The temperature of the source determines the relative amounts of energy radiated at the various wavelengths.

Absorption spectra

An atom can absorb a photon of energy whose value is just the right amount to raise the atom to a higher energy level. When white light, which contains all wavelengths, is passed through a cooler gas or vapour, photons of those energy that correspond to transitions between energy levels are absorbed. The resulting excited atoms re-radiate their excitation energy almost at once, but these photons come off in random directions with only a few in the same direction as the original beam of white light. This causes dark lines in the spectrum of the original beam. The dark lines are not completely dark. They appear dark by contrast with the bright background. The absorption spectrum of any element is identical with its emission spectrum.

Interpretation of the Franck-Hertz experiment

An atom exists in discrete energy levels, so that it can only absorb certain fixed amount of excitation energy. No intermediate energy change is allowed.

Under normal conditions, there is little stimulated emission

because the upper state is largely unoccupied. The chief events that occur will be absorption of incident photons by atoms in the ground state and the subsequent spontaneous random re-radiation of photons of the same frequency.
Stimulated emission becomes important by means of a population inversion, i.e. an upper state more occupied by atoms than the ground state.

Properties of laser

highly monochromatic, highly coherent, highly directional, can be very strong, can be very short.

Typical energies in nuclear processes

Mean kinetic energy of α-particle = 6 Mev Mean kinetic energy of β-particle = 1 Mev
Mean energy of γ-photon = 0.1 MeV
Mean value of the nuclear binding energy per nucleon = 8 MeV
Energy liberated in a fission reaction ~ 200 MeV
Energy liberated in a fusion reaction ~ several MeV

The electron energies in a β-decay

of a particular nuclide vary continuously from zero to a maximum value characteristic of the nuclide.

Decay constant

Decay constant λ is the probability of decay per unit time. For an undecayed nucleus, the probability for it to decay between now and a very short time Δt from now is λΔt.

G-M counter

A G-M counter is unable to distinguish different kinds of radiation. One particle one count. A G-M counter has poor timing capability

Ionization chamber

Further ionization multiplication does not occur. The voltmeter must has a huge internal resistance.
Total ions produced = ionization current/e
Ions produced by one particle = total ions produced/activity
KE carried by one particle = ions produced by one particle x energy required to cause an ionization.

Diffusion cloud chamber

Vapour from alcohol in the felt ring diffuses downwards, is cooled by the 'dry ice' (-78^0C) in the lower section and condenses near the floor on which air ions formed by radiation from the source in the chamber. The resulting white line of tiny liquid drops shows up as a track when illuminated.

Decay is a random process /compared with dice throwing

We cannot tell which particular atoms are going decay in unit time, just as we cannot tell which particular dice turn up a certain value in each throw.
We cannot tell when a particular atom is going to decay, only the probability of decay in unit time (λ) is known, just as we cannot tell in which throw a particular dice turn up a certain value, only the probability of this is known.

Carbon-14 dating

Most carbon that exists in the atmosphere is the stable C-12. Because of cosmic-ray bombardment, about one millionth of 1 percent of the carbon in the atmosphere is C-14. Both C-12 and C-14 join with oxygen and become carbon dioxide, which is taken by plants. Animals eat plants and therefore have a little C-14 in them. All living things contain some C-14. However, C-14 is unstable; it decays into nitrogen : $^{14}C \longrightarrow {}^{14}N + \beta$. The half-life is about 5730 years. Because living things eat and breathe, this decay is accompanied by a replenishment of C-14. There is a fixed ratio of C-14 to C-12 in them. When a plant or an animal dies, the replenishment stops. The percentage of C-14 decreases at a known rate. Measurements of this percentage enable an estimate of the time elapsed since death.

Binding energy per nucleon

The binding energy per nucleon is a measure of the energy which must be supplied from outside in order to separate the nucleus into its component nucleons. The larger the binding energy per nucleon, the more stable the nucleus is.

Moderators, control rods and coolant

Moderators are used to slow down fast neutrons. Slow neutrons have a better chance to cause further fission. Graphite and water are the commonly used moderators. A good moderator should (i) have a low mass and (ii) be able to absorb high amount of energy without becoming unstable.
Control rods are used to control the rate of fission. To maintain a constant rate, only one product neutron produces further fission. The other neutrons escape or absorbed by the control rods.
Coolant: prevent melting and extract useful heat.

Difficulties of a controlled fusion

1. A very high temperature (10^7 K) is not easily attained.
2. The confinement of material in such high temperatures.

Advantages of controlled fusion

1. The raw material cheap and abundant.
2. Fusion is cleaner. Unlike fission, fusion does not produce the dangerous and long-lived radioactive wastes.
3. Fusion is safer. Fusion will stop immediately when the process 'leaks' from the reactor to the outside because of the unavailability of high temperature.