OCR
Oxford Cambridge and RSA

Friday 10 June 2022 – Afternoon

A Level Physics A

H556/02 Exploring physics

A Level Physics Online . com

Time allowed: 2 hours 15 minutes

You must have:
- the Data, Formulae and Relationships booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

* 9 1 1 4 8 2 1 1 1 9 *

* H 5 5 6 0 2 *

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number 3 5 8 9 7 Candidate number 9 3 2 3

First name(s) Lewis

Last name Matheson

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **28** pages.

ADVICE
- Read each question carefully before you start your answer.

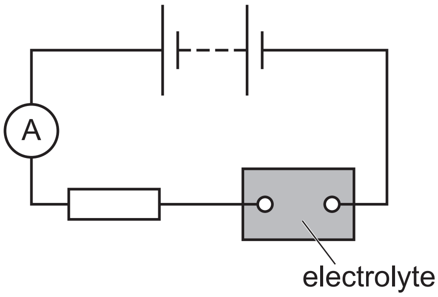
SECTION A

You should spend a maximum of 30 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

1 A current is present in the circuit below.



The resistor is made from a length of wire.

Which row gives the correct charge carriers in the resistor and in the electrolyte?

	Charge carriers in the resistor	Charge carriers in the electrolyte
A	Electrons	Electrons
B	Electrons	Ions
C	Electrons and protons	Ions and electrons
D	Electrons and ions	Ions and protons

Your answer B **[1]**

2 The half-life of fluorine-18 isotope is T.
After time $t = 4T$ the number of fluorine-18 nuclei in a source is N.

How many fluorine-18 nuclei have decayed in the time interval from $t = 0$ to $t = 4T$?

A $3N$

B $4N$

C $15N$

D $16N$

$2^4 = 16$

$\therefore$ original number $= 16N$

final number $= N$

$\therefore (16-1)N$ decayed

Your answer C **[1]**

3 The activity of an alpha-emitting source is 120 kBq. The kinetic energy of each alpha-particle is 4.0 MeV.

What is the rate of energy released by the source?

A 6.4×10^{-13} W

B 4.8×10^{-8} W

C 7.7×10^{-8} W

D 1.2×10^{5} W

Your answer C **[1]**

4 Which of the following statement(s) correctly describe radioactive decay?

1 Radioactive decay can be modelled using dice.
2 Radioactive decay of nuclei is random.
3 Radioactive decay of nuclei is spontaneous.

A Only 1

B Only 2

C 2 and 3

D 1, 2 and 3

Your answer D **[1]**

5 A gamma-ray photon of frequency 6.76×10^{22} Hz creates a particle-antiparticle pair. The particle-antiparticle pair have zero kinetic energy.

What is the mass of the particle?

A 2.49×10^{-28} kg

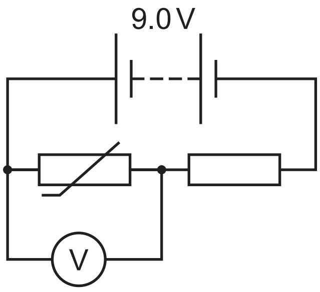
B 4.98×10^{-28} kg

C 7.47×10^{-20} kg

D 4.48×10^{-11} kg

Your answer A **[1]**

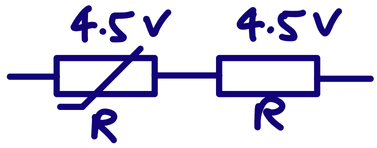
6 A potential divider circuit is shown below.



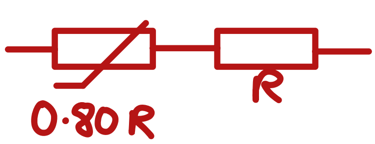
The battery has electromotive force (e.m.f.) 9.0 V and negligible internal resistance.
At room temperature the potential difference (p.d.) across the thermistor is 4.5 V.
The temperature of the thermistor is increased and its resistance decreases by 20% from its previous value.

What is the p.d. across the thermistor now?

Room temp



Higher temp



A 3.6 V

B 4.0 V

C 5.0 V

D 5.4 V

Your answer B ✓ **[1]**

$$V = \frac{0.80\ R}{1.80\ R} \times 9.0 = 4.0\ V$$

7 A particle is moving at right angles to a uniform magnetic field of flux density *B*. The particle has mass *m*, charge *q* and moves in a circular arc of radius *r* in the region of the magnetic field.

What quantities are required to determine the momentum of this particle?

A *B*, *q* and *r*

B *B*, *q* and *m*

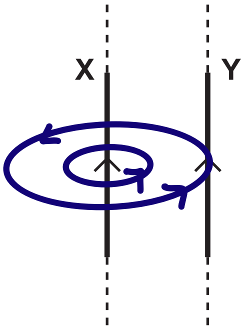
C *B*, *q*, *r* and *m*

D *q*, *r* and *m*

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

Your answer A ✓ **[1]**

8 The diagram below shows two long current-carrying conductors **X** and **Y**.



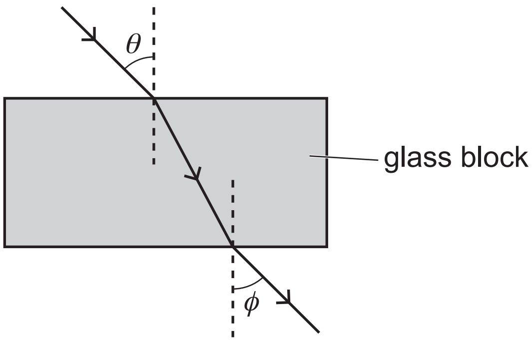
The conductors are parallel to each other.
Y experiences a force because it is in the magnetic field of **X**.

Which row gives the correct direction of the magnetic field at **Y** due to **X**, and the direction of the force experienced by **Y** due to this field?

	Direction of magnetic field	Direction of force
A	Down into the plane of paper	To the right
B	Up from the plane of paper	To the right
C	Down into the plane of paper	To the left
D	Up from the plane of paper	To the left

Your answer C **[1]**

9 A student is investigating the refraction of light by a rectangular glass block. The glass block is surrounded by air.
The diagram below shows the path of the light as it enters the block, when it is refracted within the block and when it exits the block.



Which statement is correct?

A The angles θ and ϕ are the same because the glass block is surrounded by air. ✓ parallel rays

B The product of $\sin\theta$ and the refractive index of glass is a constant. ✗

C The refractive index of glass is less than the refractive index of air. ✗

D The speed of light is the same in both air and glass. ✗

Your answer A ✓ **[1]**

10 A proton of mass 1.67×10^{-27} kg is travelling at a speed of $2.0 \times 10^{5}\,\text{m s}^{-1}$.

The table below shows the mass and speed of four particles **A**, **B**, **C** and **D**.

Particle	Mass / kg	Speed / $10^5\,\text{m s}^{-1}$
A	9.11×10^{-30}	5.0
B	8.80×10^{-28}	3.0
C	2.49×10^{-28}	2.0
D	3.34×10^{-27}	1.0

Which particle has the same de Broglie wavelength as the proton?

Your answer D ✓ **[1]**

$\lambda = \frac{h}{mv}$ $\lambda \propto \frac{1}{mv}$ Provided momentum the same, λ the same

Proton, $mv = 1.67\times10^{-27} \times 2.0\times10^{5} = 3.34\times10^{-27}$

11 A beam of sound of intensity I_0 is reflected off the surface of water.

The amplitude of the reflected sound is $\frac{1}{4}$ the amplitude of the incident sound.

What is the intensity of the reflected sound in terms of I_0?

A $\frac{I_0}{16}$

B $\frac{I_0}{8}$

C $\frac{I_0}{4}$

D I_0

$I \propto A^2$

$\left(\frac{1}{4}\right)^2 = \frac{1}{16}$

Your answer | A | ✓ **[1]**

12 A small sample of muscle has volume 1.0 cm^3 and mass 1.10 g.
The speed of ultrasound in the muscle is 1600 $m\,s^{-1}$.

What is the acoustic impedance of the muscle?

A $1.76 \times 10^3\,kg\,m^{-2}\,s^{-1}$

B $1.76 \times 10^4\,kg\,m^{-2}\,s^{-1}$

C $1.76 \times 10^6\,kg\,m^{-2}\,s^{-1}$

D $1.76 \times 10^{12}\,kg\,m^{-2}\,s^{-1}$

$\rho = \frac{m}{V} = \frac{1.10 \times 10^{-3}}{1.0 \times 10^{-6}} = 1.1 \times 10^3\ kg\ m^{-3}$

$Z = \rho c = 1.1 \times 10^3 \times 1600$

$= 1.76 \times 10^6$

Your answer | C | ✓ **[1]**

13 The mass of a proton is m_p, the mass of a neutron is m_n, and the mass of a hydrogen-3 (^3_1H) nucleus is M. The speed of light in a vacuum is c.

Which expression is correct for the binding energy (B.E.) of the hydrogen-3 nucleus?

A B.E. = $M \times c^2$

B B.E. = $(m_n + m_p - M) \times c^2$

C B.E. = $(m_n + 2m_p - M) \times c^2$

D B.E. = $(2m_n + m_p - M) \times c^2$

$2n + 1p = {}^3_1H$

$B.E. = \Delta m c^2$

$B.E. = (2m_n + m_p - M)c^2$

Your answer | D | ✓ **[1]**

14 A wire in a circuit obeys Ohm's law.

Which statement about the wire is linked to this law? $V \propto I$

A The current in the wire is directly proportional to the potential difference across it. ✓

B The current in the wire is inversely proportional to its resistance.

C The resistance of the wire is directly proportional to its length.

D The resistance of the wire is inversely proportional to its cross-sectional area.

Your answer A ✓ **[1]**

15 An electron has both mass and charge. The electron has a gravitational field and an electric field around it.

Which statement is **not** correct?

A Both field patterns look the same. ✓

B Both field patterns show parallel field lines around the electron. x radial lines

C Both field strengths obey an inverse square law with distance from the electron.

D The direction of both fields is the same at any point around the electron.

Your answer B ✓ **[1]**

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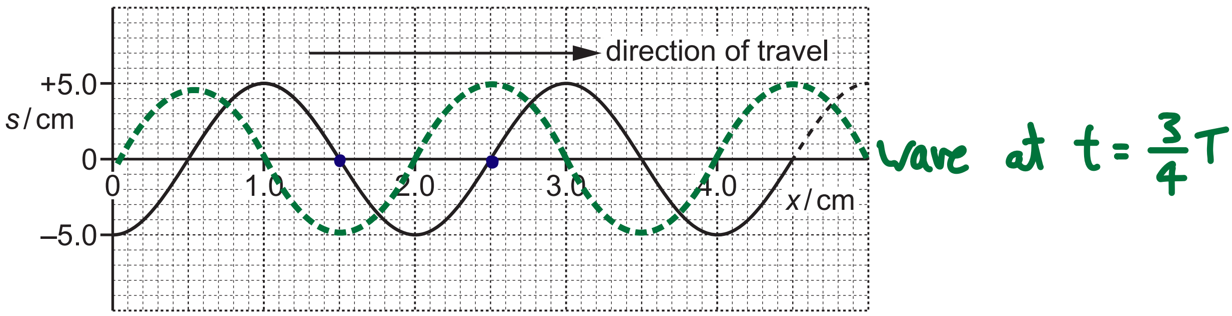
SECTION B

Answer **all** the questions.

16 **(a)** A graph of displacement s against distance x for a **progressive** wave at time t = 0 is shown below.



Determine:

(i) the phase difference ϕ in radians between the points on the wave at x = 1.5 cm and x = 2.5 cm

Half a cycle

ϕ = π ✓ rad **[1]**

(ii) the displacement s at time $t = \frac{3}{4}T$ at x = 1.5 cm, where T is the period of the oscillations of the wave.

s = −5.0 ✓ cm **[1]**

(b) A beam of coherent light of wavelength λ is incident normally at two parallel slits (double-slit). A series of bright and dark fringes are formed on a distant screen placed parallel to the line joining the slits.
The location of some of these fringes is shown in **Fig. 16.1**.

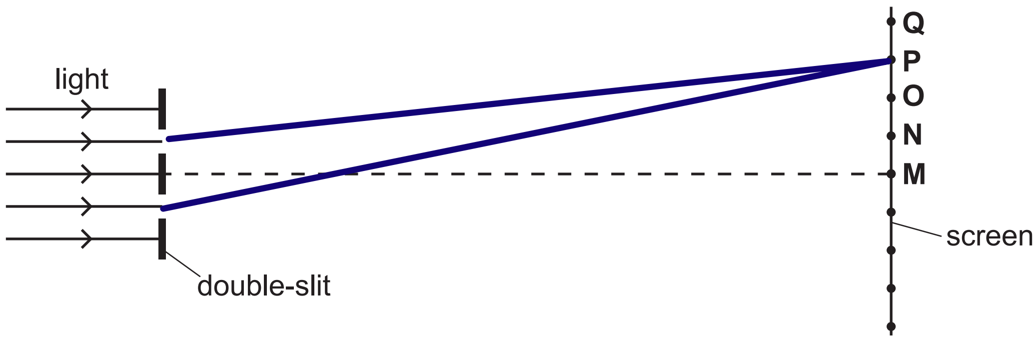


Fig. 16.1 (not to scale)

The bright fringes are seen at points **M**, **O** and **Q**. The dark fringes are seen at points **N** and **P**.

State the phase difference ϕ in degrees, and the path difference d in terms of wavelength λ, for the waves from the two slits meeting at point **P**.

ϕ = 540 ✓ ° **[1]**

d = 1.5 ✓ λ **[1]**

(c) A student is doing an experiment to determine the speed of sound in air by producing stationary waves inside a horizontal glass tube.

Fine powder is sprinkled inside the tube. A loudspeaker is placed close to the open end of the tube. The other end of the tube is closed. The loudspeaker is connected to a signal generator producing a frequency of 2.72 kHz.
The powder inside the tube forms piles at certain locations inside the tube, see **Fig. 16.2**.

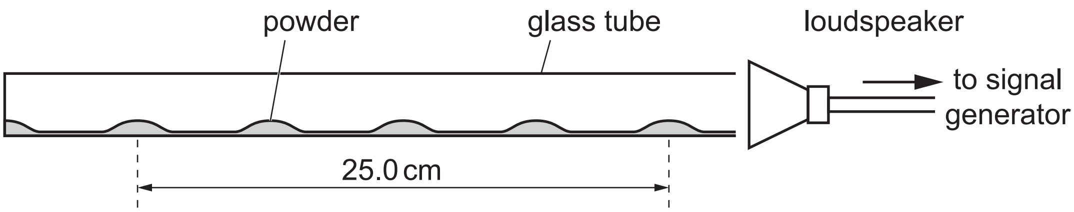


Fig. 16.2 (not to scale)

(i) Suggest why the powder piles up at the nodes within the tube.

Zero amplitude ∴ no movement ✓

[1]

(ii) Use **Fig. 16.2** to determine the speed of sound *v*.

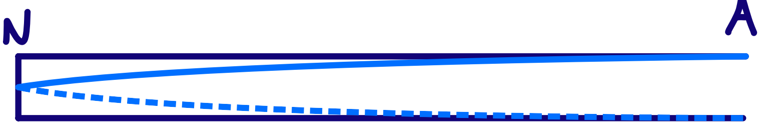
$2\lambda = 0.250\,m \quad \lambda = 0.125\,m$ ✓

$v = f\lambda = 2.72 \times 10^3 \times 0.125$ ✓

v = 340 ✓ m s^{-1} **[3]**

(iii) Determine the fundamental (minimum) frequency f_0 of the stationary wave that can be formed within this tube.

In fig 16.2, $L = 2.75\lambda = 2.75 \times 0.125 = 0.34375\,m$



$L = \frac{\lambda}{4}$

$\lambda = 4L = 4 \times 0.34375 = 1.375$ ✓

$f_0 = \frac{v}{\lambda} = \frac{340}{1.375} = 247.27$ f_0 = 247 ✓ Hz **[2]**

17 A light-emitting diode (LED) can be used to determine the Planck constant h. When the LED just starts to emit light, the equation below is valid

$$eV = \frac{hc}{\lambda}$$

$V = \frac{hc}{e} \cdot \frac{1}{\lambda}$ $\quad y = mx + c$

where V is the potential difference (p.d.) across the LED, λ is the wavelength of the light emitted, c is the speed of light in vacuum and e is the elementary charge.

(a) In the equation above, $\frac{hc}{\lambda}$ is the energy of a photon emitted from the LED.

Determine the S.I. base units for h.

$h = [\mathrm{J\,s}]$ $\quad [\mathrm{J}] = [\mathrm{kg\,m^2\,s^{-2}}]$ ✓

$h = [\mathrm{kg\,m^2\,s^{-2}.s}] = [\mathrm{kg\,m^2\,s^{-1}}]$

base units = $\mathrm{kg\,m^2\,s^{-1}}$ ✓ **[2]**

(b)* Describe how an experiment can be carried out in the laboratory to determine h from a graph. Your description must include how V and λ are accurately determined. Assume that the values of e and c are known. **[6]**

Connect LED in series with an ammeter to a variable power supply. Increase p.d across LED until a current flows (LED starts to emit light). Measure V across LED with a voltmeter. Values of λ can be looked up for that particular LED. ✓✓✓

Repeat for different colour LEDs, then plot a graph of V against 1/λ. Draw a line of best fit. This should pass through the origin. ✓✓

The gradient = hc/e ∴ h = gradient × e/c ✓

Additional answer space if required

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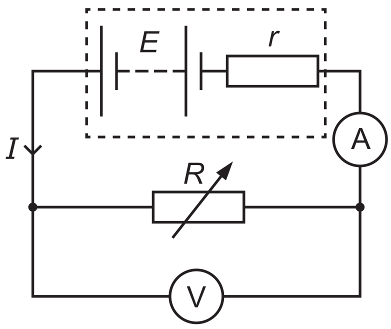
18 A battery is connected to a variable resistor.



The variable resistor is made from a length of wire. The resistance of the variable resistor is *R*. The battery has electromotive force (e.m.f.) *E* and internal resistance *r*. The current in the circuit is *I*.

(a) Compare the e.m.f. of the battery and the potential difference (p.d.) across the variable resistor in terms of energy transfers or changes.

e.m.f. work done on charges

p.d. work done by charges ✓ **[1]**

(b) State which physical quantity of the variable resistor is changed to alter its resistance.

Length of wire ✓ **[1]**

(c) A student connects up the circuit above to determine *r*.

(i) Show that $\frac{1}{I} = \frac{R}{E} + \frac{r}{E}$.

$\varepsilon = V + Ir$

$\varepsilon = IR + Ir$ ✓

$\varepsilon = I(R + r)$

$\frac{\varepsilon}{I} = R + r$

$\frac{1}{I} = \frac{R}{\varepsilon} + \frac{r}{\varepsilon}$ ✓

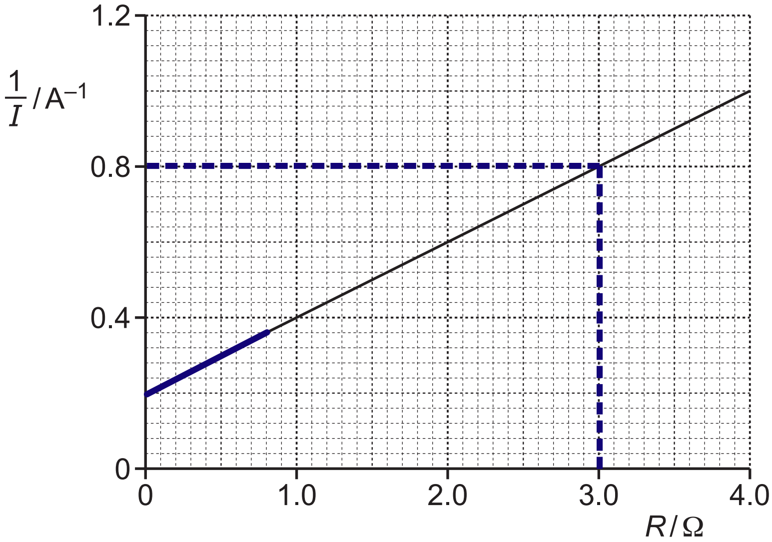
[2]

(ii) The student varies R and measures the current I.

The student plots a graph of $\frac{1}{I}$ against R.

$\frac{1}{I} = \frac{1}{\mathcal{E}}R + \frac{r}{\mathcal{E}}$

$y = mx + c$



1 Use the graph to determine the power dissipated in the variable resistor when $R = 3.0\,\Omega$.

$\frac{1}{I} = 0.80 \therefore I = 1.25\text{A}$ ✓

$P = I^2R = 1.25^2 \times 3.0 = 4.6875$

power = 4.7 ✓ .... W **[2]**

2 The e.m.f. E of the battery is 5.0 V.

Determine r from the intercept of the line with the vertical axis.

y-intercept = 0.20 ✓ = $\frac{r}{E}$

$r = 0.20 \times 5.0 = 1.0$

r = 1.0 ✓ .... Ω **[2]**

19 The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

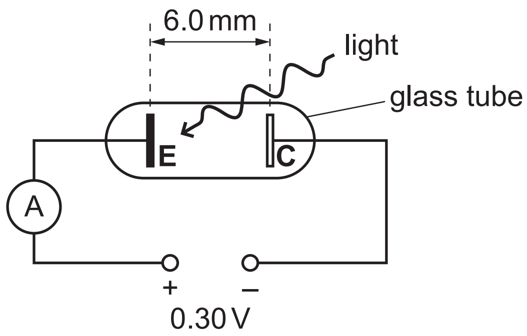


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

The separation between the plates is 6.0 mm and the potential difference between the plates is 0.30 V.

Light of frequency 6.3×10^{14} Hz is incident on plate **E**. The photoelectrons emitted from this plate have **maximum** kinetic energy 0.30 eV (4.8×10^{-20} J). The photoelectrons are repelled by the negative plate **C**. The ammeter reading is zero because these photoelectrons reach plate **C** with zero kinetic energy.

(a) Calculate the work function of potassium in eV.

$hf = \phi + KE_{max}$

$\phi = hf - KE_{max} = (6.63\times10^{-34} \times 6.3\times10^{14}) - 4.8\times10^{-20}$ ✓

$\phi = 3.6969\times10^{-19}$ J ✓ $\div 1.60\times10^{-19} = 2.31$

work function = ... 2.3 ✓ ..... eV **[3]**

(b) This question is about a photoelectron emitted perpendicular to plate **E** and with an initial kinetic energy of 4.8×10^{-20} J.

(i) Show that the magnitude of deceleration of this photoelectron is $8.8 \times 10^{12}\,\text{m s}^{-2}$.

$E = \frac{F}{Q} = \frac{V}{d}$ $\quad F = \frac{QV}{d}$ $\quad F = ma$

$a = \frac{QV}{md}$ ✓ $= \frac{1.60\times10^{-19} \times 0.30}{9.11\times10^{-31} \times 6.0\times10^{-3}}$ ✓ $= 8.782\times10^{12}$ ✓ $\approx 8.8\times10^{12}\,\text{ms}^{-2}$

[3]

(ii) Show that the initial speed of the photoelectron is about $3 \times 10^5\,\text{m s}^{-1}$.

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

$v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2 \times 4.8 \times 10^{-20}}{9.11 \times 10^{-31}}} = 3.2 \times 10^5 \approx 3 \times 10^5\,\text{ms}^{-1}$

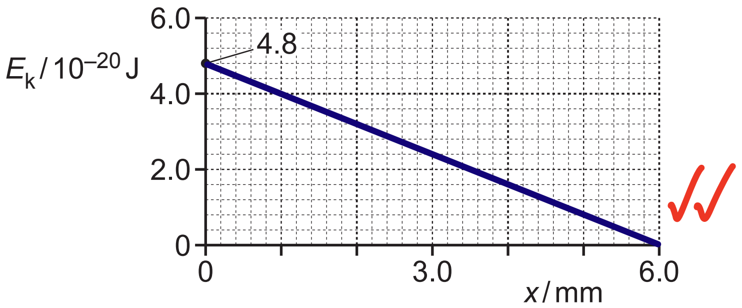
[2]

(iii) Calculate the time *t* taken by the photoelectron to travel from plate **E** to plate **C**.

$a = \frac{v-u}{t} \qquad t = \frac{v-u}{a} = \frac{3.2 \times 10^5}{8.782 \times 10^{12}} = 3.64 \times 10^{-8}$

t = 3.6×10^{-8} s **[2]**

(iv) Using the axes shown below, sketch a graph of kinetic energy E_k against distance *x* from plate **E**.



[2]

(c) Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than 6.3×10^{14} Hz is now incident on plate **E**.

Energy of photons increases ∴ KE_{max} of photo-electrons increases ∴ they reach plate C and this current causes a reading on the ammeter. **[2]**

20 **(a)** Deuterium is an isotope of hydrogen.
A nucleus of deuterium has a proton and a neutron.

Describe the nature and range of the **two** forces acting between these two hadrons.

Strong nuclear force ✓: Attractive between 0.5 – 3 fm, repulsive <0.5 fm. ✓

Gravitational force ✓: Infinite range and attractive, but negligible. ✓

[4]

(b)* Here is some data for a nucleus of carbon-14 ($^{14}_{6}C$) and a nucleus of uranium-235 ($^{235}_{92}U$).

	Carbon-14 nucleus	**Uranium-235 nucleus**
Decay mode	Beta-minus decay	Alpha decay
Mass of nucleus / u	14.0	235.0
Radius of nucleus / 10^{-15} m	2.9	7.4

Use the data to:

- describe the composition of the nuclei before and after the decay in terms of hadrons and quarks
- show that both nuclei have the same density. **[6]**

$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta^{-} + \bar{\nu}_e$

Before decay, 6 protons and 8 neutrons. After decay there are 7 protons and 7 neutrons. ✓ As a neutron (udd) decays into a proton (uud) one of the down quarks decays into an up quark. ✓

$^{235}_{92}U \rightarrow {}^{231}_{90}Th + {}^{4}_{2}\alpha$

As the uranium decays, it emits two protons and two neutrons (six up and six down quarks). ✓

Mass of carbon 14 is 14u, uranium-235 is 235u

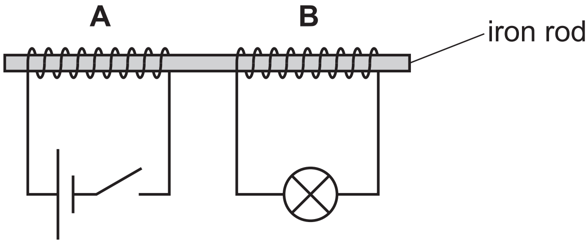
$\rho = m/V$ and $V \propto R^3$, $\rho \propto \frac{m}{R^3}$ ✓

$\frac{m_c}{R_c^3} = \frac{14}{2.9^3} = 0.574$ $\frac{m_u}{R_u^3} = \frac{235}{7.4^3} = 0.580$ ✓

Additional answer space if required

∴ Approximately the same density ✓

21 **(a)** The diagram below shows two insulated-copper coils **A** and **B** connected in circuits.



Both coils are individually wrapped around the same iron rod.
Coil **A** is connected to a cell and a switch. Coil **B** is connected to a filament lamp.

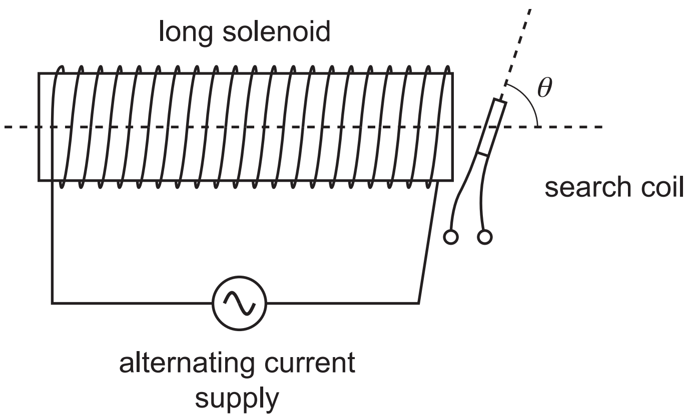
The switch is initially closed and the lamp is off.

The switch is then opened. The lamp flashes on for a brief time, and then remains off.

Explain these observations in terms of magnetic flux.

As the switch is opened, flux linkage changes ✓ ∴ induces an emf ✓ because the flux linked to B which causes lamp to light. ✓ Initially flux is constant ∴ no change in flux ∴ lamp is off. **[3]**

(b) A student is carrying out an experiment using a search coil.



A long solenoid is connected to an alternating current supply.

The search coil is placed at one end of the solenoid. The plane of the search coil is tilted such that it makes an angle θ with the central axis of the solenoid. The maximum alternating induced electromotive force (e.m.f.) across the ends of the search coil is E_0.

(i) Name an instrument that can be used to determine E_0.

Oscilloscope ✓ **[1]**

(ii) The equation for E_0 is:

$E_0 = KI_0ANf\sin\theta$

where I_0 = maximum current in the solenoid, A = cross-sectional area of the search coil, N = number of turns of the search coil, f = frequency of the alternating current in the solenoid and $K = 4.0 \times 10^{-3}\ \text{VA}^{-1}\,\text{m}^{-2}\,\text{s}$.

The magnitude of the induced e.m.f. in the search coil can be determined using Faraday's law of electromagnetic induction:

e.m.f. = rate of change of magnetic flux linkage

In the experiment, angle θ is changed and E_0 measured.

Suggest the quantity, or quantities, in the equation $E_0 = KI_0ANf\sin\theta$ linked to

1 the 'rate' part of the law

f ✓ **[1]**

2 the 'change of magnetic flux linkage' part of the law.

θ ✓ **[1]**

(iii) The student plots a straight-line graph of E_0 against $\sin\theta$.

Determine f, including the absolute uncertainty. Write your value of f to **2** significant figures.

$I_0 = (8.0 \pm 0.2)\,\text{A}$
$A = (7.8 \pm 0.1) \times 10^{-5}\,\text{m}^2$
$N = 5000$
gradient of line $= KI_0ANf = (0.62 \pm 0.03)\,\text{V}$

$E_0 = KI_0ANf\sin\theta$

$\text{gradient} = KI_0ANf$

$f = \dfrac{\text{gradient}}{KI_0AN} = \dfrac{0.62}{4.0\times10^{-3}\times8.0\times7.8\times5000} = 49.68$ ✓

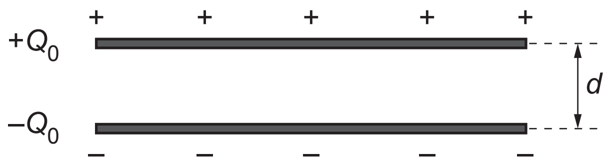
f = 50 ✓ ± 4 ✓ Hz **[4]**

$\%U_f = \%U_{grad} + \%U_{I_0} + \%U_A$

$= \left(\dfrac{0.03}{0.62} + \dfrac{0.2}{8.0} + \dfrac{0.1}{7.8}\right) \times 100 = 8.62\%$ ✓

$49.68 \times 0.0862 = 4.28$

22 **(a)** The diagram below shows a simple capacitor.



The capacitor consists of two horizontal metal plates in a vacuum. The magnitude of the charge on each plate is Q_0. The potential difference (p.d.) between the plates is V_0. The capacitor plates have capacitance C_0. The separation between the plates is *d*. The energy stored by the capacitor is E_0.

The top plate is moved vertically upwards. The new separation between the plates is 2*d*. The charge on each plate remains the **same**.
The energy stored by the capacitor **increases**.

(i) Determine the new:

1 capacitance in terms of C_0 $C \propto \frac{1}{d}$

capacitance = 0.5 ✓ C_0 **[1]**

2 p.d. between the plates in terms of V_0

$V \propto d$ p.d. = 2 ✓ V_0 **[1]**

3 energy stored in terms of E_0.

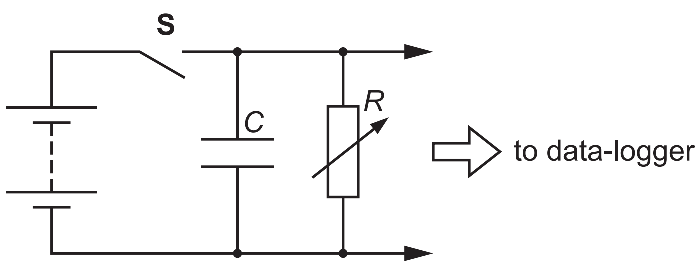
$E \propto d$ energy = 2 ✓ E_0 **[1]**

(ii) Explain, in terms of forces between the plates, why the energy stored increases.

Work is done against attractive forces. ✓

[1]

(b) A student discharges a capacitor of capacitance *C* through a variable resistor of resistance *R* using the arrangement below.



The capacitor is made from two parallel metal plates separated by a sheet of paper of thickness 8.0×10^{-5} m. The area of overlap between the plates is 3.1×10^{-2} m^2.

The capacitor is charged fully by closing switch **S**. At time *t* = 0, **S** is opened and the capacitor discharges through the resistor. After *t* = *T*, the potential difference across the capacitor is halved. The student repeats this for several values of *R*.

(i) The student decides to plot T against R to obtain a straight-line graph.

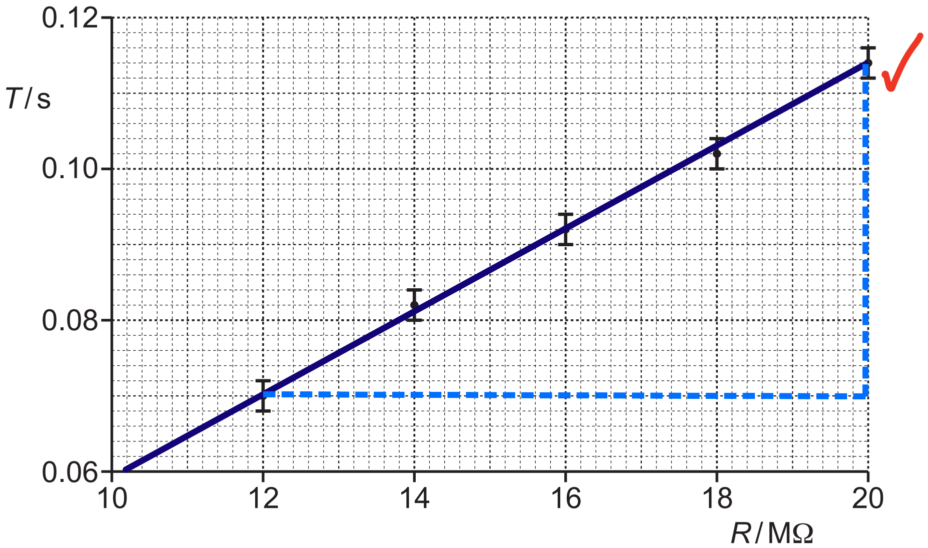
Show that the line has gradient = $C\ln 2$.

$V = V_0 e^{-t/RC} \rightarrow \ln \frac{V}{V_0} = -\frac{t}{RC} \rightarrow \ln \frac{1}{2} = -\frac{T}{RC}$ ✓

$T = RC \ln 2 \rightarrow T = C\ln 2 . R$ ✓ $y = mx + c$

[2]

(ii) The data points plotted by the student are shown below.



1 Draw a best-fit straight line through the data points and use the gradient of this line to determine C.

gradient $= \frac{0.114 - 0.070}{(20-12) \times 10^6} = 5.3 \times 10^{-9}$ ✓

$C \ln 2 = \text{gradient}$ $\quad C = 5.3 \times 10^{-9} \div \ln 2 = 7.93 \times 10^{-9}$

C = 7.9×10^{-9} ✓ F **[3]**

2 Use your answer in **(ii)1** to calculate the permittivity ε of the paper.

$C = \frac{\varepsilon A}{d}$ $\quad \varepsilon = \frac{Cd}{A} = \frac{7.93 \times 10^{-9} \times 8.0 \times 10^{-5}}{3.1 \times 10^{-2}}$ ✓ $= 2.048 \times 10^{-11}$

ε = 2.0×10^{-11} ✓ F m^{-1} **[2]**

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23 A gamma camera has several important components including a collimator, scintillator and photomultiplier tubes.

(a) Suggest why the collimator needs to be long and narrow.

So it only allows gamma photons that travel along the axis of the collimator to pass through. ✓ **[1]**

(b) State the function of the scintillator.

This turns gamma photons into many photons of visible light. ✓ **[1]**

(c) In a single photomultiplier tube, a photon of light produces a 0.32 μA pulse of current for a duration of 1.2 ns.

Calculate the number of electrons responsible for this pulse of current.

$$I = \frac{Q}{t} = \frac{ne}{t} \qquad n = \frac{It}{e} = \frac{0.32\times10^{-6} \times 1.2\times10^{-9}}{1.60\times10^{-19}} = 2400$$ ✓

number of electrons = 2400 ✓ **[2]**

(d) State one diagnostic application of a gamma camera.

Detection of cancer. ✓ **[1]**

Question 24 is on the next page

24 **(a)** Describe, in terms of X-ray photons, the attenuation mechanism of Compton scattering.

When X-ray photon interacts with an atom, an electron is removed ✓ and a lower energy X-ray scattered. ✓ **[2]**

(b) A parallel beam of X-rays is incident normally on a tissue as shown in **Fig. 24.1**.

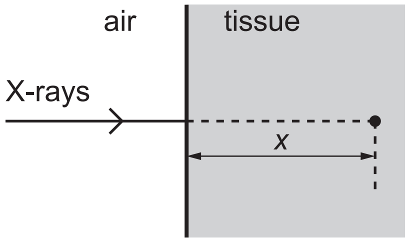

Fig. 24.1

The variation of the intensity I of the X-rays with depth x in the tissue is shown in **Fig. 24.2**.

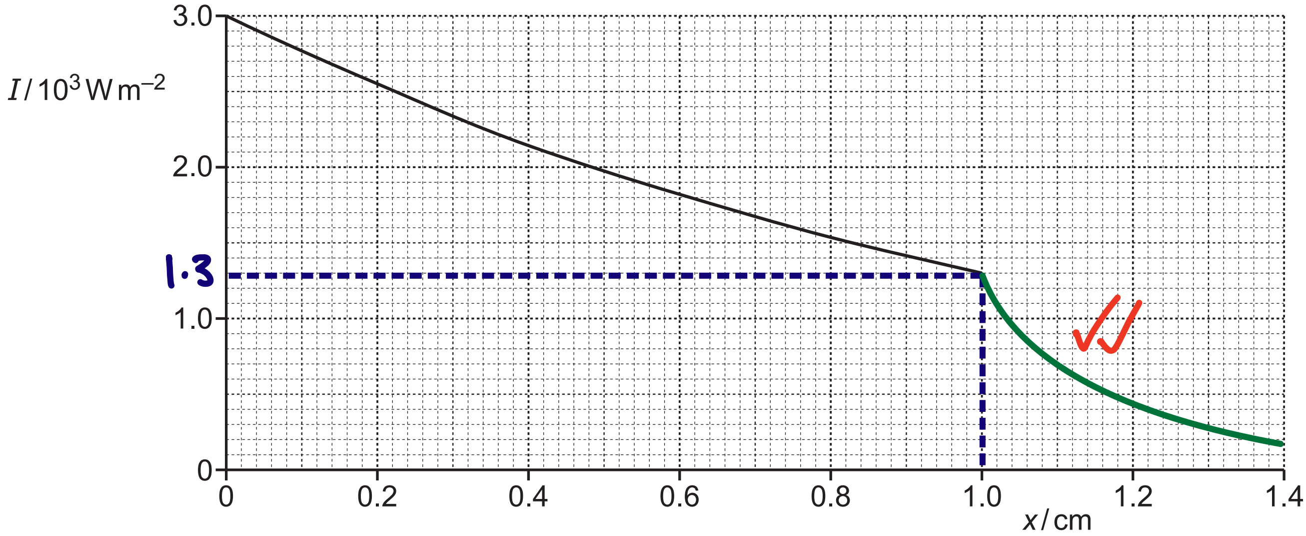

Fig. 24.2

The tissue has uniform structure between $x = 0$ and $x = 1.0$ cm.

(i) Use the graph to determine the attenuation (absorption) coefficient μ in $\mathrm{cm^{-1}}$ of the tissue.

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

$\mu = \frac{\ln(I_0/I)}{x} = \frac{\ln(3.0/1.3)}{1.0} = 0.836\ \mathrm{cm^{-1}}$ ✓

x in cm

μ = 0.84 ✓ $\mathrm{cm^{-1}}$ **[2]**

(ii) Use the graph to determine the exposure time t for the total radiant energy incident per cm^2 at a depth of 1.0 cm to be 2.6 J.

$I = 1.3 \times 10^3\ Wm^{-2}$ ✓

$I = \frac{P}{A} = \frac{E}{tA}$ $t = \frac{E}{IA} = \frac{2.6}{1.3 \times 10^3 \times (1 \times 10^{-2})^2}$ ✓

t = 20 ✓ s **[3]**

(iii) Beyond x = 1.0 cm, the tissue has a larger attenuation coefficient than the value calculated in **(i)**.

On **Fig. 24.2**, sketch the variation of I with x beyond x = 1.0 cm. **[2]**

Steeper gradient

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).