A2 Physics
Revision Notes / Lightweight Textbook
(2nd Edition)

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All chapters are arranged according to the original author's opinions.

Contents

Chapter 12 Circular Motion

12.1 Radian Measure

Radian: The angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.

$$\theta\,(\text{rad}) = \frac{\text{length of arc}}{\text{radius of circle}}$$
$$2\pi \text{ rad} = 360^\circ$$

12.2 Angular Speed

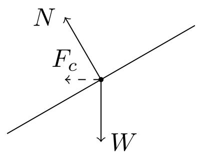
Angular Speed: The angle swept out by the radius of the circle per unit time.

$$\text{Angular Speed} \quad \omega = \frac{\mathrm{d}\theta}{\mathrm{d}t} = \frac{2\pi}{T}$$
$$\text{Linear Speed} \quad v = r \cdot w$$

12.3 Force and Acceleration of Circular Motion

$$a = \frac{v^2}{r} = \omega^2 \cdot r$$
$$F = ma = \frac{mv^2}{r} = m\omega^2 \cdot r$$

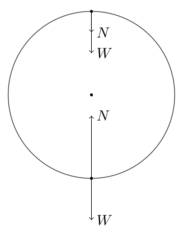
F and a always point towards the centre of the circle. E.g.,



Motion in a vertical circle:

$$\text{At the bottom of the circle} \quad F_c = N - W$$
$$\text{At the top of the circle} \quad F_c = N + W$$

where N is the normal contact force, and W is the weight of the object.



Chapter 13 Gravitational Fields

13.1 Basic Concepts

Gravitational Field: A region of space where a mass experiences a force.

Newton's law of gravitation states that the two point masses attract each other with a force that is proportional to the product of their masses and inversely proportional to the square of their separation.

$$F = G\frac{m_1 m_2}{r^2}$$

Gravitational field strength (at a point): Gravitational force per unit mass acting on a small mass placed at that point.

$$g = \frac{F}{m} = \frac{GM}{r^2}$$

- For a small distance above the earth surface, g is approximately constant and is called **acceleration of free fall** ($\approx 9.81\,\mathrm{ms^{-2}}$).
- The *force* acting on the point mass. Equal to the product of mass and the G.F. strength. $W = mg$

Gravitational field lines show the direction of the gravitational force acting on a small mass placed at that point.

- The lines never touch or cross.
- Field strength is represented by the closeness/density of the lines.

Gravitational potential (at a point): the work done (energy needed) per unit mass in bringing a small test mass from infinity to that point.

$$\Phi = -GM/r$$

1. Derivation:

$$\Phi = \int_{\infty}^{R} g\,\mathrm{d}r = \int_{\infty}^{R} \frac{GM}{r^2}\,\mathrm{d}r = \left[-\frac{GM}{r}\right]_{\infty}^{R} = -\frac{GM}{R}$$

2. Negative sign: gravitational potential at infinity is defined as being zero. Gravitational force is always attractive, so energy is released when moving a mass from infinity. As a result, gravitational potentials are negative.

Gravitational potential energy (of an object) (at a point): The energy needed in bringing the object from infinity to that point.
For small masses,

$$E_p = m\Phi = -\frac{GMm}{r}$$

13.2 Applications

For a point outside a sphere whose mass is uniformly distributed, the sphere behaves the same as a point mass with all the sphere's mass concentrated at its centre.

Kepler's third law of planetary motion: $T^2 \propto r^3$
Proof:

$$\begin{aligned} F_c &= F_g \\ m\omega^2 r &= GMm/r^2 \\ \left(\frac{2\pi}{T}\right)^2 &= \frac{GM}{r^3} \\ T^2 &= \frac{4\pi^2 r^3}{GM} \\ T^2 &\propto r^3 \end{aligned}$$

Geostationary orbit: equatorial orbits with exactly the same period of rotation as the earth $T = 24\,\mathrm{Hr}$ and that move in the same direction as the earth.

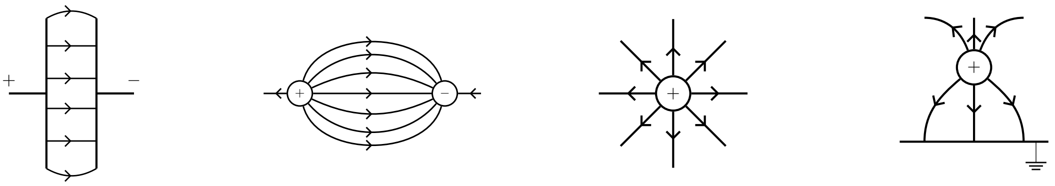
Chapter 18 Electric Fields

18.1 Basic concepts

Like charges repel; unlike charges attract.

Electric field: a region of space where a stationary charge experiences a force.

- Field line starts on a positive charge and ends on a negative charge.
- Field line is a smooth curve. They never touch or cross.
- Strength of field indicated by closeness of lines.



Electric field strength (at a point): force per unit charge acting on a small stationary positive charge.

18.2 Uniform Electric Field

Field strength is the same at all points in the field.

$$E = \frac{V}{d}$$
$$W = F \cdot d = qV$$
$$qV = \frac{1}{2}mv^2$$

Final speed v of an initially rest charge q with mass m after being accelerated by an electric field of potential difference V:

$$v = \sqrt{\frac{2qV}{m}}$$

18.3 Coulumb's law

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

Coulumb's law: The electric force between two point charges is proportional to the product of the charges and inversely proportional to the square of the distance between them.

ε_0: permittivity of free space.

Electric field strength (at a point): The force per unit charge experienced by a small positive test charge if it were put at that point.

$$E = \frac{F}{q} \stackrel{?}{=} k\frac{Q\cancel{q}}{\cancel{q}r^2} = k\frac{Q}{r^2}$$

Electric potential at a point: The work done per unit charge in bringing a small positive test charge from infinity to that point.

- Field strength is equal to the negative potential gradient at that point.

$$E = -\frac{\mathrm{d}V}{\mathrm{d}r} \Rightarrow V = -\int E \, \mathrm{d}r$$

- Electric potential due to a point charge:

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

Electric potential energe (of a charge) (at a point): The work done in bringing a charge from infinity to that point. Is equal to the product between the charge and the electric potential at that point.

$$E_p = \frac{Qq}{4\pi\varepsilon_0 r}$$

18.4 Field — Summary (Both gravitational and electric)

m in a gravitational field context plays the same role as q does in an electric field context.

$$\begin{tikzcd}
\boxed{\text{Force } F} \arrow[r, "\substack{g = F/m \\ E = F/q}"] \arrow[d, "E_p \triangleq \int F \, \mathrm{d}r"'] & \boxed{\text{Field strength } g \text{ or } E} \arrow[d, "\substack{\Phi = \int g \, \mathrm{d}r \\ V = -\int E \, \mathrm{d}r}"] \\
\boxed{\text{Potential energy } E_p} & \boxed{\text{Potential } \Phi \text{ or } V} \arrow[l, "\substack{E_p = \Phi \cdot m \\ E_p = V \cdot q}"]
\end{tikzcd}$$

Chapter 19 Capacitance

19.1 Basic Concepts

Capacitance C: ratio of charge Q to potential V of a conductor

Farad F: Unit for capacitance, $1\,\mathrm{F} = 1\,\mathrm{CV}^{-1}$

19.2 Parallel plate capacitor

The capacitance of a parallel plate capacitor is defined as the charge stored on one plate per unit potential difference between the plates.

$$C = \frac{Q}{V_{\text{plate}}}$$

There are equal and opposite charges on the two plates. The capacitor therefore does not store charge, but stores energy.

Capacitance of an air-filled capacitor can be increased by putting an insulating material between the plates. This material is called a **dielectric**.
$C = \frac{\varepsilon_0 \varepsilon_\mathrm{I} A}{d}$. Putting insulating material increases ε_I.

Capacitors in series:

$$\begin{aligned} V &= V_1 + V_2 \\ \Rightarrow \frac{Q}{C} &= \frac{Q}{C_1} + \frac{Q}{C_2} \\ \Rightarrow \frac{1}{C} &= \frac{1}{C_1} + \frac{1}{C_2} \end{aligned}$$

Capacitors in parallel:

$$\begin{aligned} Q &= Q_1 + Q_2 \\ \Rightarrow CV &= C_1 V_1 + C_2 V_2 \\ \Rightarrow C &= C_1 + C_2 \end{aligned}$$

Energy stored in a capacitor: The energy transferred from the battery when a capacitor is charged is given by the area under the graph when Q (x-axis) is plotted against V (y-axis).

$$\begin{aligned} E &= \int_0^{Q_0} V\,\mathrm{d}q = \int_0^{Q_0} \frac{q}{c}\,\mathrm{d}q = \frac{1}{2}\frac{Q_0^2}{C} \\ E &= \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}Q^2/C \end{aligned}$$

19.3 Discharging a capacitor

When discharging a capacitor C charged to voltage V_0 with a resistive load R, its stored charge, voltage and the current produced after time t follow the equations below:

$$\begin{cases} Q = Q_0 \cdot \mathrm{e}^{-t/(RC)} \\ I = I_0 \cdot \mathrm{e}^{-t/(RC)} \\ V = V_0 \cdot \mathrm{e}^{-t/(RC)} \end{cases}$$

If you have taken Further Math, you should *really* try to work out a derivation for the above equations. It is only a first-order ODE and not hard. It will make you appreciate the number e more. (And why half-life kind of sucks.)

Time constant: Time for the charge to have decreased to $1/e$ of its initial value. Equal to $R \cdot C$.

19.4 Uses of Capacitor

- Smoothing output p.d. / Reduce ripple (from a A.C. rectifier)
- Storing energy
- Blocking D.C.

Chapter 20 Magnetic Field

20.1 Basic Concepts

Like poles repel; unlike poles attract.

Magnetic field: A region of space where a permanent magnet or a current-carrying conductor or a moving charged particle experiences a force.

Magnetic field lines: show the direction in which a free magnetic north pole would move if placed in the field. Always starts from a north pole and ends at a south pole (outside a magnet).

20.2 Force on current-carrying conductor

The motor effect: Fleming's **Left-Hand** Law

- Thumb $\Leftrightarrow$ $\underline{\text{F}}$orce F $\Rightarrow$ First
- Index $\Leftrightarrow$ Field $\underline{B}$ $\Rightarrow$ Second
- Middle $\Leftrightarrow$ $\underline{\text{C}}$urrent I $\Rightarrow$ Third

Force experienced by the conductor: $F = BIL\sin\theta$

Magnetic flux density B: it is numerically equal to the force per unit length per unit current experienced by a long straight wire placed at right angles to a uniform magnetic field. Unit: Tesla T; $1\,\text{T} = 1\,\text{A}^{-1}\text{m}^{-1}$

Tesla: The unit for magnetic flux density. Defined as the uniform magnetic flux density which, acting normally to a long straight wire carrying a current of 1 A, causes a force per unit length of $1\,\text{Nm}^{-1}$ on the conductor.

20.3 Force on a moving charge

$$\begin{aligned} &F = BIL\sin\theta; I = \frac{nq}{t}; L = tv; n = 1 \\ \Rightarrow &F = Bqv\sin\theta \end{aligned}$$

Fleming's left hand rule applies here as well. NOTE: the middle finger points in the direction of the conventional current, so for electrons and other negatively charged particles, the middle finger needs to be pointing in the opposite direction.

When the particle enters a field normal to the direction of motion, it will perform circular motion. This is because:

- The magnetic force provides the centripetal force.
- The magnetic force is always perpendicular to the direction of the velocity.
- (because always perpendicular,) the speed stays constant, only the direction of the velocity changes, so the magnitude of the force is also constant

These conditions are enough to guarantee circular motion. The radius of which is deduced below:

$$Bqv = F = F_c = \frac{mv^2}{r}$$
$$r = \frac{mv}{Bq}$$

Velocity selector: a charged particle is sent into an electric field and a magnetic field. The fields are aligned in such a direction that the electric and magnetic forces on the particle are in opposite directions. The particles with some velocity v would move in a straight line. Other particles are deflected.

$$\begin{aligned} F_E &= F_B \\ qE &= Bqv \\ v &= \frac{E}{B} \quad (v \text{ is a scalar}) \end{aligned}$$

Hall effect: Electrons experience a magnetic force while moving through a conductor, so some electrons move to one side of the conductor. As they accumulate, a potential difference builds up. At hall voltage V_H, equilibrium is reached as $F_B = F_E$. (The direction of the potential gradient is perpendicular to both the current and the magnetic field.)

$$F_E = qV_H/d; F_B = Bqv; I = Anvq; A = td$$

$$V_H = \frac{BI}{ntq}$$

where n is the number density of charge carriers and t is the thickness of the conductor.

20.4 Measuring magnetic flux density

Hall probe: small current pass through a semiconductor material. Hall voltage produced is proportional to magnetic flux density if the conductor is a right angles with the field. Rotate the probe in the field until a maximum value is obtained.

20.5 Magnetic fields due to currents

Right-hand rule: holding the conductor in the right hand with the thumb pointing in the direction of current flow, then the direction of your fingers give the direction of the magnetic field.

Right-hand grip rule: Grasp the coil or solenoid with the right hand, with the fingers pointing in the direction of the conventional current. The thumb then gives the direction of the magnetic field (North pole of the coil).

Electromagnets: strength of B due to a coil may be increased by winding the coil on a bar of soft iron. The iron bar is said to be the <u>core</u> of the coil. They can be switched on and off and switch poles easily.

20.6 Electromagnetic Induction

Magnetic flux: $\Phi = B \cdot A \cdot \sin\theta$ (Unit: weber (Wb) $1\,\mathrm{Wb} = 1\,\mathrm{Tm}^2$)

Magnetic flux linkage: $N\Phi = NBA\sin\theta$

Faraday's law of electromagnetic induction: The e.m.f. induced is proportional to the rate of change of magnetic flux linkage.

$$V \propto \frac{\Delta(N\Phi)}{\Delta t}$$

Fleming's right hand rule: The fingers represent the same things as they do in Fleming's left hand rule. Left hand $\Leftrightarrow$ Force; Right hand $\Leftrightarrow$ e.m.f.

Lenz's law: The direction of the induced e.m.f. is such as to cause effects to oppose the change that is producing it.

The laws can be explained by conservation of energy and summarized using the following equation:

$$E = -\frac{\mathrm{d}\left(N\Phi\right)}{\mathrm{d}t}$$

Chapter 25 Astronomy and Cosmology

25.1 Standard candles

Standard candles: A standard candle is a stellar object of known luminosity.[1]

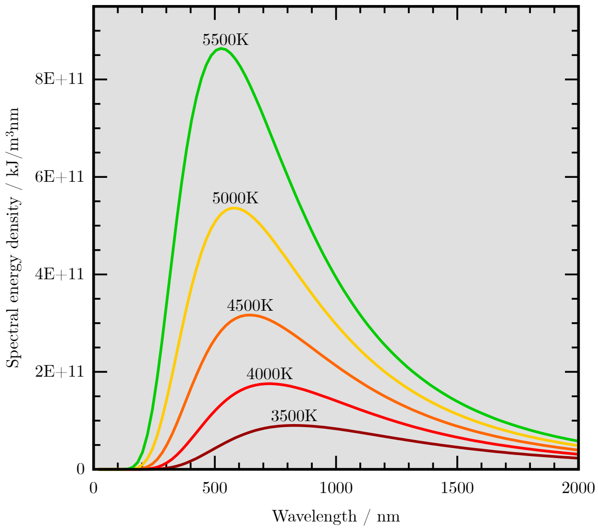
Luminosity L: Total energy emitted per unit time (by the object).

Radiant flux intensity F: Radiant power per unit area passing normally through the unit area.

$$F = \frac{L}{4\pi r^2} \quad \text{(Unit: watt per square meter, Wm}^{-2}\text{)}$$

25.2 Black body radiation

Stars behave approximately as black bodies.



- Radiation emitted over a continuous range of wavelengths.
- Peak moves to shorter wavelength as T increases
- Higher T, greater power.

Wien's displacement law: $\lambda_{\text{max}} = \frac{b}{T}$, where $b = 2.898 \times 10^{-3}\,\text{m} \cdot \text{K}$ is Wien's displacement constant.

Stefan-Boltzmann law: For a spherical object of radius r emitting black-body radiation at thermodynamic temperature T, its luminosity L is given by the following, where $\sigma = 5.67 \times 10^{-8}\,\text{Wm}^{-2}\text{K}^{-4}$ is the Stefan-Boltzmann constant.

$$L = 4\pi\sigma r^2 T^4$$

[1] The definition is from mark schemes. The original author's document for this appears to have been corrupted. The textbook defines it as "a class of stellar object which has a known luminosity and whose distance can be determined by calculation using its radiant flux intensity and luminosity."

25.3 Redshift

Redshift: Increase in wavelength of light due to the Doppler effect (relative motion of stellar objects due to gravitational interaction) or expanding universe.

$$\lambda = (c + v)/f_0 = \lambda_0 \cdot \frac{c+v}{c} = \lambda_0 \cdot \left(1 + \frac{v}{c}\right)$$
$$\Delta\lambda = \lambda - \lambda_0 = \lambda_0 \cdot \frac{v}{c}$$
$$\frac{\Delta\lambda}{\lambda_0} = \frac{\Delta f}{f_0} = \frac{v}{c}$$

$\Delta\lambda$ is positive for redshift. I.e., objects move away from each other.

Hubbles' Law: $v = H_0 \times d$

Cosmological Principle: On a large scale, the universe is both homogeneous and isotropic. The universe would have the same general appearance from anywhere else in the universe as it appears from Earth.

Age of the universe: $T = \frac{1}{H_0}$

Chapter 14 Temperature

14.1 Thermal equilibrium

Thermal equilibrium: When different regions in thermal contact are at the same temperature, they are said to be in thermal equilibrium.

14.2 Unit of temperature

Thermodynamic temperature is in Kelvin K. It starts with 0 K at absolute zero.

The unit of temperature on the celsius scale is the degree celcius °C. $1°\text{C} = 1K$. I.e. $\Theta/°\text{C} = T/K - 273.15$.

14.3 Specific heat capacity and specific latent heat

Specific heat capacity: The numerical value of the specific heat capacity of a substance is the quantity of thermal energy needed to raise the temperature of unit mass of the substance by one kelvin.

$$\Delta Q = mc\Delta T \quad (\text{Unit of } c\text{: J kg}^{-1}\text{K}^{-1})$$

Specific latent heat (of fusion) (of a substance): The numerical value of the specific latent heat of fusion is the quantity of thermal energy required to convert unit mass of a substance from the solid state to the liquid state without any change in temperature.

$$\Delta Q = m \cdot L_f$$

Specific latent heat (of vapourisation) (of a substance): (same as above), liquid to vapour, L_v

14.4 Exchange of thermal energy

Heat lost by hot object = Heat lost to surrounding + Heat gained by cold object

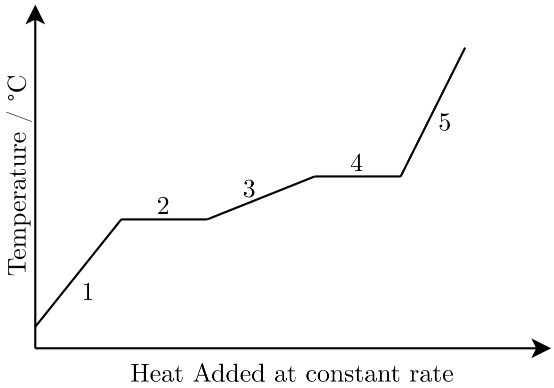
14.5 Experiments

Finding L_f using an electrical heater: $E = IVt$. Assuming heat is lost to surroundings at a constant rate, we can carry out the experiment twice with the heater at different temperatures to rule out the impact of heat loss.

$$\begin{aligned} I_1V_1t &= m_1L_r + P_{\text{loss}}t \\ I_2V_2t &= m_2L_r + P_{\text{loss}}t \\ L_f &= \frac{(I_1V_1 - I_2V_2)t}{m_1 - m_2} \end{aligned}$$

Factors affecting the rate of evaporation of liquids: temperature, area of exposure, pressure, humidity of surrounding air, nature of liquid, wind.

Heating curve:



1. Solid, $Q = mc_s\Delta T$
2. Solid–Liquid, $Q = mL_f$
3. Liquid, $Q = mc_l\Delta T$
4. Liquid–Gas, $Q = mL_v$
5. Gas, $Q = mc_g\Delta T$

Chapter 15 Ideal Gas

15.1 The mole

A base quantity of amount of substance.

The mole is the amount of substance which contains 6.02×10^{23} elementary entities.

The Avogadro Constant N_A is the number of elementary entities in one mole of any substance. $N_A = 6.02 \times 10^{23}\,\mathrm{mol}^{-1}$

15.2 Equations for ideal gases

$$\left.\begin{array}{lll} \text{Boyle's Law} & p_1V_1 = p_2V_2 & T \text{ is constant} \\ \text{Charles's Law} & \dfrac{V_1}{T_1} = \dfrac{V_2}{T_2} & P \text{ is constant} \\ \text{Gay-Lussac's Law} & \dfrac{P_1}{T_1} = \dfrac{P_2}{T_2} & V \text{ is constant} \end{array}\right\} \text{Unnecessary}$$

An ideal gas is one which obeys the equation of state $pV = nRT$ at all pressures p, volumes V and thermodynamic temperatures T.

Universal gas equation / Equation of state for ideal gases:

$$pV = nRT$$

, where n is the number of moles of gas, and $R = 8.314\,\mathrm{J\,mol^{-1}\,K^{-1}}$ is the molar gas constant.

An alternative form:

$$pV = NkT$$

, where N is the number of molecules of gas, and $k = R/N_A$ is the Boltzmann constant.

15.3 Kinetic theory of gases

Assumptions:

- All molecules are identical and behave as hard and perfectly elastic spheres
- The volume of the molecules themselves is negligible (compared to the volume of the container)
- There is no force between molecules.
- There are many molecules, all moving randomly.

Equations:

$$pV = \frac{1}{3}Nm\left\langle c^2\right\rangle \Rightarrow p = \frac{1}{3}\rho\left\langle c^2\right\rangle$$

$$pV = \frac{2}{3}N\left(\frac{1}{2}m\left\langle c^2\right\rangle\right) = \frac{2}{3}N \cdot E_k = NkT$$

$$\sqrt{\langle c^2\rangle} = \sqrt{\frac{3kT}{m}}$$

$\sqrt{\langle c^2\rangle}$ is the root-mean-square (r.m.s.) speed

Chapter 16 Thermodynamics

16.1 Internal Energy

Internal Energy (of a gas): Sum of potential energies and kinetic energies of all molecules owing to their random motion.

Note: for an ideal gas, there are no intermolecular forces, so the potential energy is 0 for ideal gas and its internal energy is due to solely the kinetic energy of its molecules.

A rise in temperature of an object is related to an increase of I.E. of the object.

16.2 First law of thermodynamics

$$\Delta U = q + W$$

The increase in I.E. of a system is equal to the sum of the thermal energy added to the system and the work done on it.

The work done by a gas when its volume changes by ΔV at constant pressure p is $W = p\Delta V$. The deduction is left as exercise for the reader.

Two special cases:

- adiabatic process: $q = 0$, no thermal energy leaves or enters the system. E.g., compressing a gas in an insulated cylinder.
- Only thermal energy: $W = 0$, only heat changes the internal energy. E.g., heating water using an electric kettle.

Change of I.E. during state changes: No change in temperature, so no change in K.E.

- Melting: intermolecular bonds broken, potential energy increase
- Boiling/Evaporation: separation of molecules increase, potential energy increase. (The increase in separation when vapourising is much greater than in melting, so the latent heat of vapourisation is normally much larger than the latent heat of fusion.)

Chapter 22 Quantum physics

22.1 Photon

A photon is the special name given the a quantum of energy when the energy is in the form of electromagnetic radiation.

$$\text{Energy} \qquad E = hf = \frac{fc}{\lambda}$$
$$\text{Momentum} \qquad p = \frac{E}{c} = \frac{h}{\lambda}$$

Common unit used (for energy): the electronvolt ($1\,\text{eV} = 1.6 \times 10^{-19}\,\text{J}$)

22.2 Photoelectric effect

22.2.1 Photoelectric emission

Photoelectric emission: The release of electrons from surface of metal when EM radiation is incident on its surface.
Electrons emitted are referred to as photoelectrons.

Eistein's theory of photoelectric emission:

$$hf = \Phi + \frac{1}{2} m_e v_{\text{max}}^2$$
$$\Phi = hf_0$$

Photon energy = work function + maximum E_k of photoelectron.

Threshold frequency f_0: The minimum frequency of incident EM radiation for photoelectric emission to take place.

Work function Φ: The minimum energy necessary for an electron to escape from the surface (of the metal).

Intensity: It is defined as the power per unit area. For a fixed wavelength, the intensity is proportional to the number of photons per unit area per unit time. For a fixed wavelength, the intensity does not affect the energy per photon.
Therefore,

- Whether or not emission takes place depends only on the frequency (and the material) and NOT on intensity.
- For a given frequency , rate of emission of photoelectrons is proportional to the intensity of the radiation.

22.2.2 Wave-particle duality

$$\text{de Broglie wavelength :} \qquad \lambda = \frac{h}{p}$$

22.2.3 Energy levels in atoms and line spectra

Electron energy level: Electrons in an atom lies in <u>discrete energy levels</u>. Electrons can have any of these energy values but not energies between levels.

Electrons are most stable when they occupy the lowest energy level. They are said to be in the ground state.
Electrons can absorb energy and be promoted to a higher energy level.
Electrons promoted into higher energy levels are said to be in an excited state.

Photons with specific frequencies are absorbed to promote electrons to an excited state. The electrons becomes unstable, thus emit photons to return to the lower energy level.

$$hf = E_2 - E_1$$
$$\lambda = \frac{hc}{\Delta E}$$

The movement of electrons between energy levels is called electron transition.

Continuous spectrum: A continuous band of different colours without gaps in the middle is called a continuous spectrum. E.g., black body radiation is a continuous spectrum; atoms in high temperature and under high pressure also produce a continuous spectrum.
Emission spectrum: When atoms are given energy, they emit light of several particular wavelengths. They appear in a spectrum as several distinct and discrete bright lines. This is an emission spectrum.
Absorption spectrum: When light with a continuous spectrum (e.g., white light) is shone through a low-pressure gas, certain wavelengths are absorbed by the gas and appear as dark lines missing from the continuous spectrum. The spectrum with these dark lines is called an absorption spectrum.
Emission and absorption spectra for one particular type of atom are complementary: the bright lines and missing lines coincide. The lines are characteristic to that one type of atoms, so the lines can be used to identify different atoms.

Chapter 23 Nuclear Physics

23.1 Basic concepts

Unified atomic mass unit (u): It is defined as being equal to 1/12 of the mass of a C-12 atom.
Mass defect: Mass defect of a nucleus is the difference between total mass of separated nucleons and combined mass of the nucleus.
Mass-energy equivalence: $E = mc^2$ (for stationary objects)
Binding energy: The energy required to separate all nucleons in a nucleus to infinity. (Equivalent to the mass defect of the nucleus.)
Binding energy per nucleon: Binding energy divided by the number of nucleons. The higher this value is, the more stable the nucleus is.
Nucleons in a nucleus are held together by the strong nucleus force.

23.2 Fusion and fission

Nuclear fusion: Occurs when two light nuclei combine to form a nucleus of greater mass. This process occurs (in stellar cores) below Fe, as they always form more stable nuclei.
Nuclear fission: Splitting of a heavy nucleus into two lighter nuclei of approximately the same mass

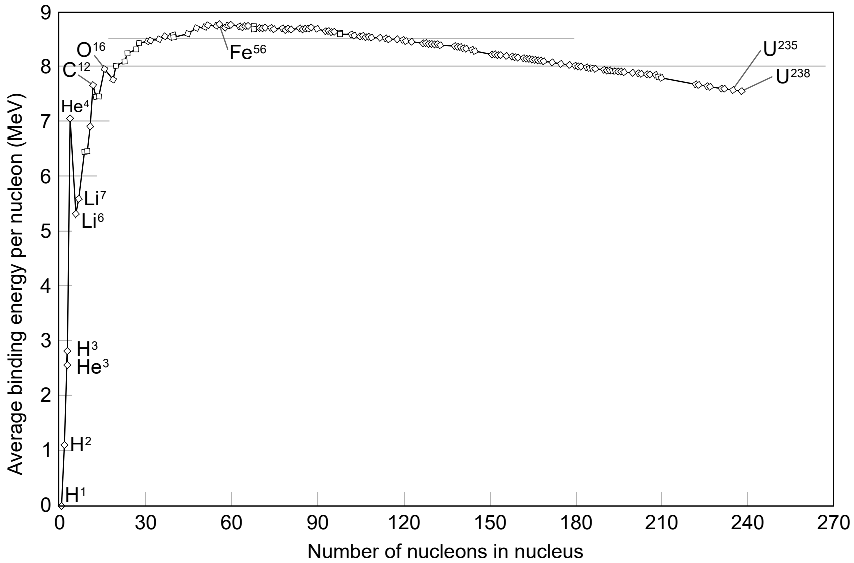


Figure 23.1: Graph of binding energy per nucleon plotted against number of nucleons

In Figure 23.1, both fusion and fission (under normal circumstances) happen upwards. You will need to know that the top of the curve (most stable nucleus) is iron.

23.3 Random decay

Radioactive decay is a random and spontaneous process.

- Random: we cannot predict which nucleus will decay first. However, because the number of nuclei is so large, there is a constant probability that a nucleus will decay in any fixed period of time.

- Spontaneous: It is not affected by external factors. E.g., temperature and pressure.

Half-life of a radioactive decay: the time taken for the number of undecayed nuclei to be reduced to half its original number.

Decay constant λ: The probability per unit time of decay of a nucleus. For a given type of nucleus, this is a constant. Unit: Becquerel (Bq), $1\,\mathrm{Bq} = 1\,\mathrm{s}$.

Activity A: The number of nucleus decay per unit time in a radioactive source.

$$A = -\frac{\mathrm{d}N}{\mathrm{d}t}; A = \lambda N$$

$$\Rightarrow N = N_0 e^{-\lambda t}; A = A_0 e^{-\lambda t}$$

$$\text{Half life: } t_{1/2} = \frac{\ln 2}{\lambda}$$

Chapter 24 Medical Physics

24.1 Ultrasound

Sound with frequency above 20 kHz. (Up to 10 MHz for medical purposes.)
It is generated using a piezo-electric transducer.

Reflection and absorption:
Specific acoustic impedance: defined as the product of the density of the material and the speed of sound in that material. $Z = \rho c$.
Intensity Reflection coefficient $\frac{I_R}{I_0} = \frac{(Z_2-Z_1)^2}{(Z_2+Z_1)^2}$

The coefficient between air and soft tissue is almost 1. (Almost all the ultrasound is reflected and very little actually is transmitted into the body.) A water-based jelly is used to overcome the problem.

Attenuation of ultrasound:

$$I = I_0 e^{-\mu x}$$

Linear absorption coefficient μ: depends on medium and frequency of ultrasound. Smaller μ means lower intensity loss when passing through unit length in the medium.

24.2 X-Rays

Generation of X-Rays: electrons are accelerated to a very high speed over an electric field and shot at a target. The sudden acceleration of the electrons produce an X-ray photon. The minimum wavelength (cutoff wavelength) is achieved when the electron is stopped in one collision and all its kinetic energy is converted into one X-ray photon.

$$hf = E = eV \Rightarrow \lambda_0 = \frac{hc}{eV}$$

Hardness: The penetrating power of an X-ray beam. (The shorter the wavelength, the harder the beam is.)

X-ray image:
White for bone with greater attenuation, dark for soft tissue.
Sharpness: The clarity of edges in the image.
Contrast: difference in the degree of blackening

CT scanning:
The object is divided up into slices. X-ray images of that slice are taken from many different angles. These images can be processed using a computer into a 3D image of the slice. Such a 3D image for each slice is taken until a full 3D image is generated. The 3D image can be rotated[2].

24.3 PET Scanning

Radioactive tracer: A chemical compound in which one or more of its atoms have been replaced by a radioactive nuclei of the same element (isotope) that can be used to locate or follow the progress of coumpounds in living tissues.

[2] Ask CAIE why they made this a point in several mark schemes.

β^+ emission:

$$^{18}_{9}\mathrm{F} \rightarrow {}^{18}_{8}\mathrm{O} + {}^{0}_{1}\mathrm{e} + {}^{0}_{0}\nu$$

Annihilation:

$$^{0}_{-1}\mathrm{e} + {}^{0}_{1}\mathrm{e} \rightarrow \gamma + \gamma$$

When a particle and its antiparticle meet, they annihilate each other, releasing their combined mass as energy in the form of photons.

Chapter 17 Simple Harmonic Oscillations

17.1 Basic concepts

Frequency f: Number of oscillations completed per unit time.

Period T: Time taken for one complete oscillation.

$$f = \frac{1}{T}$$
$$\text{Angular Frequency} \quad \omega = \frac{2\pi}{T}$$

Displacement x: Distance from equilibrium position

Amplitude A: (Magnitude of) maximum displacement. (Amplitude is a scalar.)

17.2 S.H.M.

Simple harmonic motion/oscillation: the motion of a particle about a fixed point such that its acceleration is proportional to the displacement x from the fixed point and is in the opposite direction as the displacement.

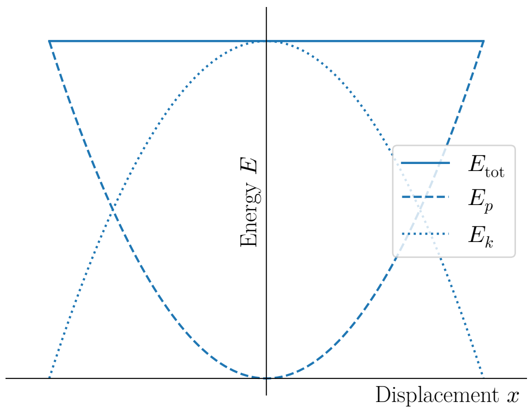
$$a = -kx$$

From the definition (and a bit of math), we can know that

$$\begin{aligned} x &= x_0 \sin \omega t \\ \text{(Differentiate)} \Rightarrow v &= \omega \cdot x_0 \cdot \cos \omega t \\ \Rightarrow v &= \pm\omega\sqrt{x_0^2 - x^2} \\ \text{Max speed: } v_0 &= x_0 \cdot \omega \\ \text{(Differentiate)} \Rightarrow a &= -\omega^2 \cdot x_0 \cdot \sin \omega t = -a_0 \sin \omega t \\ a &= -\omega^2 x \quad \text{(For all } t\text{)} \end{aligned}$$

Energy of S.H.M.:

$$\begin{aligned} v = \pm\omega\sqrt{x_0^2 - x^2} \quad E_k &= \frac{1}{2}mv^2 \\ \text{K.E.} \quad E_k &= \frac{1}{2}m\omega^2\left(x_0^2 - x^2\right) \\ F_{\text{res}} &= -m\omega^2 x \\ \text{P.E.} \quad E_p &= \frac{1}{2}m\omega^2 \cdot x^2 \\ E_{\text{tot}} &= \frac{1}{2}m\omega^2 x_0^2 \end{aligned}$$

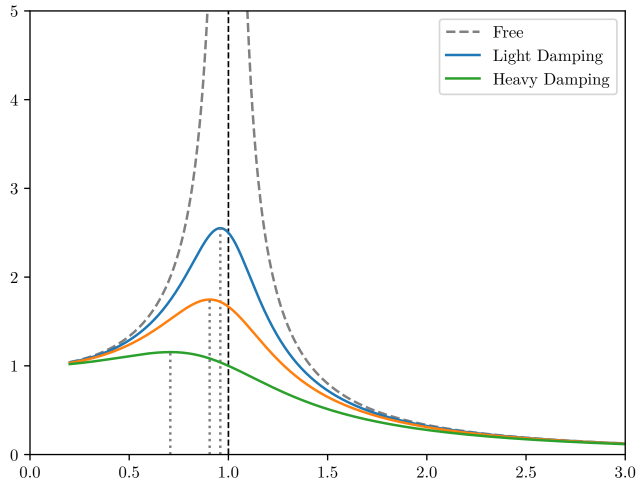


17.3 Damped and forced oscillations

Free oscillation: The only external force acting on it is the restoring force.
The object in this case vibrates at its natural frequency.

Damped: Friction and other resistive forces cause energy loss into thermal energy. Amplitude decreases over time.
Critical Damping: Displacement decreased to zero in the shortest time without any oscillations.
Overdamped / Heavy Damping: Displacement decreases to zero in a longer time than critical damping. (No oscillations either)

Forced vibration: Periodic force applied to make the object vibrate at the frequency of the force.
Resonance: Natural frequency of vibration is equal to the driving frequency. This gives a maximum amplitude of vibration.



Chapter 21 Alternating Current

21.1 Basic Concepts

Equations

$$I = I_0 \sin \omega t; \quad V = V_0 \sin \omega t$$

A (cathode-ray) oscilloscope can be used to measure period T, frequency f, V and I of A.C.
The x-axis (input) is always time on a traditional scope. Be careful of what the y-input is.

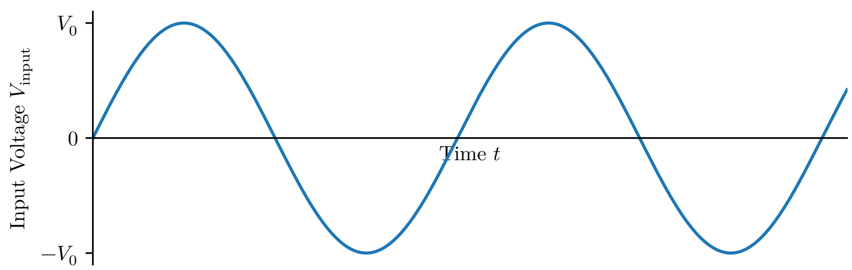
Power in a (sinusoidal) A.C. circuit

$$\begin{aligned} P &= I_0^2 R \sin^2 \omega t \\ \Rightarrow \langle P \rangle &= \frac{1}{2} I_0^2 R = \frac{1}{2} \frac{V_0^2}{R} = \frac{1}{2} P_0 \\ \Rightarrow V_{\text{r.m.s.}} &= \sqrt{\langle V^2 \rangle} = \frac{\sqrt{2}}{2} V_0 \\ \Rightarrow I_{\text{r.m.s.}} &= \sqrt{\langle I^2 \rangle} = \frac{\sqrt{2}}{2} I_0 \end{aligned}$$

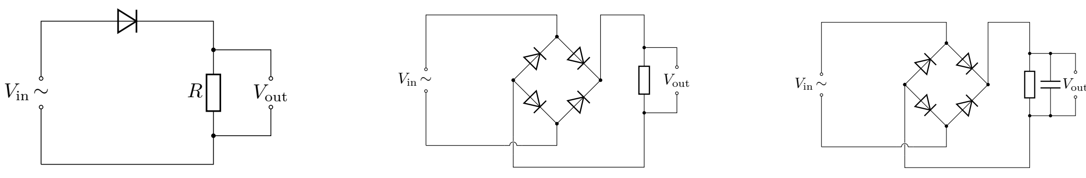
The r.m.s. (root-mean-square) value of an alternating current or voltage is the value of the direct current or voltage that would produce thermal energy per unit time / at the same rate in a resistor.

21.2 Rectification and Smoothing

Input voltage:

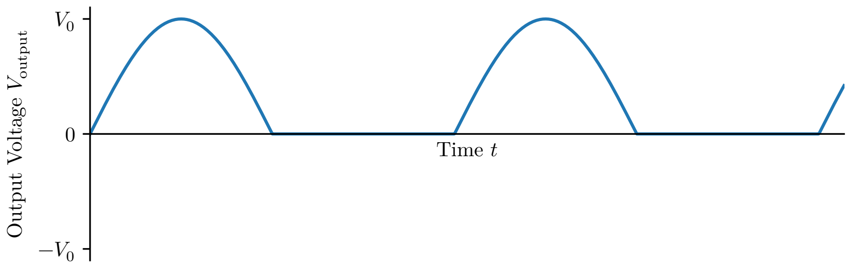


The circuit diagrams and graphs of output voltages for half-wave rectification, full-wave rectification without and with smoothing are shown in Figures 21.1 and 21.2.

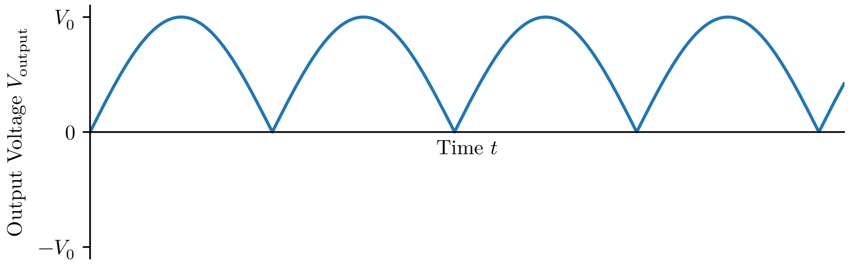


(a) Half-wave rectifier (b) Full bridge rectifier (c) Full bridge rectifier with smoothing

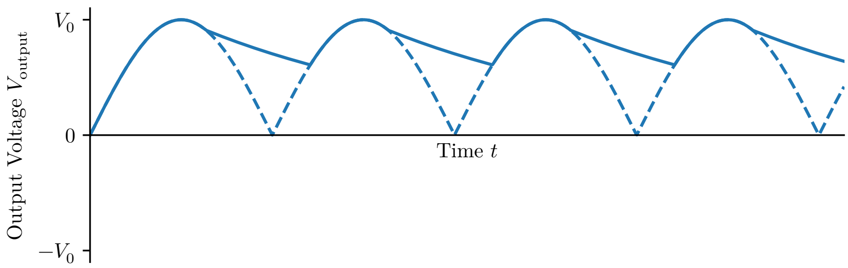
Figure 21.1: Circuit diagrams for rectifiers



(a) Half-wave rectifier



(b) Full bridge rectifier



(c) Full bridge rectifier with smoothing

Figure 21.2: Output voltage fluctuations for rectifiers

For the smoothed output, the capacitor charges up during the rising parts of the half-cycle, and discharges through the resistor as the output voltage falls.
It reduces fluctuations in the D.C. output.
The larger the time constant (RC), the smaller the ripples in the D.C. voltage (i.e., slower discharging process).

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