

PHYSICS



EXAM QUESTION PACK

MODULE 6 FIELD AND PARTICLE PHYSICS

SCORE

/461

PERCENTAGE

%

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- 1 An imagined atom can exist in five energy levels. Transitions between all levels are possible.

Which statement about the imagined atom is correct?

- A When the atom jumps to a lower level an electron gains energy.
- B When the atom emits a photon the atom jumps to a higher energy level.
- C There will be six frequencies in the line spectrum of the atom.
- D There will be ten frequencies in the line spectrum of the atom.

Your answer ☐

[1]

- 2 A proton is accelerated until its total energy is double its rest energy.

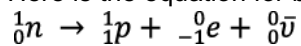
What is its speed, expressed in terms of the speed of light, c ?

- A $0.25c$
- B $0.50c$
- C $0.75c$
- D $0.87c$

Your answer ☐

[1]

3 Here is the equation for beta decay:



Which of the following quantities is / are conserved in the decay?

- 1 number of quarks
- 2 lepton number
- 3 charge number

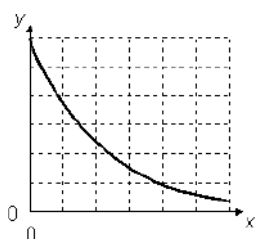
- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

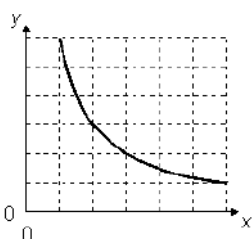
☐

[1]

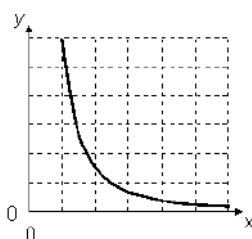
4 The graphs A–D represent different relationships between variables. The dotted lines mark out equal intervals along the x- and y-axes.



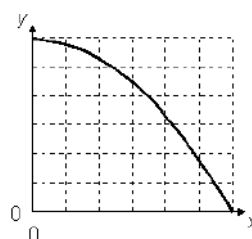
A



B



C



D

Which graph A, B, C, or D best represents the relationship between the variables x and y where:

y is the electric field strength in the space surrounding a point charge

x is the distance from the point charge.

Your answer

☐

[1]

5 Four different ions enter a region of uniform magnetic field. Each ion enters with the same velocity. The magnetic field acts at 90° to the path of the ions. Each ion is defined below in terms of its nucleon number and charge.

Which ion will travel in a circular path with the largest radius?

	nucleon number	charge
A	1	1
B	2	1
C	3	1
D	7	2

Your answer

[1]

6 The up quark (u) has charge $+\frac{2}{3}e$ and the down quark (d) a charge of $-\frac{1}{3}e$.

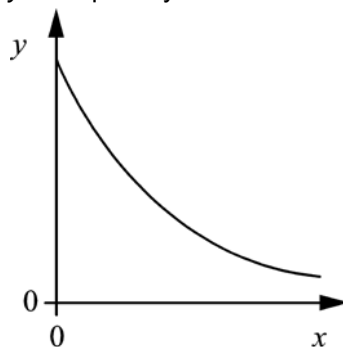
What is the correct combination of quarks that make up the proton and the neutron?

	proton	neutron
A	ddd	uud
B	udd	uud
C	uud	udd
D	ddd	udd

Your answer

[1]

- 7 The graph shows the variation in quantity y with quantity x .



Which pair(s) of quantities produce a similar graph?

- 1 mass remaining of a radioisotope (y) against time (x)
- 2 charge (y) on a capacitor against potential difference (x) across the capacitor
- 3 gravitational field strength from a point mass (y) against distance from mass (x)

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

☐

[1]

- 8 Two small metal spheres have the same electric charge. The distance between the centres of the spheres is 12 cm. The force on each sphere is 0.29 mN.

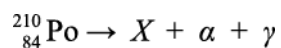
What is the electric charge on each sphere?

- A $4.6 \times 10^{-16} \text{ C}$
- B $4.6 \times 10^{-9} \text{ C}$
- C $2.2 \times 10^{-8} \text{ C}$
- D $6.8 \times 10^{-5} \text{ C}$

Your answer

[1]

- 9 ${}_{84}^{210}\text{Po}$ is a radioactive isotope. The equation for its decay is:



Where X is the daughter nucleus, α is an alpha particle and γ is a gamma photon.

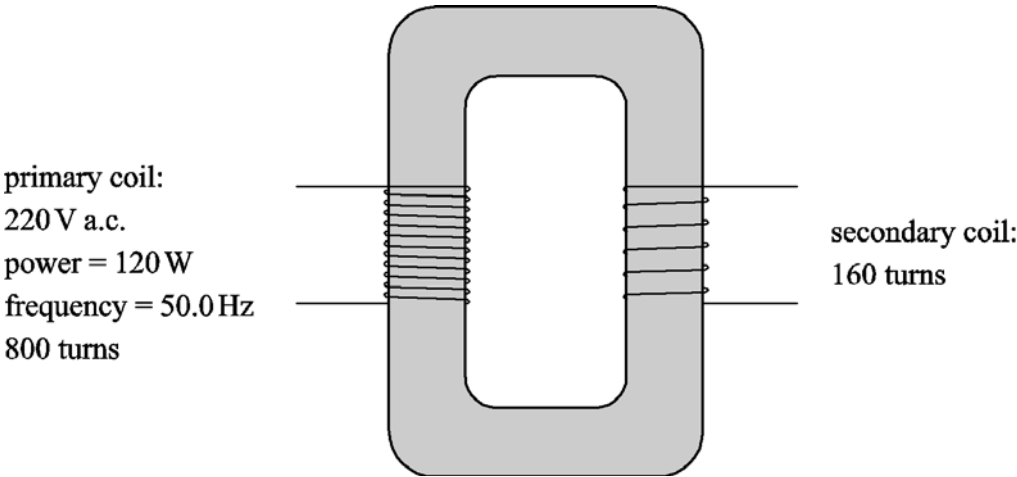
What is the atomic number of X ?

- A 80
- B 82
- C 85
- D 208

Your answer

[1]

10 The diagram shows an ideal transformer.



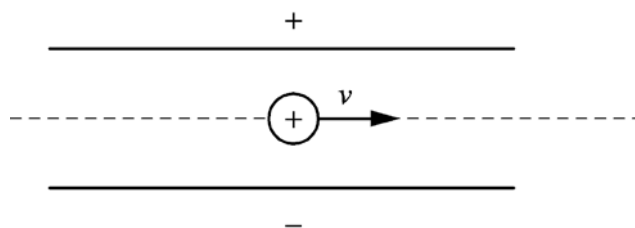
Which of the following data sets about the output of the secondary coil is correct?

	p.d. / V	<i>I</i> / A	<i>f</i> / Hz
A	44.0	2.73	10.0
B	44.0	0.11	50.0
C	44.0	2.73	50.0
D	1100	0.11	50.0

Your answer ☐

[1]

11 A proton enters the space between two oppositely charged parallel metal plates.



A magnetic field acts between the plates at right angles to the electric field and the direction of motion of the proton.

The magnetic field strength is 20 mT and the electric field strength is 100 V m^{-1} .

The proton moves in a straight line between the plates.

What is the speed of the proton?

- A 2000 ms^{-1}
- B 5000 ms^{-1}
- C 5 ms^{-1}
- D 2 ms^{-1}

Your answer

[1]

- 12 A proton ${}^1_1\text{P}$ and a ${}^4_2\text{He}$ nucleus (alpha particle) are both accelerated from rest through a potential difference of 1000 V.

What is the ratio $\frac{\text{kinetic energy of the proton}}{\text{kinetic energy of the alpha particle}}$?

A $\frac{1}{4}$

B $\frac{1}{2}$

C $\frac{2}{1}$

D $\frac{4}{1}$

Your answer

[1]

- 13 A proton ${}^1_1\text{P}$ and a ${}^4_2\text{He}$ nucleus (alpha particle) are both accelerated from rest through a potential difference of 1000 V.

What is the ratio $\frac{\text{momentum of the proton}}{\text{momentum of the alpha particle}}$?

A $\frac{1}{2\sqrt{2}}$

B $\frac{1}{\sqrt{2}}$

C $\frac{\sqrt{2}}{1}$

D $\frac{2\sqrt{2}}{1}$

Your answer

[1]

- 14 The half-life of a muon at rest is $1.52\ \mu\text{s}$. Muons in cosmic rays are observed to have half-lives of $10.4\ \mu\text{s}$.

Calculate the velocity of the muons in cosmic rays.

velocity = _____ ms^{-1} [3]

15(a) Palladium-103 is a beta-emitter with a half-life of 17 days. For some cases of cancer, 'seeds' of palladium-103 are placed in the affected organ near the tumour and remain there: they are not removed.

In a medical procedure, a cluster of cells is exposed to the beta radiation from palladium-103.
The initial activity of the source is 1.8×10^5 Bq.

Estimate the dose in gray received by a cluster of cells of mass 4.0 g after one hour.

average energy of beta particle released by palladium-103 = 3.4×10^{-15} J

dose received = _____ Gy [2]

- (b) Evaluate the benefits and risks to the patient of this type of treatment compared with using a radioactive source outside the body.

----- [2]

16(a) This question is about the electron in the hydrogen atom. A simple model shown in Fig. 39.1 pictures the electron as a standing wave in a box of length equal to the diameter of the atom. The electron can be bound to the proton if the total energy of the electron (kinetic energy + potential energy) is less than zero.

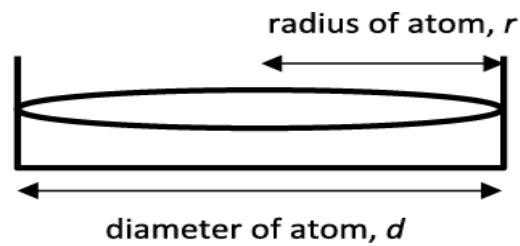


Fig. 39.1

- (i) Show that the kinetic energy of the electron in a box of diameter d is $\frac{h^2}{32mr^2}$.

[3]

- (ii) Calculate the kinetic energy of an electron trapped in a box of $r = 1 \times 10^{-10}$ m.

kinetic energy = _____ J [2]

- (iii) Calculate the electrical potential energy of an electron at a distance of 1×10^{-10} m from a proton. Use this value and your answer from (ii) to explain why an electron can be bound to a proton at this distance.

$$k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

[4]

- (b) In beta decay of a nucleus, a neutron decays into a proton and an electron.

Taking the radius of a nucleus to be about 10^{-14} m, explain, with supporting calculations, why the electron immediately leaves the nucleus.

[4]

17(a) This question is about energy from a nuclear power plant.

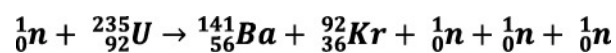
A power plant generator produces a voltage of 25 kV a.c. The electrical power output of such a plant is about 500 MW. A transformer of turns ratio 1:16 is used to step up the voltage for transmission along the high voltage cables.

Calculate the current in the cables at the higher voltage.

current = _____ A [2]

(b)

(i) The equation below shows one of many ways that uranium-235 can undergo fission.



Explain how this process can form a chain reaction and why a minimum mass of uranium is required for the reaction to proceed.

----- [3]

(ii) Here are the masses of the particles in the reaction:

neutron	=	1.0087 u
uranium-235	=	235.0439 u
barium-141	=	140.9144 u
krypton-92	=	91.9261 u

Calculate the energy released in one fission reaction:

$$u = 1.7 \times 10^{27} \text{ kg}$$

energy released = _____ J [3]

- (c) Most working power plants use enriched uranium which contains about 3% uranium-235 which undergoes fission, and 97% uranium-238 which does not undergo fission. A promising alternative fuel to uranium-235 is uranium-233. This is produced from the plentiful isotope thorium-232 which is converted into thorium-233 by neutron bombardment followed by beta-decay.

Research into uranium-233 reactors was abandoned in the 1970s as uranium-235 plants produce plutonium-239, which was needed for nuclear weapons. Research has recently resumed into obtaining fuel from thorium-232.

Here are some data about a proposed uranium-233 power plant:

energy released per reaction = 200 MeV

mean power generated by fission reactions = 1400 MW

mass of thorium-232 atom = mass of uranium-233 atom = 4×10^{-25} kg (1 significant figure)

Use this data to calculate an estimate of the total mass of thorium-232 used in one year, and suggest one reason why research into nuclear fuel obtained from thorium has started again after being abandoned for 40 years.

$$1 \text{ year} = 3.2 \times 10^7 \text{ s}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

mass used per year = _____ kg [4]

18(a) The experiment illustrated in Fig. 2.1 is to be used to investigate aspects of the electric field between parallel plates. The charged ball bounces continuously between the plates.

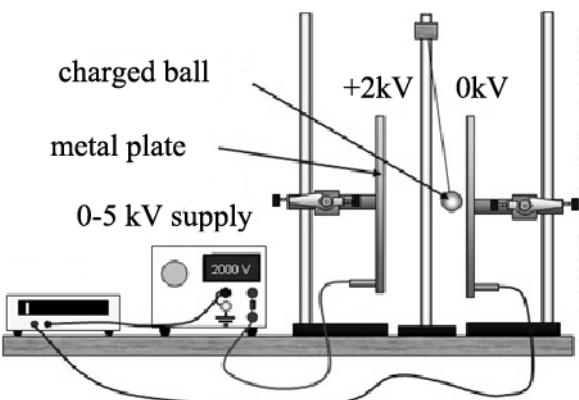


Fig. 2.1

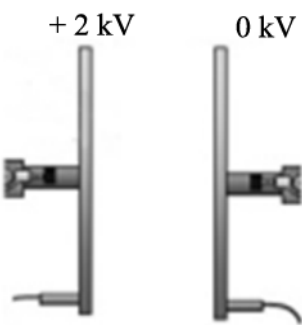


Fig. 2.2

(i) Fig. 2.2 shows a close up of the parallel plates.

Draw five lines on Fig. 2.2 to represent the uniform electric field between the plates.
Add a labelled line to represent the + 500 V equipotential.

[3]

(ii) State the effect on the electric field strength between the plates of:

1 halving the separation of the plates

2 halving the p.d. from the supply.

[2]

(b)

- (i) Calculate the force on the ball when charged to +2.0 kV and placed between the plates with a p.d. of 2.0 kV.

radius of ball = 2.0×10^{-2} m

plate separation = 8.0×10^{-2} m

force = _____ N [3]

- (ii) Calculate or state the work done by the electric field per coulomb on the ball as the ball moves across half the separation of the plates.

work done per unit charge = _____ J C⁻¹ [1]

- (c) The ball bounces between the plates at a constant rate.

Explain why the ball bounces at a constant rate although it gains energy from the electric field each time it moves between the plates.

[2]

19(a) Fig. 3.1 shows a short bar magnet being dropped vertically through a small horizontal coil.

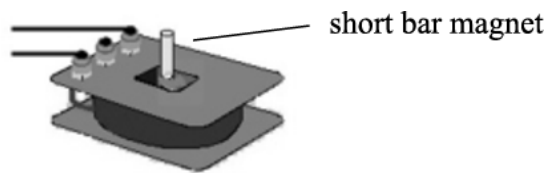


Fig. 3.1

Fig. 3.2 shows the graph of how the e.m.f. induced in the coil varies with time, as the magnet passes through the coil.

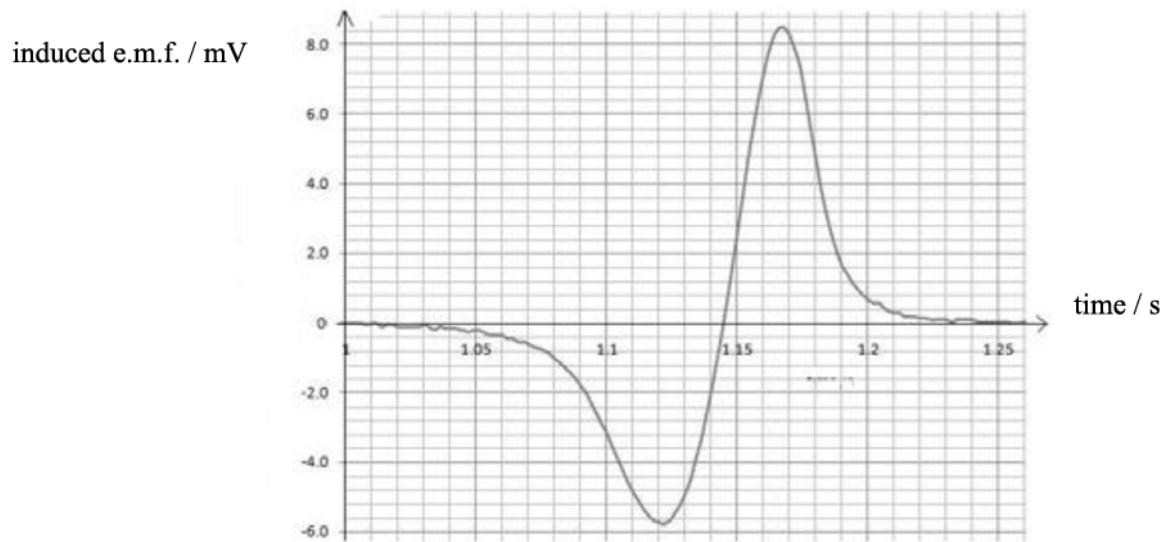


Fig. 3.2

* Identify and explain the main features of the peaks of induced emf shown on Fig. 3.2, in terms of Faraday's law of electromagnetic induction.

[6]

- (b) An experiment is being planned for dropping a much longer bar magnet through the small coil of Fig. 3.1 and measuring the induced emf.

Sketch and label an apparatus diagram.

State **one** aspect that would need to be controlled in order to obtain accurate data and explain how you would achieve this.

[3]

(c) Explain how the graph in Fig. 3.2 would change if:

1 a much longer bar magnet replaced the short bar magnet.

2 a much larger diameter coil replaced the small coil.

[4]

(d) The data in Fig. 3.2 were obtained using an 1100 turn coil.

Calculate the total flux linking the coil from when the magnet **enters** the coil to the point at which the magnet is central within the coil.

flux linked = _____ Wb [2]

20(a) In the Geiger–Marsden scattering experiment, alpha particles from a radium source were directed on thin gold foil as in Fig. 3.1. The number of alpha particles scattered at different angles from the gold foil was measured per unit time.

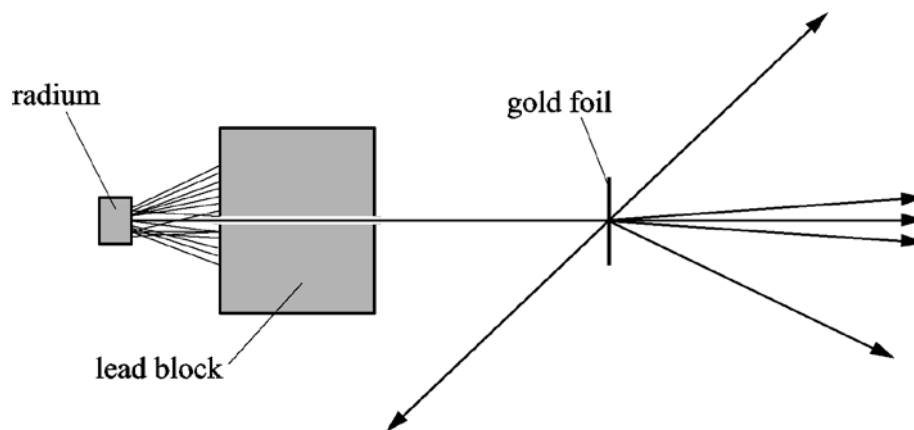


Fig. 3.1

The apparatus was set up inside a vessel from which all air had been removed. The beam of alpha particles passed through a narrow hole drilled in a lead block positioned between the radium source and the gold foil. Explain why these arrangements were necessary.

[2]

(b) Two of the paths taken by alpha particles near a gold nucleus are shown in Fig. 3.2.

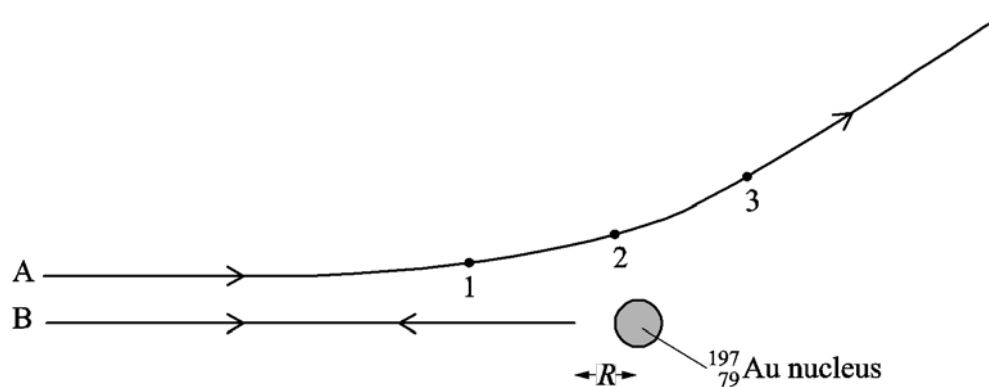


Fig. 3.2

- (i) Three points on path A are labelled 1, 2 and 3. Point 2 is the closest distance of approach to the gold nucleus, while points 1 and 3 are each twice as far from the centre of the nucleus as point 2.
Draw arrows on Fig. 3.2 to show the direction and magnitude of the force acting on the alpha particle at points 1, 2 and 3.

[3]

- (ii) Alpha particles following path B are deflected through 180° .
Calculate the minimum distance R from the centre of the nucleus for these alpha particles.
kinetic energy of alpha particles = 4.8 MeV

$$k = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

minimum distance $R =$ _____ m [4]

21(a) A student uses the simple electrical circuit shown in Fig. 4.1 to find the conductivity of a metal alloy.

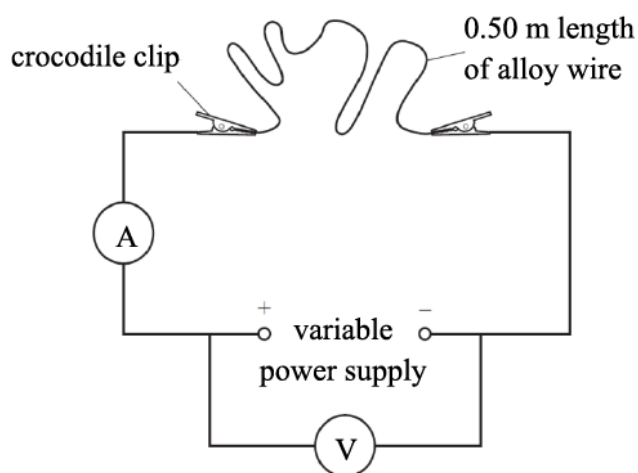


Fig. 4.1

The student uses an alloy wire of length 0.50 m and diameter of 0.213 mm. The student obtains the preliminary readings: $I = 0.18\text{ A}$, $V = 1.4\text{ V}$.

- (i) Calculate the electrical conductivity of the alloy given by the student's readings.

conductivity of alloy = _____ S m^{-1} [3]

- (ii) The accepted value for electrical conductivity of the alloy is significantly larger than the value obtained from the student's data.

Assuming the uncertainties in the student's readings are negligible, suggest and explain a reason for the difference.

----- [2]

- (b) An electromagnetic lock consists of a core and coil attached to a door-frame, and a steel plate attached to the door. In Fig. 4.2 the steel plate is very close to, but not touching, the electromagnetic core.

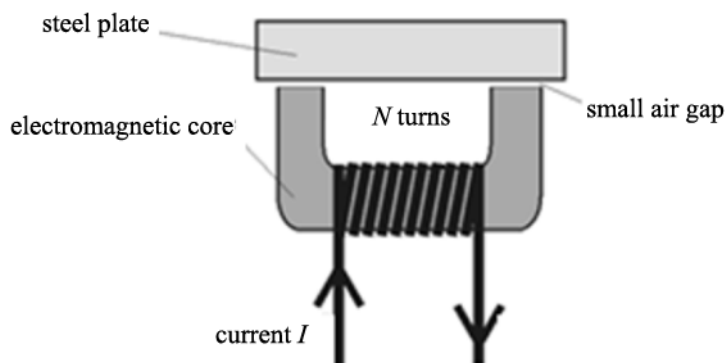


Fig. 4.2

- (i) Draw three lines of magnetic flux on Fig. 4.2 and explain why there is a strong attractive force between the electromagnetic core and steel plate.

[2]

- (ii) Use ideas of permeance to explain why the attractive force becomes much stronger when the core and plate are in contact.

[3]

(c) The experimental diagram of Fig. 4.1 and the door-lock of Fig. 4.2, repeated in Fig. 4.3, are both types of series circuit.

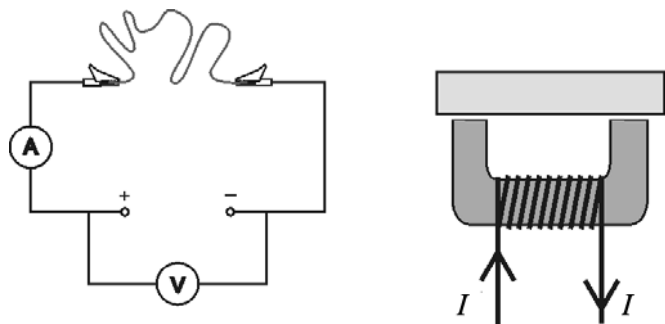


Fig. 4.3

There are analogies between electrical and magnetic circuits.
Complete the table to compare the electrical and magnetic features of the circuits shown in Fig. 4.3.

electrical circuit feature	corresponding magnetic circuit feature
power supply	
e.m.f.	
current in the circuit	
conductance	
the conductance of the connecting leads is greater than that of the alloy metal wire	

[5]

22(a) **Fig. 6.3** shows a positron–electron pair being produced by a gamma photon in a cloud chamber. There is a uniform magnetic field acting perpendicularly into the diagram, shown by the shaded area.

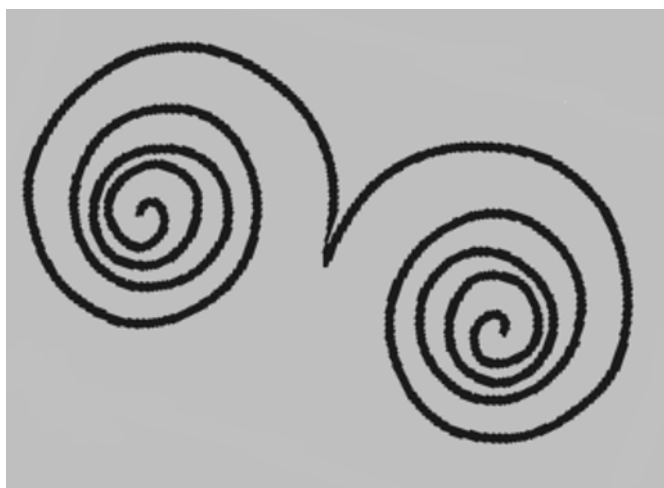


Fig. 6.3

Add a line to Fig. 6.3 to show the path of the incoming gamma photon. Explain why the gamma photon left no track in the cloud chamber, and why the positron and electron follow the paths shown in Fig. 6.3.

[6]

- (b) **Fig. 6.4** shows an annihilation in a cloud chamber. There is a uniform magnetic field acting perpendicularly into the diagram, shown by the shaded area. An antiproton (p^-) enters near the bottom and collides with a stationary proton. The annihilation creates eight hadrons numbered 1 – 8 in **Fig. 6.4**.

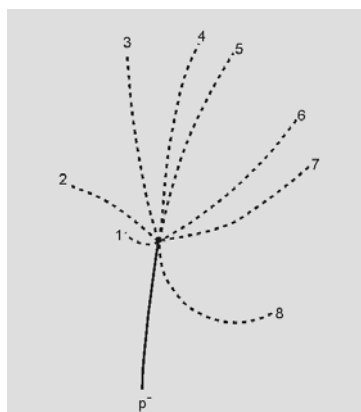


Fig. 6.4

- (i) Explain how the tracks of the particles in **Fig. 6.4** show that charge is conserved in this reaction.

[2]

- (ii) Hadron 8 in **Fig. 6.4** moves on a track with initial radius of 4.6 mm.

Calculate the velocity of this hadron.

hadron charge = 1.6×10^{-19} C

hadron mass = 2.5×10^{-28} kg

magnetic field strength = 2.2 T

velocity = _____ m s⁻¹ [3]

23 Here is a list of particles:

proton	quark	neutron	neutrino
--------	-------	---------	----------

Here are four statements about the particles in the list.

- A All the particles in the list are hadrons.
- B The quark is the only fundamental particle in the list.
- C The neutrino is the only lepton in the list.
- D The proton is the only nucleon in the list.

Choose the correct statement.

The correct statement is [1]

24 Fig. 2.1 shows a graph of electrical field strength E against distance r from a point source.

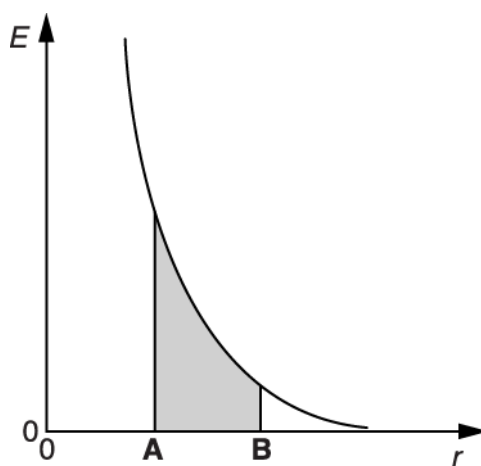


Fig. 2.1

State what is represented by the shaded area of the graph.

[2]

25(a) The biggest contributor to annual radiation dose in the UK is the gas radon. This is an alpha emitter with a half-life of a few days.

A typical dose equivalent to the lungs in one year from radon and its products is 500 μSv .

Calculate the energy absorbed by the lungs in one year to give a dose equivalent of 500 μSv .

mass of lungs = 0.8 kg

quality factor of alpha radiation = 20

energy absorbed = _____ J [2]

- (b) Calculate an estimate of the number of cases of cancer developed in a population of 50 million for an average radon dose equivalent of 500 MSv. Assume a risk factor of 3% per sievert.

number of cases = _____ [2]

26(a) Fig. 4.1 shows a positively charged sphere above an earthed metal plate. Three field lines from the sphere are partially drawn.

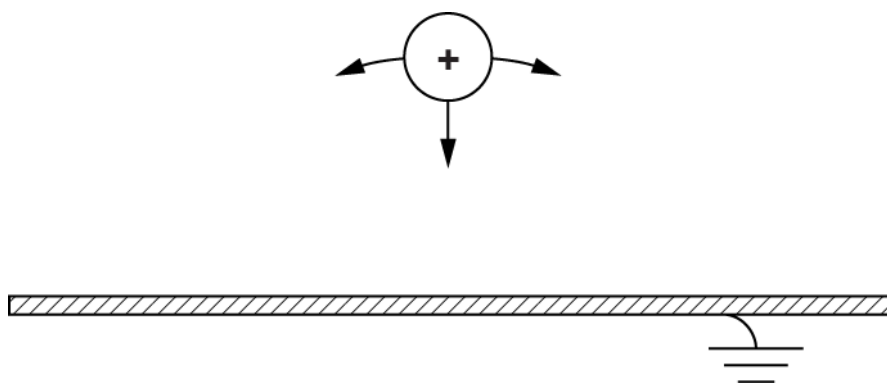


Fig. 4.1

Complete the paths of the field lines to the metal plate.

- (b) Compare the strength of the field close to the plate with the strength close to the sphere. Explain your reasoning. [1]

[2]

27 Transformers are not 100% efficient. Some of the energy loss is due to **eddy currents**.

Describe how eddy currents form in the iron core of a transformer.

Suggest and explain how such currents can be reduced.

[4]

28 Protons in an accelerator beam have a relativistic gamma factor of 2.5.

Calculate the kinetic energy in MeV of a proton in the beam.

rest energy of proton = 938 MeV

kinetic energy = _____ MeV [2]

- 29 Fig. 7.1 shows an iron rod with 200 turns of wire around it. The current in the coil produces a magnetic field in the rod. The flux density in the iron is 0.070 T. The cross-sectional area of the rod is $2.4 \times 10^{-5} \text{ m}^2$.

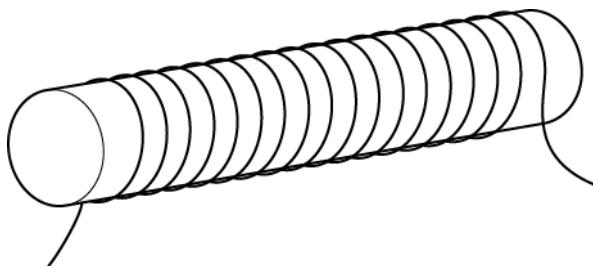


Fig. 7.1

Calculate the flux linkage of the coil. State the units.

flux linkage = _____ units _____ [3]

- 30 A high energy beam of protons is fired at a thin sheet of aluminium. A small proportion of the protons are scattered through large angles. The proportion of protons scattered through large angles increases when the aluminium sheet is replaced with a gold sheet of the same thickness.

Gold has a higher proton number than aluminium. State why the proportion of protons scattered through large angles is greater for gold than for aluminium.

[1]

31(a) This question is about an estimate of the size of a hydrogen atom.

An electron in a hydrogen atom can be modelled as a standing wave confined in a box as shown in Fig. 9.1 where d is the diameter of the atom.

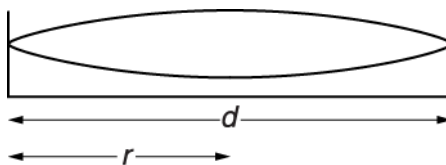


Fig. 9. 1

- (i) State the relationship between the wavelength λ of the standing wave shown and r , the radius of the atom.

[1]

- (ii) Use the two equations below with your answer to (i) to show that the kinetic energy of the electron of mass m is given by $E_k = \frac{h^2}{32 m r^2}$.

momentum $p = \frac{h}{\lambda}$

kinetic energy $E_k = \frac{p^2}{2m}$

[2]

- (iii) State the factor by which the kinetic energy of the electron increases when the radius of the atom halves.

[1]

(b) The potential energy E_p of the electron at a radius r away from the hydrogen nucleus is given by

$$E_p = -\frac{e^2}{4\pi\epsilon_0 r}$$

where e is the charge on an electron.

State the factor by which the magnitude of the potential energy of the electron increases when the radius of the atom halves.

[1]

(c) A simple model of the hydrogen atom suggests that its radius will be a minimum value when

$$E_k + E_p = 0.$$

- (i) Use the equations for E_k and E_p to show that in this model the minimum radius r of a hydrogen atom is given by

$$r = \frac{h^2 \pi \epsilon_0}{8 e^2 m}.$$

[2]

- (ii) Calculate the minimum radius of a hydrogen atom using the data below:

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$h = 6.6 \times 10^{-34} \text{ J s}$$

$$\epsilon_0 = 8.9 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

minimum radius = _____ m [2]

- (d) A hydrogen atom in a bound state cannot have a total energy greater than zero. Explain why a hydrogen atom with smaller than the minimum radius cannot be in a bound state.

[2]

32(a) This question is about pions.

Pions are particles made of up, u , and down, d , quarks combined in quark anti-quark pairs. Charged pions are represented by the symbols π^+ and π^- .

Anti-quarks have opposite charge to their quark partners. $\bar{u}$ is an anti-up quark and $\bar{d}$ is an anti-down quark.

The up quark has charge = $+\frac{2}{3}e$. The down quark has charge = $-\frac{1}{3}e$.

Complete the table below.

Pion	π^+	π^-
Pion Charge		$-e$
Quarks	$u\bar{d}$	

[2]

(b) A π^- is accelerated through a potential difference of 50 V.

(i) Show that the kinetic energy of the π^- would increase by approximately 1×10^{-17} J.

$$e = 1.6 \times 10^{-19} \text{ C}$$

[1]

(ii) Before the acceleration the π^- has a velocity of $1.0 \times 10^5 \text{ m s}^{-1}$.

The acceleration is in the same direction as the initial velocity.

Calculate the final velocity.

Ignore relativistic effects.

final velocity = _____ m s^{-1} [3]

33(a) This question is about the fission of uranium-235 ($^{235}_{92}\text{U}$).

The binding energy per nucleon of uranium-235 is about -7.6 MeV.

Explain the term 'binding energy per nucleon'. Describe how you would calculate the binding energy per nucleon of a uranium-235 nucleus from the values of the masses listed below.

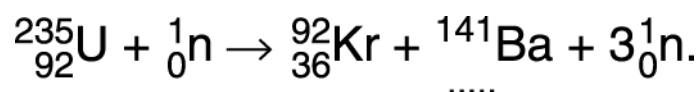
- mass of uranium-235 nucleus
- mass of a proton
- mass of a neutron



You should make each step of your explanation clear.

(b) One uranium-235 fission reaction is

[4]



Complete the equation above.

[1]

- (c) Show that the energy released when one uranium-235 nucleus splits into barium-141 and krypton-92 is about 170 MeV. Show all your working clearly.

binding energy per nucleon of uranium-235 = - 7.6 MeV

binding energy per nucleon of barium-141 = - 8.3 MeV

binding energy per nucleon of krypton-92 = - 8.5 MeV

[3]

(d) A typical uranium fission reactor produces a power of 1500 MW.

Assume each uranium fission reaction releases about 170 MeV.

(i) Calculate the number of fission reactions required per second.

$$e = 1.6 \times 10^{-19} \text{ C}$$

number of fission reactions per second = _____ s^{-1} [2]

(ii) Calculate the mass of uranium-235 fuel that must undergo fission in order to produce a power of 1500 MW for one year.

$$\text{mass of uranium-235 atom} = 4.0 \times 10^{-25} \text{ kg}$$

$$1 \text{ year} = 3.2 \times 10^7 \text{ s}$$

[2]

34(a) This question is about moving charges in a magnetic field.

Electrons are flowing in the semiconducting strip shown in Fig. 12.1.

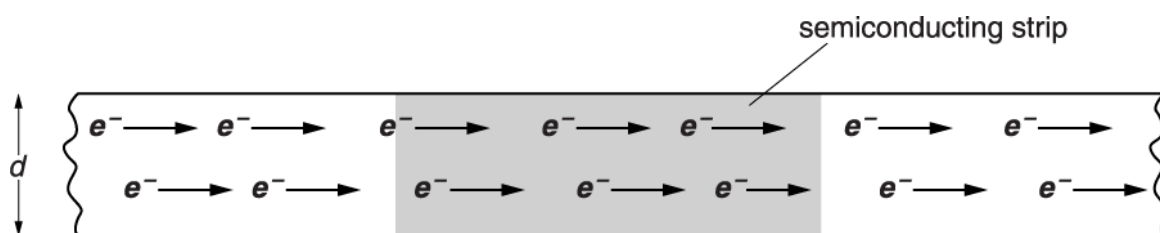


Fig. 12.1

A uniform magnetic field of strength 0.18 T acts perpendicularly up out of the paper in the shaded region of the strip.

Show that an electron, travelling at the average (drift) speed in the direction shown, will experience a force due to the magnetic field of about 3.5×10^{-20} N.

average speed of electrons = 1.2 m s^{-1}

electronic charge, $e = 1.6 \times 10^{-19} \text{ C}$

[1]

- (b) The force on the electrons from the magnetic field makes them drift towards the top edge of the strip which gains a negative charge. The lower edge has a positive charge of equal magnitude. See Fig. 12.2.



Fig. 12.2

The charges set up a uniform electric field in the shaded region.

Draw **four** electric field lines on Fig. 12.2 to represent the uniform electric field in the region.

[2]

- (c) The charges on the edges of the strip create a potential difference V across the strip given by the equation

$$V = B v d$$

where B is the magnetic field strength, v the velocity of the electrons and d the distance between the charged edges.

Calculate the potential difference V when:

$$d = 1.3 \text{ mm}$$

$$v = 1.2 \text{ m s}^{-1}$$

$$B = 0.18 \text{ T.}$$

potential difference = _____ V **[2]**

- (d) The semiconducting strip is replaced by a metal strip of identical dimensions. The current and magnetic field are kept the same. The potential difference across the strip falls to about 10^{-4} of its previous value.

Suggest and explain what this tells you about:

- the drift speed of the conduction electrons in the metal compared with the drift speed of the electrons in the semiconductor
- the number of conduction electrons per m^3 in the metal compared with the number per m^3 in the semiconductor.

[4]

35(a) This question is based on the Advance Notice *Electricity for Spacecraft*.

At the start of a mission, a typical Radioisotope Thermoelectric Generator (RTG) (line 29 in the article) will generate 4.4 kW of thermal power from alpha particle emissions.

Calculate the initial activity of the plutonium in the RTG.

energy emitted in each decay = 5.5 MeV

1 eV = 1.6×10^{-19} J

activity = _____ Bq [2]

- (b) The RTG will not be able to provide sufficient electrical power when the rate of thermal energy production falls below 2500 W.

Calculate the length of time for which the RTG will operate before the rate of thermal energy production falls below this value.

half-life of plutonium-238 = 88 years

time = _____ years [3]

- (c) Some people are concerned about the possibility of accidents during the launch of spacecraft carrying RTGs, which would result in widespread contamination by the alpha-emitting radioisotope. They have suggested that using an isotope with a much shorter half-life of just a few years would be preferable.

Discuss the concerns and suggestions in detail.



Your answer should clearly link the concern and suggestion with the properties of the radioisotope involved and alpha radiation.

[5]

36(a) This question is based on the Advance Notice *Electricity for Spacecraft*.

Long conducting cables ('tethers') hung from some satellites could be used to generate significant voltages (line 42 in the article).

- (i) Calculate the area swept out per second by a cable 20 km long moving at $8 \times 10^3 \text{ m s}^{-1}$ (Fig. 16.1).

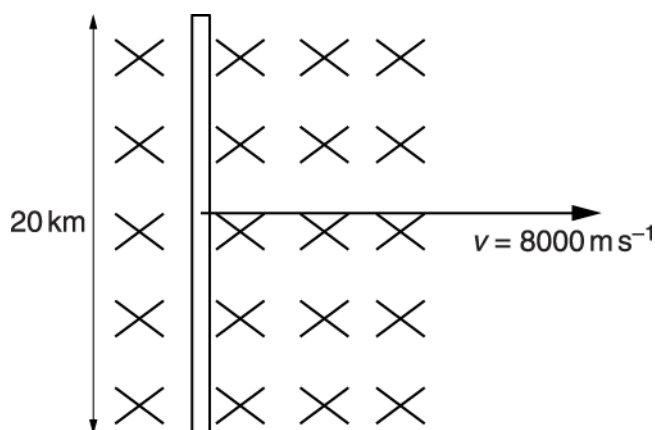


Fig. 16.1

area per second = _____ m^2 [1]

- (ii) The average flux density of Earth's magnetic field perpendicular to the cable is $2.1 \times 10^{-5} \text{ T}$.

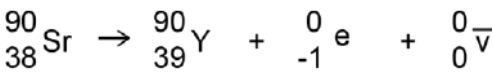
Show that the emf induced in this cable is about 3.5 kV. (line 47 in the article)

[2]

(b) Explain what effect the induced current in the cable will have on the satellite's motion.

[4]

37 The decay of a nucleus of strontium-90 is shown by the equation



What happens to the total charge number, nucleon number and lepton number as a result of this decay?

	charge number	nucleon number	lepton number
A	decreases	conserved	increases
B	conserved	conserved	conserved
C	conserved	conserved	decreases
D	increases	decreases	decreases

Your answer

[1]

38 Two radioactive sources of equal mass are freshly prepared.

One is a β emitter ^{225}Ra with a half-life of 15 days.

The other is an α emitter ^{225}Ac with a half-life of 10 days.

After 30 days, which one of A to D below gives the ratio: $\frac{\text{number of } ^{225}\text{Ra atoms}}{\text{number of } ^{225}\text{Ac atoms}}$?

A 2.0

B 1.33

C 1.0

D 0.5

Your answer

[1]

39 Two radioactive sources of equal mass are freshly prepared.

One is a β emitter ^{225}Ra with a half-life of 15 days.

The other is an α emitter ^{225}Ac with a half-life of 10 days.

After 30 days, which one of A to D below gives the ratio: $\frac{\text{activity of } ^{225}\text{Ra atoms}}{\text{activity of } ^{225}\text{Ac atoms}}$?

A 2.0

B 1.33

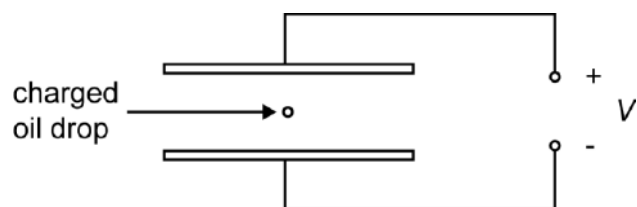
C 1.0

D 0.5

Your answer

[1]

40 The diagram shows a charged oil drop between two parallel plates connected to a high **constant** voltage V .



Which of the following correctly describe(s) changes to the electrical force on the drop?

- 1 If the plates were closer together, the electrical force on the drop would be larger.
- 2 If the drop acquires more charge the electrical force on it increases.
- 3 If the drop moves nearer to the top plate the electrical force on it increases.

- A 1, 2 and 3 are correct
B only 1 and 2 are correct
C only 2 and 3 are correct
D only 1 is correct

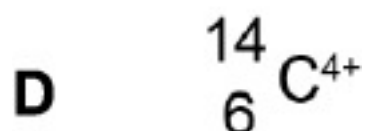
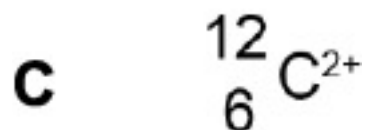
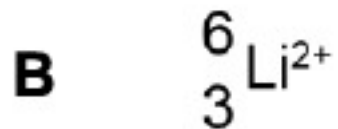
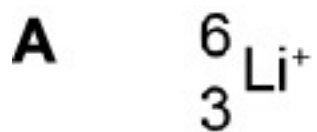
Your answer

☐

[1]

- 41 The differently charged ions of several isotopes are all fired at the same speed. They pass into a region of uniform magnetic flux density perpendicular to their path.

Which of the ions A to D will travel in the circular path of **smallest** radius?



Your answer

[1]

42(a)

Radon decays by α -decay into polonium $^{218}_{84}\text{Po}$.

The α -particle in this decay always has kinetic energy of 5.5 MeV.

The table shows the precise masses of these nuclei in atomic mass units / u.

$$1 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$$

nucleus	nuclear mass / u
Radon 222	221.9703
Polonium 218	217.9628
Helium (α) 4	4.0015

* Show that in this process the mass of the products is less than the mass of the original nucleus. Explain the term *binding energy* and show that the binding energy released is greater than the 5.5 MeV of the α -particle. Use ideas about forces and momenta during the α -decay to suggest why the α -particle does not take away all the energy from the decay.

[6]

(b) This part considers some algebraic reasoning to help to account for the difference between the energy of the α -particle and the binding energy released in (a).

(i)

$$m_{\alpha} v_{\alpha} = m_{\text{Po}} v_{\text{Po}} \rightarrow \frac{v_{\text{Po}}}{v_{\alpha}} = \frac{m_{\alpha}}{m_{\text{Po}}}$$

Where:

m_{α} = mass of α -particle,
 v_{α} = velocity of α -particle

m_{Po} = mass of polonium nucleus,
 v_{Po} = velocity of polonium nucleus.

State the physics principle used in this algebraic reasoning.

-----[1]

(ii) Use (i) to show that the ratio of

kinetic energy of the polonium nucleus
kinetic energy of the α -particle

is given by:

$$\frac{\frac{1}{2} m_{\text{Po}} v_{\text{Po}}^2}{\frac{1}{2} m_{\alpha} v_{\alpha}^2} = \frac{m_{\alpha}}{m_{\text{Po}}}$$

[1]

(iii) The fraction of total kinetic energy taken by α -particle = $\frac{1}{(1 + m_{\alpha} / m_{\text{Po}})}$

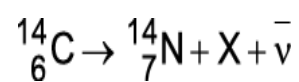
Use the equations above to calculate the kinetic energy of the α -particle and comment on the value.

kinetic energy of α particle = _____ MeV

 -----[3]

43 This question is about carbon-14 in the body.

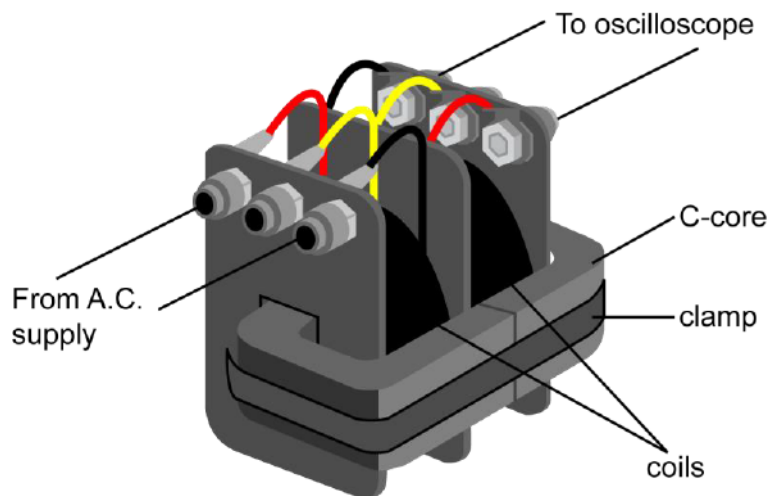
All living matter contains carbon-14, which decays, following the equation:



Identify the particle X in this equation.

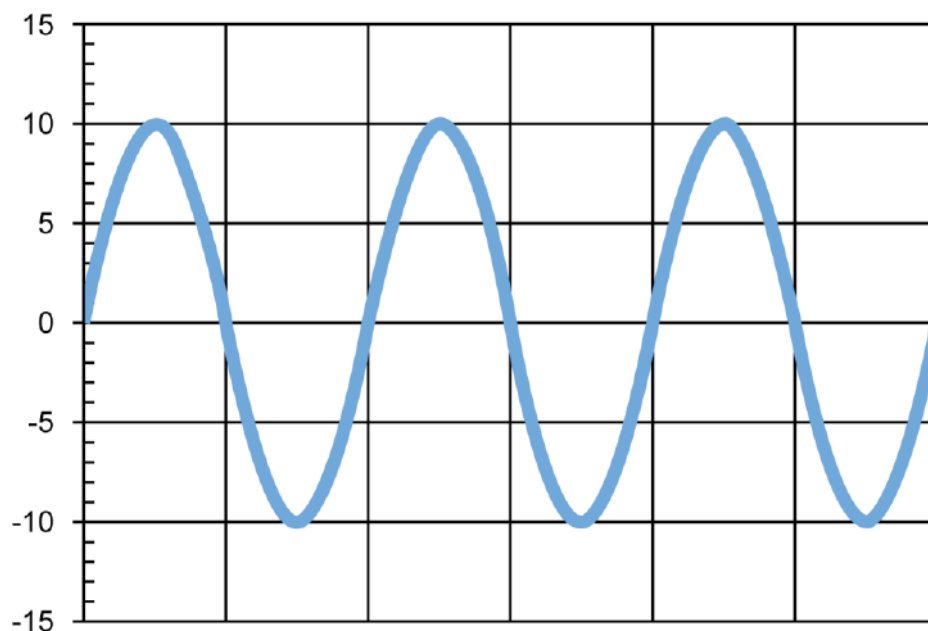
-----[1]

In an experiment to verify the relationship between the primary and secondary voltage and the number of turns on the primary and secondary windings, some pre-wound coils were assembled onto a laminated iron C-core as shown below.



The voltages were measured using an oscilloscope. The y axis was set to 5 volts per division and the x axis to 10 milliseconds per division. The voltage gain and time base settings remained constant throughout the experiment.

The trace shown below was obtained with a secondary coil of 300 turns.



(i) Mark with an X three points on the trace where the flux in the transformer core is zero.

[1]

(ii) Show that the maximum rate of change of flux in the core is about $3 \times 10^{-2} \text{ Wb s}^{-1}$.

[1]

(iii) Explain why the peak flux in the core is unlikely to exceed 0.17 mWb.

----- [2]

45(a) Here is a list of units.

J J C⁻¹ J s⁻¹ J m⁻¹ J kg⁻¹

Which unit from the list is a correct unit for:

force

----- [1]

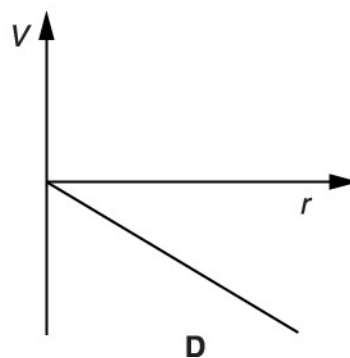
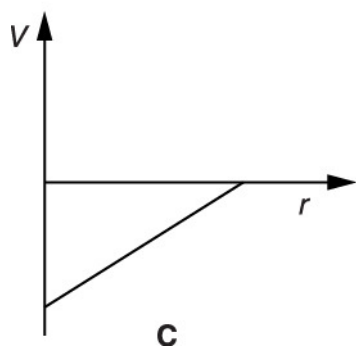
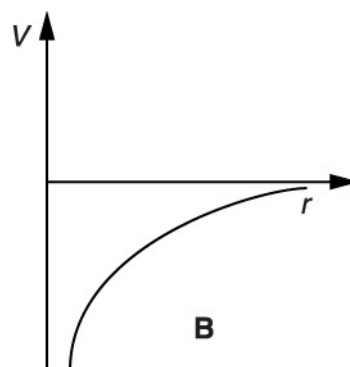
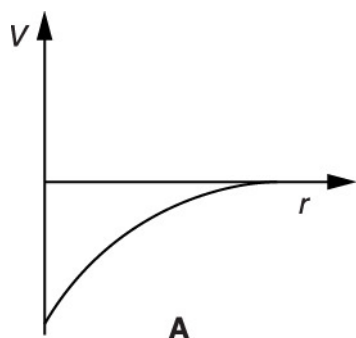
(b) **absorbed** radiation dose

----- [1]

(c) potential in an electric field?

----- [1]

46 Which of the graphs, A, B, C or D, shows the variation of electrical potential V with distance r from an electron?



answer = ... [1]

47(a) Fig. 3.1 shows the paths of an electron and a positron in a uniform magnetic field.

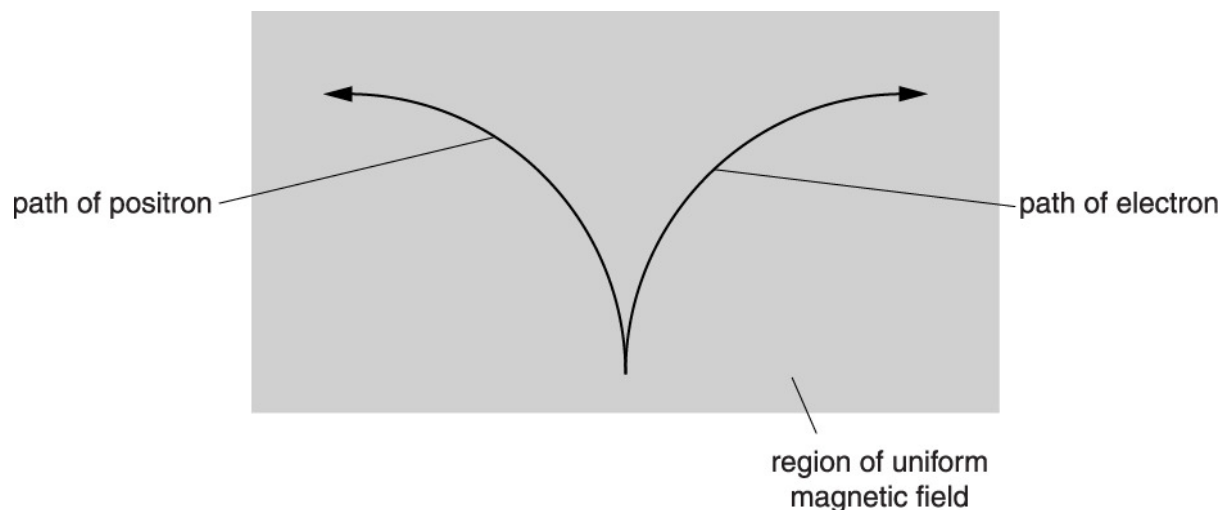


Fig. 3.1

State the feature of the paths that shows that the electron has a different sign of charge from a positron.

- (b) State the feature of the paths that shows that the electron and the positron have the same magnitude of momentum.

[1]

- (c) Calculate the force on the positron as it moves through the uniform magnetic field with a speed of $1.7 \times 10^7 \text{ m s}^{-1}$.

[1]

magnetic field strength = 0.45 T

charge on positron = $1.6 \times 10^{-19} \text{ C}$

force = _____ N [2]

48(a) Fig. 4.1 shows an ideal transformer.

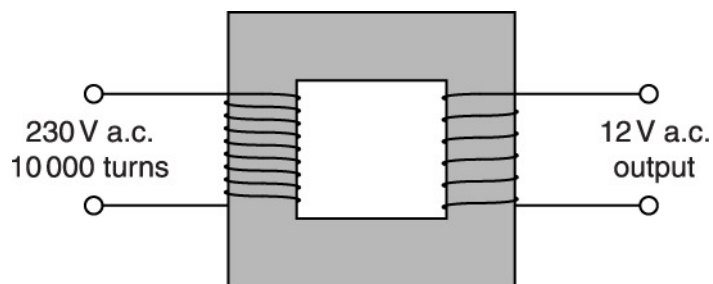


Fig. 4.1

State the ratio $\frac{\text{maximum flux in primary}}{\text{maximum flux in secondary}}$.

ratio = ... [1]

(b) Calculate the number of turns on the secondary coil.

number of turns = ... [2]

49 Fig. 5.1 shows how the average binding energy per nucleon varies with nucleon number.

average binding energy per nucleon

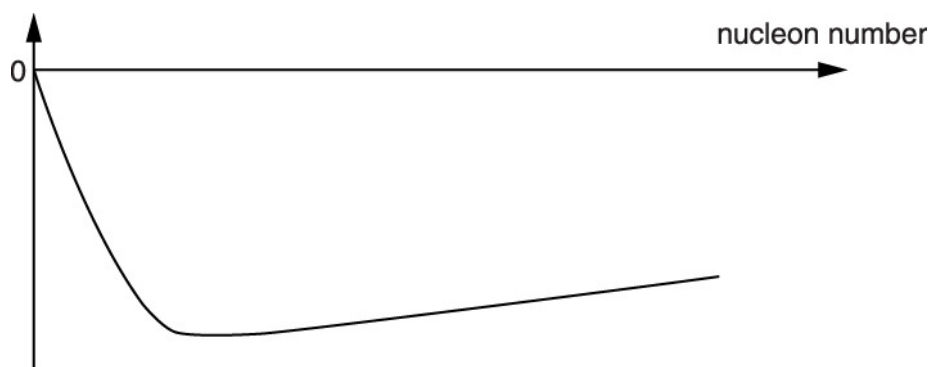


Fig. 5.1

Draw a ring around the section on the graph in which energy can be released from nucleons by the process of fusion.

[1]

50 In a demonstration, a short unmagnetised iron rod is dropped through a vertical copper tube as shown in Fig. 6.1.

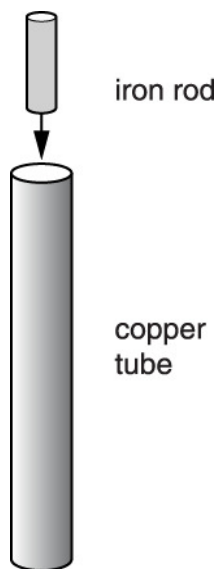


Fig. 6.1

An identical, **magnetised** iron rod takes considerably longer to fall through the copper tube.
Explain this demonstration using ideas about the induced emf in the copper tube.

[3]

51 A radioactive source contains two isotopes, X and Y.

Isotope X has a half life of 3 hours

Isotope Y has a half life of 6 hours

At the beginning of an experiment the source contains twice as many X nuclei as Y nuclei.

Here is a list of numbers:

2 3 4 6 9

Which number represents the ratio $\frac{\text{activity of X}}{\text{activity of Y}}$ at the beginning of the experiment?

[1]

52(a) This question is about an alpha particle scattering experiment. Fig. 9.1 shows the basic experimental set up.

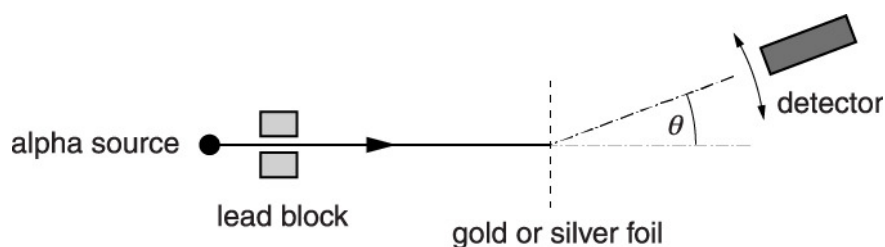


Fig. 9.1

Fig. 9.2 shows the graph of the results of the original experiment published in 1913. It shows the number of alpha particles scattered at different angles θ . The experiment was carried out with gold foil ($^{197}_{79}\text{Au}$) and silver foil ($^{108}_{47}\text{Ag}$). You may assume that there were the same number of target nuclei in the path of the alpha particle in each foil.

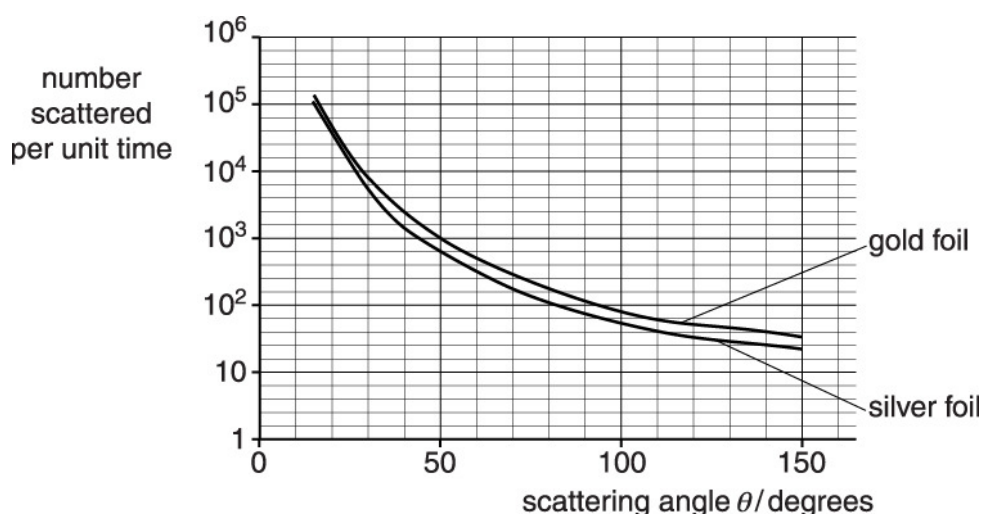


Fig. 9.2

The experimenters looked at the numbers of particles scattered at a wide range of angles, over times long enough to count many particles at each angle. Describe what the graph shows about the scattering from gold foil. Compare this with the observations using silver foil.



Your answers should clearly link to the data from the graph.

[4]

- (b) Consider a 6.0 MeV alpha particle striking the foil and bouncing directly back. Calculate the distance between the alpha particle and the centre of a target gold nucleus at the instant of closest approach. Assume that at this point all the initial kinetic energy of the alpha particle is electrical potential energy.

electronic charge, $e = 1.6 \times 10^{-19} \text{ C}$

electric force constant, $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

charge on a gold nucleus = +79 e

charge on an alpha particle = + 2 e

closest distance = _____ m [3]

- (c) Further experiments show that the radii of nuclei are proportional to $A^{1/3}$, where A is the number of nucleons in a nucleus.

- (i) Explain why this relationship suggests that the density of nuclei is independent of the number of nucleons within a nucleus.

[2]

- (ii) Calculate the ratio $\frac{\text{radius of a gold-197 nucleus}}{\text{radius of an aluminium-27 nucleus}}$.

ratio = _____ [2]

53(a) This question is about beta decay.

In beta decay the following two processes can occur:

neutron $\rightarrow$ proton + electron + anti-neutrino

proton $\rightarrow$ neutron + positron + neutrino.

State **two** of the quantities that must be conserved in beta decay processes.

[2]

(b)

- (i) A neutron can spontaneously decay into a proton. Assuming a neutrino has zero mass, calculate the amount of energy, in J, released when a neutron undergoes beta decay.

Data: neutron mass = 1.6749×10^{-27} kg

proton mass = 1.6726×10^{-27} kg

electron mass = 0.0009×10^{-27} kg

energy = _____ J [2]

- (ii) Explain why a free proton cannot spontaneously undergo beta decay to a neutron, positron and neutrino.

[1]

(c) In particle physics energies are given in units of eV where $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$. Similarly, the mass of particles is often given in units of eV/c^2 where c is the speed of light.

(i) Show that eV/c^2 is a unit of mass.

[2]

(ii) Particle physicists have not been able to assign a precise value to the mass of a neutrino but estimate that it is no more than $2 \text{ eV}/c^2$.

Calculate the maximum value of the mass of a neutrino.

maximum mass = _____ kg [2]

54(a) This question is about the emf induced in a simple generator. Fig. 11.1 shows a square coil initially perpendicular to a uniform magnetic field.

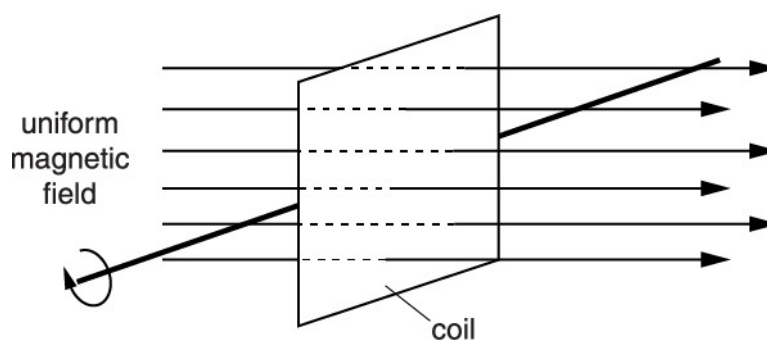


Fig. 11.1

Fig. 11.2 shows how the flux linkage through the coil changes as it rotates in the field.

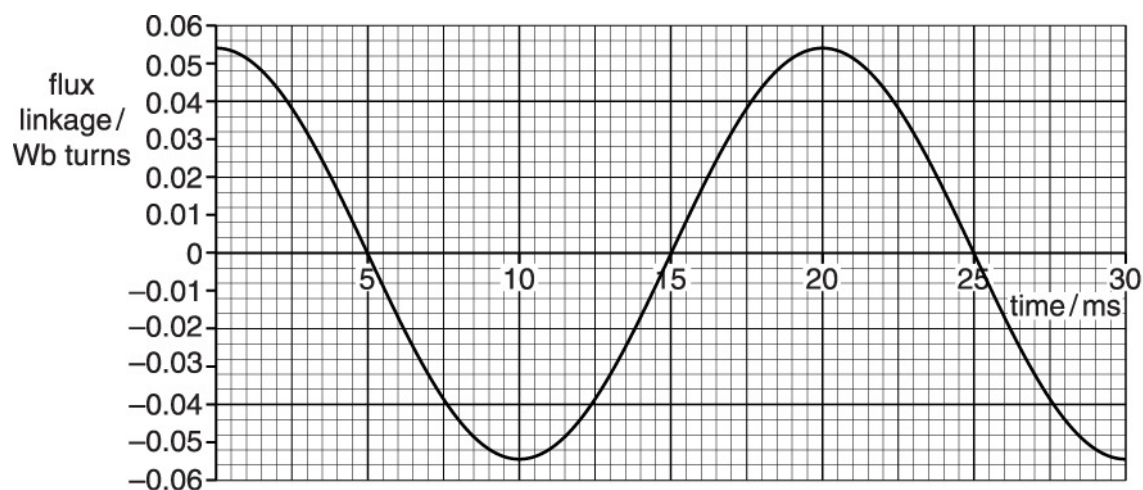


Fig. 11.2

The coil has 200 turns. The magnetic field has a flux density of $7.5 \times 10^{-2} \text{ T}$.

Use these data and data from the graph to calculate the length of a side of the square coil.

length of side = _____ m [2]

- (b) An emf is induced in the coil as it rotates. Data from the graph may be used to estimate the maximum emf by two methods. Method 1 uses the maximum gradient of the graph.

Method 2 uses the equation

$$\text{emf} = \text{maximum flux linkage} \times 2\pi f \sin(2\pi ft)$$

where f is the frequency of the emf and t is the time.

Use both methods to calculate the maximum emf. Explain which answer you have most confidence in.

Method 1:

maximum emf = _____ V

Method 2:

maximum emf = _____ V

Comments on the methods and results:

[8]

55(a) This question is about a test of Special Relativity. In 1962 William Bertozzi designed an experiment which measured the velocity of electrons with a range of kinetic energies. He wanted to test Einstein's prediction that particles could not travel faster than the speed of light.

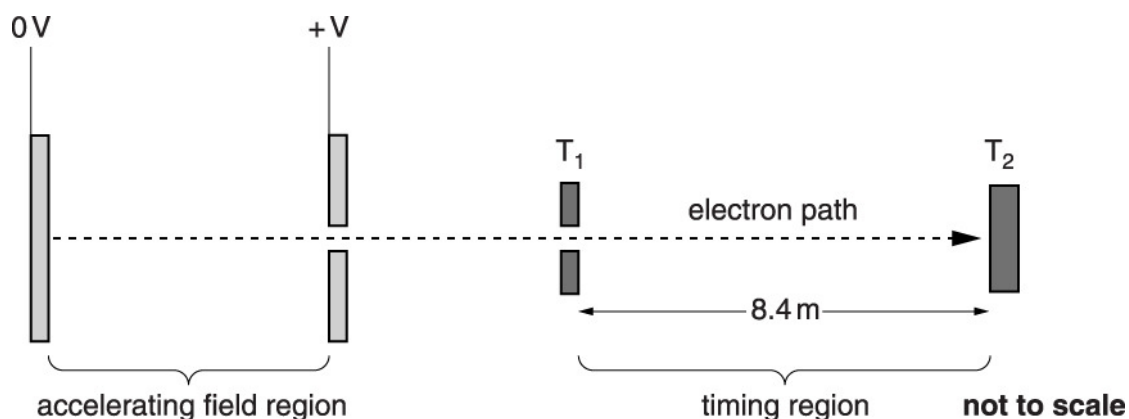


Fig. 12.1

Simplified experimental design of Bertozzi's experiment.

Electrons are accelerated in a region of uniform electric field. The time taken to travel the 8.4 m between timing sensors T₁ and T₂ is recorded. The experiment is carried out in a vacuum.

Draw four field lines representing the uniform electric field in the accelerating region.

[2]

(b) In one run of the experiment the accelerating p.d. was $5.0 \times 10^5 \text{ V}$.

- (i) Show that the kinetic energy gained by the electrons passing through the accelerating field region is $8.0 \times 10^{-14} \text{ J}$.

$$e = 1.6 \times 10^{-19} \text{ C}$$

[1]

- (ii) Show that the speed v of an electron of kinetic energy $8.0 \times 10^{-14} \text{ J}$ would be calculated to be about $4 \times 10^8 \text{ m s}^{-1}$ when relativistic effects are ignored.

$$\text{mass of electron} = 9.1 \times 10^{-31} \text{ kg}$$

[2]

- (c) In the experiment, the $8.0 \times 10^{-14} \text{ J}$ electrons took $3.2 \times 10^{-8} \text{ s}$ to travel across the timing region. Show that the measured velocity of the electrons was $2.6 \times 10^8 \text{ m s}^{-1}$.

[1]

(d)

- (i) Show that the kinetic energy $8.0 \times 10^{-14} \text{ J}$ is comparable to the rest energy of an electron. Hence calculate the relativistic factor γ .

$$\text{speed of light} = 3.0 \times 10^8 \text{ m s}^{-1}$$

$$\text{relativistic factor } \gamma = \text{-----} [2]$$

- (ii) Use your value for the relativistic factor γ to calculate a value for the velocity of the electron when relativistic effects are considered.

$$\text{velocity of electron} = \text{-----} \text{ m s}^{-1} [2]$$

- (iii) Comment on your answer to d(ii).

[1]

- (e) Bertozzi could have designed this experiment to use protons. Suggest and explain why he chose to use electrons in the experiment rather than protons.

[2]

56 This question is based on the insert.

LiF chips have taken over from photographic film as a means of monitoring ionising radiation dose. State and explain **three** properties of the LiF chips which make them better than photographic film for this purpose.

Property 1

Property 2

Property 3

[6]

57(a) This question is based on the insert.

Explain why *dose equivalent* in Sv (line 4) rather than *absorbed dose* in Gy is used to monitor radiation exposure.

[2]

- (b) Physicists in hospital departments have their absorbed dose monitored continuously to check if their dose equivalents lie within safe margins. Use the data in Fig. 14.1 to calculate the total dose equivalent for a particular physicist in one year. The radiation received is a mixture of gamma rays and neutrons; assume the radiation is received by the whole mass.

Mass of physicist	62 kg
Total ionising radiation received	0.12 J
Gamma ray percentage of total energy	75%
Neutron percentage of total energy	25%
Gamma ray quality factor	1
Neutron quality factor	10

Fig. 14.1

total dose equivalent = _____ Sv [4]

58(a) This question is based on the insert.

This question is about the use of lithium fluoride (LiF) crystals in measuring radiation dose.

Show that the number of magnesium defect sites in a single chip is about 5×10^{17} . Assume a doping level of one magnesium ion per thousand pairs of LiF ions.

dimensions of a chip: $3.0 \text{ mm} \times 2.0 \text{ mm} \times 1.5 \text{ mm}$

density of LiF = 2600 kg m^{-3}

molar mass of LiF ion pairs = $26 \times 10^{-3} \text{ kg mol}^{-1}$

Avogadro constant = $6.0 \times 10^{23} \text{ mol}^{-1}$

[4]

- (b) The energy received by a single chip from a dose of 2 Gy is about $6 \times 10^{-5} \text{ J}$. 0.5% of this is used to promote electrons within the crystal (line 20). For this dose, 1 in 10^6 defect sites gain a promoted electron. Show that the energy provided for each electron transition is about 4 eV.

electronic charge = $1.6 \times 10^{-19} \text{ C}$

energy provided by radiation for each electron transition = _____ eV [4]

- (c) Calculate the wavelength of the light emitted when an electron returns to the ground level after heating (line 30). Assume that all this energy is given to the emitted photon.

$$h = 6.6 \times 10^{-34} \text{ J s}$$

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

wavelength = _____ m [2]

59(a) This question is based on the insert.

During the TLD reading process, the photons emitted from the heated LiF chips are detected by a sensitive photomultiplier tube (line 44 and Fig. 18.1 below). Electrons are emitted from the photocathode. Secondary electron emission from a series of dynodes along the tube produces a small but measurable current at the anode.

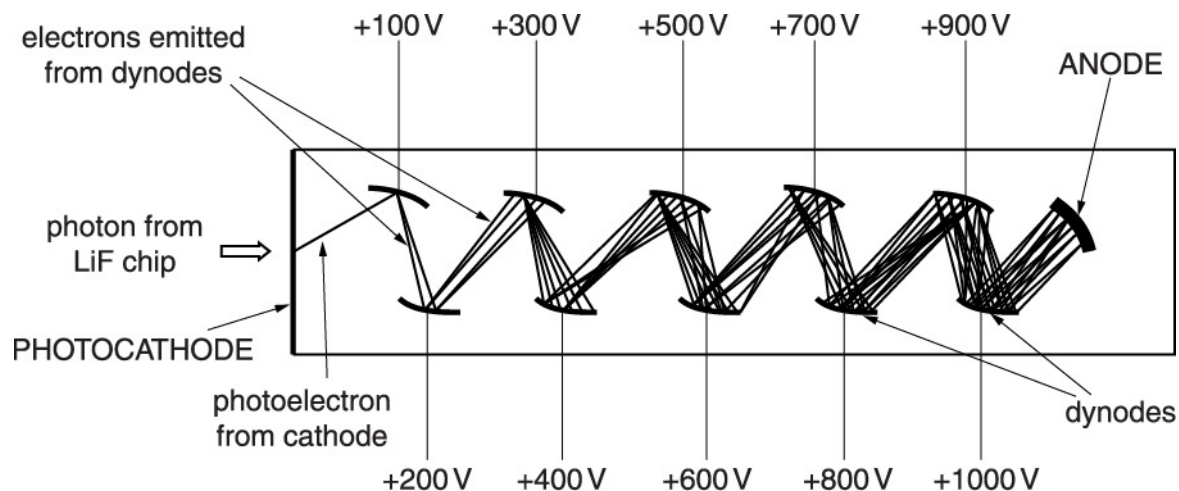


Fig. 18.1

The expression

$$eV = \frac{1}{2} mv^2$$

can be used to calculate the speed with which the photoelectron reaches the +100 V dynode. State two assumptions necessary for this to be a valid calculation.

(i) Assumption 1

(ii) Assumption 2

[2]

- (b) Explain why electrons reaching the last dynode have approximately the same speed as those reaching the first dynode.

[2]

60(a) Look at the list of particle names and properties.

lepton negative neutral hadron nucleon quark

Choose **two** words from the list that describe neutrinos.

----- and -----

[1]

(b) Choose **two** words from the list that describe protons.

----- and -----

[1]

61 Fig. 2.1 shows the path of an alpha particle as it passes a nucleus.

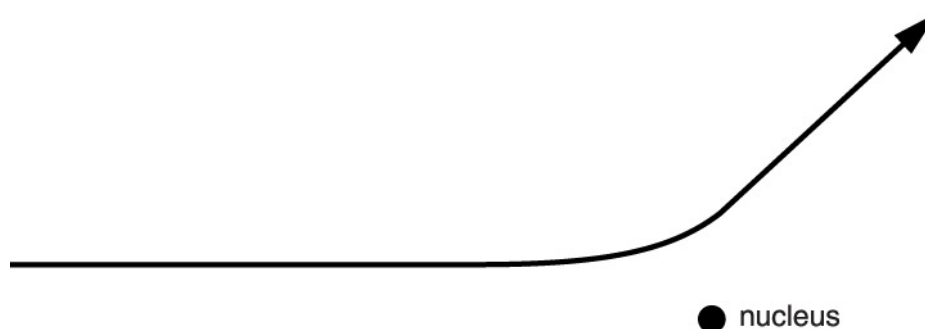


Fig. 2.1

Draw a second line on the diagram representing the path of an alpha particle with **lower** energy taking the same initial path. Give a reason why the paths are different.

[3]

62 Fig. 3.1 shows two metal plates. There is a potential difference between the plates.

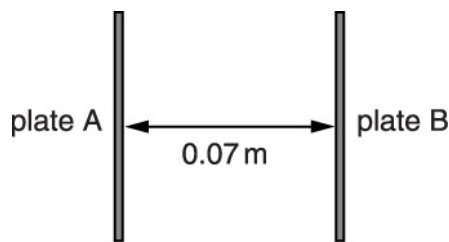


Fig. 3.1

Fig. 3.2 shows the variation in potential between the plates.

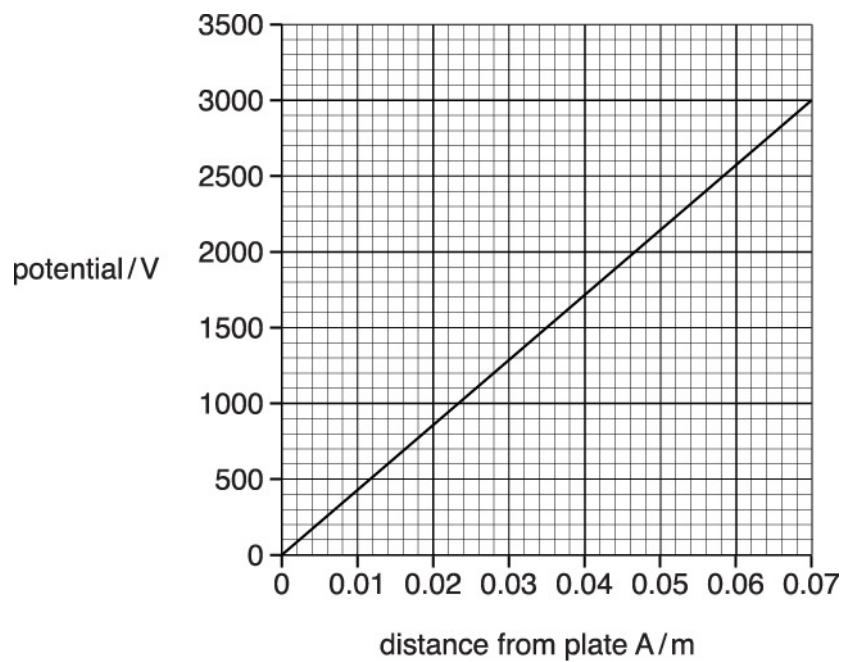


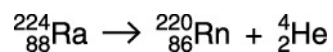
Fig. 3.2

Use the graph to describe the electric field between the plates. Explain your reasoning.

You may use data from the graph for calculations in your answer.

[3]

63(a) The radium isotope $^{224}_{88}\text{Ra}$ decays into radon through alpha decay as shown:



Here is a list of quantities.

nucleon number

charge

mass

quark number

Choose the **one** quantity which is **not** conserved in this decay process.

[1]

(b) A student makes this statement about alpha decay:

“Isotopes which emit alpha radiation mainly cause serious damage to body tissue only when they are swallowed or breathed in.”

Explain why you agree or disagree with the statement, making reference to the properties of alpha particles.

[2]

- 64 An ideal transformer has 1500 turns on its primary coil and 750 turns on its secondary coil. The alternating voltage across the primary is 12 V and the primary current is 0.18 A.

Choose which pair of data correctly shows the values for the secondary coil.

- | | | |
|---|-----|-------|
| A | 24V | 0.09A |
| B | 24V | 0.36A |
| C | 6V | 0.36A |
| D | 6V | 0.09A |

The correct pair of values for the secondary coil is _____.

[1]

65(a) Fig. 6.1 shows an iron core. There is a magnetic flux in the core produced by the current-carrying coil. The shaded region Z has half the cross-sectional area of the rest of the core.

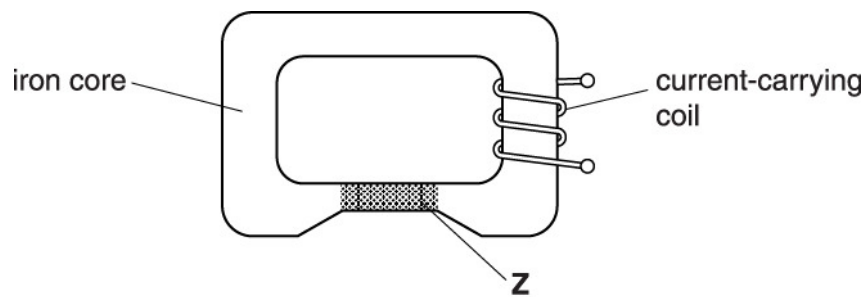


Fig. 6.1

State how the values of the flux and flux density in the shaded region Z compare with those in the rest of the core.

flux:

flux density:

[2]

(b) A crack forms across the core at X as shown in Fig. 6.2.

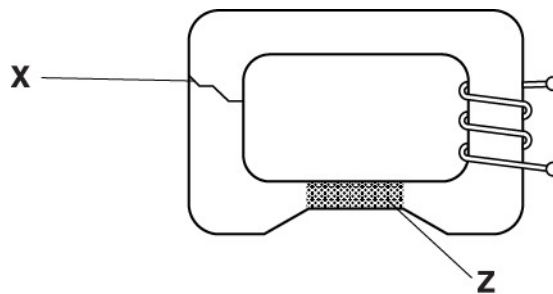


Fig. 6.2

State and explain the effect the crack will have on the values of flux and flux density in region Z.

[2]

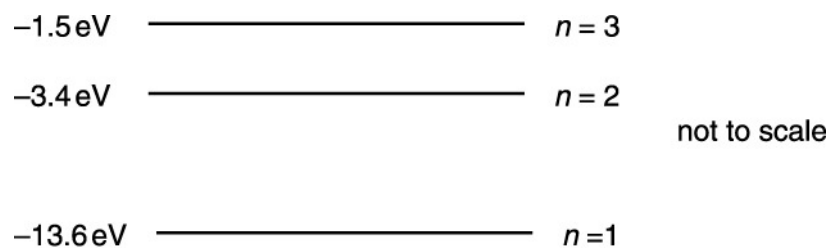


Fig. 7.1

Calculate the frequency of the photon emitted when an electron falls from the $n = 3$ energy level to the $n = 2$ energy level.

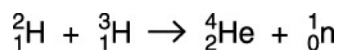
The Planck constant $h = 6.6 \times 10^{-34} \text{ J s}$

Electronic charge $e = 1.6 \times 10^{-19} \text{ C}$

frequency = _____ Hz

[2]

67(a) Physicists are investigating the possibility of using nuclear fusion as an energy source. One possible reaction is given below:



The mass of the products of the reaction is $3.1 \times 10^{-29} \text{ kg}$ less than the mass of the original nuclei.

Calculate the energy released in the reaction.

$c = 3.0 \times 10^8 \text{ m s}^{-1}$

energy = _____ J

[2]

(b) State why high temperatures are needed for this reaction to take place.

[1]

68(a) This question is about the electric field near point charges.

The field near a charge is represented by the field lines shown in Fig. 9.1.

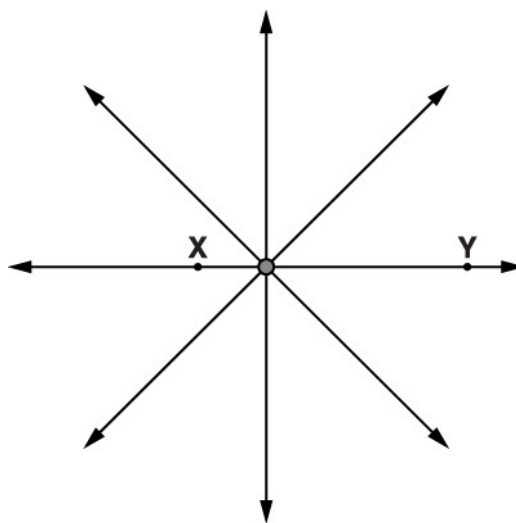


Fig. 9.1

(i) State the feature of the diagram in Fig. 9.1 that shows that the field is stronger at point X than at point Y.

[1]

(ii) Draw a complete equipotential line through point X.

[1]

(b) As shown in Fig. 9.2, point Y is four times the distance of point X from the charge.

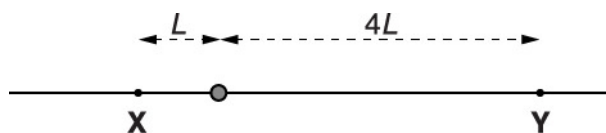


Fig. 9.2

(i) The potential at X is +1800 V. Calculate the potential at Y.

potential = ... V

[1]

(ii) The electric field strength at X is $9.7 \times 10^4 \text{ N C}^{-1}$. Calculate the field strength at Y.

field strength = ... N C^{-1}

[1]

- (c) Fig. 9.3a shows two positive charges of the same magnitude. Fig. 9.3b shows two charges also of the same magnitude but of the opposite sign.

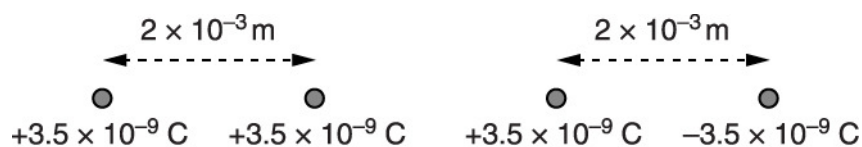


Fig. 9.3a

Fig. 9.3b

- (i) Explain using calculations why the field strength at the midpoint between the charges in Fig. 9.3a is zero but is $6.3 \times 10^7 \text{ N C}^{-1}$ at the midpoint between the charges in Fig. 9.3b.

electric force constant $k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

[3]

- (ii) Explain why the **potential** at the midpoint between the charges in Fig. 9.3b is zero.

[2]

69(a) This question is about a simple d.c. motor. Fig. 10.1 shows a square current-carrying coil between two permanent magnets.

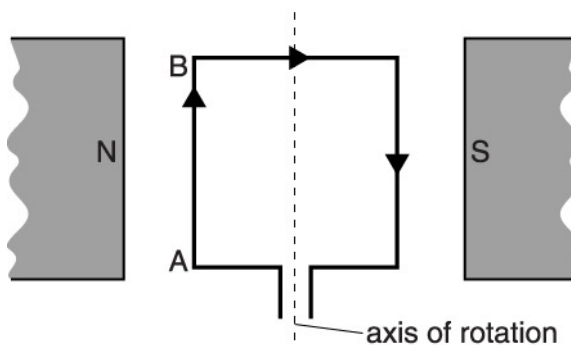


Fig. 10.1

- (i) Use the data below to calculate the force on side AB of the coil.

length of AB = 6.0×10^{-2} m

current in coil $I = 0.57$ A

magnetic field strength $B = 90$ mT

number of turns $N = 75$

force = ... N

[1]

- (ii) The force on the coil makes the coil rotate. Suggest and explain how you expect the rate of rotation to change if all the sides of the square coil are reduced to 3.0×10^{-2} m. The current in the coil is not changed.

[2]

- (b) An emf is generated in the coil in Fig. 10.1 when it rotates in the magnetic field. Fig. 10.2 shows the coil in positions of zero flux linkage and maximum flux linkage viewed along the axis of rotation.

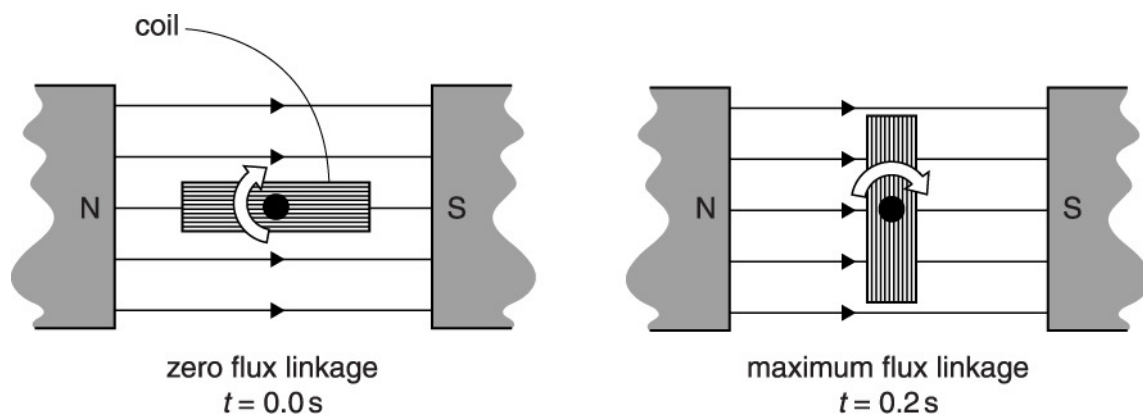


Fig. 10.2

- (i) Use the data below to calculate the force on side AB of the coil.

length of AB = 6.0×10^{-2} m

current in coil $I = 0.57$ A

magnetic field strength $B = 90$ mT

number of turns $N = 75$

Calculate the maximum flux linkage of the **square** coil.

maximum flux linkage = _____ Wb-turns

[1]

- (ii) The coil moves through one quarter turn in 0.2 s as shown in Fig. 10.2. Calculate the average emf induced during this time.

average emf induced = _____ V

[1]

- (iii) If the motor is jammed so that it stops turning, the current in the coil increases. Explain why.



In your answer you should use ideas about electromagnetic induction to explain why the current is higher when the motor turns more slowly.

[4]

70(a) This question is about the deflection of particles in a magnetic field.

Fig. 11.1 shows the path of an alpha particle in a uniform magnetic field.

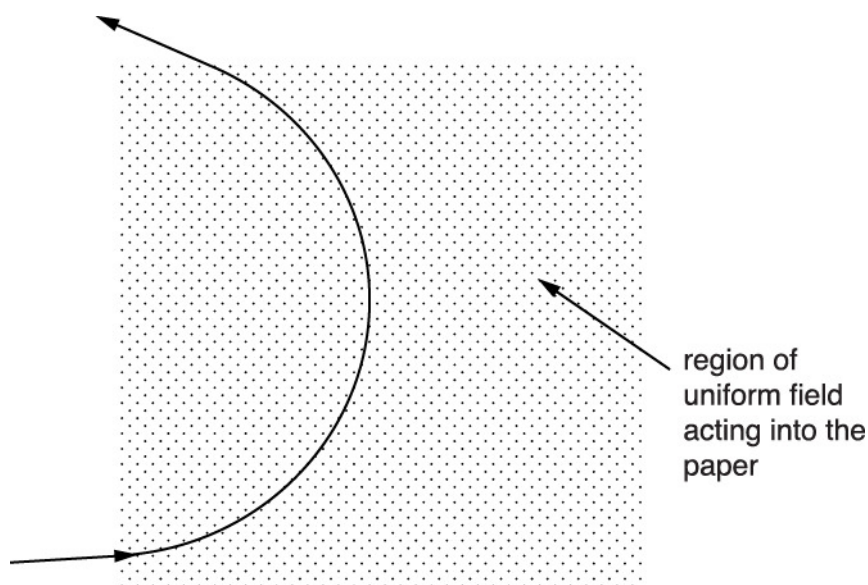


Fig. 11.1

The magnetic field produces a force on the alpha particle which travels in a circular path.

- (i) State why the force on the alpha particle deflects the particle in a circular path.

[1]

- (ii) Use equations for the force on a moving charge in a magnetic field and for the force on a mass moving in a circle to show that the radius r of the path taken by a particle moving at speed v at right angles to a magnetic field of flux density B is given by

$$r = \frac{mv}{Bq}$$

where m is the mass of the particle and q is the charge on the particle.

[1]

- (b) Fig. 11.2 shows a diagram that often appears in physics textbooks. It gives a misleading impression of how much alpha and beta particles are typically deflected by a magnetic field. The diagram is not to scale.

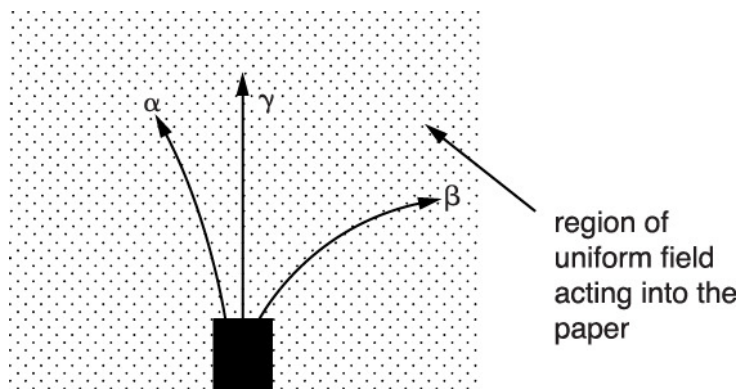


Fig. 11.2

Suggest why the diagram is correct to show that an alpha particle is deflected less than a beta particle, and that a gamma ray is not deflected.

[2]

(c) Here are some typical data about alpha and beta particles released in radioactive decays.

Particle	Mass / kg	Typical velocity on release / m s ⁻¹	Charge / C
alpha	6.6×10^{-27}	1.0×10^7	$+3.2 \times 10^{-19}$
beta	9.1×10^{-31}	2.0×10^8	-1.6×10^{-19}

Use these data and the equation given below to explain why Fig. 11.2 does not accurately compare the paths of the alpha and beta particles.

$$r = \frac{mv}{Bq}$$



In your answer you should link the results of any calculations to the paths shown on Fig. 11.2.

[4]

71(a) This question is about a radioisotope used in medicine.

Iodine-131 is a beta emitter. It decays to xenon as shown.



Each xenon nucleus produced in the decay immediately emits a gamma ray photon of energy 364 keV.

Describe how the decay equation shows that lepton number is conserved in this process.

[2]

(b) In a medical procedure, 1.20×10^{-13} kg of iodine-131 is absorbed into the thyroid gland in the neck.

(i) The initial activity of the iodine is stated to be about 5×10^5 Bq.

Confirm this value of the activity, showing each step of your calculation.

mass of iodine-131 atom = 2.18×10^{-25} kg

half life of iodine-131 = 6.95×10^5 s (8 days)

[3]

(ii) It is said that a person treated with iodine-131 may still emit enough gamma rays to set off airport alarms twelve weeks after the treatment. Calculate the activity of the iodine sample in (i) after twelve weeks.

activity = _____ Bq

[2]

- (c) Calculate the maximum dose in gray delivered to the thyroid gland from the beta emission, assuming all the iodine-131 decays in the gland. State why your answer is a maximum value.

average energy of beta particle = $2.9 \times 10^{-14} \text{ J}$

mass of thyroid gland = $1.8 \times 10^{-2} \text{ kg}$

maximum dose = _____ Gy

[3]

- (d) Iodine-131 has been used as a 'tracer'. The movement of the iodine through the body is detected by gamma sensors around the body.

Explain why isotopes that emit gamma rays are required for use as tracers, and suggest why iodine-131 is now rarely used for this purpose.

[3]

72 This question is based on the insert.

While in operation, an electron microscope produces a continuous beam of electrons travelling along an evacuated tube (line 50).

The beam of electrons carries a current of 2.0×10^{-12} A.

Calculate the number of electrons leaving the electron gun each second.

electronic charge $e = 1.6 \times 10^{-19}$ C

number of electrons per second = _____

[1]

73 This question is base on the insert.

In a typical scanning electron microscope, the electrons are accelerated from rest through a potential difference of 40 kV.

- (i) Show that the kinetic energy gained by each electron is about 6×10^{-15} J.

electronic charge $e = 1.6 \times 10^{-19}$ C

[1]

- (ii) Calculate the momentum gained by each electron. Ignore relativistic effects.

mass of an electron $m_e = 9.1 \times 10^{-31}$ kg

momentum gained = _____ kg m s⁻¹

[2]

74(a) This question is based on the insert.

In electron microscopes, beams of electrons are focused using circular solenoids producing strong magnetic fields (line 46), typically about 1 tesla in TEMs.

Show that the number of turns required to produce this field strength in a circular solenoid of mean diameter 0.010 m which carries a current of 2.0 A is about 4000.

$$\text{field strength in solenoid } B = \mu_0 \frac{IN}{d}$$

where

B is magnetic field strength in tesla

μ_0 is permeability of free space = $1.3 \times 10^{-6} \text{ N A}^{-2}$

I is current in amps

N is number of turns

d is diameter of solenoid in metres

[2]

(b) Estimate the potential difference needed across this coil to produce the required field strength.

resistance per unit length of the wire used = $1.6 \text{ } \Omega \text{ m}^{-1}$

potential difference = _____ V

[2]

75(a) This question is based on the insert.

In some SEM systems, sideways deflection of the beam (for scanning) can be obtained using a uniform electric field (line 70) between two parallel plates (Fig. 18.1).



Fig. 18.1

Show that the electric field between a pair of plates 1.8 mm apart with a potential difference across them of 200 volts is more than 10^5 V m^{-1} .

[1]

- (b) The electrons move through the field at a speed of 40% of the speed of light so relativistic effects can be ignored.

Calculate the length of plates required to produce a deflection of 5×10^{-4} m at the end of the plates.

electronic charge $e = 1.6 \times 10^{-19}$ C

electron mass $m_e = 9.1 \times 10^{-31}$ kg

length of plates = _____ m [4]

- (c) Explain why the size of the deflection of an electron passing through the middle of the gap between the plates would be unchanged if it entered the gap closer to the negative plate.

[2]

- 76 Transmission electron microscopes use electrons of high energy, at which relativistic effects ($\gamma > 1$) are significant.

Calculate the velocity of an electron accelerated through a potential difference of 200 kV, taking relativistic effects into account.

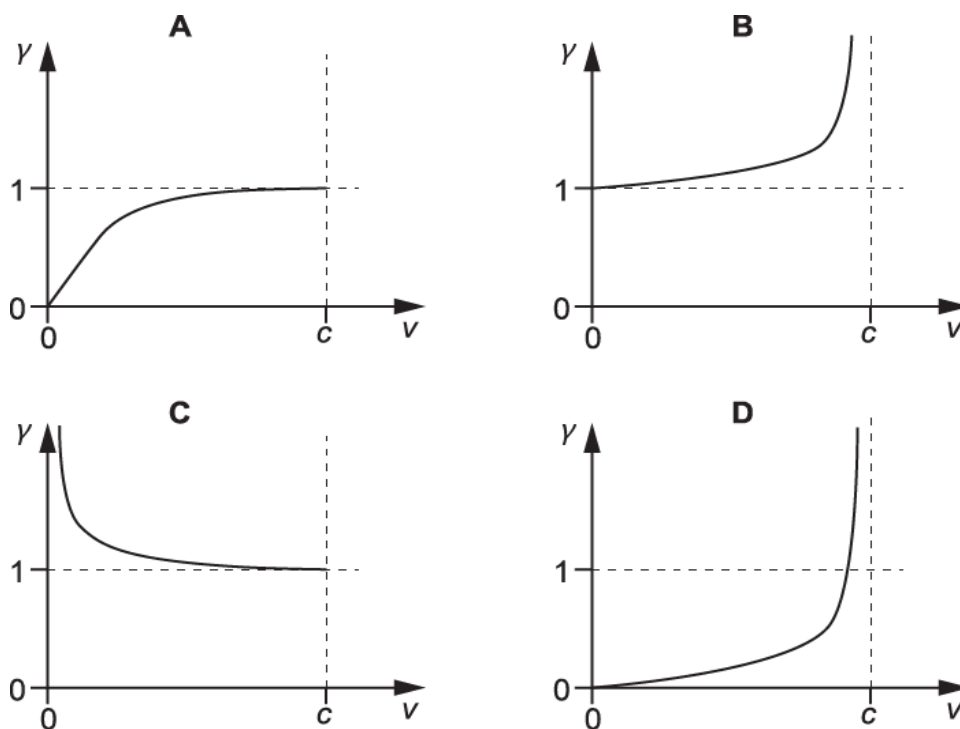
rest energy of the electron = 0.511 MeV

speed of light $c = 3.0 \times 10^8 \text{ ms}^{-1}$

velocity = _____ ms^{-1}

[3]

- 77 Which graph shows the correct relationship between the relativistic γ factor and the speed v of a moving particle?



Your answer

[1]

78 Which is the best estimate for the order of magnitude of the energy, in electronvolts, of a photon of visible light?

- A 10^{-19} eV
- B 10^{-10} eV
- C 1 eV
- D 10^{19} eV

Your answer

[1]

79 Protons and neutrons consist of smaller particles called quarks.

The ‘up’ quark has a charge $+\frac{2}{3}e$ and the ‘down’ quark has a charge $-\frac{1}{3}e$, where e is the elementary charge.

How many up quarks and down quarks must a proton contain?

	Up quarks	Down quarks
A	0	3
B	1	1
C	1	2
D	2	1

Your answer

[1]

80 The grid shows the number of nucleons and the number of protons for different nuclides.

number of nucleons

237				Np		
236		A				
235				C	D	
234						
233				B		
	89	90	91	92	93	94

number of protons

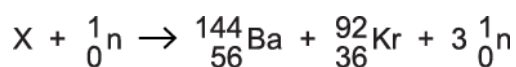
The isotope of Neptunium (Np) shown on the grid decays by emitting an alpha particle and then a beta particle.

Which box represents the resulting nuclide?

Your answer

[1]

81 A nucleus X interacts with a neutron and undergoes fission:



What is nucleus X?

- A ${}^{234}_{92}\text{U}$
- B ${}^{238}_{92}\text{U}$
- C ${}^{235}_{92}\text{U}$
- D ${}^{237}_{93}\text{Np}$

Your answer

[1]

- 82 A fixed mass of gas occupies a volume V . The temperature of the gas increases so that the root mean square speed of the molecules doubles. The pressure remains constant.

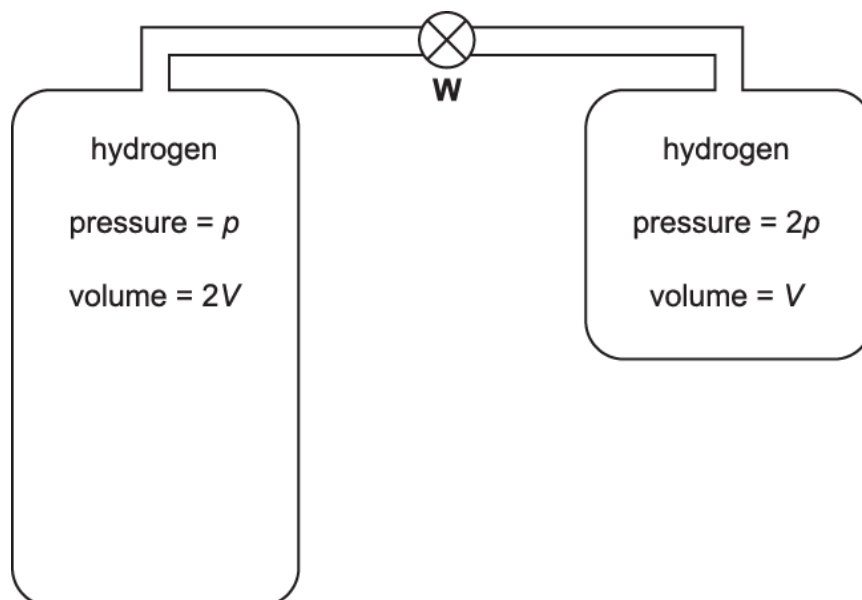
What is the new volume of the gas?

- A $\frac{V}{2}$
B $\frac{V}{\sqrt{2}}$
C $2 V$
D $4 V$

Your answer

[1]

83 Two large gas bottles are connected by a tube of negligible volume as shown.



Initially the valve **W** is closed.

Valve **W** is opened so that gas can slowly flow, but remain at room temperature.

What is the new gas pressure in the bottles when flow has stopped?

- A $\frac{2}{3}p$
- B $\frac{4}{3}p$
- C $\frac{3}{2}p$
- D $\frac{5}{3}p$

Your answer

[1]

- 84 A thick aluminium disc has its plane perpendicular to a uniform magnetic field as in Fig. 29.1.
The disc is then turned through 90° until its plane is parallel to the magnetic field as in Fig. 29.2.

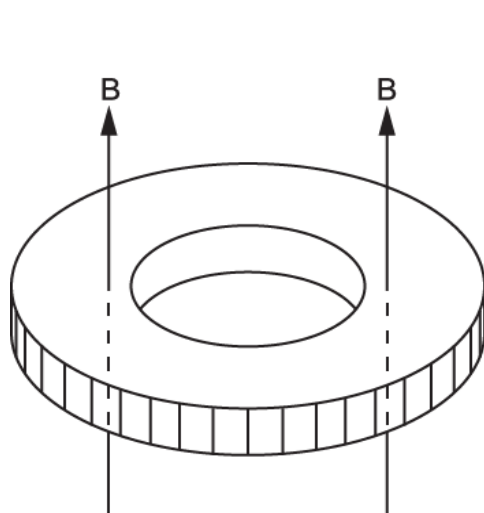


Fig. 29.1

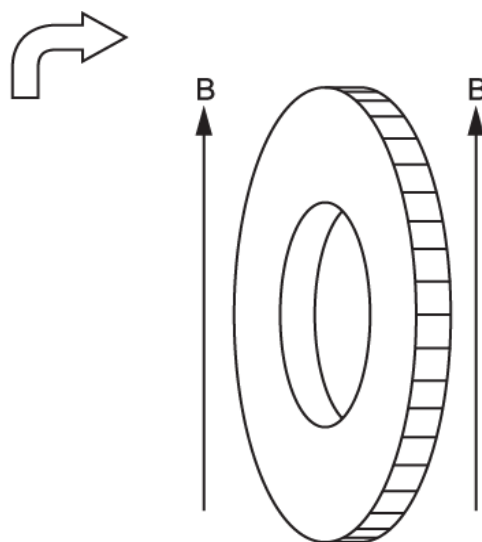


Fig. 29.2

The movement cuts magnetic flux, so there is an induced e.m.f. and hence an induced current is produced in the disc.

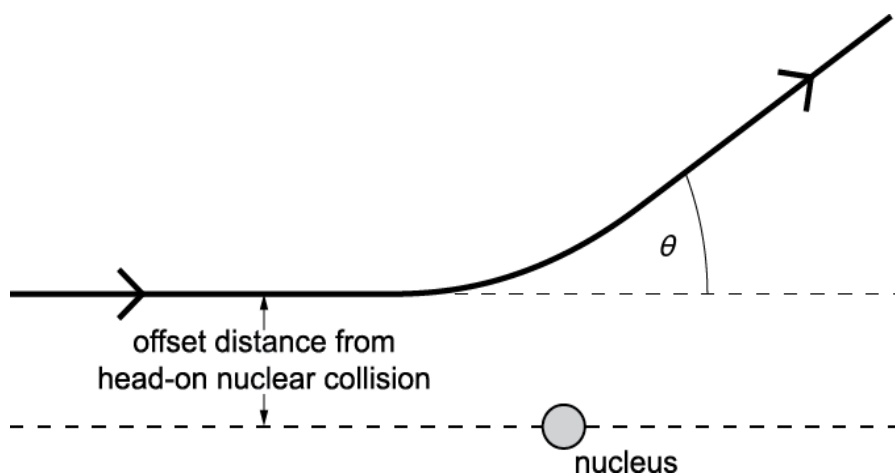
This **induced current** could be increased by

- A increasing the size of the central hole.
- B increasing the speed of turning the disc.
- C using metal of a lower conductivity for the disc.
- D turning the disc in the opposite direction.

Your answer

[1]

- 85 An α particle approaches an atomic nucleus and is scattered through angle θ .
The path of the particle is offset as shown.



Which of the following changes on its own would cause the scattering angle θ to decrease?

- A Use an α particle with lower kinetic energy.
- B Have a smaller offset distance for the initial trajectory.
- C Use a target nucleus with a smaller charge.
- D Use a target nucleus with a larger mass.

Your answer

[1]

86(a) This question is about a circular particle accelerator called a cyclotron.

The cyclotron consists of two hollow semicircular metal “dees”, dee 1 and dee 2, in a vacuum. The dees are in a uniform magnetic field B of 0.80 T and are separated by a narrow gap as shown in Fig. 40.1.

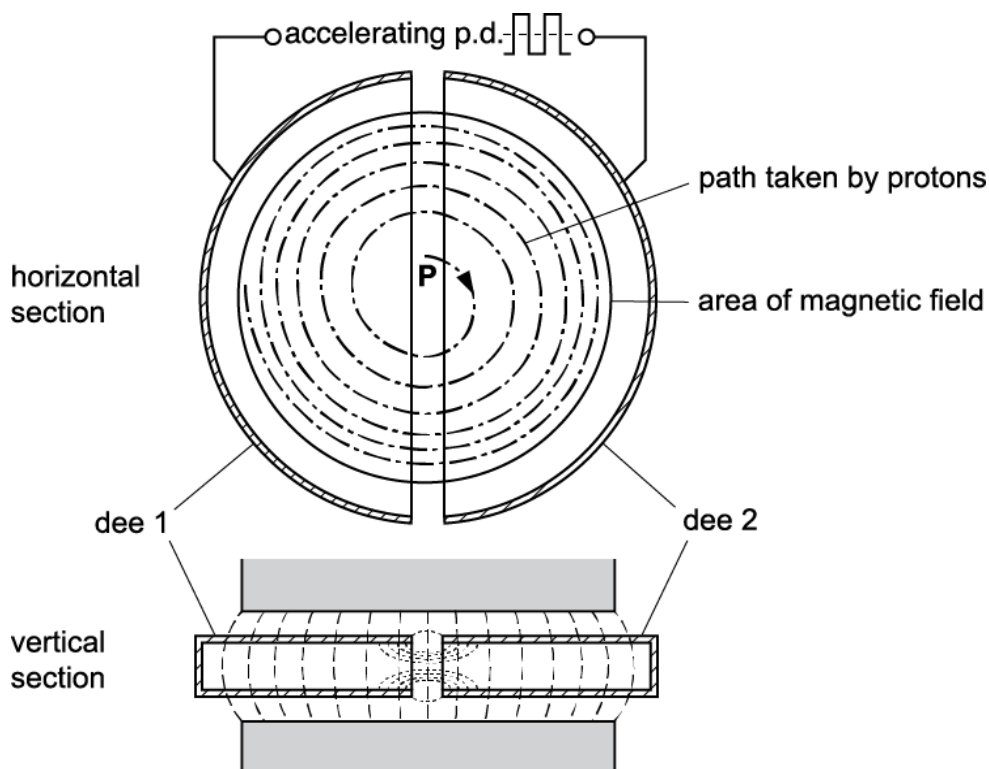


Fig. 40.1

Protons are injected into the gap between the dees at P and are accelerated by the electric field between the dees. The dees are horizontal and the magnetic field is in the vertical direction. The protons move in horizontal semi-circular paths within the dees, the path diameter increases after each crossing of the gap.

Show that the protons of mass m and charge q move in a circular path of radius $r = \frac{mv}{Bq}$ with constant speed v inside each dee. Assume non-relativistic conditions.

----- [2]

(b)

- (i) Show that the time T to travel around a semi-circle within a dee is independent of v .

[1]

- (ii) State the implication this has on the frequency of the alternating accelerating p.d. across the dees.

----- [1]

- (iii) The frequency f of the accelerating p.d. is given by $f \approx \frac{1}{2T} = \frac{Bq}{2\pi m}$.

Calculate this frequency for protons in a uniform magnetic field of 0.80 T.

frequency = ----- Hz [1]

- (iv) Each time the protons cross the gap between the dees they are accelerated through a p.d. of 5.0 kV.

Calculate the number of loops in their spiral path that is needed to accelerate them to an energy of 1.2 MeV.

number = ----- [2]

- (v) Use the relativistic factor γ to show that a non-relativistic approach for this cyclotron is a reasonable approximation.

rest energy of proton = 940 MeV

[2]

87(a) This question is about the first three minutes of the big bang, the formation of protons and neutrons and their fusion to produce the first nuclei of hydrogen and helium.

The table shows a time line at some interesting moments.

Time from big bang / s	0.02	1.1	180
Temperature / K	10^{11}	10^{10}	10^9
Energy kT / MeV	8.8	0.88	0.088
Density / kg m^{-3}	3.8×10^{12}	3.8×10^8	3.8×10^4

The big bang represents an incredibly hot and dense state of matter that was rapidly expanding and cooling.

(i) Show that at a temperature of 10^{11} K the thermal energy of particles and photons is around 9 MeV per particle.

[1]

(ii) Show that electron and positron pairs can easily be created from photon collisions at 10^{11} K

[2]

(iii) Explain why the creation of proton – antiproton pairs requires an earlier, hotter period of time during the big bang.

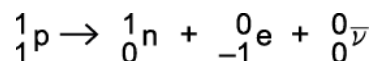
[1]

- (b) Free neutrons decay into protons with the emission of an electron and antineutrino. Free neutrons have a half-life of about 10 minutes. Once bound in a nucleus they become stable. Neutrons are more massive than protons.

$$m_{\text{PROTON}} = 1.007276 \text{ u} \quad m_{\text{NEUTRON}} = 1.008665 \text{ u} \quad m_{\text{ELECTRON}} = 0.000549 \text{ u}$$

$$1 \text{ u} = 1.661 \times 10^{-27} \text{ kg} = 931.3 \text{ MeV}$$

A proton can convert to a neutron by the process:



- (i) Show that the minimum energy for this process is about 1.8 MeV.

[2]

- (ii) 1.8 MeV is the activation energy for the conversion of a proton into a neutron. Use the Boltzmann factor to suggest why the ratio of numbers of protons : neutrons rises as the early universe cools, and at a temperature of 10^{11} K it is 1 : 0.812.

[3]

(c) As the universe cools to 10^{10} K, the proton : neutron ratio continues to rise. Neutrons can be fused to protons forming the simplest compound nucleus of deuterium ${}^2_1\text{H}$.

(a) Show that the binding energy for ${}^2_1\text{H}$ is about 2 MeV.

$$m_{\text{DEUTERON}} = 2.013553 \text{ u}$$

[2]

(b) Explain why some of the deuterons formed will also break apart at this temperature

----- [1]

- (i) A photoelectron is released from rest at a photocathode. Calculate its velocity just before it strikes the +100 V dynode, assuming non-relativistic behaviour.

mass of electron = 9.1×10^{-31} kg

velocity = _____ m s⁻¹ [2]

- (ii) The rest energy of an electron is 0.51 MeV. Explain whether it is reasonable to ignore relativistic effects when an electron is accelerated through 100 V. You may include calculations in your explanation.

[2]

89(a) This question is about the absorption of gamma rays (lines 67–73).

Material Y has a half-thickness of 2.5 cm. Show that the absorption coefficient of material Y is about 0.3 cm^{-1} .

[2]

- (b) A detector placed 10 cm from a gamma source records a corrected count rate of 900 cps. The source-detector distance is increased to 40 cm and a sheet of material of thickness 0.5 cm and an absorption coefficient of 0.3 cm^{-1} is placed in front of the detector. Calculate the expected corrected count rate at the detector.

corrected count rate = _____ cps [4]

- (c) Gamma rays used in imaging are required to pass through body tissue. Gamma rays used for treatment of tumours are required to be absorbed by body tissue. Explain how gamma rays fulfil both requirements.

[2]

Fluorine-18 has a half-life of 110 minutes.

Describe and explain why PET scanning facilities need easy access to particle accelerators and why patients who have been given fluorine-18 must remain in the radiography room for a few hours after the procedure. Include an explanation of any precautions the medical personnel should take.

You may include calculations in your answer. You may find it helpful to assume that the activity of the fluorine-18 at the beginning of the procedure is 3000 Bq.

[6]

91(a) This question is about the attenuation of gamma radiation as it passes through lead.

Fig. 4.1 shows the experimental set up using a Geiger-Müller tube to detect gamma radiation emitted from a sample of cobalt-60. Different thicknesses of lead sheet are placed between the source and the Geiger-Müller tube and a counter is used to measure the number of counts per minute (cpm).

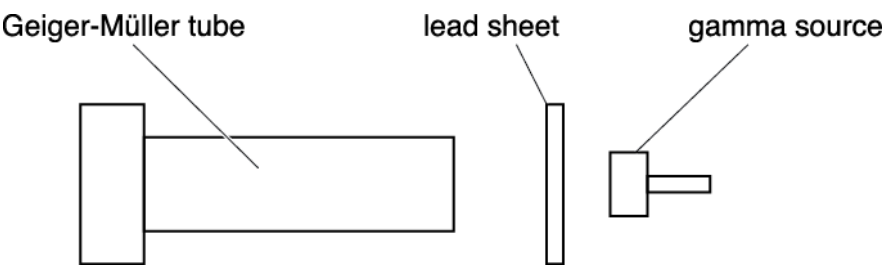


Fig. 4.1

Describe the safety precautions necessary for handling the gamma source.

[2]

(b) The values in the table below have been corrected for background radiation.

thickness of lead x / cm	Intensity I / cpm
0.5	890
1.0	651
1.5	442
2.0	310
2.5	222
3.0	154
3.5	112

(i) Explain why it is important to correct for background radiation.

[2]

Fig. 4.2 shows a plot of I against x .

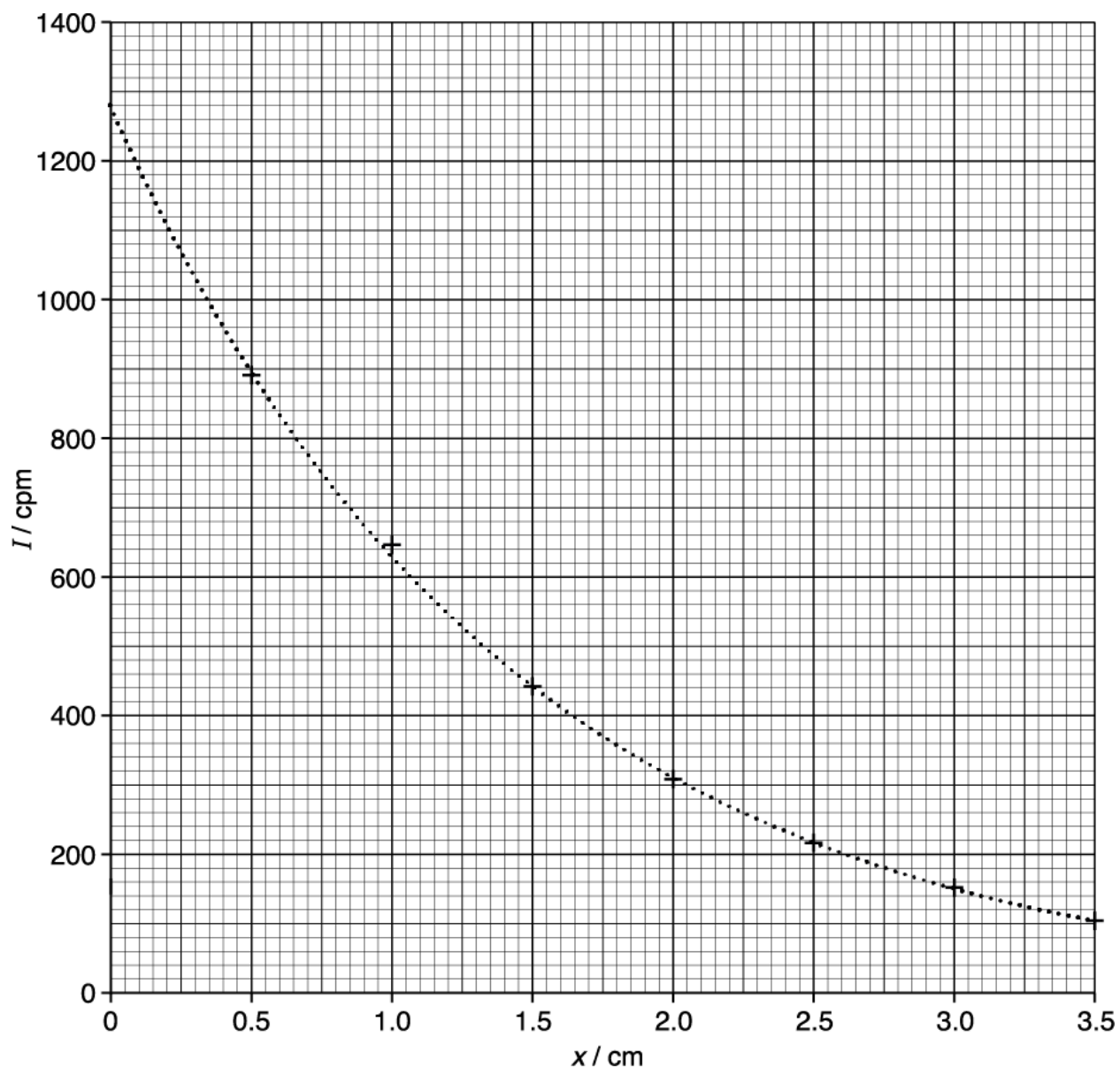


Fig. 4.2

- (ii) The *half-thickness* is the thickness of a shielding material required to halve the intensity received by the Geiger-Müller tube. Use the graph to calculate a reliable value for the half-thickness of lead.

half-thickness = _____ cm [3]

(c) The attenuation of gamma radiation in lead can be described by the equation:

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

where: I is the intensity of radiation reaching the Geiger-Müller tube

I_0 is the intensity of radiation with no lead sheet

x is the thickness of lead in cm

μ is the attenuation coefficient in cm^{-1} .

(i) Show that this equation can be written as

$$\ln(I) = -\mu x + \ln(I_0).$$

[1]

The table shows the data with the values of $\ln(I/\text{cpm})$ calculated.

thickness of lead x / cm	Intensity I / cpm	$\ln(I/\text{cpm})$
0.5	890	6.79
1.0	651	6.48
1.5	442	6.09
2.0	310	5.74
2.5	222	5.40
3.0	154	5.04
3.5	112	4.72

(ii) Plot a graph on the grid provided in Fig. 4.3 of $\ln(I/\text{cpm})$ against x . Three points have already been plotted. Draw a line of best fit through the points.

[2]

(iii) Calculate the gradient and intercept of the line of best fit and use your answer to (c)(i) to determine I_0 and μ .

$I_0 =$ cpm

$\mu =$ cm^{-1}

[4]

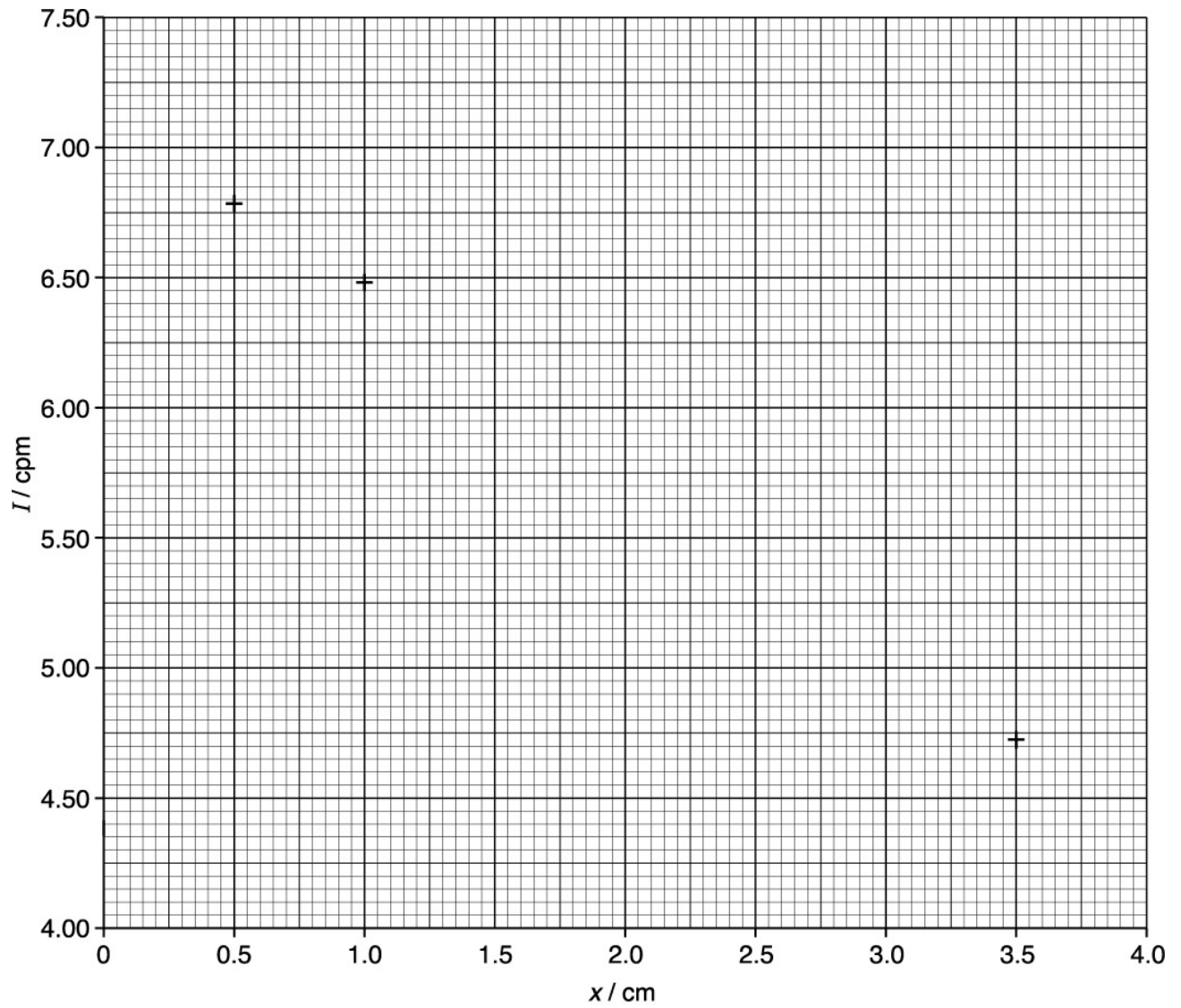


Fig. 4.3

(i) Use the value of μ calculated in (c)(iii) to calculate the half-thickness of lead.

(ii) Suggest and explain which of the methods used, in parts (b)(ii) and (d)(i), to determine the half-thickness is the most reliable.

[3]

92(a) This question is about muon decay. Muons are charged leptons. They are formed by cosmic rays interacting with the upper atmosphere.

The decay equation of a negative muon, μ^- is:

$$\mu^- \rightarrow e^- + \bar{\nu} + \nu$$

where $\bar{\nu} + \nu$ represent an antineutrino and a neutrino respectively.

Explain how the decay equation shows that charge and lepton number are both conserved and name one other property that is conserved in the decay.

[3]

(b) The maximum total energy of the particles formed from the muon is about 106 MeV.

Show that this suggests that the mass of the muon is about 200 times that of an electron.

[3]

(c) Muons travel through the atmosphere at 98% of the speed of light.

The half-life of a muon at rest is about 1.5×10^{-6} s. Show that about 0.0005% of the original muons will remain after travelling 8 km through the atmosphere, ignoring relativistic effects.

[3]

(d)

- (i) In a measurement it is found that about 9% of the muons remain after travelling through 8 km of atmosphere. Explain why a greater number of muons remain than suggested by the non-relativistic calculation in (b).

----- [3]

- (ii) Use your answer to (c) and the measured value of 9% of muons remaining after passing through 8 km of atmosphere to calculate the relativistic factor γ for the muons.

relativistic factor γ = ----- [3]



(See Insert for H557/02, Scientific literacy in physics (AS/A level), June 2017) This question is about spectroscopic measurements of stellar distances.

Describe how absorption spectra are formed and how they are useful in establishing the spectral class of a star. Explain how determining the value for the absolute brightness and apparent brightness of a star can lead to a measurement of the distance to a star.

The following example may help in your explanation:

Star X is known to have three times the absolute brightness of star Y but both appear to be equally bright in the sky. The distance to star Y has been measured as 12 parsecs.

[6]

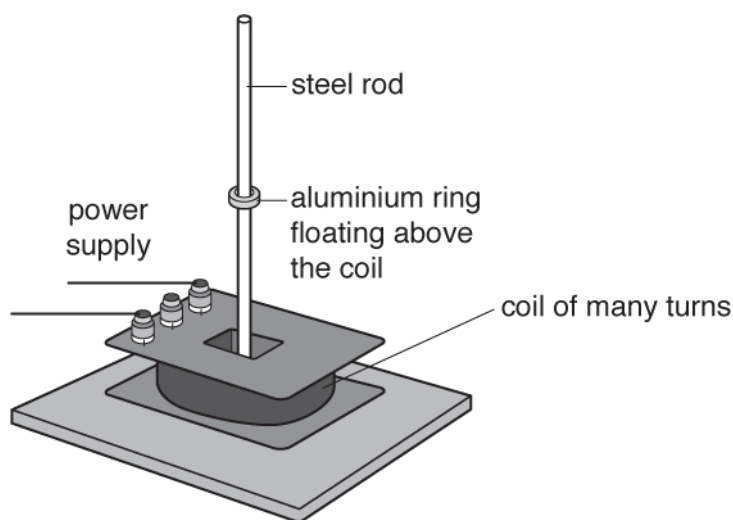
94 Which of the following changes doubles the flux in a magnetic circuit?

- 1 doubling the permeance
- 2 doubling the current-turns
- 3 halving the circuit length
- A 1, 2 and 3 are correct
- B only 1 and 2 are correct
- C only 2 and 3 are correct
- D only 1 is correct

Your answer

[1]

95 An aluminium ring is free to move on a steel rod.
When the power supply is on, the ring floats.



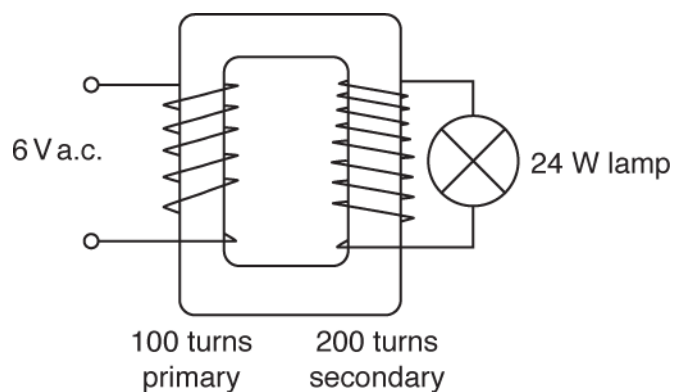
Which of the following is correct?

- A An a.c. or d.c. power supply can be used.
- B The induced current in the ring is in the same direction as the current in the coil.
- C The only purpose of the steel rod is to support the ring.
- D When the ring is pushed down towards the coil more flux links it and the induced current increases.

Your answer

[1]

- 96 A 6 V a.c. supply is connected to the 100 turn primary coil of an ideal transformer. The 200 turn secondary coil runs a lamp which dissipates 24 W.



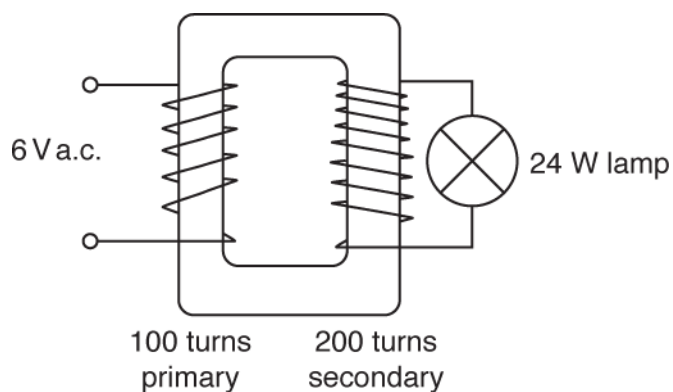
Which is the best estimate of the current in the secondary coil?

- A $\frac{1}{4}$ A
- B $\frac{1}{2}$ A
- C 2 A
- D 4 A

Your answer

[1]

- 97 A 6 V a.c. supply is connected to the 100 turn primary coil of an ideal transformer. The 200 turn secondary coil runs a lamp which dissipates 24 W.



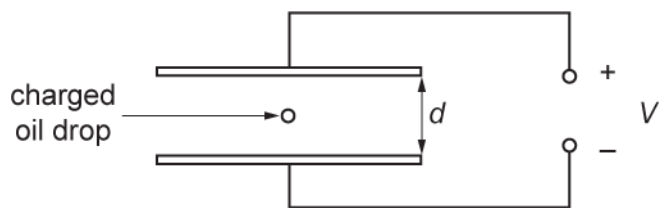
Which is the best estimate of the current in the primary coil?

- A $\frac{1}{4}$ A
- B $\frac{1}{2}$ A
- C 2 A
- D 4 A

Your answer

[1]

- 98 An oil drop of mass m charged by one electron is balanced between two parallel horizontal metal plates. A potential difference V is applied between the plates as shown.



Which expression shows the balanced electrical and gravitational forces acting?

A $eVd = mg$

B $\frac{eV}{d} = mg$

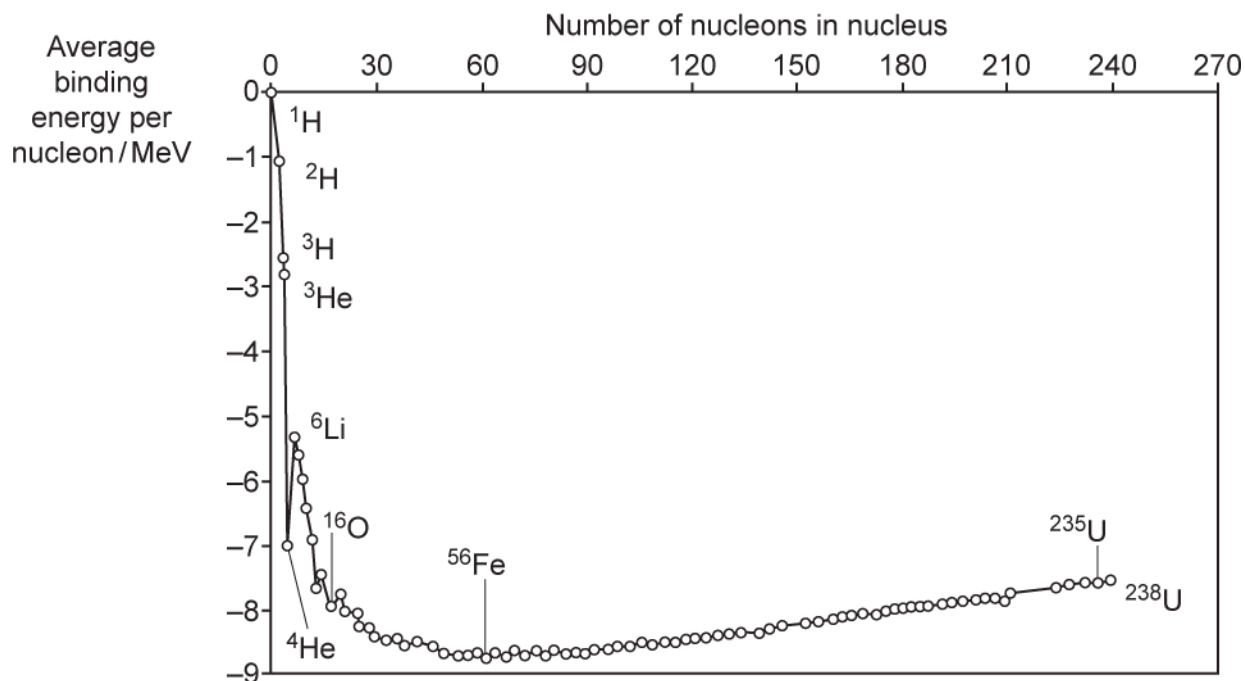
C $\frac{V}{ed} = mg$

D $\frac{dV}{e} = mg$

Your answer

[1]

- 99 The graph shows how the binding energy per nucleon varies with the nucleon number for stable nuclei.



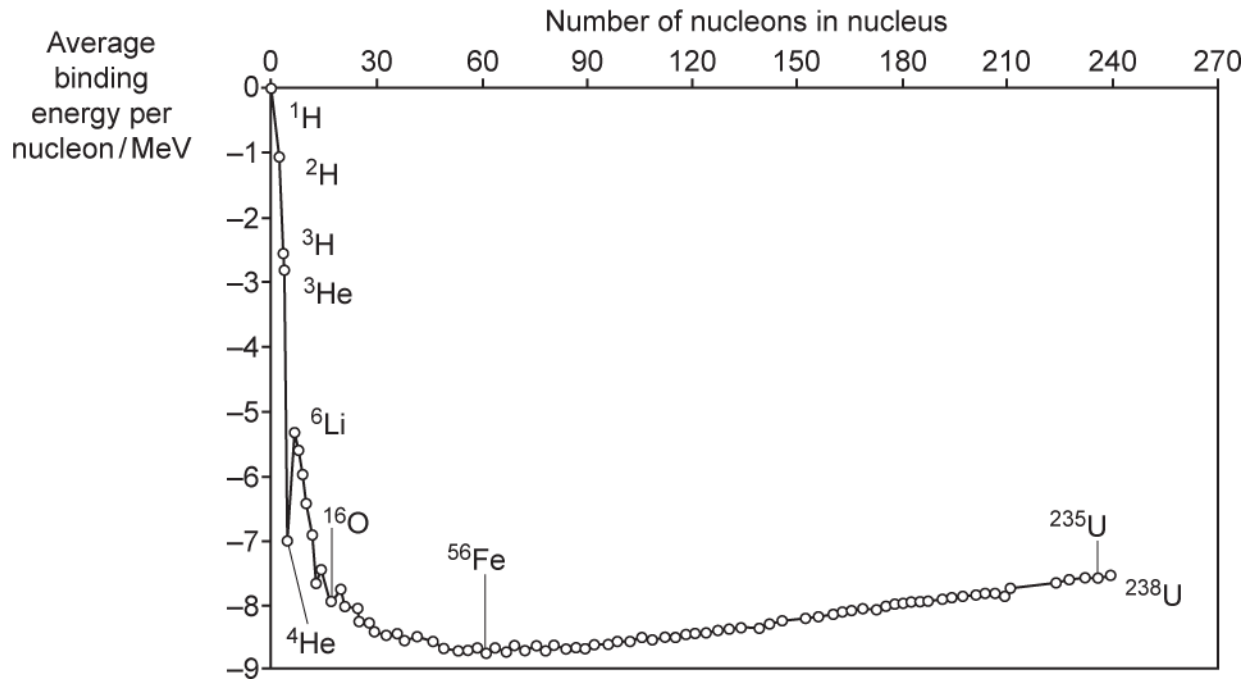
Which **one** of the following statements is correct?

- A All unstable nuclei have less binding energy than stable nuclei.
- B ^{56}Fe requires less energy per nucleon than other stable nuclei to pull it apart into individual nucleons.
- C Binding energy can be released in the fission of some heavy elements
- D Binding energy is the energy released when a nucleus breaks down into individual nucleons.

Your answer

[1]

100 The graph shows how the binding energy per nucleon varies with the nucleon number for stable nuclei.



Which is the best estimate for the total binding energy for a nucleus of $^{16}_8\text{O}$ (Oxygen)?

- A - 10 pJ
- B - 20 pJ
- C - 64 pJ
- D - 128 pJ

Your answer

[1]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1			D	1	
			Total	1	
2			D	1	
			Total	1	
3			A	1	
			Total	1	
4			C	1	
			Total	1	
5			D	1	
			Total	1	
6			C	1	
			Total	1	
7			D	1	
			Total	1	
8			C	1	
			Total	1	
9			B	1	
			Total	1	
10			C	1	
			Total	1	
11			B	1	
			Total	1	
12			B	1	
			Total	1	
13			A	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14			$\gamma = 6.84$ (1) $= 1/\sqrt{1 - v^2/c^2}$ Working through to $v^2/c^2 = 0.979$ (1) Working through to $v = 2.97 \times 10^8$ (m s ⁻¹) (1)	3	
			Total	3	
15	a		$1.8 \times 10^5 \times 60 \times 60 \times 3.4 \times 10^{-15} / 4 \times 10^{-3}$ (1) $= 0.000\ 55$ (Gy) (1)	2	
	b		Benefit: will destroy cancerous cells more effectively if it is in the organ will prevent cancer returning in the following days will have less affect on surrounding tissues. Risk: radioactive emission will continue for some time and could damage other tissues surgery may damage the patient the actual 'seed' could be poisonous.	2	One mark in each category not just 'will kill the cancer'
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a	i	$ke = p^2/2m$ (1) $p^2 = h^2/\lambda^2$ (1) $\lambda = 4 r$ (1) therefore $E = h^2/32mr^2$	3	Some steps can be in different order but the derivation must be clear. Allow starting point of $\lambda = h / mv$ and $ke \frac{1}{2}mv^2$ to reach same conclusion.
		ii	$ke = ((h^2/(32 \times 9.1 \times 10^{-31} \times 1 \times 10^{-20})))$ (1) 1.5×10^{-18} (J) (1)	2	
		iii	potential energy = $-8.9 \times 10^9 \times (1.6 \times 10^{-19})^2/1 \times 10^{-10}$ (1) $= -2.3 \times 10^{-18}$ (1) Total energy = -0.8×10^{-18} J (1) This is negative, hence electron bound to proton. (1)	4	Must include negative sign for second marking point.
	b		Calculation of k.e = 1.5×10^{-10} J (1) Calculation of p.e. = -2.3×10^{-14} J (1) Total energy = 1.5×10^{-10} J (1) This is a positive value hence electron will escape AW (1)	4	Calculations are expected to be made by simple ratio of results from (a) and change in ratio. Recalculations are acceptable. Negative sign required. 'Total energy now positive' without support gains one mark.
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a		current = $500 \times 10^6 / (25 \times 10^3 \times 16)$ (1) = 1250 (A) (1)	2	
	b	i	neutrons released can cause other fission events (1) if at least one neutron released per event triggers a second event the reaction is self sustaining (1) If mass too small too many neutrons will escape without triggering secondary fissions AW (1)	3	
		ii	mass difference = 0.186 u (1) mass difference / kg = 3.16×10^{-28} kg (1) energy released = 2.85×10^{-11} (1)	3	
	c		energy output per year = 4.48×10^{16} J (1) energy per fission = $200 \times 10^6 \times 1.6 \times 10^{-19}$ J = 3.2×10^{-11} J number of fissions = 4.48×10^{16} J / 3.2×10^{-11} J = 1.4×10^{27} (1) Mass of thorium used = $1.4 \times 10^{27} \times 4 \times 10^{-25}$ kg = 600 kg (1) Reason for resuming research into thorium reactors: any one from: shortage of uranium makes thorium more economic / end of nuclear arms race makes plutonium less needed / so much energy is needed that all potential sources must be used (1)	4	accept 560 kg. Award final mark only for answers recorded to no more than 2sf.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18	a	i	5 lines parallel, symmetric and evenly spaced ✓ field direction – ← + ✓ straight equipotential ¼ across from earthed plate and perpendicular to E field ✓	3	
		ii	1 ($E = V/d \times \frac{1}{2}$ for d) doubles E ✓ 2 ($E = V/d \times \frac{1}{2}$ for V) halves E ✓	2	
	b	i	$F = E Q = VQ / d$ ✓ $= V^2 r / kd$ ✓ $= 2000^2 \times 0.02 / (9.0 \times 10^9 \times 0.08) = 1.1 \times 10^{-4} \text{ (N)}$ ✓	3	apply uniform field equation combine with $V = k Q / r$ algebraic manipulation / numerical evaluation
		ii	1000 (J C^{-1}) ✓	1	accept half the p.d. across the plates or complete calculation of $Fd / Q = 1000 \text{ (J C}^{-1}\text{)}$
	c		The ball can lose k.e. at each bounce to sound or heat and to the air by air resistive drag forces ✓ so ball accelerates until energy gained per passage = energy lost per passage (between the plates) ✓	2	alternative Allow credit for same charge transferred each time Thus experiences the same accelerating force
			Total	11	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
19	a	* Level 3 (5–6 marks) All 3 features fully explained: sense and amplitude explained in terms of changes of flux linking coil. Explanations involve reference to Faraday's Law or $\epsilon = (-) N \Delta \Phi / \Delta t$. Sense: increase in $N \Delta \Phi$ is + ve and decrease – ve. Amplitude: peak occurs when rate of change of flux linkage is greatest, may be mathematically expressed. Area: equated to total change of flux linkage with coil = $\sum \epsilon \Delta t = (-) N \Delta \Phi$ or sum of strips and same flux links coil on way in as unlinks from coil on way out. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) 2 or 3 features quite well explained: sense and amplitude explained in terms of changes of flux through coil. Explanation may involve reference to Faraday's Law or $\epsilon = (-) N \Delta \Phi / \Delta t$. Area simply equated to change of flux and idea that increase = decrease in flux or both end points have zero flux through coil. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) 1 or 2 features explained at a low level in terms of cutting lines of magnetic field e.g. cut in opposite direction, cut at a different rate, total field cut on way in equals field cut on way out. Some attempt at $\Delta B / \Delta t$. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i>	6	Indicative scientific points may include: Features of induced peaks to be explained • Sense of each peak opposite • Amplitude of 2nd peak larger because greater speed or greater $(-)N \Delta \Phi / \Delta t$ • area under peaks is equal because $\sum \epsilon \Delta t = (-) N \Delta \Phi$ Vocabulary guidelines • Level 3 in terms of changing flux linkage $N \Phi$ with coil • Level 2 in terms of changes of flux Φ through coil • Level 1 in terms of field lines B being cut by coil Marking guidelines • accept arguments using mathematical symbolism

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			0 marks No response or no response worthy of credit.		
	b		Labelled sketch: horizontal coil connected to data-logger or oscilloscope and vertical magnet ✓ OR plastic guide tube to keep long magnet vertical.... etc. identify uncertainty in timing as control variable ✓ method: increase sampling rate to reduce uncertainty in time or increase sensitivity in scale for p.d. or use automatic trigger on d-logger or identify using longer bar magnet increases transit time and thus reduces percentage uncertainty ✓	3	ignore clamps stands / unlabelled parts max 1 marks for diagram credit up to 2 sensible points – max 2 marks for method
	c		1 Peaks separate in time or a period of no emf between ✓ because only change in flux linking coil when magnetic poles enter or leave coil ✓ OR Second peak much greater amplitude and shorter duration ✓ due to higher velocity (under acceleration of gravity) as pole leaves coil and flux linkage changes at much greater rate ✓ 2 Very small or zero induced emf ✓ because flux of magnet loops close to magnet and does not reach to link with the much larger diameter coil ✓	4	
	d		Total flux linking coil = area under graph N $\Phi = \Sigma \epsilon \Delta t$ or counting squares or area Δ ✓ $(\Phi = A / N = \frac{1}{2} \times 0.08 \times 5.8 \times 10^{-3} / 1100)$ $= 0.21 \times 10^{-6} \text{ (Wb)} \checkmark$	2	
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a		Narrow hole to collimate or ensure all alpha particles following same track to start with or create a parallel beam ✓ air removed because it would absorb alpha particles before they reached detector ✓	2	
	b	i	All arrows radially outward from the nucleus ✓ arrows 1 and 3 of equal length and shorter than arrow 2 ✓ arrow 2 is 4 × longer than the others ✓	3	
		ii	At closest approach, PE = initial alpha KE ✓ $PE (= VQ_{\text{He}}) = kQ_{\text{Au}}Q_{\text{He}} / R$ ✓ $9.0 \times 10^9 \times (79e) \times (2e) / R = 4.8 \times 10^6 \times e$ ✓ $(R = 9.0 \times 10^9 \times 158e^2 / (4.8 \times 10^6 \times e) = 9.0 \times 10^9 \times 158 \times (1.6 \times 10^{-19}) / (4.8 \times 10^6))$ $= 4.7 \times 10^{-14} \text{ (m)}$ ✓	4	1 st mark is for applying conservation of energy 2 nd mark is for choice of the appropriate equations 3 rd mark is for correct substitution into energy equation 4 th mark is for correct evaluation. Correct answer gains 4 marks
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21	a	i	$G = I/V = 0.18 / 1.4 = 0.129 \text{ (S)} \checkmark$ $G = \sigma A/L \Rightarrow \sigma = GL/A = 0.129 \times 0.5 / (\pi \times [\frac{1}{2} \times 0.213 \times 10^{-3}]^2) \checkmark$ $= 1.8 \times 10^6 \text{ (S m}^{-1}\text{)} \checkmark$ <i>alternative method</i> $R = V/I = 0.18 / 1.4 = 7.8 \text{ (}\Omega\text{)} \checkmark$ $R = \rho L/A \Rightarrow \rho = RA/L = 7.8 \times (\pi \times [\frac{1}{2} \times 0.213 \times 10^{-3}]^2) / 0.5 = 5.54 \times 10^{-6} \text{ (}\Omega\text{m)} \checkmark$ $\sigma = 1/\rho = 1/(5.54 \times 10^{-6}) = 1.8 \times 10^6 \text{ (S m}^{-1}\text{)} \checkmark$	3	If done through resistance, the method mark for finding σ must include inversion of ρ. correct answer gains 3 marks
		ii	(σ too low means that is G also too low so) either I should be larger or V should be smaller $\checkmark$ there are p.d. losses across ammeter or croc clips / places where clips grip wire $\checkmark$ <i>alternative</i> Resistance R increases or G decreases $\checkmark$ current heats wire due to increased atomic vibrations hindering electron transport $\checkmark$	2	1st mark is for the suggestion and the 2nd for the explanation
	b	i	Three complete continuous loops through core, air gap and plate (not crossing) $\checkmark$ Flux lines tend to contract or straighten $\checkmark$	2	
		ii	Air has a much lower permeability than steel or the core $\checkmark$ Overall permeance of the magnetic circuit is much lower when air is present $\checkmark$ Giving smaller flux and so less force with air gap $\checkmark$	3	allow suitable alternative terms
	c		Power supply ~ current carrying coil $\checkmark$ emf ~ NI $\checkmark$ I ~ flux or ϕ $\checkmark$ conductance ~ permeance $\checkmark$ value for circuit leads / electromagnet core is greater than that for the alloy wire / steel plate $\checkmark$	5	award 1 mark for each correct row
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22	a		Straight line diagonally up to point of pair creation roughly bisecting the 'V' ✓ Gamma is uncharged / not very ionising ✓ e^- and e^+ have opposite charges (so qvB has opposite sign) so they curve in opposite directions ✓ paths are spirals or radius of paths becomes less as they go on ✓ (because) the positron and electron are slowing down ✓ due to energy loss through ionising the air particles (which is why you can see the tracks) ✓	6	3rd marking point needs both the observation (paths curve opposite ways) and the inference (particles have opposite charges) allow $r = mv / Bq$
	b	i	total charge before = 0 (p^+ and p^-) ✓ 4 hadron tracks curve clockwise and 4 anticlockwise, so for every + charge there is a – charge ✓	2	
		ii	$mv^2/R = Bqv$ ✓ so $v = BqR/m$ ✓ $= (2.2 \times 1.6 \times 10^{-19} \times 4.6 \times 10^{-3}) / 2.5 \times 10^{-28}$ $= 6.5 \times 10^6 \text{ (m s}^{-1}\text{)} \checkmark$	3	
			Total	11	
23			C	1	Examiner's Comments The opening question relied on simple recall and nearly all candidates chose the correct answer. The most common incorrect answer was B.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
24			(electrical) potential difference (1) Between A and B (1)	2	Accept: p.d. ; 'work done per unit charge/per coulomb ' 'voltage' ; 'energy difference per unit charge/per coulomb ' 'potential' alone does not get the mark. Second mark dependent on first Examiner's Comments This proved far more challenging. Many candidates confused potential difference and potential.
			Total	2	
25	a		$E = 500 \times 10^{-6} \times 0.8/20$ (1) = $2 \times 10^{-5} \text{ J}$ (1)	2	2 marks for correct bald answer Examiner's Comments This question relied upon fairly simple calculations of dose and risk. The majority scored highly on the question.
	b		Number of cases = $50 \times 10^6 \times 500 \times 10^{-6} \times 0.03$ (1) = 750 (1)	2	2 marks for correct bald answer Accept POT error for one mark if working shown and consistent with answer Examiner's Comments This question relied upon fairly simple calculations of dose and risk. The majority scored highly on the question.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
26	a		Correct lines meeting plate at right angles by eye, symmetrical	1	Accept right angle symbol if the line is reasonable. In cases difficult to judge, use protractor tool, angles greater than 80° acceptable. Examiner's Comments Many candidates failed to gain the mark due to lack of care. Field lines often did not meet the plate at right angles and the fields drawn were often unsymmetrical. Perhaps candidates were rushing through Section A to leave more time for the longer questions. It may be worthwhile to remind students of the need for careful drawing.
	b		It is weaker (closer to the plate) or it is stronger near the sphere (1) (as) Field lines are further apart (at the plate) or closer together at the sphere	2	Don't accept radial field arguments Accept 'lines are closer together near sphere' but not 'equipotential lines' unless drawn. Second mark dependent on first Examiner's Comments Whilst answered correctly by the majority, did reveal some misunderstandings and a small but significant proportion of the candidates considered the field to be radial between the sphere and the plate.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
27			Changing flux (in the core) (1) Induced emf produces eddy currents(1) Laminations reduce eddy currents AW (1) As the laminations are (layers) separated by a poor conductor AW (1)	4	Accept changing field. Quoting Faraday equation alone is not creditworthy. Accept voltage for emf Ignore reference to emf or current in coils 'Laminating with an insulator' is insufficient for two marks. Examiner's Comments Candidate always find questions on electromagnetism rather challenging and this was no exception. Common errors were to consider that a flux induces an emf, rather than a changing flux. Some candidates merely stated that a changing flux induces a current (ignoring the role of emf). Candidates were familiar with the idea of laminating the core but often did not explain how laminations help in this situation.
			Total	4	
28			$(938 + E_k) / 938 = 2.5$ (1) $E_k = 1400 \text{ MeV}$(1)	2	One mark for total energy identified as 2345 MeV Two marks for correct bald answer Accept 1407, 1410 Examiner's Comments Although the majority gained both marks here, a relatively common error was to assume that the total energy (2345 MeV) was the kinetic energy of the proton.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29			Flux linkage = $0.07 \times 2.4 \times 10^{-5} \times 200$ (1) = 3.4×10^{-4} (1) Wb turns (1)	3	2 marks for correct bald value Accept Wb, T m ² , T m ² turns Examiner's Comments This proved accessible to the large majority of the candidates.
			Total	3	
30			Greater charge on gold nucleus	1	Ignore references to nuclear diameter Examiner's Comments Many candidates incorrectly assumed that the protons physically collide with the nuclei and hence framed their responses in terms of greater nuclear radius leading to more collisions. Another source of error was to consider the properties of the gold atom rather than the gold nucleus.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
31	a	i	$\lambda = 4r$ or $\lambda/2 = 2r$	1	Or $r = \lambda/4$ etc
		ii	Showing $\frac{p^2}{2m}$ or $E_k = \frac{h^2}{2m\lambda^2}$ (1) Consistent analysis leading to final relationship (1)	2	1st mark accept: $p^2 = \frac{h^2}{16r^2}$ Accept ecf from(i) for first mark only.
		iii	k.e. increases by a factor of 4 (1)	1	Accept '4' or 'increases by 4' Examiner's Comments All sections were well answered by the majority of candidates.
	b		p.e. increases by a factor of 2 (1)	1	Accept '2' or 'increases by 2' Examiner's Comments All sections were well answered by the majority of candidates.
	c	i	$\frac{h^2}{32 m_e r^2} = \frac{e^2}{4\pi\epsilon_0 r}$ (1) -> Consistent analysis leading to final relationship	2	Penalise inconsistent use of negative sign for one mark.
		ii	$r =$ $(6.6 \times 10^{-34})^2 \times 8.9 \times 10^{-12} \times \pi / (8 \times (1.6 \times 10^{-19})^2 \times 9.1 \times 10^{31})$ $= 6.5 \times 10^{-11}$ (1)	2	Correct bald answer to 2 s.f. worth two marks s.f penalty 2 s.f. only Examiner's Comments This was well answered with only a small proportion not gaining full marks.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		Smaller radius, k.e. would be greater than (modulus of) p.e. AW (1) because k.e. has a greater change than p.e. with change of radius AW(1)	2	Do not credit k.e + p.e. > 0 (repeating stem) Accept comparison of inverse square and inverse relationship. Accept 'k.e. changes more quickly'. Examiner's Comments was less-confidently answered. Many candidates repeated the stem of the question, stating that kinetic energy plus potential is greater than zero without stating that the magnitude of the kinetic energy is greater than that of the potential energy for radii less than the minimum. Only the best responses clearly compared the $1/r^2$ variation of kinetic energy with the $1/r$ variation of potential energy even though this was clearly flagged in the earlier parts of the question.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32	a		Pion π^+ π^- Pion Charge $+e$ $-e$ Quarks $u??? \quad ???d$	2	+ve sign not required This question is about pions. Candidates were not expected to recall any factual material about pions but use data given to reach conclusions about pion – anti-pion annihilation. Examiner's Comments Nearly all the responses gained both marks here.
	b	i	$\Delta E = 1.6 \times 10^{-19} \times 50$ $= 0.80 \times 10^{-17} \text{ J (1)}$	1	Or 8.0×10^{-18} (1 sf OK)
		ii	$\frac{1}{2}mv^2 = \frac{1}{2}mu^2 + \Delta E \quad 1$ $v^2 = u^2 + \frac{2\Delta E}{m}$ $= (1.0 \times 10^5)^2 + \frac{2 \times 8 \times 10^{-18}}{2.5 \times 10^{-28}} \text{ (1)}$ $v = \sqrt{7.4257 \dots \times 10^{10}}$ $= 2.7(25) \times 10^5 \text{ (1) ms}^{-1}$	3	Or: initial k.e. = $1.25 \times 10^{-18} \text{ (J) (1)}$ final k.e. = $9.25 \times 10^{-18} \text{ (J) (1)}$ $\Delta E = 1 \times 10^{-17}$ gives $11.25 \times 10^{-18} \text{ (J)}$ $v = 2.7(25) \times 10^5 \text{ (ms}^{-1}\text{)(1)}$ $\Delta E = 1 \times 10^{-17}$ gives $3.0 \times 10^5 \text{ (ms}^{-1}\text{)}$ $v = 3.53 \times 10^5$ scores zero Bald correct answer of 2.7×10^5 or 3.0×10^5 worth 3 marks Examiner's Comments This calculation was straightforward.(ii) This calculation proved more challenging. A common error was to calculate the velocity for a pion of kinetic energy $1 \times 10^{-17} \text{ J}$ and then add this value to the original velocity. However, it was encouraging to see that most candidates avoided this trap.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33	a		Energy required to separate the nucleons in a nucleus (divided by the number of nucleons) (1) Calculate the total mass of individual protons and neutrons. (1) Subtract this value from the mass of the (U-235) nucleus (1) Calculate energy from $E = \Delta mc^2$ and divide energy calculated by number of nucleons in uranium 235/divide by 235(1)	4	NB 'per nucleon' is not required at this stage as it is in stem of question. Or difference in (rest) energy between nucleons when bound in a nucleus and when separated. Don't accept: energy to remove one nucleon; energy to bind nucleus together or contradictory statements. Don't accept 'uranium atom' Allow mass of nucleons – mass of bound nucleus Credit use of individual rest energies rather than masses. QWC mark awarded for complete and logically presented argument. 4th annotation (if required) goes against the pencil icon. Examiner's Comments This question is about uranium-235 fission. It begins by requiring candidates to explain the term 'binding energy per nucleon' and to describe how this can be found from given data. Many candidates showed a lack of understanding of binding energy – commonly describing it as the energy needed to bind a nucleus together. They were more confident in describing the calculation but weaker responses were characterised by a lack of clarity that suggested a hazy grasp of the process.
	b		56 (1)	1	Examiner's Comments Confidently answered.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Total binding energy of U-235 = $235 \times -7.6 = -1786$ MeV (1) Binding energy of daughters = $(-8.3 \times 141) + (-8.5 \times 92) = -1952$ MeV (1) Change in energy = (-166) MeV (1)	3	Accept treatment of all binding energies as positive. Any clear, complete working to correct value gains three marks Working must be shown.. Bald correct answer to more than two s.f. gains one mark. Using: $(-8.3 \times 92) + (-8.5 \times 141)$ leading to a value of 176.1 MeV gains first mark only. Examiner's Comments Confidently answered.
	d	i	reactions per second = $1500 \times 10^6 / (170 \times 10^6 \times 1.6 \times 10^{-19})$ (1) = 5.5×10^{19} (1)	2	Allow 166 MeV giving 5.6×10^{19} Ecf allow 176 MeV giving 5.3×10^{19} Correct bald answer gains two marks.
		ii	$5.5 \times 10^{19} \times 3.2 \times 10^7 \times 4 \times 10^{-25}$ (1) = 700 kg (1)	2	ecf from (i) accept 704 kg allow 5.6×10^{19} giving 720 kg 5.51×10^{19} gives 705 kg Calculator answer from (d) (i) gives 706 kg allow this even if 5.5×10^{19} is written in working (710 to 2 .s.f) Examiner's Comments The standard calculations proved accessible to all but the weakest candidates.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
34	a		$F = q v B = 1.6 \times 10^{-19} \times 1.2 \times 0.18 \text{ (1)}$ $= 3.5 \times 10^{-20} \text{ N}$	1	Clear substitution required. Calculator value = $3.456 \times 10^{-20} \text{ N}$ Examiner's Comments This question was about the Hall Effect – although the candidates were not required or expected to know details of the effect and would not be disadvantaged if they did not. This was an easy opener and proved accessible to nearly all.
	b		Four equally spaced vertical lines across shaded area spaced at least two charge symbols apart(1) with arrows directed upwards.(1)	2	Field uniform throughout shaded region Examiner's Comments This was straightforward but many candidates did not represent a uniform field in the region. The Examiners expected careful drawings showing equally-spaced lines throughout the region. Unfortunately, many drawings were rushed and suggested that an area of uniformity within the region rather than across the whole region.
	c		$V = 0.18 \times 1.2 \times 1.3 \times 10^{-3} \text{ (1)}$ $= 2.8 \times 10^{-4} \text{ (1)}$	2	POT error -1 Correct bald answer two marks Examiner's Comments This proved a straightforward calculation but only the best candidates gained all four marks.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		Charge carriers have lower velocity (1) by a factor of 10^4 (1) the number of charge carriers (m^{-3}) must increase by factor of 10^4 (1) as the current is the same and $I = \Delta Q / \Delta t$ (1)	4	Or: to deliver (AW) the same number of electrons per second to provide the same current Or: because $n = I / veA$ and I is the same. Examiner's Comments This part required careful thinking and the use of the emboldened factor of 10^{-4}. It is always useful to remind candidates that if they see data in the stem of a question they should use it in their answer. Many candidates simply assumed that as metals are better conductors than semiconductors the drift speed of conduction electrons must be greater. The better answers used the logic of the preceding parts of the question to develop a coherent explanation of the differences in drift speed and number density of conduction electrons. The best answers were admirably clear. This section was based on an Advance Notice article about electrical power for spacecraft. It was a wide-ranging article which touched many areas of physics. As usual, the majority of the candidates were well-prepared for this section of the paper but, as ever, there were a few surprises which revealed some misunderstandings.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
35	a		$\text{Activity} = 4400\text{J} / (5.5 \times 10^6 \times 1.6 \times 10^{-19})$ (1) $= 5.0 \times 10^{15} \text{ Bq (1)}$	2	Correct bald answer gains both marks Accept 1sf Examiner's Comments This question, on radioisotope thermal generators (RTGs), was more challenging. Although it was based on standard calculations the context, though familiar through the article, increased the difficulty of the task.
	b		$\lambda = \ln 2 / 88 (= 7.88 \times 10^{-3} \text{ y}^{-1})$ (1) $t = \ln(4.4/2.5) \times 88 / \ln 2$ (1) $= 71.8 \text{ years (1)}$	3	$\lambda = 2.46 \times 10^{-10} \text{ s}^{-1}$ $t = 2.30 \times 10^9 \text{ s}$ $= 71.8 \text{ yrs}$ Credit using different yr → s conversions for slightly different answers. Or: $0.5^n = 2500/4400$ (1) So $n = 0.816$ half-lives (1) So $t = 0.816 \times 88 = 71.8\text{yrs}$ (1) Correct bald answer gains three marks Examiner's Comments This was difficult for the mathematically less-confident candidates.
	c		Reasons to be concerned: ◦ Alpha emitting materials would enter respiratory system or be ingested AW (1) ◦ Alpha particles have large quality factor / are very ionising (1) Shorter half life: max 3 from : • Initial activity would be higher so initially more dangerous • (Activity fades more quickly so) hazard	5	Do not credit answers which confuse inhalation/ingestion of alpha-emitting materials (which can travel large distances) with inhalation/ ingestion of short-range alpha particles.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			reduces more quickly • Power output reduces more quickly/would not provide power for so long • Needs more of the isotope in order to last lifetime of spacecraft		Don't credit 'needs more isotope to provide the same power' unless qualified by 'in the long term' AW Don't credit answers discussing more satellites being launched. QWC mark for clear link of arguments to properties of isotopes. Examiner's Comments This asked candidates to consider the dangers of launching RTGs and the possibility of using a shorter half-life isotope was not well-answered by many candidates. A large proportion of the responses confused or conflated the properties of the alpha emitters with the properties of alpha particles. Examiners saw many statements about the dangers of alpha particles entering the respiratory system having been released by the RTG, rather than alpha emitters being ingested and releasing alpha particles <i>in situ</i>. Whereas it was clear that many candidates understood why a short half-life source may not be suitable, they rarely explained this sufficiently clearly to gain maximum marks. Statements of the form 'A short half-life source would not supply enough power' were too vague to be worthy of marks.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
36	a	i	Area per second = speed $\times$ length = $8000 \text{ m s}^{-1} \times 20000 \text{ m}$ = $1.6 \times 10^8 \text{ m}^2$ (1)	1	Zero if POT error 7750 m s^{-1} gives $1.55 \times 10^8 \text{ m}^2$
		ii	Induced emf = rate of change of flux linkage (1) = $d(BA) / dt = B \, dA/dt$ = $1.6 \times 10^8 \times 2.1 \times 10^{-5}$ = 3360 V (1)	2	Ecf from ci. First mark can be credited in working if $dt = 1 \text{ s}$ is explicit $1.6 \times 10^8 \times 2.1 \times 10^{-5} = 3360 \text{ V}$ alone gains one mark only Examiner's Comments Required candidates to show that the emf induced in the cable is a certain value was not well-answered; it was an easy calculation to reach the expected answer but only the best responses showed how they reached the answer.
	b		Any four from: (induced) current in tether produces magnetic field (1) Force (= ILB) acts to oppose motion/slow satellite (Lenz's Law)(1) power loss in system due to current in cable (1) Energy transferred from satellite (1) Moves to a lower orbit (1)	4	Examiner's Comments This returned to electromagnetic induction and once again the best responses showed clarity of thought and understanding whereas weaker responses did not set out the explanation in sufficient depth. For example, many responses suggested (correctly) that a force on the wire acted in opposition to the movement of the wire but did not explain the nature of the force or how it was generated.
			Total	7	
37			B	1	
			Total	1	
38			A	1	
			Total	1	
39			B	1	
			Total	1	
40			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
41			B	1	
			Total	1	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
42	a	Level 3 (5–6 marks) Marshals argument in a clear manner and includes clear explanation of three strands: • change in mass • binding energy equivalent • forces and momentum <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument or covers all three at a superficial manner and does not include enough indicative points for level 3. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks <i>No response or no response worthy of credit</i>	6	Indicative scientific points may include: Change in mass • protons and neutrons in a nucleus are bound by the strong nuclear force, which is a short-range attractive force sufficient to overcome the electrostatic repulsion between the protons in a nucleus. • For a nucleus with Z protons and N neutrons • $\Delta m = \text{mass of nucleus} - (Z m_p + N m_n)$ - OR • change in mass = $221.9703 - (217.9628 + 4.0015) = 0.0060 \text{ (u)}$ Binding energy equivalent • to pull nuclei apart requires energy called the binding energy of the nucleus • binding energy of a nucleus can be calculated from the difference in mass between the nucleus and its separate neutrons and protons • binding energy = $\Delta m c^2$ • rest energy of the nucleus is less than that of its constituent particles. Since the rest energy • $E_{\text{rest}} = m c^2$, the mass of the nucleus is also less than • that of its constituent particles. • $\Delta E = \Delta m C^2 = 0.0060 \times 1.661 \times 10^{-27} \times (3.00 \times 10^8)^2$ $= 8.969 \times 10^{-13} \text{ (J)}$ $= 8.969 \times 10^{-13} / (1.6 \times 10^{-19} \times 10^6) = 5.61 \text{ (MeV)}$ • OR accept knowledge of $1 \text{ u} = 931 \text{ MeV}$ Forces and momenta • during emission α and remnant nucleus repel with equal and opposite

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					electrostatic forces (for equal times) or $F = k Q_1 Q_2 / r^2$ • by Newton's 3rd Law nucleus recoils • so impulses are equal and opposite on α and nucleus • so gaining equal and opposite momenta • nucleus carries away some k.e. from binding energy released • accept well labelled diagrams throughout for credit if integrated into the explanation
	b	i	conservation of momentum	1	accept momentum before = momentum after = zero or equal magnitude opposite direction for two particles momenta
		ii	$= m_{po} V_{po}^2 / m_{\alpha} V_{\alpha}^2 = m_{po} m_{\alpha}^2 / m_{\alpha} m_{po}^2 = m_{\alpha} / m_{po}$	1	mid step must be clear for mark
		iii	= 0.98(2) ✓	1	accept evaluation of energy or fractional energy
		iii	5.61 MeV $\times$ 0.982 = 5.5(1) MeV ✓	1	allow nuclear fraction of total k.e. = 0.018 or nuclear recoil k.e. = 0.10(1) MeV
		iii	value of α k.e. 5.5 MeV agrees at 2 S.F. level ✓	1	comparison of energy to actual value
			Total	11	
43			Electron / beta particle ✓	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
44		i	Any three crosses at a maximum (10 V) or minimum (–10 V)	1	Accept any cross vertically above or below the trace.
		ii	$\text{Emf} = - \frac{dN\phi}{dt}$ $10 = (-) 300 \frac{d\phi}{dt}$ $\frac{d\phi}{dt} = 10 / 300 = 0.033 \text{ (Wb s}^{-1}\text{)} \checkmark$	1	Evidence of the calculation must be seen
		iii	Φ goes from zero to maximum in $\frac{1}{4}$ cycle (5×10^{-3} s) $\checkmark$ $d\Phi = \Phi_{\text{max}} = \frac{d\phi}{dt} \cdot dt = 3.3 \times 10^{-2} \times 5 \times 10^{-3}$ $\Phi_{\text{max}} = 0.165 \text{ mWb } \checkmark$	2	Accept Φ goes from minimum to maximum in half a cycle $2 \Phi_{\text{max}} = 3.3 \times 10^{-2} \times 10 \times 10^{-3}$ Accept sinusoidal integration giving $\Phi_{\text{max}} = 0.105 \text{ mWb}$ for full credit
			Total	4	
45	a		J m^{-1}	1	Examiner's Comments This is a straightforward opening to the paper. The only problem here was recognising that the unit of force can be written as Jm^{-1} .
	b		$\text{J kg}^{-1} \text{ (1)}$	1	
	c		$\text{J C}^{-1} \text{ (1)}$	1	Examiner's Comments This is a straightforward opening to the paper. The only problem here was recognising that the unit of force can be written as Jm^{-1} .
			Total	3	
46			B (1)	1	Examiner's Comments This easy recall question was correctly answered by the majority of the candidates.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
47	a		Opposite curvature/deflection (1)	1	Accept implication of opposite e.g. “one curves left, the other curves right”. Reject “different curvature”; reject reference to movement or travel. Examiner's Comments This proved a more challenging task. Many candidates wrote of the particles travelling in opposite directions (which they do not do for the majority of the track) and weaker responses incorrectly suggested that the positron and electron repelled each other. This will be a useful question to discuss in class to show the importance of choosing words carefully.
	b		Same radius/ same curvature (1)	1	Allow symmetrical paths. Credit indication of equal deviation. Examiner's Comments This was answered with more confidence with most candidates recognising the link between the magnitude of the momentum of the particle and the curvature in the magnetic field.
	c		$F = 0.45 \times 1.7 \times 10^7 \times 1.6 \times 10^{-19} \text{ (1)}$ $= 1.2 \times 10^{-12} \text{ N (1)}$	2	Allow correct bald answer for 2 marks Examiner's Comments This was a simple calculation that was clearly answered by the majority. (Answer: $1.2 \times 10^{-12} \text{ N}$)
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
48	a		1 (1)	1	Allow 1:1 Examiner's Comments Was very poorly answered. This shows that candidates are able to gain marks from mechanical calculations (as they did in part (b)) without having a clear idea of the physics of the situation. Electromagnetism questions always prove challenging but it was surprising how few candidates could recall that the flux in an ideal transformer is considered to be constant throughout the core.
	b		$12 \times 10\,000/230$ (1) $= 520$ (1)	2	Allow use of $10\,000/19.2$ Accept 522, 521. Allow correct bald answer. SF penalty for more than 3 SF. NB: this is the only SF penalty on the paper. Examiner's Comments Nearly all candidates scored both marks here and reached acceptable answers of 520 (2sf), 521 or 522.
			Total	3	
49			All of ring to the left of the minimum (1)	1	Examiner's Comments This was one of the most accessible questions on the paper. The most common error was to circle the bottom of the slope (that is, the point of most negative binding energy), but only very few candidates failed to gain the mark.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
50			Any 3 from: • Changing magnetic field/flux in copper / tube (1) • Currents produced in copper / tube (1) • Currents set up their own magnetic fields/flux (1) • Two fields interact (1) • (Providing) an upwards force on magnet / force acting against weight of the magnet (1) • Change in net force leads to deceleration / reduced acceleration / reduced relative motion between magnet and tube (1)	3	No mark for stating that emf induced in copper (in the stem) No credit for bald statement of Lenz's Law Allow field / flux lines cut by the copper tube Must be clear that current is in the copper Accept arguments in terms of magnetic force on current Don't credit 'two fields repel' because they don't repel when the magnet is leaving the tube. Examiner's Comments An explanatory question on electromagnetism is a departure from the norm but about half the candidates gained two or three marks. The majority of candidates scored the mark for considering a flux change in the copper. The better responses described the induced emf driving current that sets up a field. The mark scheme allowed a number of ways to gain marks but did not allow a bald statement of Lenz's Law, and those candidates who did state the relationship often failed to gain marks due to confused explanations. For example, many candidates incorrectly suggested that the emf created the magnetic field or that the emf opposed the motion of the iron rod.
			Total	3	
51			4 (1)	1	Examiner's Comments This proved a little more challenging with weaker candidates choosing the value 2 rather 4.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
52	a		1st 3 marks Number of scattered particles decreases with angle (1) Most particles show little scatter/decrease with angle is great(1)AW Gold scatters more than silver(1) Fourth mark: clear reference to quantitative data from graph with data pairs (1)	4	Accept log scale implies large range of values (1) Synonyms for 'great' include dramatic, drastic, significant etc. Not 'sudden' or 'exponential'. requires statement of at least two pairs of x and y values. Fourth mark only achievable if other 3 marks awarded [QWC] Examiner's Comments This question was about Rutherford scattering and used results from the original 1913 paper. Only the very best candidates gained four marks. About half the responses gained the two easiest marks, that number of scattered particles per unit time decreases with increasing angle and that gold generally scatters more particles than silver. Few candidates commented on the dramatic difference in number of particles scattered as the angle changes. This may show that they did not look at the y-axis values with sufficient care. Responses often included theoretical justification for the results even though this was not asked for. It is clear that candidates were well-versed in the scattering experiment but, perhaps in a rush to write down what they knew, they moved away from the point of the question.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		$6 \times 1.6 \times 10^{-13} = 9 \times 10^9 \times 79 \times 2 \times (1.6 \times 10^{-19})^2 / r(1)$ $r = 9 \times 10^9 \times 79 \times 2 \times (1.6 \times 10^{-19})^2 / 6 \times 1.6 \times 10^{-13} (1)$ $= 3.8 \times 10^{-14} \text{ m} (1)$	3	Accept bald figure Two marks if 6×10^6 used for energy giving answer $6.1 \times 10^{-33} \text{ m}$ Two marks if $(6 \times 10^6 / 1.6 \times 10^{-19})$ used for energy giving answer 9.7×10^{-52}. Annotation, two ticks and ecf. Two marks if original energy miscalculated in other ways if leading to consistent ecf. Two marks if POT missing out 10^6 gives $3.8 \times 10^{-8} \text{ m}$. Continuing in the manner of recent papers, the arithmetical part of the question, giving a value of $3.8 \times 10^{-14} \text{ m}$ was answered with much more confidence than the descriptive parts. ☐ Examiner's Comments ☐ Continuing in the manner of recent papers, the arithmetical part of the question, giving a value of $3.8 \times 10^{-14} \text{ m}$ was answered with much more confidence than the descriptive parts.
	c	i	Volume of nuclei is proportional to A (1) mass of the nucleus is proportional to A (1)	2	Mass (of nucleus) proportional to volume is given one mark. Algebraic statement of proportionality acceptable Examiner's Comments The explanation of nuclear density being independent of the number of nucleons was rather poor from the middle and lower-ranked candidates, many of whom produced circular arguments of little worth.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$19^{1/3}/27^{1/3} (1) = 1.9(4) (1)$	2	Accept bald answer. 1.93 is a rounding error and should be penalised one mark. Accept rounding to 2 only if working shown. Accept 1.9:1 or 2:1 but do not accept unevaluated ratios such as 5.8/3 or 5.8:3 Examiner's Comments Once again, notwithstanding a poor performance in (i), most candidates gained the marks for the calculation (answer: 1.9(4)). The comparison is stark: over 70% of the candidates failed to score on (i) whilst over 80% gained full marks for part (ii). This simply shows that explaining points of physics has a very high-level demand.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
53	a		Any two from: • mass - energy • momentum; • angular momentum • charge • lepton number • hadron / baryon / mass / nucleon / quark number	2	Mark first two answers Not just mass or just energy. Don't accept 'mass and energy' in place of mass-energy. Examiner's Comments This question was about beta decay. It was the most accessible of the questions. This question asked for two conserved quantities. 'lepton number' and 'charge' were the most popular correct choices. Some candidates incorrectly suggested that 'energy' or 'mass' were conserved.
	b	i	$E = (1.6749 \times 10^{-27} - 1.6726 \times 10^{-27} - 9 \times 10^{-31}) \times 9 \times 10^{16} \text{ (1)}$ $= 1.3 \times 10^{-13} \text{ J (1)}$	2	For information: $\Delta m = 1.4 \times 10^{-30} \text{ kg}$ Accept 1.26×10^{-13} Ecf for arithmetic error in Δm, one mark maximum Accept correct bald answers Accept negative answers Examiner's Comments This standard calculation leading to a value of $1.3 \times 10^{-13} \text{ J}$ caused very few problems.
		ii	$m_p < m_n + m_e$, accept $m_p < m$ (1)	1	Accept as BOD, $m_n > m_p$ Accept "because there would be an increase in mass" Accept rest energy instead of mass Examiner's Comments This part was rather more discriminating. Many candidates gave circular answers of the form 'because protons are stable particles'. This is a useful lesson in examination technique: part (ii) will refer to part (i).

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	$m = E/c^2$ (1) Substitution of eV for E (1) OR eV/c^2 is an equivalent unit to $\text{J}/\text{m}^2 \text{ s}^{-2}$ (1) $\text{J}/\text{m}^2 \text{ s}^{-2} = \text{N}/\text{m} \text{ s}^{-2} = \text{kg}$ (1)	2	Complete derivation required for two marks Allow any other dimensionally consistent routes. Examiner's Comments Unit manipulation is always problematic for the medium and lower-ranked candidates. Although marks could be gained through a very simple method many candidates did not complete the derivation clearly enough to gain both marks.
		ii	$2 \frac{\text{eV}}{c^2} = \frac{2 \times 1.6 \times 10^{-19}}{(3 \times 10^8)^2} = \frac{3.2 \times 10^{-19}}{9 \times 10^{16}}$ $= 3.6 \times 10^{-36} \text{ kg (1)}$	2	Bald answer gains two marks. Penalise rounding error (e.g. 3.5×10^{-36} , 3.55×10^{-36}) Penalise recurring decimal in final answer Examiner's Comments Once again, a straightforward calculation. Most candidates achieved the correct value of $3.6 \times 10^{-36} \text{ kg}$.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
54	a		Flux linkage= NBA $A = 0.054 / (200 \times 7.5 \times 10^{-2}) = 3.6 \times 10^{-3} \text{ (1)}$ Side= $A^{1/2} = 0.06 \text{ m (1)}$	2	Correct bald answer 2 marks Accept range of flux linkages from 0.053 to 0.057 giving A range of 3.5×10^{-3} to 3.8×10^{-3} giving side range 0.059 to 0.062 No ecf for correctly square rooting incorrect area unless POT error Examiner's Comments This question, about a simple generator, was more discriminating and, as although the context will have been familiar to many, the form of questions took a little thinking about. This required candidates to calculate the length of the side of the square coil. This was challenging as the candidates had to take a value for maximum flux linkage from the graph, realise that this occurs when the coil has maximum effective area, calculate the cross sectional area and then square root the value. Nearly all the candidates who evaluated the cross sectional area gained both marks, reaching the value 0.06 m.
	b		Method 1 : Evidence of gradient at maximum slope (1) Data consistent with maximum slope substituted correctly (1) Answer in range 16 – 18 V (1) Method 2 Identification off= 50 Hz (may be implicit) (1) Recognising max emf is when $\sin 2\pi ft = 1$ (can be implicit) leading to $\text{Emf} = 0.054 \times 2 \times \pi \times 50 \text{ (1)}$ = 17.0 V (1) (range 16.6 to 17.9)	8	Do not allow bald answers for either method. Ignore sign of the answer in both methods. Look at graph in fig. 11.2, annotate tangent if present Evidence on graph not needed if data clearly shows method. Zero marks for method 1 if evaluating gradients other than the maximum Using $\Delta x / \Delta y$ instead of $\Delta y / \Delta x$ only gains mark for identifying greatest slope. Lose one mark if failing to convert correctly from milliseconds to seconds (giving answers in range 0.016 V to 0.018 V) 3 marks for using 0.05 Hz as frequency leading to answers in range 0.0166 to 0.0179 V IF this is consistent with same

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Comments Most confident in method 2 because the uncertainty in measuring the gradient (1) is greater than the uncertainty in the value of the maximum flux linkage used in method 2. (1)		mistake in method 1. (i.e. two answers of approx. 0.017 V can gain 5 marks) Penalise a new POT error –1 . If values substituted into $\sin 2\pi ft$, t must be 5, 15 or 25 ms otherwise one mark max for correct frequency Examiner's Comments This part revealed lack of mathematical knowledge in some candidates and rather hurried reading of the question leading to contradictory answers. This will be another useful question to discuss in class. The first method required finding the maximum gradient of the graph line(giving a value between 16 and 18 V). Most candidates attempted this and gained some credit. Assuming that the time axis was in seconds was a common error. The second method required the use of an equation that was given to the candidates. Many candidates assumed that the emf would be the greatest when the flux linkage was the greatest (rate of change = zero) even though they had used the maximum rate of change of flux linkage in the previous part of the question. This gave some candidates an emf value of zero whilst others assumed the angle was in degrees and so reached an incorrect, non-zero value. The presence of 2π in the sine was a sufficient memory jog for the better candidates to work in radian, and the most mathematically confident recognised the maximum value of sine is 1. The final part of the question required candidates to compare methods of obtaining the emf. Many recognised the difficulty of establishing a gradient with confidence but only the very best compared this to the uncertainty in the data used in the second method.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
55	a		Uniformly spaced straight lines, perpendicular to electrodes(1) Arrow right to left(1)	2	Lines must be symmetrical about electron path and extend from plate to plate Examiner's Comments The question was about Bertozzi's demonstration of the relativistic effects on accelerated particles. About a quarter of the candidates drew field lines with the arrows towards the positive plate. Others lost marks through poor drawing, non-uniform fields and field lines not ending at the plates. The best responses showed that great care had been taken.
	b	i	$5.0 \times 10^5 \times 1.6 \times 10^{-19} (1) = 8.0 \times 10^{-14} \text{ J}$	1	
		ii	Algebraic rearrangement to give $v^2 = 2E/m$ OR $v^2 = (2 \times 8 \times 10^{-14}/9.1 \times 10^{-31}) (1)$ evaluation = $4.2 \times 10^8 (1)$	2	Do not accept bald answer for both marks. For information $v^2 = 1.76 \times 10^{17}$ Own value required. Reverse argument acceptable.
	c		$V = 8.4/3.2 \times 10^{-8} (1) = 2.6 \times 10^8$	1	Examiner's Comments Similarly, this part was a very easy calculation of velocity giving the result of $4.2 \times 10^8 \text{ m s}^{-1}$.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d	i	$m_e c^2 = 8.19 \times 10^{-14} \text{ J (1)}$ $\gamma = (8.0 \times 10^{-14} + 8.19 \times 10^{-14}) / 8.19 \times 10^{-14} = 1.98 \text{ (1)}$	2	Don't accept calculation of gamma from velocity calculated in (c) 1 mark max for rounding incorrectly to 1.97 Accept '2 x rest energy/ rest energy = 2' and similar arguments for second mark. Rest energy must be calculated for both marks Examiner's Comments This part of the question required candidates to calculate the rest energy of an electron and from this the gamma factor of the accelerated particle. This was more challenging to the weaker candidates. Some just divided kinetic energy by rest energy, others attempted to calculate the gamma factor through another method and could not gain the mark for calculating the rest energy of the electron.
		ii	substitution of γ value into $= 1/(1-v^2/c^2)^{0.5}$ or into a correctly rearranged formula (1) $V = 2.6 \times 10^8 \text{ (1)}$	2	Ecf from d(i) Evidence of calculation required. Bald answers score zero in this part of the question Examiner's Comments This was more challenging again. Only the top 40% gained both marks, reaching a value of $2.6 \times 10^8 \text{ m s}^{-1}$. Many came unstuck in attempting to rearrange the gamma factor equation and missed a relatively easy mark (no pun intended) for substituting the gamma factor correctly into the equation.
		iii	Agrees with measured velocity (so supports Einstein's prediction) (1)	1	Do not accept 'they are the same' as it is not clear which velocities are being referred to. No ecf. Examiner's Comments The comments on the value obtained in (ii) were often too broad to gain credit 'less than too broad to gain credit 'less than the speed of light' was a common response.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	e		Any two from: - Protons are more massive - Protons have a lower gamma factor for same k.e. - Protons would behave classically at this energy - Experiment would not be a suitable test of Special Relativity - Protons require higher energy or p.d for relativistic/the same speed	2	O.R.A. throughout Allow “heavier”, “weigh more”, higher rest energy Don't credit comments just about acceleration Examiner's Comments Most candidates gained at least one mark by stating that protons are more massive than electrons. The second mark, explaining the consequence of this greater mass, was harder to gain.
			Total	13	
56			Any three pairs from - TL effect is repeatable/electrons return to ground state after heating (1), So chips can be re-used (1) - Wide range of doses can be monitored/can cope with a wide range of exposure levels (1) useful for more situations (in which monitoring is needed)(1) - Similar absorption characteristics to soft tissue/similar absorbed dose to the wearer of the TLD chip (1) Measurement of Absorbed Dose easier (1) - TL gives linear response to dose(1) Easier to determine the dose/calibrate the chip (1)	6	Within each pair, the second marking point cannot be credited without the first marking point being awarded. Do no credit properties that do not make direct comparisons with photographic film. Eg do not credit: hardness, brittleness, density, solubility, transparency, crystal structure. Ignore cost implications. Examiner's Comments This question asked candidates to identify and explain advantages of LiF chips over photographic film. Many candidates gained marks for correctly identifying advantages as required, but some veered into discussions of material properties that did not address the ease of monitoring dose. Many candidates missed a mark through stating that the chips can be reused whilst omitting to provide an explanation for this property; others mistakenly suggested that this property is a consequence of the natural fading of electrons to the ground state.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
57	a		Dose equivalent includes (effect of) quality factor(1) Different radiations have different effects on tissue(1)	2	Do not credit bald statement $Sv = QF \times Gy$ though this can be used as part of an explanation. Reference to tissue(AW) is needed for mark. Examiner's Comments Most candidates correctly identified the importance of the quality factor in the dose equivalent and gave answers that showed greater understanding than merely quoting the relevant equation. Fewer gained the second mark, although many made reasonable but insufficient statements. For example, candidates rarely considered the different effects on tissue – just stating that different radiations are 'more damaging'.
	b		Marks awarded for: Division by 62 kg (1) 0.75 and 0.25 of dose applied correctly (1) Quality factor 10 applied correctly for neutron dose (1) Final answer= 6.3×10^{-3} Sv (1)	4	Correct bald answer worth four marks These steps may occur in any order Allow methods using weighted quality factor (3.25) Penalise rounding error (giving 6.2×10^{-3}) Examiner's Comments This multi-stage calculation was performed well by many candidates with about 70% scoring all four marks, reaching the answer 6.3×10^{-3} Sv. The most common error was multiplying the absorbed energy by the mass.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
58	a		Mass of chip = density $\times$ volume (1) No. of moles= mass of chip / relative atomic mass (1) No. of particles= no. of moles $\times$ Avogadro (1) No. of defect centres = $10^{-3} \times 5.4 \times 10^{20}$ $= 5.4 \times 10^{17}$(1)	4	Only credit rearranged equation - not quoting directly from data sheet Reward mass = 2.34×10^{-5} kg Reward number of moles = 9×10^{-4} Reward number of particles = 5.4×10^{20} Must give own value Examiner's Comments This question consisted of three calculations. Nearly half the candidates gained all ten marks here and showed confidence and clarity in their working. Nearly all candidates gained four marks for this part.(final answer = 5.4×10^{17}).

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		No. promoted = $5 \times 10^{17} / 10^6 = 5 \times 10^{11}$ (1) Energy used = $0.5\% \times 6 \times 10^{-5} = 3 \times 10^{-7}$ J (1) Energy per transition = $3 \times 10^{-7} / 5 \times 10^{11} = 6 \times 10^{-19}$ J (1) = $6 \times 10^{-19} / 1.6 \times 10^{-19} = 3.75$ eV (1)	4	If 5.4×10^{17} used from (a) number promoted = 5.4×10^{11} If 5.4×10^{17} used from (a) Energy per transition = 5.56×10^{-19} J = 3.5 eV (2sf) Need own answer. If candidate misses out 10^6 factor, 2 marks maximum. If candidate miss out 0.5%, 2 marks maximum. Examiner's Comments This part, requiring candidates to show the energy of a transition to be about 4 eV, was more challenging with the lower fifth of the candidates gaining no marks. The working of the weaker candidates showed rather random calculations which sometimes reached a reasonable-looking value but gained no credit. The better answers showed that the candidate had considered the question before putting pen to paper. There is a lot of information in the stem of the question which needs a little thought to marshal into a data set that can be worked with.
	c		$\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^8 / 6 \times 10^{-19}$ (1) = 3.3×10^{-7} m (1)	2	Credit using 4 eV (6.4×10^{-19}), 3.5 eV (5.6×10^{-19}) leading to 3.1×10^{-7}, 3.5 or 3.6×10^{-7} m. Calculating frequency as 9.7×10^{14}, 9.1×10^{14}, 8.5×10^{14} Hz gains one mark. Accept correct bald answers Examiner's Comments This was a straightforward question and the majority reached the correct value of 3.3×10^{-7} m.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
59	a		Any two from: Zero initial KE/ speed/ velocity/ starts from rest No collisions/in a vacuum Dynode fields independent of one another Non-relativistic behaviour/mass remains constant	2	Mark the first two assumptions NOT “no energy is lost” Accept speed of electron not close to speed of light Examiner's Comments This question was about the photomultiplier tube. This part required a statement of the assumptions made in using the equation $eV = \frac{1}{2}mv^2$. This proved to be a challenging question, with only about one in ten candidates gaining both marks. Common errors included suggesting that ‘air resistance’ had to be ignored rather than considering collisions at the scale of particles. Candidates often gave the same suggestion twice; for example, stating that relativistic effects are not important and then stating that the mass of the electron doesn't change. Some candidates made statements that showed a lack of understanding of the situation; for example, stating that an assumption is that the electrons do not change their velocity.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		Electrons start with same/zero KE/speed at each stage (1) Accelerated through same potential difference each stage (1)	2	Need indication of 'each stage' or 'first and last stage' eg "each dynode", "first and last electrode" etc. Allow velocity as alternative to speed Allow same energy gain through each stage Examiner's Comments This part of the question was aimed at higher-ranked candidates and was challenging to many. The most common incomplete response was to consider that the electrons 'shared' energy as the number multiply at each stage without explaining that all electrons are emitted with approximately the same value of kinetic energy and pass through the same p.d between each pair of dynodes.
			Total	4	
60	a		lepton and neutral (1)	1	order irrelevant
	b		hadron and nucleon (1)	1	order irrelevant Examiner's Comments This question tested recall of terms. This was correctly answered by the majority of the candidates.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
61			second path never below original path and shows greater deflection less than 180° (1) Smooth curve which finishes in a clear straight line (1). Reason: force acts for longer time / longer interaction time / longer time near nucleus (1)	3	If the second track does not start on the same original path, NAQ. Second mark can only be given if the first marking point has been awarded. Examiner's Comments This question required careful drawing and many candidates lost a mark through insufficient care. A small minority of responses failed to gain marks as they drew trajectories which did not take the same path as the original track. The explanation for the difference in tracks proved more challenging. A common error was to state that the slower particle had 'more' force on it.
			Total	3	
62			Straight line therefore uniform field (1) (Field strength =) gradient of line = $3000/0.07$ (1) = $4.3 \times 10^4 \text{ Vm}^{-1}$ or N C^{-1} (1)	3	Not just 'uniform field'. Accept 'straight line therefore constant field' Alternative for first mark: field is right to left as potential increases from left to right Do not penalise $E = V/r$ Range $4.2 - 4.5 \times 10^4 \text{ V m}^{-1}$. Units required for 3rd mark. Examiner's Comments This proved accessible to most of the candidates who easily linked the straight line to a uniform field and then calculated the field strength from the gradient. A sizeable proportion of the candidates lost marks through not including units in their answer.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
63	a		mass (1)	1	
	b		alpha particles have short range / stopped by skin / low penetration (1) (because they are) highly ionising / high quality factor (1)	2	Marks are for properties rather than the conclusion drawn. Examiner's Comments Another accessible question. The majority of candidates recalled basic facts about alpha particles and used their understanding to explain a possibly unfamiliar situation.
			Total	3	
64			C	1	Examiner's Comments This was intended to be a very accessible question but a surprising proportion of the candidates failed to gain the mark.
			Total	1	
65	a		No change in flux (1) Flux density <u>twice/double</u> (than that in the 'rest of the core') (1)	2	Independent marking points.
	b		Both values will decrease (1). Air has lower permeability (than iron)/ permeance (of magnetic circuit) has decreased (1)	2	Accept 'air is less permeable'. Accept 'reluctance (of magnetic circuit) has increased'. Reject 'permeance of air has decreased'. Examiner's Comments This question, on flux and flux density, proved challenging to many. Whilst the majority of the candidates stated that the flux remains constant throughout the core, a sizeable proportion failed to state that the flux density is double in the part of the core of half the cross-sectional area, merely writing that the flux density would increase was not enough to gain the mark. The second part of the question was also challenging; many candidates lost marks through confusing the terms 'permeance' and 'permeability'.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
66			$f = (1.9 \times 1.6 \times 10^{-19}) / 6.6 \times 10^{-34} \text{ (1)}$ $= 4.6 \times 10^{14} \text{ (Hz) (1)}$	2	Correct bald answer acceptable for two marks. Use of 6.63×10^{-34} gives 4.59×10^{14}. SF penalty for more than 3 SF. THIS IS THE ONLY SF PENALTY ON THE PAPER Examiner's Comments This was one of the most accessible questions on the paper.
			Total	2	
67	a		$E = 3.1 \times 10^{-29} \times (3.0 \times 10^8)^2 \text{ (1)}$ $= 2.8 \times 10^{-12} \text{ (J) (1)}$	2	Correct bald answer acceptable for two marks. 2.7×10^{-12} only gains one mark as rounding error
	b		(energy for work done in) overcoming repulsive force of nuclei. AW	1	Allow reference to 'a strong repulsive force' but not 'strong (nuclear) force'. Allow closest distance of approach argument if well-reasoned in terms of PE and KE. Reference to 'high energy' alone not sufficient. Reference to 'high activation energy' alone not sufficient. Examiner's Comments Fewer candidates gained the mark in the second part of the question. A common error was to cite 'high activation energy' as the reason for the need for high temperatures without making the link between high temperatures and the energy of the nuclei. A sizeable minority of the candidates suggested that high temperatures are required to overcome the strong nuclear force.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
68	a	i	(Field) lines closer together (at X) / field lines are further apart <u>at Y</u> (1)	1	Do not accept 'arrows closer together'.
		ii	Approximately circular (by eye) through X centred on charge	1	Examiner's Comments This question concerns electric fields near point charges. Parts of the question proved challenging and showed that many candidates don't have a confident grasp of the concepts of field strength and, in particular, potential. This is one of the more conceptually stretching parts of the course so it is unsurprising that the question caused candidates problems. The opening was well-answered by the majority.
	b	i	450 (V) (1)	1	
		ii	$6.1 \times 10^3 \text{ (N C}^{-1}\text{)}$	1	Calculator value = $6.0625 \times 10^3 \text{ (N C}^{-1}\text{)}$ Ignore sign Examiner's Comments This part, involving calculating the potential and field strength, was differentiating. Candidates who scored well on the paper overall tackled these calculations with ease whereas weaker candidates failed to use inverse and inverse-square relationships correctly.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	Fig. 9.3 a: <u>forces/fields</u> from the charges are equal and opposite at the midpoint (1) Fig. 9.3b: Calculation of field due to a single charge: $E = k \cdot 3.5 \times 10^{-9} / (1 \times 10^{-3})^2$ (1) (= 3.15×10^7) forces from the charges act in the same direction so net force $= 3.15 \times 10^7 + 3.15 \times 10^7 = 6.30 \times 10^7$. (1)	3	can be shown by calculation ($3.15 \times 10^7 - 3.15 \times 10^7 = 0$) Not arguments based on resultant charge = zero. Allow field = $\frac{2 \times k \times 3.5 \times 10^{-9}}{(1 \times 10^{-3})^2}$ $= 6.3 \times 10^7 \text{ NC}^{-1}$ for two marks Allow arguments based on an equivalent single charge of $7.0 \times 10^{-9} \text{ C}$ at range $1 \times 10^{-3} \text{ m}$ for two marks. Not any arguments based on distance = $2 \times 10^{-3} \text{ m}$ Examiner's Comments Candidates scoring well over the whole paper scored 2 or 3 marks on this question and gave a good explanation of the equal and opposing fields in the first case and successfully calculated the field strength in the second case. Some candidates reached the desired value of $6.3 \times 10^7 \text{ N C}^{-1}$ through using an incorrect separation of $2 \times 10^{-3} \text{ m}$. This showed a lack of understanding of the physics of the situation.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Potential due to both charges at midpoint is the same magnitude (1) but opposite sign (1)	2	Accept 'equal' to mean 'the same magnitude' Not 'opposite direction' 'equal and opposite potentials' worth one mark only Calculation of $3.15 \times 10^4 \text{ V}$ and $-3.15 \times 10^4 \text{ V}$ (1) showing these add to zero (1) Give benefit of doubt for $3.15 \times 10^4 \text{ V} - 3.15 \times 10^4 \text{ V} = 0$ for both marks Examiner's Comments This was a challenging question for many and revealed common misconceptions. Common errors included considering potentials to have opposite directions and reference to the force at the centre point. Many candidates talked about the potential of (or at) the charges rather than the potential at the midpoint. This may be a helpful question to discuss in class.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
69	a	i	$F = 0.57 \times 0.06 \times 0.09 \times 75 = 0.23 \text{ (N)}$ (1)	1	Correct bald answer worth one mark Examiner's Comments This question concerns a simple motor and touches on a number of concepts from electromagnetism. Candidates always find this topic challenging, and this year was no exception. This simple calculation proved to be less accessible than expected. The majority of the candidates failed to gain the mark because they did not take into account the number of turns on the coil.
		ii	Force on the coil / on AB is halved / half answer to (i) (1) Rotation rate also depends on named factor(s) (other than the force on the coil or length of coil) (1)	2	Ecf from (i) if numerical value used. e.g.: drag force / friction, mass of coil, torque. Accept any suggested change in rotation rate linked to other factor. Examiner's Comments Most candidates gained the first mark here for stating that the force on the side of the coil would halve although some failed to give the factor by which the force changes, a similar error to that discussed in question 6. The second mark – that there are other factors affecting the rate of rotation of the coil so it will not simply double – was not gained by many.
	b	i	$\text{Max flux linkage} = (6.0 \times 10^{-2})^2 \times 75 \times 90 \times 10^{-3} = 0.024 \text{ (1)}$	1	Correct bald answer worth one mark. No ecf from a(i)
		ii	Average emf = $0.024/0.2 = 0.12 \text{ V}$	1	Correct bald answer worth one mark. Ecf from (b) (i) Ignore sign Examiner's Comments A return to relatively straightforward calculations allowed many candidates to pick up marks.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Flux in coil changes when coil rotates / coil cuts flux when rotating (1) Induced emf related to speed of rotation / emf is rate of change of flux (linkage) (1) Induced emf / back emf opposes supply p.d.(1) So, current is lower when coil is turning / current increases as the induced emf reduces (to zero) (1)	4	Reverse argument acceptable (i.e. 'when coil is not rotating there is no change of flux' AW) R.A. acceptable: 'no emf when not rotating' BOD 'Induced emf opposes current' NOT 'induced current opposes supply current' Argument needs to be complete and correctly sequenced to gain QWC mark. (The fourth mark is dependent on the first three marks) Examiner's Comments This question was designed to stretch the candidates. The majority of responses gained marks for successfully describing the relationship between rate of change of flux and emf. However, significant misunderstandings were also evident. Many candidates wrote of an induced current opposing the supply current. Some responses suggested that the induced emf produces the current in the coil and the emf will be greatest when the flux linkage is greatest.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
70	a	i	(Constant) force acts at right angles to velocity / direction of motion. (1)	1	AW force at right angles to momentum / motion Not 'perpendicular to field' Not 'perpendicular to particle'. Not just 'centripetal force'
		ii	$\frac{mv^2}{r} = Bqv(1) \quad (\therefore r = \frac{mv}{Bq})$	1	Examiner's Comments This question is about the deflection of particles in a magnetic field and requires the candidates to think critically about a well-known representation of particle deflection. These questions were answered correctly by the majority of the candidates. Some candidates missed out on the first mark by simply stating that the motion of the alpha particle was 'centripetal' rather than stating why the motion was of this form.
	b		Beta particle has less mass / less momentum (than alpha particle) ORA (1). Gamma is uncharged (1)	2	Not 'lighter' or 'heavier' or more / less weight Not 'gamma is a wave not a particle' Examiner's Comments Although the better candidates gave clear answers, there were some quite common misunderstandings revealed. Weaker answers considered 'weight' to be a factor and suggested that the zero deflection of the gamma ray was due to its lack of mass.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$r_{\alpha} = 6.6 \times 10^{-27} \times 1 \times 10^7 / (B \times 3.2 \times 10^{-19})$ (1) = 0.21/B $r_{\beta} = 9.1 \times 10^{-31} \times 2 \times 10^8 / (B \times 1.6 \times 10^{-19})$ (1) = 1.1 $\times 10^{-3}$ /B Statement of ratio of radii, eg. 0.21: 1.1 $\times 10^{-3}$ or 'alpha radius of path is about 180 times that of the beta particle' (1) Comment that the diagram shows a much smaller difference in the two radii AW (1)	4	Accept arbitrary values of B (including B = 1 explicitly stated or explicitly substituted) for the first two marks. Penalise one mark only for ignoring B or using it inconsistently in explanation. Accept ratio of about 200 (or inverse ratios = 0.054 and 0.005) Allow ecf from r_{α} and r_{β} . This is a QWC mark: comment must be clear and consistent with ratio of radii as calculated and with the diagram Examiner's Comments This is a challenging question and it was encouraging to see many high-scoring responses to a context the candidates are unlikely to have considered. This shows a good understanding of basic physics and the ability to apply such understanding to unfamiliar situations. The best responses explicitly stated that B is a constant so cancels when considering the ratio of radii of paths. Many correctly calculated such a ratio and used their value to discuss the inaccuracy of the well-known representation.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
71	a		iodine (nucleus) has zero lepton number / lhs of equation has zero lepton number(1) Electron is a lepton, anti-neutrino is an anti-lepton (1)	2	Accept zero lepton number on both sides for first mark Accept eg $0 = 0 + 1 - 1$ (2 marks) $0 = 0 - 1 + 1$ (1 mark) Examiner's Comments This question is about using iodine-131 as a tracer. The first part of the question is the familiar challenge to show that lepton number has been conserved. Although there was some evidence of a lack of understanding of the term 'lepton number' (typically confusing it with the proton numbers of the nuclei shown), most marks were lost through giving incomplete explanations. Many candidates failed to state that the lepton number on the left hand side of the equation is zero, so correctly showing a zero value for the right hand side can only gain one out of two marks.
	b	i	$N = 1.2 \times 10^{-13} / 2.18 \times 10^{-25} = 5.50 \times 10^{11}$ (1) $\lambda = \ln 2 / 6.95 \times 10^5 = 9.97 \times 10^{-7}$ (1) activity = $9.97 \times 10^{-7} \times 5.50 \times 10^{11} = 5.49 \times 10^5$ (1)	3	Don't penalise rounding error Need own value to 2 s.f. or more and clear working, but stages can be conflated. Correct bald answer to 2 s.f. or more worth one mark only. Ignore sign in the final answer Examiner's Comments This 'show that' question proved straightforward for the majority of the candidates.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$A = 5 \times 10^5 \times e^{-((0.693/8) \times 84)} (1)$ $= 350 (1)$ OR $A = 5 \times 10^5 \times 0.5^{10.5} (1)$ $= 345 (1)$	2	Correct bald answer worth two marks Expect and accept answers in range 340 – 400 dependent on data used and rounding Allow one mark only for rounding to ten or eleven half-lives with consistent answer. Examiner's Comments Most candidates performed this calculation with confidence. Some candidates realised that the 12 weeks represents 10.5 half-lives and so divided the original activity by $2^{10.5}$ whilst others used the exponential decay equation.
	c		$\text{dose} = 5 \times 10^{11} \times 2.9 \times 10^{-14} / 1.8 \times 10^{-2} (1)$ $= 0.81 (1)$ Assumes all energy / beta particles deposited in gland (1)	3	Expect (and accept) 0.89 if 5.5×10^{11} used. No credit for calculation if mixing up initial number of nuclei with initial activity. (This is not a POT error) Don't accept 'dose' for 'energy' Examiner's Comments Many candidates gained the two marks available for the calculation but did not make a comment about the assumption or merely restated the stem of the question through stating that the assumption is that all the iodine decayed in the gland. The only common error in the calculation was to use the value for activity rather than the number of particles.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		Gamma passes through tissue (1) Iodine also emits β particles (1) which damage tissue / cells / dna / causes cancer (1) AW	3	Property of gamma must be linked to passage through body / tissue / possibility of external detection. Don't accept 'passes through skin'. Not simply 'causes damage' Examiner's Comments Although the majority of candidates gained some credit here, only a minority gained all three marks. Once again there were errors of omission such as not clearly stating that iodine-131 emits beta particles. Some candidates suggested that gamma emitters are used because gamma radiation can pass through skin; whilst this statement is correct it is not markworthy as the radiation must pass through a greater thickness of absorber than a layer of skin.
			Total	13	
72			$2 \times 10^{-12} / 1.6 \times 10^{-19} = 1.3 \times 10^7$ (1)	1	Accept correct bald answer Calculator answer = 1.25×10^7 Do not accept 1.2×10^7 (RE) Examiner's Comments This long question is about accelerating electrons in an evacuated tube. This simple calculation was correctly answered by all but a few candidates.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
73		i	$40000 \times 1.6 \times 10^{-19} = 6.4 \times 10^{-15}$ (1)	1	Must have own value
		ii	Re-arrange $KE = p^2 / 2m$ to give $p = (2mE_k)^{1/2}$ (1) $p = 1.08 \times 10^{-22} \text{ kg m s}^{-1}$ (1)	2	Correct bald answer worth two Calculation of $v = 1.19 \times 10^8 \text{ m s}^{-1}$ (1) $p = mv = 1.08 \times 10^{-22} \text{ kg ms}^{-1}$ (1) If 6×10^{-15} used, $v = 1.15 \times 10^8 \text{ m s}^{-1}$ and $p = 1.04 \times 10^{-22}$ Examiner's Comments This long question focuses on the acceleration of electrons. These proved to be straightforward calculations.
			Total	3	
74	a		From given equation, $N = Bd / \mu_0 I$ $= 1 \times 0.01 / (1.3 \times 10^{-6} \times 2)$ (1) $= 3846$ (1)	2	Condone missing 1 (T) in substitution Need own value to at least 2 sf Examiner's Comments This question proved more challenging than many in this section even though the physics involved is straightforward. Although the majority gained the marks for part (a), the simple calculation of resistance given the resistivity and the data required to calculate the resistance proved more difficult than expected. Many candidates simply assumed that the resistance was 1.6 ohm. The poor performance on this question may be due to this area of physics being covered early in the AS year, similar to question 13.
	b		$R = \pi r d \times N \times \text{resistance per unit length} = 201 \Omega$ (1) $V = IR = 2 \times 201 = 402 \text{ V (400V)}$ (1)	2	$R = 193 \Omega$ if calculator value used giving $V = 387 \text{ V}$ Accept different roundings from (a) Allow ecf from R to V
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
75	a		$E = V/d = 200 / 1.8 \times 10^{-3} = 1.1 \times 10^5$	1	Need own value Allow $E = V/r$ Examiner's Comments This question is about the deflection of electron beams. A straightforward 'show that' question.
	b		$F = Eq = 1.1 \times 10^5 \times 1.6 \times 10^{-19} = 1.78 \times 10^{-14}$ (1) $a = F/m = 1.78 \times 10^{-14} / 9.1 \times 10^{-31} = 1.96 \times 10^{16} \text{ m s}^{-2}$ (1) Then from $s = \frac{1}{2} at^2$, $t = 2.26 \times 10^{-10} \text{ s}$ since $s = 0.5 \text{ mm}$ (1) And so $x = vt = 0.4 \times 3 \times 10^8 \times 2.4 \times 10^{-10} = 27.1 \times 10^{-3} \text{ m}$ (1)	4	Can use 1×10^5 to give a force = $1.6 \times 10^{-14} \text{ N}$; acceleration = $1.75 \times 10^{16} \text{ m s}^{-2}$ $t = 2.38 \times 10^{-10}$ $s = 2.86 \times 10^{-2} \text{ m}$ allow ecf from wrong force / wrong acceleration Credit answers which take relativistic factor (1.1) into consideration. Correct bald answer worth 4. Examiner's Comments This question proved to be highly discriminating. Weaker responses tried to calculate the force on the electron using $F = qvB$. This error did not stop candidates gaining credit for a correct use of an incorrect value for force, but most responses that confused electric and magnetic effects failed to get beyond a force calculation. The markscheme allowed for the possibility of a candidate using relativistic effects but none of the markers reported any examples of this. The best candidates produced clear calculations that showed complete confidence in using ideas from different parts of the course to reach an answer.
	c		Uniform electric field (1) Force (or acceleration) would be the same (1)	2	AW: constant field strength 2 nd mark is dependent on the first Examiner's Comments Just under half the responses gained both marks for this question. Candidates who could not see the simple reasoning tended to fill the answer space with a description of varying forces somehow balancing out.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	7	
76			$\gamma = \text{total energy} / \text{rest energy} = (0.511 + 0.2) / 0.511$ $= 1.39(1)$ substitution of gamma value into $\gamma = 1 / (1 - v^2/c^2)^{1/2}$ or into rearranged equation (1) $v = 2.1 \times 10^8 \text{ ms}^{-1} (1)$	3	Correct bald answer greater than 1 s.f. worth three marks Allow ecf from wrong gamma Do not award second or third marks for 2.65×10^8 (using $ke = \frac{1}{2} mv^2$) NOW SCROLL THROUGH ADDITIONAL PAGES INSERTING 'BP' Examiner's Comments This question was a calculation of the gamma factor for an electron leading to a calculation of its velocity. In the past such a question may have been split into two to make the route to the answer more obvious. It is encouraging that around half the candidates gained full marks for this extended calculation at the end of a two hour paper. A few of the weaker candidates gained two marks for correct use of an incorrectly calculated gamma factor, but most of the answers which showed an incorrect gamma factor showed further errors.
			Total	3	
77			B	1	
			Total	1	
78			C	1	
			Total	1	
79			D	1	
			Total	1	
80			B	1	
			Total	1	
81			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
82			D	1	
			Total	1	
83			B	1	
			Total	1	
84			B	1	
			Total	1	
85			C	1	
			Total	1	
86	a		Lorentz force / Bqv supplies centripetal force ✓	L	accept Bqv force remains perpendicular to v and pulls path into a circle keeping speed constant, acceleration causing only a change in direction
			$Bqv = mv^2 / r \rightarrow Bq = mv / r \rightarrow r = mv / Bq$ ✓	M	
	b	i	$T = \pi r / v = \pi mv / Bqv = \pi m / Bq$ (independent of v) ✓	M	
		ii	(faster protons go further but time to traverse dee remains constant so) accelerating frequency can remain constant ✓	H	
		iii	$f = 0.8 \times 1.6 \times 10^{-19} / \{2 \pi \times 1.673 \times 10^{-27}\}$ = 12 M(Hz) ✓	L	accept 12.17 MHz OR 1.217×10^7 Hz
		iv	2 crossings per spiral loop OR 10 k eV per loop	H	evaluation Award 1 mark for correct method and evaluation using 5 keV
		iv	number of loops = $1.2 \text{ MeV} / 10 \text{ keV} = 120$ ✓	H	
		v	$\gamma = E_{\text{TOTAL}} / E_{\text{REST}} = \{940 + 1.2\} \text{ MeV} / 940 \text{ MeV}$ ✓	M	method
		v	= 1.001(3) ≈ 1 so non-relativistic approach reasonable ✓	M	evaluation and conclusion accept is a small deviation from 1
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
87	a	i	$kT = 1.4 \times 10^{-23} \times 10^{11} / \{1.6 \times 10^{-19}\} \text{ (eV)}$ $= 8.75 \times 10^6 \text{ eV } (\approx 9 \text{ MeV}) \checkmark$	L	method and show that evaluation to 8.75 or 8.8 MeV accept 8.63 MeV using $k = 1.38 \times 10^{-23}$
		ii	rest energy of electron or positron $\approx 9.11 \times 10^{-31} \times (3 \times 10^8)^2 / (1.6 \times 10^{-13}) = 0.512 \text{ MeV}$ OR pair = 1.02 MeV $\checkmark$	H	
		ii	$\ll 9 \text{ MeV}$	H	
		iii	but for proton or antiproton is $\approx 1000 \text{ MeV} \gg 9 \text{ MeV}$ for a substantial proportion of photons to have sufficient energy the temperature needs to be higher / about x10 to x100 higher $\checkmark$	H	
	b	i	mass created = $m_{\text{NEUTRON}} - m_{\text{PROTON}} + m_{\text{ELECTRON}}$ OR $= \{1.008665 - 1.007276 + 0.000549\} \text{ u } \checkmark$	M	accept mass / energy of neutrino may be zero / negligible as standalone alternative for first mark
		i	$= 0.001938 \text{ u} = 1.810 \text{ MeV } \checkmark$	M	
		ii	As T falls $e^{-\frac{E}{kT}}$ gets smaller, the number of p with enough energy to become n reduces. so ratio of p to n increases. $\checkmark$	H	method
		ii	fraction of particles with activation energy to create	S & C	evaluation
		ii	neutrons = Boltzmann factor = $e^{-\frac{E}{kT}} = e^{-\frac{1.8}{8.8}} \checkmark$ $e^{-0.209} = 0.812 \text{ (p : n = 1 / 0.812)} \checkmark$	S & C	
	c	i	mass released as binding energy = $m_{\text{DEUTERON}} - m_{\text{PROTON}} + m_{\text{NEUTRON}} = 0.002388 \text{ u } \checkmark$	M	Evaluation accept calculation of mass and use of $E = mc^2$
		i	$= 0.002388 \times 931.1 \text{ MeV / u} = 2.2(2) \text{ MeV } \checkmark$	M	and conversion to MeV gives 2.23 MeV

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	thermal energy of particles / photons will be ≈ 0.9 MeV but in the Boltzmann / Planck distribution tail there will be particles with 2.2 MeV energy to break deuterons apart ✓	S&C	accept alternative words or estimated calculations e.g. fraction with activation energy $\approx$ $e^{-\frac{2.2}{0.88}} = 0.082$
			Total	12	
88		i	$v = (100 \times 1.6 \times 10^{-19} \times 2/9.1 \times 10^{-31})^{1/2}$ ✓ $= 5.9 \times 10^6 \text{ m s}^{-1}$ ✓	2	correct bald answer gains both marks
		ii	Gamma factor = $(5.1 \times 10^5 + 1 \times 10^2)/5.1 \times 10^5$ ✓ $= 1.0002$ which is almost unity, so relativistic effects can be ignored. ✓	2	'gamma factor will be roughly one so relativistic effects can be ignored' gains one mark
			Total	4	
89	a		$I/I_0 = 0.5 = e^{-0.25\mu}$ ✓ $\ln 0.5 = -2.5 \mu$ $\mu = 0.28 \text{ cm}^{-1}$ ✓	2	Must show working and own answer
	b		Reduction in count rate due to inverse square law: Count rate = $900 \times 10^2/40^2$ ✓ $= 56(.25)$ ✓ Reduction due to absorber: Count rate = $56.25 e^{-0.28 \times 0.5}$ ✓ $= 49 \text{ Bq}$ ✓	4	
	c		Fraction of gamma rays absorbed per cm in material ✓ If the intensity of gamma rays is high enough the fraction absorbed will represent many photons and provide a therapeutic dose ✓	2	AW throughout.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance								
90			Level 3 (5–6 marks) Marshals argument in a clear manner. All technical vocabulary is used with accuracy and clarity. The candidate's response shows an understanding of the properties of gamma radiation and the answer is informed by quantitative reasoning based on the data given. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) The response may cover the three aspects listed in the guidance but may lack clarity or depth. A calculation, if present, may not be clearly linked to the main argument. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) The calculation may be incorrect or missing, the answer is based on assumptions rather than analysis of the article or question. The specific properties of gamma radiation may not be considered (i.e. why the patient can irradiate others) <i>The information is basic and communicated in an unstructured way.</i> 0 marks No response or no response worthy of credit No response or no response worthy of credit.	6	Indicative scientific points may include: Safety: Minimise time of exposure from patient, minimise close contact. Access to accelerator: short half-lives mean that the useful time of the radiochemical is limited. proximity to accelerator (which produces the radioisotope) reduces transit time, giving more time to prepare chemical. Patient remaining in location: Radiochemical will still be emitting gamma rays at a rate above background Gamma rays can pass through patient and irradiate other people. Candidate includes a calculation of activity of fluorine-18 in patient. Values from possible calculations: <table><tr><td>time elapsed/hr</td><td>Activity of fluorine-18</td></tr><tr><td>1</td><td>2060</td></tr><tr><td>2</td><td>1400</td></tr><tr><td>3</td><td>950</td></tr></table>	time elapsed/hr	Activity of fluorine-18	1	2060	2	1400	3	950
time elapsed/hr	Activity of fluorine-18												
1	2060												
2	1400												
3	950												
			Total	6									

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
91	a		Any 2 from: ✓✓ Handle radioisotope with tongs; Always point open side away from body; Keep exposure time as short as possible; Always store in lead lined containers.	2	
	b	i	Background radiation is always present/from cosmic rays and natural radioactive materials ✓	1	
		i	(The value for background count has to be subtracted from all readings) to avoid a systematic error ✓	1	
		ii	Half thickness calculated		
		ii	Method ✓	1	
		ii	Evaluated ✓	1	Anticipated values in the range 0.9 to 1.1cm
		ii	More than one value found from the graph and mean calculated ✓	1	
	c	i	Ln taken on both sides and rearranged ✓	1	Expect to see $\ln(I) = \ln(I_0 e^{-\mu x})$ $\ln(I) = \ln(I_0) + \ln(e^{-\mu x})$
		ii	All 4 data points plotted correctly ✓	1	
		ii	Line of best fit drawn through the plots ✓	1	
		iii	Gradient correctly calculated from two points on the line drawn ✓	1	
		iii	Intercept read off graph correctly or calculated using substitution into $y = m x + c$ and coordinates of a point on the line ✓	1	
		iii	$\mu = \text{gradient} \checkmark$	1	
		iii	$I_0 e^{\text{intercept}} \checkmark$	1	There must be evidence of this calculation. i.e. not just read from Fig. 4.2
	d	i	Use of $I = \frac{I_0}{2} \checkmark$	1	
		i	Either $\frac{I_0}{2} = I_0 e^{-\mu x}$ OR $\ln\left(\frac{I_0}{2}\right) = -\mu x + \ln(I_0)$ and rearrange to $\frac{\ln 2}{\mu} = x_{1/2} \checkmark$	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	$x_{1/2} = \checkmark$	1	
		ii	Any three from $\checkmark\checkmark\checkmark$ On an exponential scale: Need to find several values of half-thickness in different parts of curve and average in order for it to be reliable OR Radioactive decay is a random process and at small values of A the randomness will affect readings more. On a logarithm scale: Value determined for half-thickness from logarithm graph is more reliable as it is determined from the gradient of the line reducing the effect of the random nature of radioactive decay	3	i.e. Not reliable as only one/a few value(s) of half thickness calculated
			Total	20	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
92	a		Charge: one negative charge on LHS, one on RHS as neutrinos are neutral ✓ Lepton number: neutrino and antineutrino sum to zero lepton number as neutrino = +1 and antineutrino -1 ✓ Other conserved quantity: mass-energy; momentum ✓	3	Accept cancel out Accept implicit assumption that the lepton number of muon and electron are the same. Don't accept 'mass' or 'energy' Accept spin, total energy, angular momentum Examiner's Comments This question was about muon decay and relativistic time dilation. Part (a) required candidates to show that charge and lepton number are conserved in the decay of a muon into an electron, neutrino and anti-neutrino. This was not performed as well as expected as many candidates did not give sufficient detail, for example, by omitting to state that neutrinos are neutral when considering charge conservation. More interestingly, some candidates assumed that a muon has a lepton number of -1, or that it is not a lepton, even though the stem makes a clear statement to the contrary. It was also assumed, by many, that neutrinos are not leptons. In contrast, the calculations in parts (b) and (c) were confidently answered by the majority of the candidates.
	b		Rest energy of electron = $9.1 \times 10^{-31} \text{ kg} \times 9 \times 10^{16} \text{ m}^2 \text{ s}^{-2}$ = $8.19 \times 10^{-14} \text{ J}$ ✓ = 0.51 MeV ✓ Ratio: muon / electron = 207 ✓ ORA	3	Or calculate mass of muon: Rest energy (J) = $1.7 \times 10^{-11} \text{ J}$ ✓ Mass = $1.9 \times 10^{-28} \text{ kg}$ ✓ Ratio = 207 ✓
	c		time of travel = $8000 / (0.98 \times 3 \times 10^8) = 27 \mu\text{s}$ ✓ % remaining = $100 \times e^{-(0.693 \times 2.7 \times 10^{-5} / 1.5 \times 10^{-6})}$ ✓ = 0.0004% ✓	3	All working must be shown. Intermediate value for time not required. Alternative method: no. of half-lives = 18.1 ✓ Fraction remaining = $1/2^{18.1}$ ✓ = $3.6 \times 10^{-6} = 0.0004 \%$ ✓

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d	i	Muons are moving at an appreciable fraction of c ✓ Relativistic factor appreciably greater than 1 ✓ Observed half life will be dilated as $t = \gamma\tau$ ✓	3	AW throughout. Credit discussion of fewer half-lives (or 'wristwatch time' dilated) leading to higher numbers reaching ground 1 mark.
		ii	Number of half lives from (c) = 18.1 ✓ Number of half-lives for 9% remaining = 3.47 ✓ γ = ratio 18.1/3.5 = 5.2 ✓	3	Other routes possible. Eg: $\log 0.000004 \checkmark / \log 0.09 \checkmark$ = 5.2 ✓ (5.1 if 0.000005 used) ECF from 6 (c) on this method. Calculation via speed of muons only worth 1 mark, leading to 5.03 OR: number of half-lives = 3.47 ✓ Time for 3.47 half-lives = $5.2 \times 10^{-6} \text{ s}$ ✓ Dilation = $2.7 \times 10^{-5} / 5.2 \times 10^{-6} \text{ s} = 5.22 \checkmark$ ECF from (c) Examiner's Comments Part (d)(i), required a clear explanation of the greater than previously suggested number of muons reaching the ground level. Weaker candidates struggled with this and wrote rather vague statements about 'less (or even more) time for the muons' whereas the better responses clearly explained that the observer records the muon time as dilated. Not all responses linked the relativistic effect to the muons travelling at a high percentage or proportion of the speed of light.
			Total	15	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
93	Level 3 (5–6 marks) Clear description of process of absorption line formation including use of photon model of light and reference to energy levels within atoms. Discussion of inverse-square law and using it to find correct distance to star Y. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Incomplete description of absorption line formation – perhaps omitting a clear description of the quantum aspect or the idea that different elements have different spectra. Reasonable attempt at description of inverse-square law and distance may be correctly calculated but the working may not be clear <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Little development of ideas, no attempt or poor attempt at calculating the distance. Discussion of spectra superficial. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	6	Indicative scientific points may include: Absorption spectra: • Photons / light travelling through cold gas • Certain frequencies of light absorbed • Energy of photons matches energy differences between energy levels (in cold atoms) • Different elements have different spectral lines because of different energy levels. • Stars can be grouped into classes by their spectra which gives a good indication of the absolute brightness of a star. Absolute and apparent brightness: • Brightness of a star varies with $1/\text{distance}^2$ from the star • Example to explain (eg 3 times the distance, $1/9$ the apparent brightness) • $1/12^2 = 3 / (\text{distance to } x)^2$ • Calculation to 20.8 parsec • Recognition that answer can be found from $12 \times (3)^{1/2}$ Examiner's Comments The last question on the paper was a level of response question focusing on measuring distances to stars using real and apparent magnitudes. The majority of the candidates correctly calculated the distance to 'star X' in parsecs and many made a clear link between absorption spectra and atomic energy levels. The best responses clearly linked all three aspects of the explanation together – that is, the role of energy levels in producing an absorption spectrum, the value of

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					identifying the spectral class of a star and the calculation of distance. Some candidates, however, wrote a great deal but essentially closely paraphrased or quoted the article.
			Total	6	
94			A	1	Examiner's Comment Candidates found this question on a magnetic flux circuit hard. By far the most common incorrect answer was B. This showed that many candidates did not realise that halving the length of the magnetic circuit would double the flux (by halving the reluctance).
			Total	1	
95			D	1	Examiner's Comment This question was about a jumping induction ring. It was well answered by a good majority, D. Incorrect answers were split between A and C, where candidates thought the demonstration would work equally well on a.c. or d.c. power, or that the only purpose of the steel rod was to support the jumping aluminium ring.
			Total	1	
96			C	1	Examiner's Comment This pair of questions on transformers was well answered by a good majority of candidates, Q24 to calculate the primary coil current being the slightly more discriminating.
			Total	1	
97			D	1	Examiner's Comment This pair of questions on transformers was well answered by a good majority of candidates, Q24 to calculate the primary coil current being the slightly more discriminating.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
98			B	1	Examiner's Comment Most candidates recognised the correct formulation for balancing a charged drop in the oil drop experiment. Many wrote down the forces balance and reorganised the equation.
			Total	1	
99			C	1	Examiner's Comment These were discriminating questions about a graph of average binding energy per nucleon against nucleon number. It was pleasing that nearly half the candidates managed to select the correct answer for each.
			Total	1	
100			B	1	Examiner's Comment These were discriminating questions about a graph of average binding energy per nucleon against nucleon number. It was pleasing that nearly half the candidates managed to select the correct answer for each.
			Total	1	