Definitions, Principles, Laws and Formulae

18.0 Electrostatics

18.1 *Coulomb's law* states that the electric force between 2 **point charges** is directly proportional to the **product** of their charges, and is inversely proportional to the **square** of the distance between them.

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$$

18.2 Electric field = the region in which electric force exerts on a charge.

18.3 Electric field strength = **electric force per unit positive charge** acting on a small test charge placed in the electric field.

$$E = \frac{F}{+q}, F = qE$$

For a point charge, $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

18.4 Electric flux = product of electric field intensity and the area of the surface through which the electric lines pass normally.

$$\phi = E.\ A.$$

18.5 *Gauss law* states that the total electric flux passing through a closed surface is the ratio of the total charged enclosed in surface to the permittivity of free space.

$$\Phi = \frac{Q}{\varepsilon_0}$$

18.6 Relationship between E and V: Electric field strength = – potential gradient.

$$E = -\frac{dV}{dr} \text{ or } E = -\frac{dV}{dx}.$$

If E is constant, then $E = \frac{V}{d}$.

18.7 Electric potential = **work done** per **unit positive charge** in bringing a charge from **infinity** to the point in the electric field.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

18.8 Electric potential energy = work done in bringing a positive charge from infinity to a point in the electric field.

$$U = q\,V \Rightarrow U = \frac{qQ}{4\pi\varepsilon_0\, r}$$

19.0 Capacitance

19.1 Capacitance = Charge stored in the capacitor per unit potential difference.

$$C = \frac{Q}{V};\ Q = CV$$

19.2 Farad = 1 farad is the value of capacitance when a charge of **1 coulomb** is stored in the capacitor when a potential difference of **1V** is applied across it.

19.3 Additional formula: $C = \frac{\varepsilon A}{d}$;

Capacitors in series $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$;

two capacitors in series, $C = \frac{C_1}{2}$.

Capacitors in parallel $C = C_1 + C_2 + C_3$

Energy stored on capacitor: = area under the graph of V against Q.

$$W = \frac{1}{2}QV,$$

$$W = \frac{1}{2}\frac{Q^2}{C},$$

$$W = \frac{1}{2}CV^2$$

Energy supplied by source of e.m.f. E: energy $W = QE$ (compared with energy, $W = QV$)

Capacitor is being charged, $Q = Q_0; \left(1 - e^{-\frac{1}{CR}t}\right)$;

Capacitor discharges. $Q = Q_0\, e^{-\frac{1}{CR}t}$

20.0 Electric Current

20.1 Electric current = rate of flow of charge.

$$I = \frac{dQ}{dt};$$

$$I = \frac{Q}{t}$$

$$Q = It$$

20.2 Charge = **product** of current flow and the time taken. $Q = It$

20.3 Coulomb = **1 coulomb** is the quantity of charge that flows when a current **1 A** flows in **1 second.**

$I = \frac{dQ}{dt}$. If the current is constant, $I = \frac{Q}{t}$.

20.4 Drift velocity = average speed acquired by free electrons in a metal when subjected to electric field. $I = Anev$

20.5 Resistivity of a conductor = Resistance per unit length of the conductor when the cross-sectional area is one unit. $\rho = \frac{RA}{l}$

20.6 Current density = Electric current per unit cross-sectional area of the conductor.

$$J = \frac{I}{A}$$

20.7 Additional formulae: $\sigma = \frac{ne^2t}{m}$; $J = \sigma E$.

21.0 Electric Circuits

21.1 Potential difference = **Energy** transferred per **unit charge** to drive a charge across 2 points. The transfer of energy is from electrical energy to other forms of energies.

$$V = \frac{E}{Q}\text{. Energy, } E = QV$$

21.2 Volt = **1 volt** is the energy of **1 joule** transferred to drive **1 coulomb** of charge across 2 points.

21.3 Resistance = ratio of potential difference to current flow.

$$R = \frac{V}{I}\text{. } V = IR$$

21.4 Ohm = **1 ohm** is the value of the resistance when a potential difference of **1 volt** causes a current flow of **1 A.**

21.5 Ohm's law = the current flow is directly proportional to the potential difference applied, provided other physical quantities such as temperature remains constant. $I \propto V$

21.6 Electro-motive-force (e.m.f.) = **energy** per **unit** charge supplied by an electric source to drive a charge round a complete circuit. The transfer of energy is from other forms of energies to electrical energy.

$$E = \frac{W}{Q}\text{, where } W \text{ is the energy supplied.}$$

Hence, total energy supplied, $E = E_0 Q$.

$$E = IR + Ir. \quad E = V_R + Ir. \quad V_R = E - Ir.$$

21.7 *Kirchhoff's first law* states that at any **junction**, the algebraic sum of current = 0. $\Sigma I = 0$ That is, the total current enters a junction = total current leaving the junction. (Principle of conservation of charge)

21.8 *Kirchhoff's second law* states that for any **closed loop**, the algebraic sum of e.m.f = algebraic sum of the potential drops across all the resistors in the loop. (Principle of conservation of energy)

$$\Sigma E = \Sigma V\text{. Hence } \Sigma E = \Sigma RI$$

21.9 For *potentiometer wire* (a form of potential divider) ratio of V = ratio of l.

21.10 For *wheatstone bridge* $\frac{R_1}{R_2} = \frac{R_3}{R_4}$; $\frac{R_1}{R_2} = \frac{l_1}{l_2}$

21.11 Shunt = A resistor of very low resistance connected in parallel to a milliammeter so that most of the current will pass through it.

21.12 Multiplier = A resistor of high resistance connected in series with the milliammeter so that most of the potential difference will develop across it.

21.13 Additional formulae: $E = I^2Rt$, $E = \frac{V^2}{R}E = QV$,

$E = VIt$ (Q = It); $E = I^2Rt$, $E = \frac{V^2t}{R}$.

Power, $P = \frac{E}{t}$, $P = VI = I^2R = \frac{V^2}{R}$

For *potential divider*: Ratio of V = ratio of R

22.0 Magnetic Field

22.1 Magnetic field = the region in which magnetic force acts.

22.2 Magnetic field strength = magnetic force per unit charge moving with unit velocity perpendicular to the direction of magnetic field. $F = qvB \sin\alpha$

or

Magnetic flux density (magnetic field intensity/magnetic field strength) = force per unit length of a conductor per unit current when the conductor is placed perpendicular to a magnetic field. $F = BIl \sin\theta = BIl$

22.3 Tesla = 1 tesla is the value of the magnetic flux density when a force of **1 N** acts on **1 m** of the conductor which carries a current of **1 A,** when the conductor is placed at a **right angle** to the magnetic field.

22.4 Definition of *ampere*:

One ampere is the value of equal currents passing through two long, straight and parallel conductors, with negligible area of cross-section, separated 1.0 m apart, in vacuum, which will produce a force of **2.0×10^{-7} newton per meter** between the conductors.

21.5 For a coil with its plane parallel to a magnetic field, torque $\tau = BINA$

21.6 Hall voltage, $V_H = \frac{BI}{net}$

Additional formulae:

Long straight wire $B = \frac{\mu_0 I}{2\pi d}$

Circular coil. $B = \frac{\mu_0 NI}{2r}$

Solenoid: $B = \mu_0 nI$

23.0 Electromagnetic induction

23.1 Magnetic flux = the product of magnetic flux density and area through which the magnetic field passes through normally. $\phi = BA$

23.2 Weber = 1 weber is the value of magnetic flux when a magnetic flux density of **1 tesla** passes normally through an area of 1 m^2.

23.3 Magnetic flux linkage = the total magnetic flux passing normally through the area of a coil of N turns. $\Phi = N\phi$; $\Phi = NBA$

23.4 *Faraday's law* states that the magnitude of induced e.m.f. is directly proportional to the rate of change of magnetic flux linkage in the conductor. $E = \frac{d\Phi}{dt}$

23.5 *Lenz's law* states that the direction of the induced current flows in such a direction to produce an effect which opposes the **change** of magnetic flux producing it.

(The induced current will produce another magnetic field, and this second magnetic field produced will oppose the **change** of the original magnetic field.)

23.6 Self-induction = Induction of back e.m.f. in the circuit itself when there is change in magnetic flux in it. $E = L\frac{dI}{dt}$; $\Phi = LI$

23.7 Back e.m.f. = induced e.m.f. which opposes the supply voltage of the source when there is a change in magnetic flux in the circuit.

23.8 Mutual induction = induction of an e.m.f. in the secondary coil when there is a change of magnetic flux in it due to a change of current in the primary coil.

$$E_2 = -M\frac{dI_1}{dt}$$

23.9 Mutual inductance = induced e.m.f. in the secondary coil per unit change of current in the primary coil. $\Phi_2 = MI_1$

Or

Mutual inductance = magnetic flux linkage in the secondary coil per unit current in the primary.

23.10 Transformer: $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

23.11 Eddy current = a large induced current which flows in a circular manner in a solid metal when there is a change of magnetic flux in the solid.

23.12 Back e.m.f. in motor = induced e.m.f. which opposes the potential difference of the source due to the changing magnetic flux in the coil when the coil is rotated in magnetic field.

Applying Ohm's law, $V_o - E_b = IR_a$.

Additional formulae: For an inductor, energy stored, $E = \frac{1}{2}LI_0^2$

24.0 Alternating Current (A.C.)

24.1 Period of A.C. = time taken for 1 complete cycle of the alternating current $T = \frac{t}{N}$.

24.2 Frequency of A.C. = number of cycles per unit time of the alternating current. $f = \frac{N}{t}$.

24.3 Root-mean-square (r.m.s) value of an A.C. is numerically equal to the value of a **steady** direct current which produces the **same** rate of heat in a given resistor.

24.4 Peak value = the greatest value of the potential difference or current in a cycle.

$$V_{rms} = \frac{V_o}{\sqrt{2}}; \ I_{rms} = \frac{I_o}{\sqrt{2}}$$

24.5 Half-wave rectification = the conversion of alternating current to direct current with only half of a cycle of the A.C. passing through the load in one direction.

24.6 Full-wave rectification = the conversion of A.C. to D.C. when both the positive and negative cycle of the A.C. pass through the load in the **same** direction.

24.7 Reactance = ratio of peak voltage to the peak current of an A.C.

24.8 *Physical concept*: Reactance = opposition to the flow of A.C.

For an inductor: reactance, $X_L = 2\pi fL$

For a capacitor, inductance, $X_C = \frac{1}{2\pi fC}$

24.9 Additional formulae:

Power, $P = VI$.

$$P = (V_o \sin \omega t)(I_o \sin \omega t)$$
$$= V_o I_o \sin^2 \omega t$$

$P = I^2R \sin^2 \omega t$ $(V = IR)$.

$$P = \frac{V^2}{R}\sin^2 \omega t$$

24.10 *Instantaneous power*. For an inductor,

$$P = VI = V_o \cos \omega t.\ I_o \sin \omega t,$$
$$= \frac{V_o I_o}{2} \sin 2\omega t.$$

Average power dissipated = 0

For a capacitor, instantaneous power,

$$P = VI = V_o \sin \omega t\ .\ I_o \cos \omega t$$
$$= \frac{V_o I_o}{2} \sin 2\omega t$$

Average power dissipated = 0

25.0 Electronics

25.1 Open-loop gain = ratio of the output to **input difference.**

$$A_o = V_{out} / V_{diff.}$$

25.2 Negative feedback = a fraction of the output is returned out of phase to the inverting input.

25.3 Closed-loop gain = Ratio of output voltage to the input voltage of the amplifier with negative feedback

For inverting amplifier, $A = -\frac{R_f}{R_i}$;

For non-inverting amplifier, $A = \frac{R_f}{R_1} + 1$

26.0 Electromagnetic Waves

26.1 For oscillation of electric field,

$$E_y = E_o \sin(\omega t - kx).\ \left(k = \frac{2\pi}{\lambda} x\right)$$

For oscillation of magnetic field,

$$B_z = B_o \sin(\omega t - kx)$$

Relationship between ε_o, μ_o and c : $c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$

27.0 Geometrical Optics

27.1 Linear magnification,

$$m = -\frac{\text{size of image}}{\text{size of object}};\ m = -\frac{h_1}{h_o}.\ m = -\frac{v}{u}$$

27.2 Additional formulae

For curved mirror, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

For curved surface, $\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{r}$

Lens maker's formula, $\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

For a lens in air, $n_1 = 1.00$, refractive index of lens, $n_1 = n$, $\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

28.0 Physical Optics

28.1 Coherent sources = 2 sources are coherent if the phase difference between the sources is constant.

28.2 Additional formula, $\phi = \frac{2\pi}{\lambda} x$,

Young's double-slit interference pattern, $\frac{y}{D} = \frac{\lambda}{a}$

For air wedge, dark fringes $2t_m = m\lambda$, $\Rightarrow \Delta t = \frac{\lambda}{2}$. Bright fringes, $2t_m + \frac{\lambda}{2} = m\lambda$.

For thin film, optical path difference

$= n(2t) + \frac{\lambda}{2}$.

For constructive interference, path difference

$= m\lambda\ .\ 2nt + \frac{\lambda}{2} = m\lambda$, $m = 0, 1, 2, 3, \ldots.$

if $n_2 > n_1 > n_0$

For destructive interference, path difference

$= \left(m + \frac{1}{2}\right)\lambda$, $m = 0, 1, 2, 3, \ldots\ldots\ldots\ldots.$

if $n_2 > n_1 > n_0$

$\Rightarrow 2nt + \frac{\lambda}{2} = \left(m + \frac{1}{2}\right)\lambda \Rightarrow 2nt = m\lambda$

For single slit diffraction, $d \sin \theta = m\lambda$. For first dark fringe, $d \sin \theta = \lambda$

For diffraction grating, $d \sin \theta = m\lambda$ for bright maxima.

For polarization, intensity of polarized light, $I_2 = I_1 \cos^2 \theta$.

29.0(a) Photons

29.1 Photoelectric effect = the emission of electrons from the surface of a cold metal when electromagnetic radiations of sufficiently high frequency incident on it. The frequency of the e.m. radiation must be greater than a certain threshold frequency.

29.2 Photon = discrete packet of energy of **e.m. radiation**. It behaves like a particle of e.m. radiation.

29.3 Threshold frequency = the **minimum** frequency of the e.m. radiation to emit photoelectrons from a cold metal.

29.4 Threshold wavelength = the **maximum** wavelength of the e.m. radiation to emit photoelectrons from a metal.

29.5 Work function = the **minimum** energy required to emit an electron from a cold metal.

29.6 Electron-volt = **energy** acquired by an electron when it is accelerated by a potential difference of 1 volt.
Form $E = VQ$, energy of electron = $1.0 \times e$ joule.
Hence, 1 eV = e J

29.7 Additional formulae: energy of a photon, $E = hf$.

$$hf = (E_k)_{mak} + w_o \text{, unit in joule}$$

$$h\frac{c}{\lambda} = (E_k)_{mak} + w_o \text{, unit in joule}$$

$$\text{or, } \frac{1}{e}hf = (E_k)_{mak} + w_o \text{, unit in eV}$$

$$\frac{1}{e}h\frac{c}{\lambda} = (E_k)_{mak} + w_o \text{, unit in eV}$$

29.8 Stopping potential = The reversed minimum potential difference between the anode and the cathode to just reduce the photocurrent to zero, that is, to just stop the photoelectrons with the maximum k.e. from reaching the anode. (V_s = maximum k.e. of photoelectron in unit eV.)

29.9 Emission line spectra = **bright** spectra lines on a dark background. The bright spectra lines are produced by the lights emitted by atoms having discrete values of wavelengths. Each line is the image of the slit of the spectrometer on which the light falls.

29.10 Absorption line spectra = **Dark** lines observed against a bright continuous spectrum of white light. It occurs when light passes through a cooler gas or vapour before it enters the slit of the spectrometer.

29.0(b) Duality of Particle and Wave

29.1 The de Broglie relationship, $p = \frac{h}{\lambda}$; wavelength of a particle, $\lambda = \frac{h}{p}$.

30.0 Atomic structure

30.1 Quantization of angular momentum,
$L = \frac{nh}{2\pi}$, $n = 1, 2, 3, ...$ (n = quantum number).

k.e. of electron, $E_k = -\frac{1}{2}\text{U}$.

Total energy of atom, $E = \frac{1}{2}\text{U}$

For hydrogen atom, energy levels,

$E_n = -\frac{13.6}{n^2}$ eV. Production of photon, $\Delta E = hf$

30.2 Excitation energy = energy required by an atom to make a transition from ground state to a state of higher energy level.

30.3 Ionization state = state in which the outer orbit electron is removed from the atom to infinity.

30.4 Ionization energy = minimum energy required to remove an electron from the atom at ground state to infinity.

30.5 Emission line spectra = **bright** lines on a dark background of definite wavelengths of lights emitted by luminous gases and vapours at low pressure. Each line is the image of the slit of the spectrometer on which the light falls.
Absorption line spectra = **Dark** lines observed against a bright continuous spectrum of white light. It occurs when light passes through a cooler gas or vapour before it enters the slit of the spectrometer.

31.0 X-rays

31.1 Bragg's relationship, $2d \sin\theta = n\lambda$.

32.0 Lasers

32.1 Metastable state = an excited state of an atom which stays longer than usual before it makes a transition to a lower energy state.

32.2 Population inversion = a condition in which the number of atoms in the metastable state is more than that in the ground state.

33.0 Radioactivity

33.1 Radioactivity = the spontaneously and random decay of unstable nucleus to a more stable daughter nucleus with the emission of radiations.

33.2 Spontaneous = happen by itself, without external stimuli. The radioactive decay is not affected by temperature or chemical combinations.

33.3 Random = Time of decay of **each** atom cannot be predicted.
The probability of decay of **each** atom is the same.

33.4 Decay constant = the probability of decay of each radioactive atom per unit time. It is also the rate of decay per unit number of the remaining radioactive atoms present.

$$\frac{dN}{dt} = -\lambda N$$

33.5 Half-life = **Average time taken** for a radioactive element to decay to **half** of its initial number of **atoms**.

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

33.6 Additional formulae: $N = N_o e^{-\lambda t}$, $m = m_o e^{-\lambda t}$, and $A = A_o e^{-\lambda t}$. $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$

34.0(a) Nucleus and Nuclear Reaction

34.1 Nucleon number (mass number) = number of nucleon (proton and neutron) **in the nucleus.**
Proton number (atomic number) = number of proton **in the nucleus**.

34.2 Isotope = atom that has the same proton number but difference nucleon number. (same number of protons but different number of neutrons in the nucleus)
Proton number/atomic number = number of **proton** in the nucleus.

34.3 Mass and energy equivalence: $E = mc^2$

34.4 Principle of conservation of mass-energy: The total mass and energy of a closed system is constant.

34.5 Mass defect = the difference in mass between the sum of masses of the individual nucleons and the mass of the nucleus. That is, the loss in mass when the nucleus is formed from its constituent nucleons.

34.6 Binding energy of nucleus = **minimum** energy supplied to separate completely the nucleons in a nucleus to infinity.
OR
Total energy released to bring the constituent nucleons from infinity to form a nucleus.

34.7 Binding energy per nucleon = minimum energy **per nucleon** required to separate completely the nucleons in a nucleus to infinity.
OR
The energy released **per nucleon** when the individual nucleons are brought from infinity to form a nucleus.

34.0(b) Nuclear Reaction

34.1 Nuclear fission = the breaking up of a heavy nucleus into two or more nuclei of almost equal mass, with the emission of energy.

34.2 Chain reaction = A fission reaction that occurs continuously by itself.

34.3 Nuclear fusion = the combination of 2 small nuclei to form a large nucleus with the emission of energy.

35.0 Elementary Particles

35.1 Lepton = a group of elementary particles which does not interact with strong nuclear force.

35.2 Hadron = particles which interacts with strong nuclear force.

35.3 Elementary particles = particles which are not formed from other smaller particles.

35.4 Anti-particles = anti-particles have the same mass as the corresponding particles, but with opposite charge to that of the particles. When anti-particles and particles meet, they annihilate each other and their masses are converted into e.m. radiation.

35.5 Quark = elementary particles which form other hadron particles. They interact with strong nuclear force, and also other fundamental forces.