OCR
Oxford Cambridge and RSA

Monday 17 June 2024 – Morning

A Level Physics A

H556/03 Unified physics

Time allowed: 1 hour 30 minutes

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

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

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

Centre number 9 1 0 9 3 Candidate number 8 3 7 0

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 page at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answers 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 **70**.
- 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 **20** pages.

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

Answer **all** the questions.

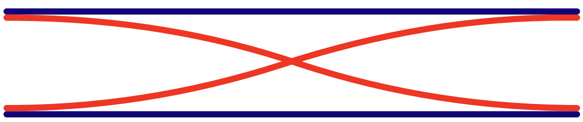
1 A flute is a musical instrument made from a long tube that is open at both ends.

A stationary sound wave in the tube produces a musical note.

The lowest frequency note that a standard flute produces in air is 262 Hz.

The speed of sound in air at a temperature of 20 °C is 340 m s^{-1}.

(a) Show that a standard flute has an approximate length of 0.65 m.



$v = f\lambda \quad \lambda = \frac{v}{f} = \frac{340}{262} = 1.298\,m$ ✓

$\lambda = 2L$ ✓

$L = \frac{\lambda}{2}$

$L = 0.649$ ✓ $\approx 0.65\,m$

[3]

(b) In an ideal gas, the speed v of sound is given by

$$v = \left(\frac{\gamma RT}{M}\right)^{1/2}$$

where

γ is a dimensionless constant that depends on the gas

R is the molar gas constant

T is the absolute temperature

M is the molar mass of the gas.

The table below shows values of γ and M for both air and helium.

Gas	**γ**	**M / g mol^{-1}**
Air	1.40	29.0
Helium	1.67	4.00

(i) The kinetic model of an ideal gas assumes that there are a large number of particles in rapid, random motion.

State **two** further assumptions for the kinetic model of an ideal gas.

1 Collisions are perfectly elastic. ✓

2 The volume of the particles is negligible compared to the volume of the container. ✓ **[2]**

(ii) A standard flute is placed inside a sealed chamber.

The chamber is filled with helium at a temperature of –10 °C.

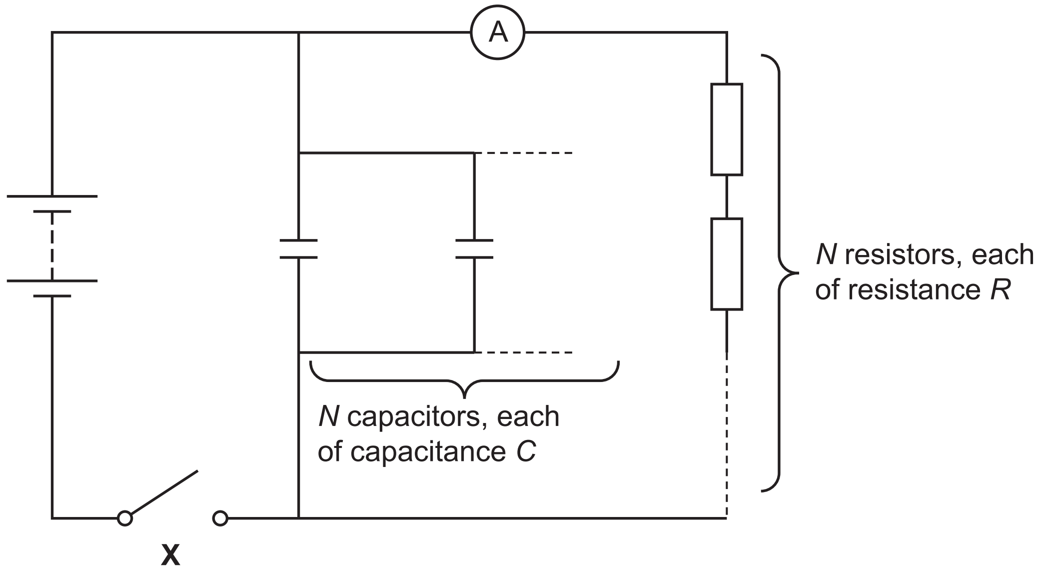
Calculate the lowest frequency that the flute could produce inside the chamber.

$$v = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{1.67 \times 8.31 \times 263}{4.0 \times 10^{-3}}} = 955.2\ \text{ms}^{-1}$$ ✓ ✓ ✓

$$f = \frac{v}{\lambda} = \frac{955.2}{1.298} = 735.9$$

frequency = 740 ✓ Hz **[4]**

2 A group of students investigate the circuit shown in the figure below.



There are N capacitors, each of capacitance C, connected in parallel.

There are N resistors, each of resistance R, connected in series.

Initially, the students close the switch **X**. They then note the reading on the ammeter.

The students then open the switch. They record the time T for the reading on the ammeter to fall to half of its initial value.

The table below shows the students' results.

N	***T*/ s**				
	1	**2**	**3**	**Mean**	Range
1	14.7	14.1	14.3	....	0.6
2	50.3	49.6	50.1	....	0.7
3	126.6	126.3	125.2	126.0	1.4
4	224.4	224.3	225.9	224.9	1.6
5	356.1	354.3	345.6	352.0	10.5
6	500.4	512.7	499.5	504.2	13.2

(a) Show that $T = (\ln 2)N^2RC$.

$I = I_0 e^{-t/RC}$

$t = T$ when $I = \frac{1}{2} I_0$

$R_T = NR$ $C_T = NC$

$\frac{1}{2} = e^{-T/NR\,NC}$

$\ln\frac{1}{2} = \frac{-T}{NRNC}$ ✓ $\ln 2 = \frac{T}{N^2RC}$ $T = \ln 2 . N^2RC$ ✓

[2]

(b) The students write in their lab books, "Our data is precise".

Evaluate this statement.

Precise means that repeat readings are close together. ✓

From the data in the table, the small values have a small range so are precise, but the larger values have a larger range so are less precise. ✓

[2]

Question 2 continues on page 6

(c) The results table is repeated below.

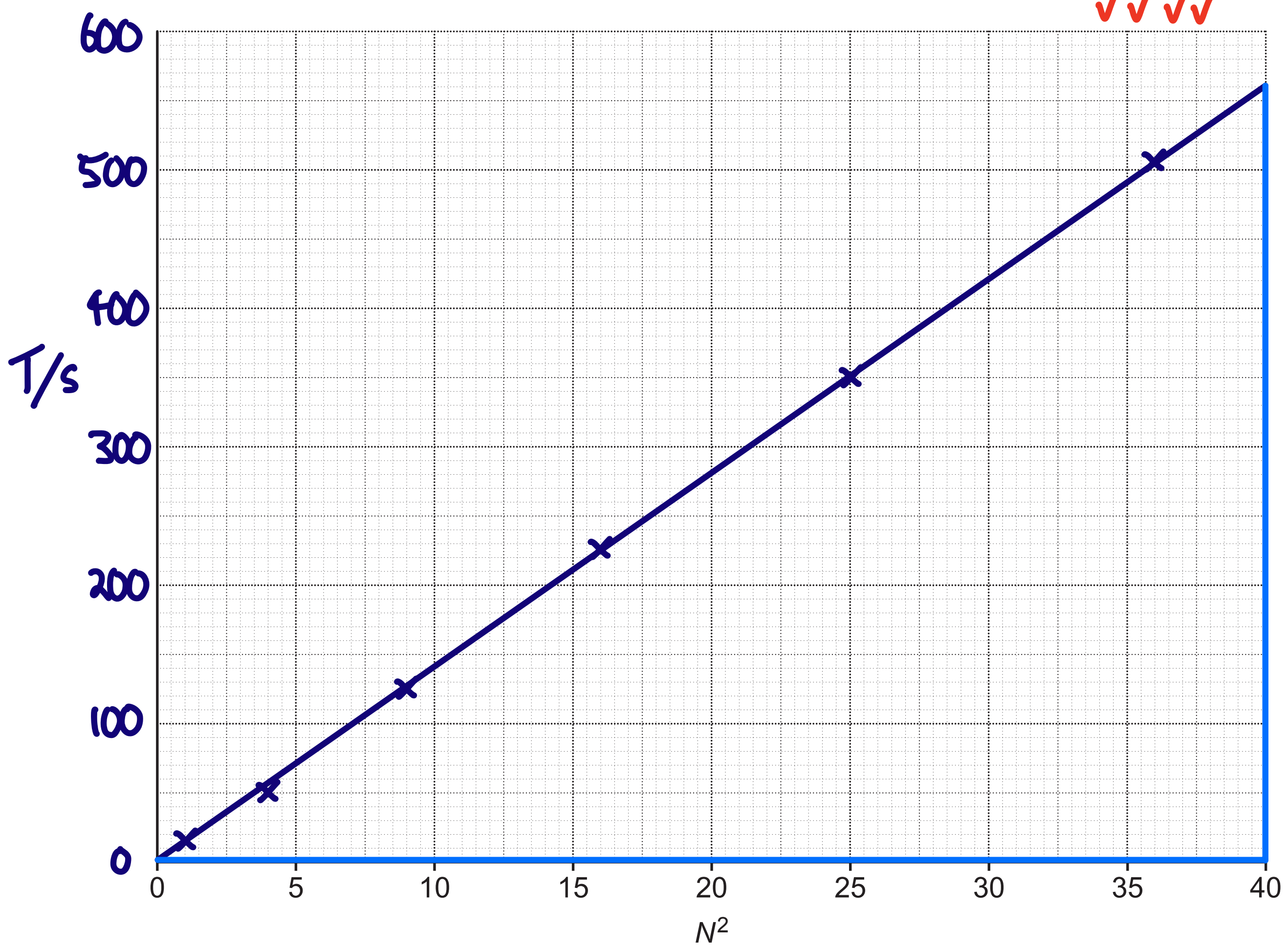
Complete the last column for $N = 1$ and $N = 2$ in the table below.

N	T / s				N^2
	1	2	3	Mean	
1	14.7	14.1	14.3	14.4	1
2	50.3	49.6	50.1	50.0	4
3	126.6	126.3	125.2	126.0	9
4	224.4	224.3	225.9	224.9	16
5	356.1	354.3	345.6	352.0	25
6	500.4	512.7	499.5	504.2	36

[1]

(d) The students begin to plot a graph of T (y-axis) against N^2 (x-axis).

(i) Complete the graph below and plot the 6 results from the table. You are **not** expected to include error bars. **[4]**



(ii) Draw a straight line of best fit on the graph. ✓ **[1]**

(iii) Calculate the gradient of the straight line of best fit.

$$\frac{\Delta y}{\Delta x} = \frac{560-0}{40-0} = 14$$ ✓

gradient = 14 ✓ s **[2]**

(iv) The value of C is known to be 1000 μF ± 5%.

Use your gradient value from **(iii)** to find a value for R, in units of kΩ, including an **absolute** uncertainty.

$T = \ln 2 . N^2 RC$

$T = \ln 2 RC . N^2$

$y = m \quad x + c$

gradient $= \ln 2\ RC$

$R = \frac{\text{gradient}}{\ln 2 . C} = \frac{14}{\ln 2 \times 1000 \times 10^{-6}}$

$R = 20{,}200\ \Omega$

$\%R = \%C = 5\%$

$0.05 \times 20{,}200 = 1010$

R = 20 ✓ ± 1 ✓ kΩ **[2]**

(e) Following the investigation, the students discovered that the sixth 1000 μF capacitor connected to the circuit was actually two 470 μF capacitors connected in parallel.

(i) State the type of error caused by this mistake.

Systematic ✓ **[1]**

(ii) Explain the effect that this error would have had on the calculated value of R.

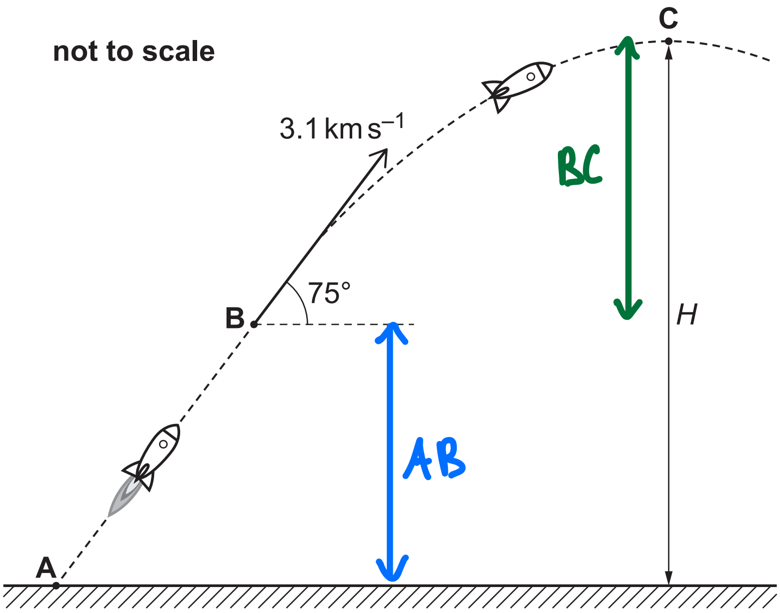
A smaller gradient ∴ smaller value for R ✓ (as the T value for N=6 is smaller).

[1]

3 A scientist uses a rocket to study the Earth's atmosphere.

The scientist launches the rocket from rest at the point **A** at $t = 0$ seconds. The force produced by the rocket's engine causes it to accelerate.

At $t = 50$ seconds, the rocket's engine no longer produce an accelerating force as all of the fuel has been used. The rocket has reached point **B**. Its velocity is now $3.1\,\text{km}\,\text{s}^{-1}$ at an angle of 75° to the horizontal.



(a) The rocket engine works by expelling hot gas backwards.

Explain, using Newton's laws of motion, how the engine causes the rocket to accelerate between $t = 0$ and $t = 50$ s.

The rocket exerts a force on the gas backwards ✓ ∴ by Newton's 3rd law the gas exerts a force on the rocket of equal magnitude.✓ If this forwards force is greater than the weight of the rocket down, the resultant force, according to Newton's 2nd law, will cause it to accelerate. ✓ **[3]**

***(b)** The rocket reaches its maximum height at point **C**.

- Estimate the vertical displacement H between **A** and **C**. Assume that $g = 9.81\,\mathrm{m\,s^{-2}}$ throughout.
- Clearly state any other assumptions required at each stage in your calculations.
- Evaluate the assumption that $g = 9.81\,\mathrm{m\,s^{-2}}$ between **A** and **C**, supporting your discussion with a calculation. Assume that the radius of the Earth ≈ 6400 km.

AB : Vertical direction, assume constant acceleration ✓

$s = ?$

$u = 0\ \mathrm{ms^{-1}}$ $\qquad s = \frac{1}{2}(u+v)t$

$v = 3100 \sin 75^\circ\ \mathrm{ms^{-1}}$ $\qquad s = \frac{1}{2} \times 3100 \sin 75 \times 50$ ✓

a

$t = 50\mathrm{s}$ $\qquad s_{AB} = 7.486 \times 10^4\ \mathrm{m}$

BC : Assume no air resistance ✓

$s = ?$ $\qquad v^2 = u^2 + 2as$

$u = 3100 \sin 75\ \mathrm{ms^{-1}}$ $\qquad s = (v^2 - u^2)/2a$

$v = 0$ $\qquad s = \dfrac{0^2 - (3100 \sin 75)^2}{2 \times -9.81}$

$a = -9.81\ \mathrm{ms^{-2}}$

t $\qquad s_{BC} = 4.570 \times 10^5\ \mathrm{m}$

Additional answer space if required

Total height $= 7.486 \times 10^4 + 4.570 \times 10^5 = 5.3 \times 10^5\ \mathrm{m}$ ✓

$g = \dfrac{-GM}{r^2}$ $\qquad g r^2 = k$ $\qquad g_A r_A^2 = g_C r_C^2$

$g_C = g_A \cdot \dfrac{r_A^2}{r_C^2} = 9.81 \times \dfrac{6400^2}{(6400 + 532)^2} = 8.4\ \mathrm{ms^{-2}}$ ✓

At a height of 5.3×10^5 m, g decreases to a smaller value than 9.81, so H could be larger than the calculated value as g not constant ✓

[6]

4 The length of an unloaded spring is approximately 4 cm.

The force constant k of the spring is $0.62\,N\,cm^{-1}$.

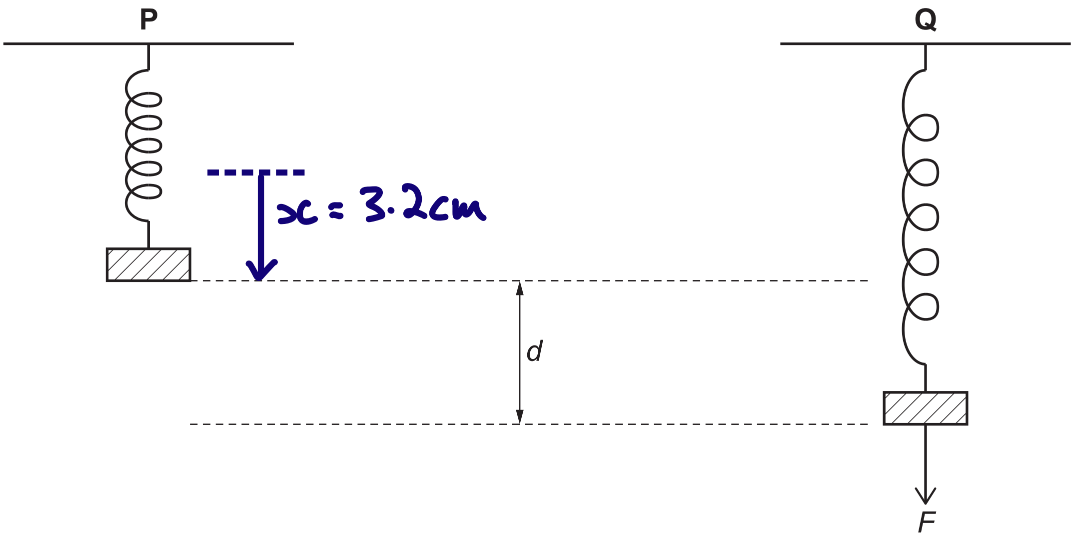
(a) Describe how you could determine k using an appropriate experiment.

Add masses to a spring. The length of the spring measured with a ruler, with the extension calculated from the final length – initial length. ✓ Force on spring determined from W = mg. ✓ Plot force on the y-axis and extension on the x-axis. Gradient of the straight line equal to spring constant. ✓ **[3]**

(b) The figure below shows a block of mass 0.20 kg attached to one end of the spring. The other end of the spring is attached to a fixed support vertically above the block.

In position **P** the block rests in equilibrium. The extension of the spring is 3.2 cm.

In position **Q** a downwards force F has been applied to the block, so that it now rests a distance d below its position at **P**. The extension of the spring is now 8.5 cm.



The force F is removed.

(i) Calculate the magnitude of the block's initial acceleration at the instant that the force F is removed.

Assume that the spring is not extended beyond its limit of proportionality.

$k = \frac{F}{x} = \frac{9.81 \times 0.20}{0.032} = 61.3125\ \text{Nm}^{-1}$ ✓ $\quad d = 8.5 - 3.2 = 5.3\ \text{cm}$

$F = kd \quad F = ma \quad a = \frac{kd}{m}$ ✓ $= \frac{61.31 \times 0.053}{0.20} = 16.2$

acceleration = 16 ✓ .... m s^{-2} **[3]**

(ii) The block now moves with simple harmonic motion.

Calculate the frequency of this motion.

$a = -\omega^2 x \quad \omega = \sqrt{\frac{a}{x}} = \sqrt{\frac{16.2}{0.053}} = 17.5\ \text{s}^{-1}$ ✓

$\omega = 2\pi f$ ✓ $\quad f = \frac{\omega}{2\pi} = \frac{17.5}{2\pi} = 2.79$

frequency = 2.8 ✓ .... Hz **[3]**

(c) The block is replaced by a strong magnet **L** of slightly greater mass.

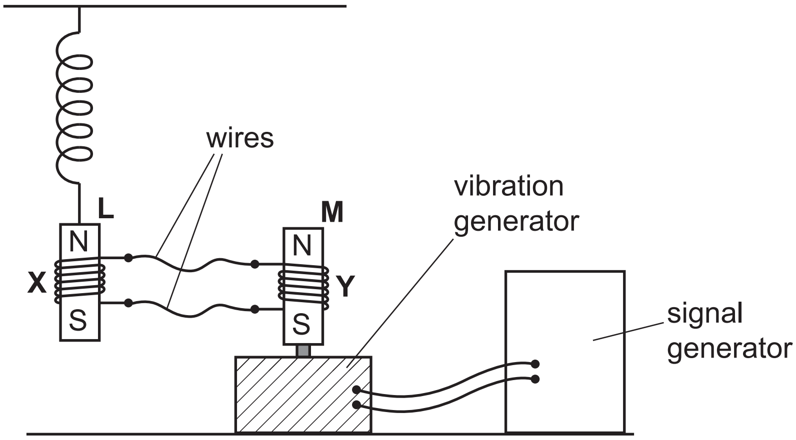
The oscillation frequency of this new arrangement is 2.5 Hz.

The magnet **L** is placed inside a coil **X** of insulated copper wire.

The coil **X** is connected with long wires to a second, identical coil **Y**.

A second strong magnet **M** is placed inside **Y** and attached to a vibration generator.

The vibration generator is then forced to oscillate with a frequency of approximately 2.5 Hz by adjusting the signal generator.



(i) As magnet **M** oscillates, it moves in and out of coil **Y**.

The magnet **L** also begins to oscillate.

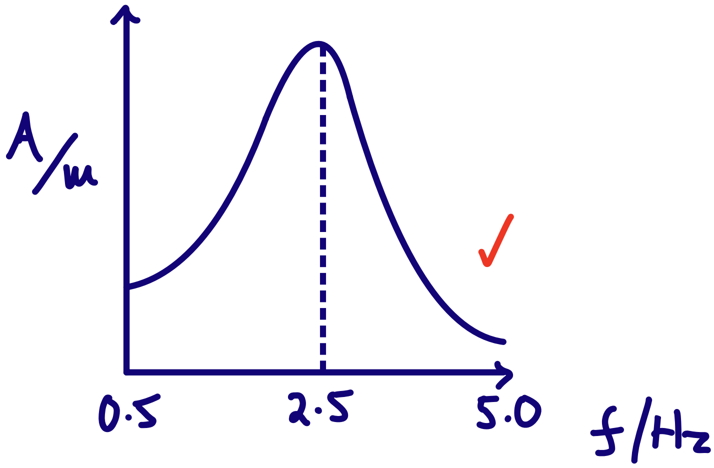
Explain why **L** oscillates.

The oscillations of M cause a change of flux linkage in coil Y ✓, inducing an emf ∴ producing a current in Y and ∴ in X ✓. This alternating current produces a changing magnetic field that interacts with the magnetic field around magnet L. ✓ **[3]**

(ii) The frequency of the vibration generator is now varied between 0.5 Hz and 5.0 Hz.

Suggest how the amplitude and frequency of the oscillations of **L** will change as the frequency of the generator is varied.

You may draw a diagram to support your answer.



The frequency of L is equal to the driving frequency of the vibration generator.

Resonance occurs at 2.5 Hz, at which point the amplitude is a maximum value. **[3]**

5

(a) Explain what is meant by

(i) internal resistance of a cell

Resistance as charge carriers pass through the cell. ✓

.... **[1]**

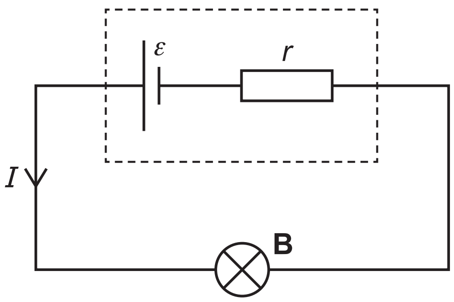
(ii) e.m.f. of a cell.

Energy transferred per unit charge to charge carriers by the cell. ✓

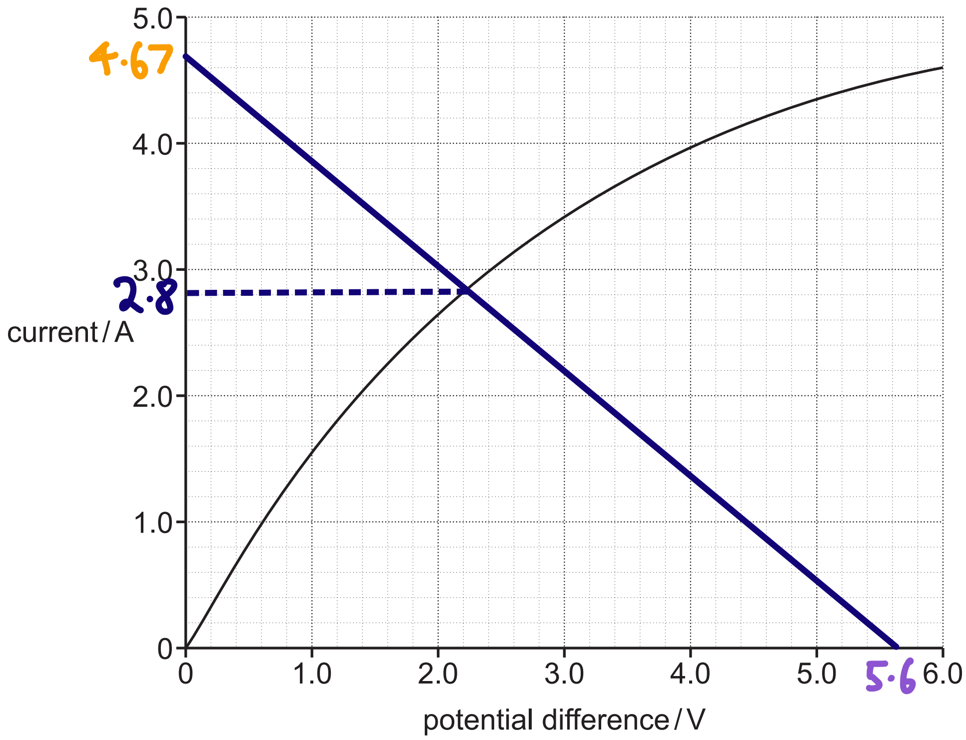
.... **[1]**

(b) A cell has internal resistance r = 1.2 Ω and e.m.f. ε = 5.6 V.

When the cell is connected to a filament lamp **B**, as shown in the circuit diagram below, the current in the circuit is I.



The I-V characteristic for **B** is shown in the figure below.



Determine the current I in the circuit.

$E = V + Ir$

$Ir = -V + E$

$I = -\frac{1}{r}V + \frac{E}{r}$ ✓

$y = mx + c$

$I = -\frac{1}{1.2}V + \frac{5.6}{1.2}$

$I = -0.833V + 4.67$ ✓

Draw this on the graph

$I = 0$, $V = 4.67/0.833 = 5.60$

Read off at 2.8 A

current = 2.8 ✓ A **[3]**

Question 5 continues on page 16

***(c)** A student wants to determine the internal resistance *r* and the e.m.f. ε of a different cell.

The student knows that the internal resistance is approximately 0.1 Ω.

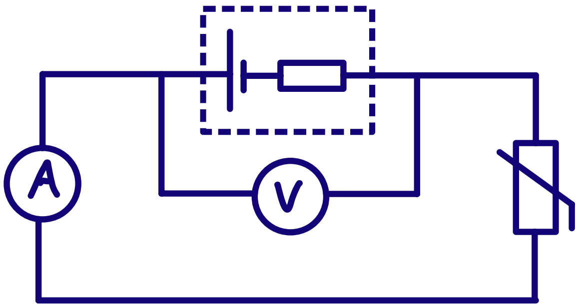
The only other **electrical** equipment available is as follows:

- one voltmeter
- one ammeter
- one sensitive thermistor, known to have resistance of approximately 0.1 Ω at 20 °C
- several connecting wires and crocodile clips.

Describe how the student can determine *r* and ε for the cell.

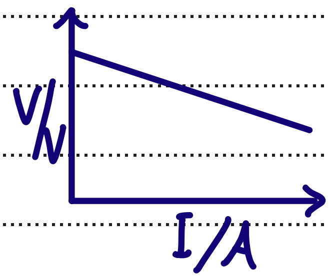
Include how the student should:

- collect and analyse the data
- determine the uncertainties in the values of *r* and ε.



Connect up the circuit shown above, with the voltmeter across the terminals, and the ammeter in series with the thermistor.
Put the thermistor in a water bath at 5°C increments measured with a thermometer. This will change its resistance. Record values for I and V for at least 7 temperatures of water and repeat.

Plot a graph of V against I



$V = -rI + E$ ∴ Read of y-intercept to find E.

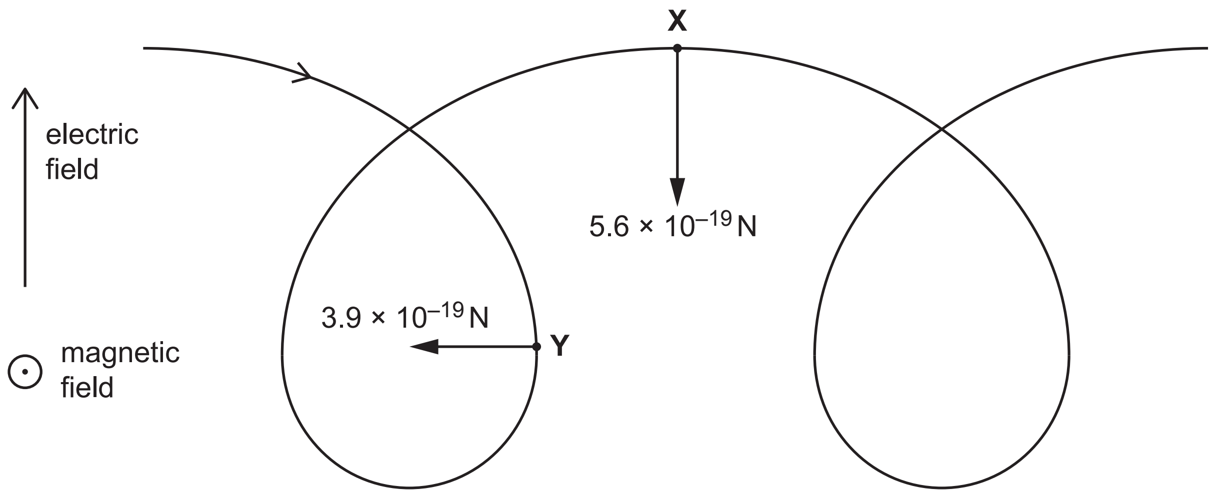
Calculate the gradient, multiply by -1 to find r. ✓

Additional answer space if required

The absolute uncertainty in the voltmeter and ammeter is used to draw error bars on the graph.
The worst acceptable line of best fit is drawn. ✓
The value for this y-intercept is used to calculate the percentage uncertainty in the intercept = percentage uncertainty in E.
The percentage uncertainty in the gradient = percentage uncertainty in r. ✓ **[6]**

6 The figure below shows the path of a proton moving in a region occupied by both an electric field and a magnetic field.

The direction of the electric field lines is perpendicular to the direction of the magnetic field lines.



The uniform electric field is directed upwards, with electric field strength $E = 0.90\,\mathrm{N\,C^{-1}}$.

The uniform magnetic field is directed out of the plane of the paper, with magnetic flux density $B = 5.0 \times 10^{-5}\,\mathrm{T}$.

At point **X** the proton is moving horizontally to the right. The magnitude of the **magnetic** force at **X** is $5.6 \times 10^{-19}\,\mathrm{N}$.

At point **Y** the proton is moving vertically downwards. The magnitude of the **magnetic** force at **Y** is $3.9 \times 10^{-19}\,\mathrm{N}$.

The **electric** forces acting on the proton at **X** and **Y** are **not** shown in the figure.

(a) Show that the magnitude of the constant **electric** force acting on the proton is about $10^{-19}\,\mathrm{N}$.

$F = EQ = 0.90 \times 1.60 \times 10^{-19} = 1.44 \times 10^{-19}\,\mathrm{N} \approx 1 \times 10^{-19}$ ✓

[1]

(b)
(i) Suggest why the **magnetic** force acting on the proton has a different magnitude at **X** than at **Y**.

$F = BQv \;\therefore\; F \propto v$

The velocity is different at X to Y. ✓

[1]

(ii) At **X**, the motion of the proton is instantaneously equivalent to motion in a circle at a constant speed.

Calculate the radius of this circular motion.

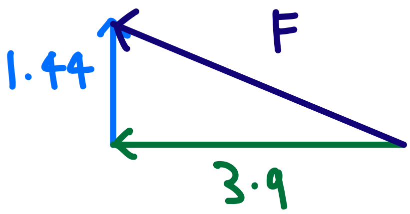
$F = BQv \quad v = \frac{F}{BQ} = \frac{5.6\times10^{-19}}{5.0\times10^{-5}\times1.60\times10^{-19}} = 7.0\times10^{4}\ ms^{-1}$ ✓

$F = \frac{mv^2}{r} \quad r = \frac{mv^2}{F}$ ✓ $= \frac{1.673\times10^{-27}\times(7.0\times10^{4})^2}{4.16\times10^{-19}} = 19.7$

$F = F_B - F_E = 5.6\times10^{-19} - 1.44\times10^{-19}$ ✓

radius = 20 ✓ .... m **[4]**

(iii) 1 Calculate the magnitude of the resultant force on the proton at **Y**.



$F = \sqrt{1.44^2 + 3.9^2}$ ✓

$F = 4.16$

resultant force = 4.2×10^{-19} ✓ .... N **[2]**

2 Explain why the motion of the proton at **Y** is **not** instantaneously equivalent to motion in a circle at a constant speed.

Because the resultant force on the proton is not perpendicular to its velocity, ✓ this force does work on the proton changing its kinetic energy and therefore speed. ✓ **[2]**

END OF QUESTION PAPER

EXTRA ANSWER SPACE

If you need extra space use this lined page. You must write the question numbers clearly in the margin.