Advanced Extension Award:
2003 Friday 27th June, Afternoon paper
Soloutions

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Contents

1 Question 1 : Total 21 marks

*Material in this question relates to syllabus item **1.5** detailed on page 36. Related review material in Section 8.0.1.*

(a) 4 marks

A physical assembly of particles is called matter.

A physical assembly of antiparticles is called antimatter.

Properties of antimatter:

(i) Every particle of matter has a corresponding antiparticle.

(ii) Antiparticles have the same mass and spin as particles.

(iii) Antiparticles have opposite signs of electric charge.

When some antimatter interacts with some matter the matter and antimatter are annihilated. The combined energies associated with the matter and antimatter reappears.

(b) 3 marks

If an antimatter asteroid were to collide with the Earth (made of matter) then the asteroid and an equivalent amount of matter would be annihilated, releasing a vast amount of energy which was previously associated with the (anti)particles mass and velocity.

If a matter asteroid were to collide with the Earth then there would simply be an exchange of kinetic energy and no annihilation of mass.

(c (i)) 4 marks The annihilation of an electron-positron pair.

$$e^- + e^+ \rightarrow \gamma + \gamma \tag{1}$$

As the particles and antiparticles are at rest the only change in energy is due to the change in mass of the system.

One conclusion from Einstein's theory of relativity is that energy has mass. A change in energy is linked to a change in mass through the following relation:

$$\Delta E = \Delta m c^2 \tag{2}$$

An electron has a rest mass of $m_e = 9.11 \times 10^{-31}$ kg.

A positron has a rest mass of $m_p = 9.11 \times 10^{-31}$ kg

Therefore, the total change in mass of the system is $\Delta m = 1.822 \times 10^{-30}$

This has a corresponding energy change associated with it of
(given to 3 d.p.)

$$\Delta E = \Delta m \cdot c^2 \tag{3}$$
$$\Delta E = 1.640 \times 10^{-13} \text{ J} \tag{4}$$
$$\tag{5}$$

After the annihilation of the electron and positron this energy becomes associated with two gamma rays. Each ray has an energy of

$\frac{\Delta E}{2} = 8.2 \times 10^{-14}$ J.

Using the relation $E = \frac{hc}{\lambda}$ we obtain a gamma ray wavelength of

$$\lambda = \frac{h \cdot c}{8.2 \times 10^{-14}} = 2.42 \times 10^{-12} \text{ m} = 2.42 \text{ pm} \tag{6}$$

Where pm is short for picometers, 10^{-12}m.

(c ii) 2 marks

Momentum will be conserved during this interaction and so the emitted photons both must have opposite directions.

(d i) 4 marks

Within the electric field all the particles under consideration (electron, proton and positron) would be deflected, as they carry a charge.

The electron would be attracted towards the positive plate as an electron carries a negative charge.

The proton and positron would be attracted towards the negative plate as they both carry a positive charge.

(d ii) 4 marks

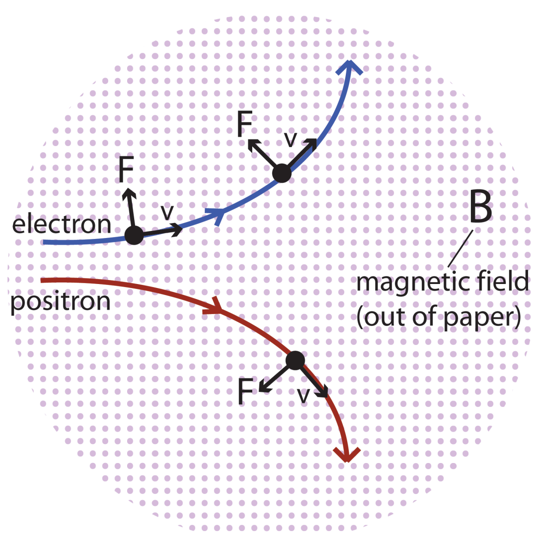
Within a uniform magnetic field acting at right angles to the direction of motion we would observe an electron being deflected by a magnetic force acting at right angles to the direction of motion. The direction of this force can be found by applying Fleming's left-hand rule (see Section 8.0.1), remembering of course that an electron has negative charge and so the propagation of an electron to the right represents a *conventional current* to the left. This force acts in such a way as to force a circular path on the electron.

In the case of a positron the magnetic force would bend its path in the opposite direction to that of the electron, as the direction is dependent on sign of the charge. As a positron has the same mass as the electron then the path taken would mirror the electron.

In the case of a proton, the deflection direction would be the same as that of the positron. However as the proton has a mass $\sim$ 1800 times greater than that of the electron or positron then for equivalent velocity the angle of deflection would be much smaller for the heavier proton. This can be seen mathematically with reference to the equation of motion:

$$F = ma = QBv \tag{7}$$

$$a = \frac{QBv}{m} \tag{8}$$



2 Question 2 : Total 21 marks

Material in this question relates to syllabus item ***2.1*** *and* ***3.5*** *detailed on page 41 and 44 respectively.*
Related review material in Section 8.0.2.

(a i) 2 marks

A precise experimental determination of θ_B is difficult due to the small rate of change of I_{min} near θ_B. The turning point of the graph is extremely broad.

(a ii) 2 marks

The observers estimate of θ_B is usually too low due to the asymmetric change of I_{min} around θ_B, smoother at lower angle.

(b i) 2 marks

By inspection of **Table 2.1** on page 7 and observing which value of Ψ results in maximum transmitted intensity it can be deduced when the polarising direction of the filter is in alignment with the plane of polarisation of the incident light, i.e. $\Psi = 80°$.

$\Psi/°$	**I/arbitrary units**
0	0.15
20	1.25
40	2.85
60	4.40
80	5.00
100	4.40
120	2.85
140	1.25
160	0.15
180	0.15

Table 2.1

(b ii) 1 marks

Re-tabulating the data with respect to the angle ϕ between the plane of polarisation of the incident light and the polarising direction of the filter gives **Table 2.2**.

$\phi/^\circ$	**I/arbitrary units**
0	5.00
20	4.40
40	2.85
60	1.25
80	0.15
100	0.15
120	1.25
140	2.85
160	4.40
180	5.00

Table 2.2

(b iii) 7 marks

We are given the following equation:

$$I = I_0(\cos\ \phi)^n \tag{9}$$

We are asked to rearrange it into a form which allows us to find the constant through graphical means. A nonlinear equation such as Equation 9 can be easily reduced to a linear form through the use of logarithms. A linear relation facilitates a simple graphical method for solving (see Section 8.0.2).

Taking logs of both sides of the equation results in

$$\log I = \log[I_0(\cos\phi)^n] \tag{10}$$

$$\log I = \log I_0 + \log[(\cos\phi)^n] \tag{11}$$

$$\log I = \log I_0 + n \cdot \log(\cos\phi) \tag{12}$$

We are interested in find out the parameter n. We have values for I, I_0 (the maximum intensity) and ϕ. Equation 12 is in the form of a straight line

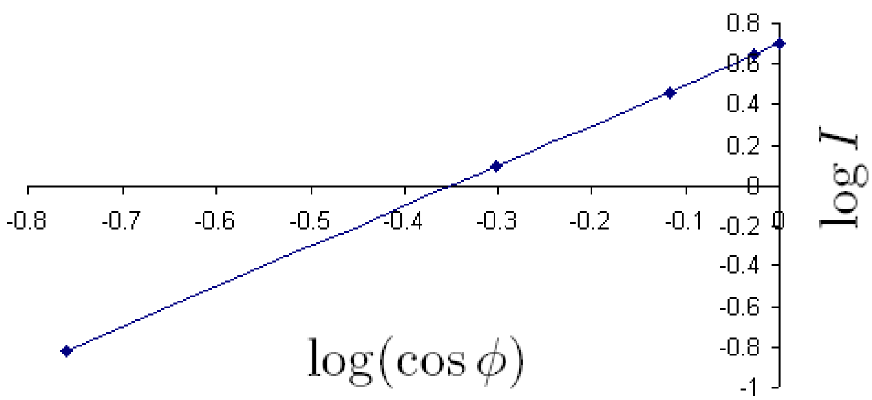
$y = m \cdot x + c$, therefore a plot of $\log I$ vs $\log(\cos\phi)$ will result in a straight line of gradient n and y axis intercept of $\log I_0$.

Always give the data used (given to 3 d.p.) to draw the graph:

$\log(\cos\phi)$	$\log I$
0	0.699
-0.027	0.643
-0.116	0.455
-0.301	0.097
-0.760	-0.824
Undefined	Undefined
Undefined	Undefined
Undefined	Undefined
Undefined	Undefined
Undefined	Undefined

Table 2.3

Once plotted this graph has the form



From which we obtain (to 2 d.p.) $n = 2$ and $I_0 = 5$.

3 Question 3 : Total 19 marks

*Material in this question relates to syllabus item **1.4.5** and **1.5.2** detailed on page 35 and 36 respectively.*
Nucleonic radioactivity is reviewed in Section 8.0.3.
Capacitor discharge circuits are reviewed in Section 8.0.4.

(a i) 1 mark

The decay constant of a radioactive nuclide, λ is defined as the constant of proportionality between the activity and the number of undecayed nuclei.

$$-\frac{dN}{dt} = \lambda N \tag{13}$$

(a ii) 1 mark The time constant, RC, of a capacitor discharge circuit is defined as the time taken for the charge stored to reduce to e^{-1} of the initial value, where e is the exponential constant with a value of 2.718. The charge on a capacitor is defined as:

$$Q = Q_0 e^{-t/RC} \tag{14}$$

so when $t = RC$, the time constant, we have

$$Q = Q_0 e^{-RC/RC} = \frac{Q_0}{e} \tag{15}$$

(b i 1) 2 marks

The rate of change R_A of the number n_A of nuclei A is given by

$$R_A = R_{A\to B} + R_{A\to C} \tag{16}$$

$$= \frac{\mathrm{d}n_A}{\mathrm{d}t} = \left.\frac{\mathrm{d}n_A}{\mathrm{d}t}\right|_{A\to B} + \left.\frac{\mathrm{d}n_A}{\mathrm{d}t}\right|_{A\to C} \tag{17}$$

$$= -\lambda_B n_A - \lambda_C n_A \tag{18}$$

There is a negative sign as the rate of change is decreasing.

(b i 2) 2 marks The rate of change R_B of the number n_B of nuclei B is given by

$$R_B = -R_{A\to B} \tag{19}$$
$$= \lambda_B n_A \tag{20}$$

This is a positive rate as the total number of nuclide B is increasing.

(b ii) 4 marks

The equation relating n_B to n_A is:

$$n_B = -\frac{\lambda_B n_A}{(\lambda_B + \lambda_C)} + K \tag{21}$$

where K is a constant.

We want an expression for n_B at any time t.

n_A can be expressed as:

$$n_A = n_0 e^{-\lambda t}$$
$$= n_0 e^{-(\lambda_B+\lambda_C)t}$$

and n_B can be expressed as:

$$n_B = \int_0^t R_b \mathrm{d}t$$

$$= \int_0^t \lambda_B n_A \mathrm{d}t$$

$$= \lambda_B n_0 \int_0^t e^{-\lambda t} \mathrm{d}t$$

$$= -[\frac{\lambda_B n_0}{\lambda} e^{-}\lambda t]_0^t$$

$$= -\frac{\lambda_B n_0}{\lambda} e^{-\lambda t} + \frac{\lambda_B n_0}{-\lambda}$$

which gives

$$n_B = \frac{\lambda_B n_0}{\lambda_B + \lambda_C} - \frac{\lambda_B n_0}{\lambda_B + \lambda_C} e^{-\lambda t} \tag{22}$$

(c i) 3 marks

Capacitor C_1 initially has a charge of Q_0 and C_2 is uncharged.

Capacitor C_1 partially discharges through C_2 and R. At $t \to \infty$ the two capacitors have an equivalent potential of V_e.

$$V_1 = V_2 = \frac{Q_1(t)}{C_1} = \frac{Q_2(t)}{C_2} = V_e$$

where the total charge Q_0 comprises:

$$Q_0 = Q_1 + Q_2$$

at $t = 0$, we have:

$$V_1(0) = \frac{Q_1(t)}{C_1} = \frac{Q_0}{C_1}$$

$$V_2(0) = \frac{Q_2(t)}{C_2} = \frac{0}{C_2} = 0$$

Therefore,

$$2V_e = \frac{Q_1}{C_1} + \frac{Q_2}{C_2}$$

$$= \frac{Q_1}{C_1} + \frac{Q_0 - Q_1}{C_2}$$

Now at equilibrium ($t = \infty$) $Q_1 = 0$, therefore

$$V_e = \frac{Q_0}{2C_2}$$

(c ii 1) 1 mark

Power dissipated by resistor at a give instant is given by

$$P = IV$$

rearranging gives:

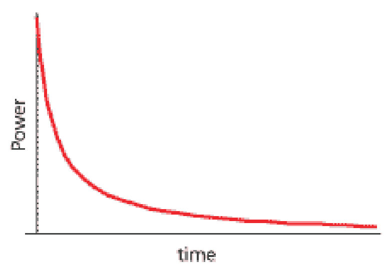
$$P = \frac{V^2}{R}$$

the potential across the resistor V_R is given by $V_R = V_1 - V_2$, therefore

$$P = \frac{(V_1 - V_2)^2}{R} \tag{23}$$

(c ii 2) 3 mark

A sketch showing the variation of power dissipated with time would be



The area under a power versus time curve is the energy.

(c ii 3) 3 mark

4 Question 4 : Total 9 marks

Material in this question relates to syllabus item ***1.4.5*** *detailed on page 35.*

(a) 4 marks

In one mole of anything there are 6.02×10^{23}units. This is known as Avogadro's number, N_A. Therefore in one mole of hydrogen there are 6.02×10^{23} H_2 molecules. We are told that one mole of hydrogen weighs 0.002 kg.

We are also told that hydrogen at s.t.p. has a density, $\rho_{H_2} = 0.09 \text{ kg} \cdot \text{m}^{-3}$.

Therefore, one mole of hydrogen takes up the following volume

$$V = \frac{M}{\rho_{H_2}} = \frac{0.002 \text{ kg}}{0.09 \text{ kg} \cdot \text{m}^{-3}} = 0.022m^3 \tag{24}$$

As stated before this volume is shared between 6.02×10^{23} other molecules. Therefore each molecule may occupy $0.022/6.02 \times 10^{23} = 3.65449 \times 10^{-26}$ m^3

Therefore assuming that the molecules are momentarily stationary at the center of their allocated volume the distance between molecules would be equal to

$$\sqrt[3]{3.65449 \times 10^{-26} \text{ m}^3} = 3.319 \times 10^{-9} \text{ m} = 3.319 \text{ nm} \tag{25}$$

(b) 5 marks

The capacitance of a parallel-plate capacitor is given by

$$C = \frac{\varepsilon_0 \cdot A}{d} \tag{26}$$

where A is the area of the plates and d is the distance between them; ε_0 is the permittivity of free space.

In this question we have a capacitor with $d = 1$ mm, charged to a potential of 100 V

The capacitance, C is related to the charge, Q and potential, V through

$$C = \frac{Q}{V} \tag{27}$$

equating Equations 26 and 27 gives

$$\frac{Q}{V} = \frac{\varepsilon_0 A}{d} \tag{28}$$

This can be rearranged to give the amount of charge per area

$$\frac{Q}{A} = \frac{\varepsilon_0 V}{d} = 8.85 \times 10^{-7}\ \mathrm{m}^2 \tag{29}$$

The square root of this area gives an approximation to the average separation distance between electrons

$$\sqrt[2]{8.85 \times 10^{-7}\mathrm{m}^2} = 9.407 \times 10^{-4}\ \mathrm{m} \tag{30}$$

5 Question 5 : Total 13 marks

*Material in this question relates to syllabus item **1.7** detailed on page* *38**.*

(a i) 2 marks

Qualitatively:

The principle of superposition states that when two or more waves traverse the same point in space, the amplitudes of the wave at the given point is the sum of amplitudes from the individual waves.

Quantitatively:

$$y'(x,t) = y_1(x,t) + y_2(x,t) \tag{31}$$

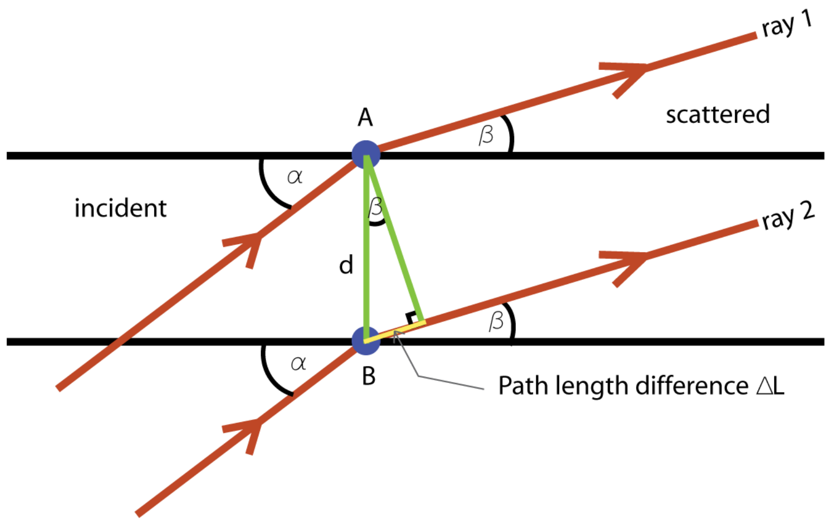
(a ii) 1 marks

In order to have fully constructive interference the two combining waves y_1 and y_2 must be exactly in phase. We must have

$$\phi = 0 \tag{32}$$

(b i) 3 marks

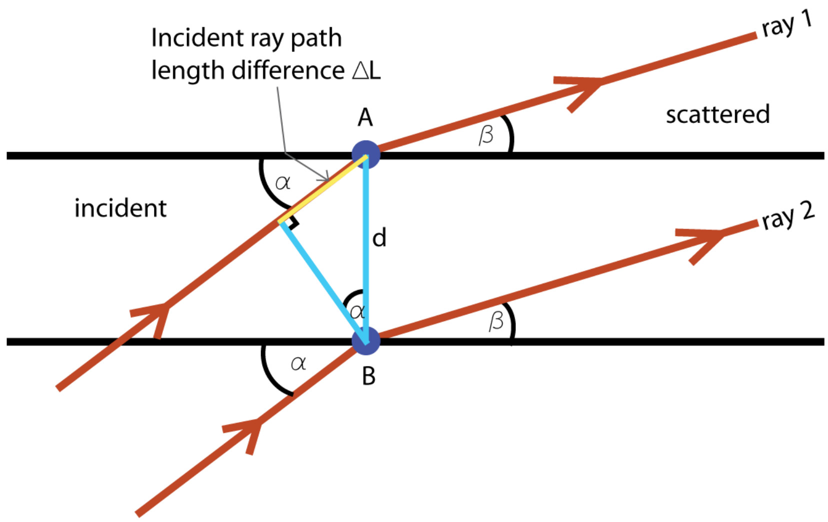
A parallel beam of coherent electromagnetic radiation, as described in the question, is incident upon the atoms. The path length difference between the two scattered rays is shown below as ΔL.



The green triangle shown in the diagram above contains the scattered ray path length difference ΔL_S. This triangle has an angle $\sin \beta = \Delta L_S / d$, therefore

$$\Delta L_S = d \sin \beta \tag{33}$$

However, this is the path length difference in the scattered ray only. We must take into consideration the path length difference due to the incident ray, ΔL_I.



The blue triangle shown in the above diagram has a highlighted path length difference (in yellow) of ΔL_I.

This triangle has an angle $\sin\alpha = \Delta L_I/d$, therefore

$$\Delta L_I = d\sin\alpha \tag{34}$$

To obtain constructive interference the total path length difference ΔL_T must be equal to zero or an integer number of wavelengths. Therefore we obtain constructive interference when $\alpha = \beta$ or when

$$\Delta L_T = n\lambda \tag{35}$$

where n is an integer.

Therefore we have

$$n\lambda = d\cdot(\sin\alpha - \sin\beta) \tag{36}$$

(b ii) 1 mark

X-rays are used to investigate diffraction in crystalline solids as they have a wavelength which is commensurate with atomic spacing.

(c) 6 marks

In order to find the directions of strongly scattered radiation we need only find the values of β which satisfy Equation 36 with the given values substituted in

$$n\ 0.14\text{nm} = 0.5\text{nm} \cdot (\sin 30 - \sin\beta) \tag{37}$$

Therefore

$$\beta = \arcsin\left(\sin 30 - \frac{n \cdot 0.14}{0.5}\right) \tag{38}$$

The first three values of β are

n	$\sin 30 - \frac{n \cdot 0.14}{0.5}$	β
1	0.22	12.5
2	-0.06	-3.4
3	-0.34	-19.1

The first value being the most intensive.

6 Question 6 : Total 10 marks

Material in this question relates to syllabus item ***1.9*** *detailed on page 40.*

(a i) 2 marks

The wire may become horizontal by moving in the upwards direction. Movement of the wire requires a force to be exerted, this force is the magnetic force as described in Section 8.0.1. The direction of the wire movement depends on the direction of the *conventional* current.

In order for the wire to move up a conventional current from left to right must exist (corresponding to an electron flow from right to left). This requires the left hand side of the wire to be at a positive potential whilst the right hand side is at a negative potential.

(a ii) 3 marks

In order to find the potential difference, V_0, required to make the wire horizontal (ignoring any effect of Earth's magnetic field) we must firstly equate the two competing forces acting on the wire, namely the gravitational potential force and the magnetic force. We want the situation in which the magnetic force is equal to the gravitational force $F_{mag} = F_{grav}$. This occurs at voltage V_0 (with associated current I_0). Giving

$$BI_0L = mg \tag{39}$$

Substituting the above current for voltage using Ohm's law results in

$$\frac{BV_0L}{R} = mg \tag{40}$$

Rearranging for V_0 gives

$$V_0 = \frac{mgR}{BL} \tag{41}$$

Substituting for R, using the resistivity relation $R = \frac{\rho L}{A}$ results in

$$V_0 = \frac{mg\rho L}{ABL} = \frac{mg\rho L}{BV} \tag{42}$$

Subbing in the material density gives

$$V_0 = \frac{dg\rho L}{B} \tag{43}$$

(b) 5 marks

In order to answer this question we must find the conditions when the torque acting on the wire loop due to gravity is equal to the torque induced by the em field.

Torque due to gravity
Due to the wire shape we must split this up into the torque produced by the long side of wire and the two short sides.

Torque due to the long side:

$$\frac{m}{L} \times \frac{L}{3} \times \sin\theta g = \tau_{\text{longside}} \tag{44}$$

Torque due to the short side:

$$2 \times \int_0^{L/3} \frac{m}{L} \times r \sin\theta \mathrm{dr} \times g = \tau_{\text{shortside}} \tag{45}$$

$$\tau_{\text{shortside}} = 2\frac{m}{L}\sin\theta \left[\frac{r^2}{2}\right]_0^{L/3} \times g \tag{46}$$

$$\tau_{\text{shortside}} = 2\frac{m}{L}\sin\theta \frac{L^2}{18} g \tag{47}$$

Which gives in total:

$$\tau_{\text{grav}} = \tau_{\text{shortside}} + \tau_{\text{longside}} \tag{48}$$

$$\tau_{\text{grav}} = \frac{m}{L}\sin\theta \left(\frac{L^2}{18} + \frac{2L^2}{18}\right) \times g \tag{49}$$

$$\tau_{\text{grav}} = \frac{m}{L}\sin\theta \left(\frac{L^2}{6}\right) \times g \tag{50}$$

Torque due to electromagnetic force

$$\tau_{\text{em}} = BI_0 \frac{L}{6} \sin\theta \frac{L}{3} \tag{51}$$

$$\tau_{\text{em}} = BI_0 \sin\theta \frac{L^2}{18} \tag{52}$$

Equating τ_{em} and τ_{grav} gives

$$\frac{m}{L} \sin\theta \left(\frac{L^2}{6}\right) g = BI_0 \sin\theta \frac{L^2}{18} \tag{53}$$

Subbing in $I_0 = V_0/R$ and $m/L = dA$ and rearranging for V_0 gives

$$V_0 = \frac{m/LRg}{B} \times 3 = \frac{3dA\rho Lg}{AB} \tag{54}$$

$$V_0 = \frac{3Ag\rho L}{B} \tag{55}$$

which is the final answer.

7 Question 7 : Total 14 marks

*Material in this question relates to syllabus item **1.6** detailed on page 37.*

7.1 Answer

Wave particle duality. The wave nature of light can be shown through Thomas Young's double slit experiment (1801). Incident monochromatic light is diffracted by a single slit, this single slit then acts as a point source of light that emits semicircular wavefronts, which are then diffracted at the double slits, which then act as two point sources of light. The light waves travelling from the double slits overlap and undergo interference, forming an interference pattern of maxima and minima on the the viewing screen. This gives rise to the description of light as a wave, with a wavelength λ, a frequency f and a speed c, which relate through

$$c = \lambda \cdot f \tag{56}$$

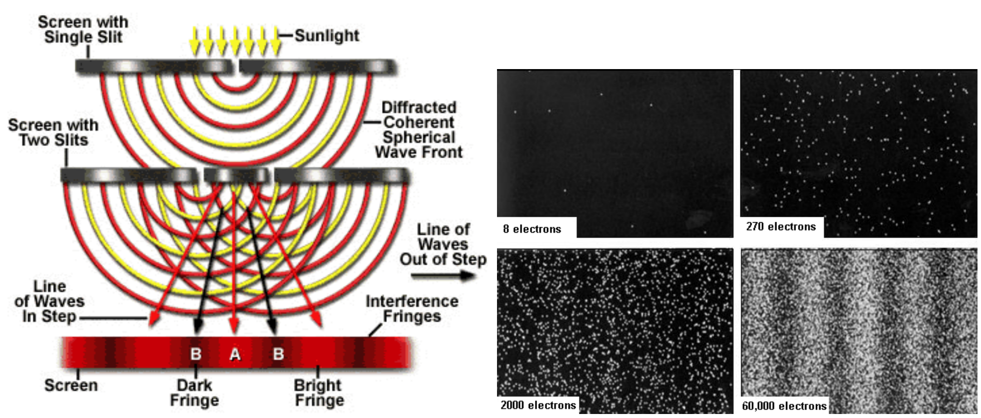


Figure 1: LHS: A diagram showing interference may help explain your answer. RHS: Electron diffraction interference fringes, acknowledgement of the existence of the above experimental data would suffice.

The particle nature of light can be shown experimentally through the photoelectric effect experiment. This experiment verifies that

- light of a specific frequency has a specific energy which is independent of the intensity.
- atomic processes have a cutoff frequency, or minimum energy and do not vary continuously.

In 1905 Einstein proposed that when an atom emits or absorbs light, energy is transferred in discrete 'lumps' of energy and not in a continuous fashion. These lumps are now known as photons. According to Einstein's proposal the energy transferred by a single photon is associated with a light wave of frequency f through

$$E = hf \tag{57}$$

In 1916 Einstein added to his photon concept by stating that not only energy is transferred in this way but also linear momentum is transferred in photons. The magnitude p of momentum associated with a photon of frequency f is

$$p = \frac{hf}{c} = \frac{h}{\lambda} \tag{58}$$

This was experimentally verified by Arthur Compton at Washington University in St. Louis in 1923.

In 1924 Louis de Broglie made the appeal to symmetry that as light waves transfer energy in photon sized lumps, why shouldn't a beam of particles also have an associated wave like nature. For example, why shouldn't an electron behave like a *matter wave.*? Specifically, de Broglie suggested that $p = h/\lambda$ (assigning a momentum to a wavelength) might apply not just to photons but also particles of matter. Why not assign a wavelength to a momentum? This gives

$$\lambda = \frac{h}{p} \tag{59}$$

Which is known as the de Broglie wavelength.

Experimental verification of this relation occurred in 1989 when a beam of electrons were diffracted and used to build up an interference pattern. The diagram in the right hand side (RHS) of Fig. 1 shows the build up of an electron diffraction pattern on a scintillation screen. This is an example of how matter waves (probability waves) interfere with each other.

The **energy mass relation** was developed in 1905 by Einstein as a consequence of his special theory of relativity, he showed mass can be considered to be another form of energy. The relation between mass and energy is given below

$$E = mc^2 \tag{60}$$

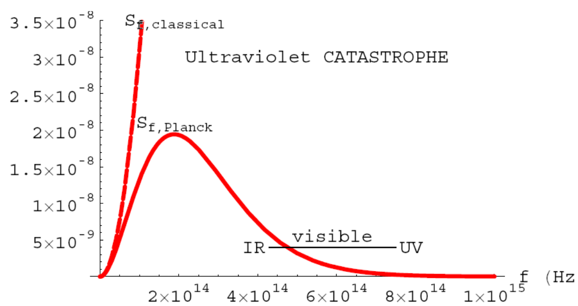
For most chemical reactions the amount of mass that is transferred into other forms is such a tiny fraction of the total mass involved that there is no hope of measuring the mass difference before and after a reaction. However, in a nuclear reaction the release of energy is about one million times greater than in a chemical reaction and the change in mass can be easily measured.

Quantum physics states that energy is not transmitted in a continuum but rather is quantised in discrete lumps, as was discussed in Einstein's photoelectric effect on page 24. The origin of quantum physics can actually be traced back further than Einstein's photoelectric effect to the 'Ultraviolet catastrophe'.

The 'Ultraviolet catastrophe' is an event which refers to the discrepancy between *classical* physics and modern *quantum* physics over the power emitted by a black body. Classical statistical mechanics states that all modes (degrees of freedom) of a system at equilibrium have an average energy of $kT/2$. According to classical electromagnetism, the number of electromagnetic modes in a 3-dimensional cavity, per unit frequency, is proportional to the square of the frequency. This therefore implies that the radiated power per unit frequency should follow the Rayleigh-Jeans law, and be proportional to frequency squared. Thus, both the power at a given frequency and the total radiated power go to infinity as higher and higher frequencies are considered: this is clearly an impossibility.

In 1905 three scientists: Einstein, Lord Rayleigh and Sir James Jeans; stated independently that is was clearly unreasonable. Einstein proposed the adoption of the Max Planck formalism, which was proposed some 5 years earlier. Planck had postulated that electromagnetic energy did not follow the classical description, but could only oscillate or be emitted in discrete packets of energy proportional to the frequency (as given by Planck's law). This has the effect of reducing the number of possible modes with a given energy at high frequencies in the cavity described above, and thus the average energy at those frequencies.

These packets of energy later came to be called photons.

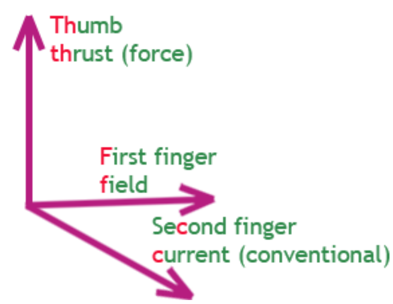


8 Review material

Review 8.0.1 *Magnetic force and Flemming's left hand rule*

Question 1 and 6 are related to this subject matter.

The magnetic force on a positive charge is found using Flemming's left-hand rule, as shown below.



Mathematically this handled by realising that in a time t *the charge travels a distance* vt*. This is therefore equivalent to a current* Qt *in a wire of length* vt*. Now, the force on a current carrying wire is:*

$$F = BIL \tag{61}$$

There fore we have:

$$F = B \times \frac{Q}{t} \times vt \tag{62}$$
$$F = BQv \tag{63}$$

Review 8.0.2 ***Straight line equations***

Click to go back to Question 2

A straight line can be written mathematically as:

$$y = mx + c \tag{64}$$

Where y and x are values along the axis and m is the gradient of the line and c is the y axis intercept.

Therefore this equation can be formulated if we know the gradient, m and y axis intercept c.

If the gradient, m is known and one point $P = (x1, y1)$ then we can write:

$$\frac{y - y_1}{x - x_1} = m \tag{65}$$

This is simplified to:

$$y = m(x - x_1) + y_1 \tag{66}$$

If two points are known $P = (x_1, y_1)$ and $O = (x_2, y_2$

The gradient can be written as:

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \tag{67}$$

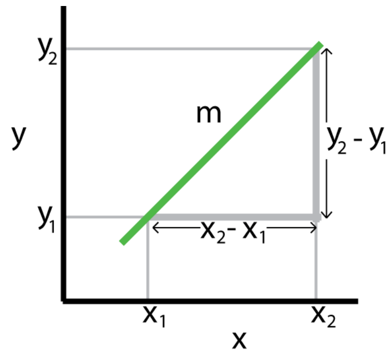


Figure 2: A straight line

Review 8.0.3 ***Nucleonic decay and half-life***

Click here to go back to question 3

For a collection of radioactive nuclei the more undecayed nuclei the frequently a decay is likely to occur.

$$activity \propto number\ of\ undecayed\ nuclei \tag{68}$$

Activity is defined as $-dN/dt$*. The minus sign indicating that a decrease in* N *gives positive activity.*

Adding in a suitable constant, λ*, known as the* ***radioactive decay constant*** *and defining the number of undecayed nuclei after a time* t *by* N *we can rewrite the proportionality as:*

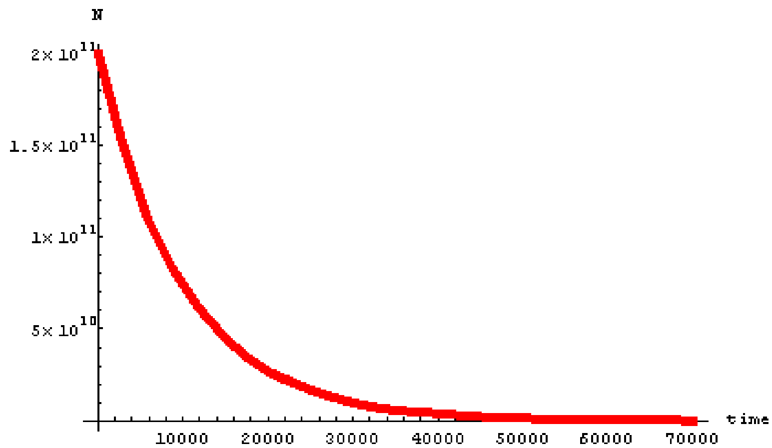
$$-\frac{dN}{dt} = \lambda N \tag{69}$$

This equation may be integrated to yield:

$$N = N_0 e^{-\lambda t} \tag{70}$$

This is known as the ***radioactive decay law****.*

Choosing a suitable range for the time, t and arbitrary values for λ and N_0 the relation can be observed graphically.



*The **half-life** of a material has two equally valid definitions.*

(1) *The average time taken for the number of undecayed nuclei to halve in value.*

(2) *The average time taken for the activity to halve.*

The half-life, $t_{1/2}$, is defined, according to (1), as $N = \frac{N_0}{2}$. If this is substituted for N in equation (31) then t represents $t_{1/2}$. Taking logs and rearranging yields:

$$t_{1/2} = \frac{ln2}{\lambda} \tag{71}$$

In order to get a clearer picture of what is happening equations (30) and (31) can be combined to give:

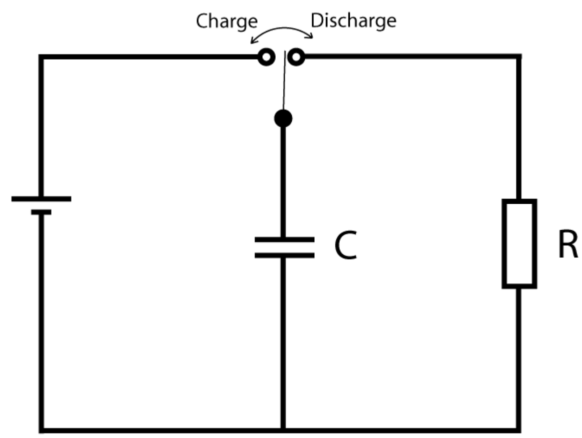
$$-\frac{dN}{dt} = \lambda N_0 e^{-\lambda t} \tag{72}$$

Which demonstrates that the activity ($-dN/dt$) decreases exponentially with time.

Review 8.0.4 ***Capacitor discharge circuits***

Click here to go back to question 3

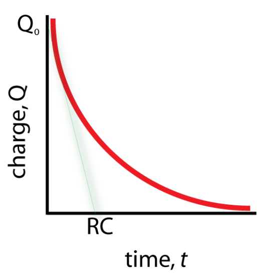
The capacitor below receives electrical charge from a battery and is then discharged through a resistance R.



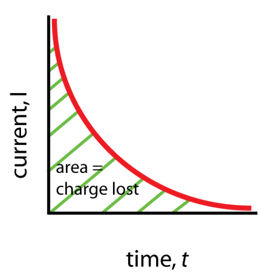
The charge stored on a capacitor, Q, decreases with time according to the following relationship

$$Q = Q_0 e^{-t/RC} \tag{73}$$

RC in the above relation is known as the ***time constant****. The time constant can be thought of as the time which the charge would take to fall to zero if the initial rate of loss of charge were maintained. Increasing R or C gives a higher time constant, and therefore a slower discharge.*



GRAPH A: The gradient at any time *t* is equal to the current at that time



GRAPH B: Current decrease with time. Area under graph is equal to the charge lost

9 Syllabus

The Advanced Extension Award in physics will be based on assessment of the following knowledge, understanding and skills.

9.1 Knowledge, Understanding and Skills

9.1.1 Skills

Students should develop

- knowledge of SI units
- an understanding of the distinction between vector and scalar quantities
- an awareness of the order of magnitude of physical quantities

9.1.2 Mechanics

	Area of study	Amplification
1.2.1	Vectors	Resolution of vectors into two components at right angles to each other. Addition rule for two vectors, mathematical calculations limited to two perpendicular vectors.
1.2.2	Kinematics	Graphical representation of uniformly accelerated motion. Use of kinematic equations in one dimension for motion with constant velocity or constant acceleration.
		Two dimensional motion under constant force. Independent effect of perpendicular components of a force.
		Interpretation of speed and displacement graphs for motion with non-uniform acceleration.
1.2.3	Dynamics	Use of $F = ma$ in situation where mass is constant.

9.1.3 Momentum and energy

	Area of study	Amplification
1.3.1	Momentum concepts	Definition of momentum, p = mv.
		Application of principle of conservation of momentum to problems in one dimension.
		Force as rate of change of momentum in situations where mass is constant.
1.3.2	Energy concepts	Calculation of work done, for constant forces, when force is not along the line of motion. Quantitative application of conservation of energy including use of gravitational potential energy $mg\Delta h$, kinetic energy $\frac{1}{2}mv$ and energy required for change of temperature $= mc\Delta u$
1.3.3	Molecular kinetic theory	Concept of internal energy as the random distribution of potential and kinetic energy amongst molecules.
		Ideal gas equation, $pV = nRT$.
		Concept of absolute zero.
		T $\propto$ average kinetic energy of molecules for an ideal gas.

9.1.4 Electricity

	Area of study	Amplification
1.4.1	Current	Electric current as rate of flow of charge, $I = \Delta q/\Delta t$.
1.4.2	Emf and potential difference	The definition of emf and concept of internal resistance.
		Potential difference in terms of energy transfer, $V = W/q$, $V = P/I$.
1.4.3	Resistance	Resistance defined by $R = V/I$.
		Resistivity defined by $\rho = RA/l$.
		Ohms law as a special case where $I \propto V$. Power dissipated $P = I^2R$.
1.4.4	DC circuits	Conservation of charge and energy in simple DC circuits.
		The relationships between currents, voltages and resistances in series and parallel circuits.
		Potential divider, excluding the potentiometer as a measuring instrument.
1.4.5	Capacitance	Definition of capacitance $C = q/V$.
		Use of $E = \frac{1}{2}qV$.
		Quantitative treatment of discharge curves.

9.1.5 Atomic and nuclear physics

	Area of study	Amplification
1.5.1	Probing matter	Scattering as a means of probing matter, including a qualitative discussion of the choice of bombarding radiation or particle, the physical principles involved in the scattering process, the processing and interpretation of data.
1.5.2	Ionising radiation	Connections between nature, penetration and range for ionising particles.
		The activity of unstable sources; modelling using constant decay probability leading to exponential decay and the idea of half life.
		Changes in the sources due to the particles emitted, for example, changes to nucleon and proton number as a result of emissions.
1.5.3	Energy	$E = mc^2$ applied to nuclear processes.
		Appreciation that $E = mc^2$ applies to all energy changes.
		Simple calculation relating mass difference to energy change.
		Descriptions of the processes of fission and fusion.

9.1.6 Quantum physics

	Area of study	Amplification
1.6.1	Photons	The use of the photon model in explaining observable phenomena. The evidence supporting the photon model of electromagnetic radiation making use of effects associated with its interactions with matter. A study of one of the following would provide a suitable depth of treatment . the photoelectric effect, the formation of line spectra, the action of gas lasers or of measurable transitions in electronic devices.
1.6.2	Matter	The use of the quantum model when extended to particles. The experimental evidence supporting the quantum model for particles. A study of particle diffraction would provide a suitable depth of treatment.

9.1.7 Waves and oscillations

	Area of study	Amplification
1.7.1	Waves	Qualitative treatment of polarisation and diffraction.
		Concepts of path difference, phase and coherence. Quantitative treatment of superposition of waves from two sources.
		Graphical treatment of standing waves.
1.7.2	Oscillations	Simple harmonic motion.
		Quantitative treatment, limited to $a = -(2\pi f)x$ and the solution $x = A\cos 2\pi f t$. Velocity as gradient of displacement vs. time graph.
		Qualitative treatment of free and forced vibration, damping and resonance.

9.1.8 Fields

	Area of study	Amplification
1.8.1	Force fields	Concept of a force field as a region in which a body experiences a force, $E = F/q$, $g = F/m$.
		Application of $F = ma = mv^2/r$ to motion in circle at constant speed.
		Use of equations for force and field strength for spherical charges and masses treated as points in a vacuum.
		Force between two point charges $F = k\frac{q_1 \cdot q_2}{r_2}$, $k = \frac{1}{4\pi\epsilon_0}$
		Force between two point masses, $F = G\frac{m_1 \cdot m_2}{r}$
		For a point charge $E = kq/r^2$
		For a point mass $g = Gm/r^2$
		For a uniform electric field, $E = V/d$.
		Similarities and differences between electric and gravitational fields.

9.1.9 Magnetic effects of currents

	Area of study	Amplification
1.9.1	B-fields	Force on a straight wire $F = BIl$ and force on a moving charge $F = Bqv$ in a uniform field with field perpendicular to current or motion.
1.9.2	Flux and electromagnetic induction	Concepts of magnetic flux, ϕ and magnetic flux linkage, $N\phi$. $\phi = BA$.
		Laws of Faraday and Lenz.
		Emf as equal to rate of change of magnetic flux linkage, including simple calculation.tational fields.

9.2 Experiment and investigation

	Area of study	**Student should:**
2.1	Analysing evidence and drawing conclusions	(a) present work appropriately in written, graphical or other forms; (b) analyse observations and show awareness of the limitations of experimental measurements when commenting on trends and patterns in the data; (c) draw valid conclusions by applying knowledge and understanding of physics.
2.2	Evaluating evidence and procedures	(a) assess the reliability of data and the conclusions drawn from them; (b) show awareness of the limitations inherent in their activity.

9.3 Mathematical requirements

In order to be able to develop the knowledge, understanding and skills in sections **1.1** to **1.9.2** and **2.1** to **2.2** above which are taken from the Advanced Subsidiary and Advanced GCE Level subject criteria for physics, students need to have been taught, and to have acquired, competence in the areas of mathematics set out below.

	Area of study	Student should be able to:
3.1	Arithmetic and computation	• recognise and use expressions in decimal and standard form; • use ratios, fractions and percentages; • use calculators to find and use x^n, $1/x$, $\sqrt{x}$,$\log_1 0x$, e^x, $log_e x$; • use calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians.
3.2	Handling data	• make order of magnitude calculations; • use an appropriate number of significant figures; • find arithmetic means.
3.3	Algebra	• change the subject of an equation by manipulation of the terms, including positive, negative, integer and fractional indices; • solve simple algebraic equations; • substitute numerical values into algebraic equations using appropriate units for physical quantities; • understand and use the symbols: $=$, $<$, $\ll$, $\gg$, $>$, $\propto$, $\sim$.

	Area of study	Student should be able to:
3.4	Geometry and trigonometry	• calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres; • use Pythagoras' theorem, and the angle sum of a triangle; • use sines, cosines and tangents in physical problems; • understand the relationship between degrees and radians and translate from one to the other.
3.5	Graphs	• translate information between graphical, numerical and algebraic forms; • plot two variables from experimental or other data; • understand that $y = mx + c$ represents a linear relationship; • determine the slope and intercept of a linear graph; • draw and use the slope of a tangent to a curve as a measure of rate of change; • understand the possible physical significance of the area between a curve and the x axis and be able to calculate it or measure it by counting squares as appropriate; • use logarithmic plots to test exponential and power law variations; • sketch simple functions including $y = k/x$, $y = kx^2$, $y = k/x^2$, $y = \sin x$, $y = \cos x$, $y = e^{-kx}$