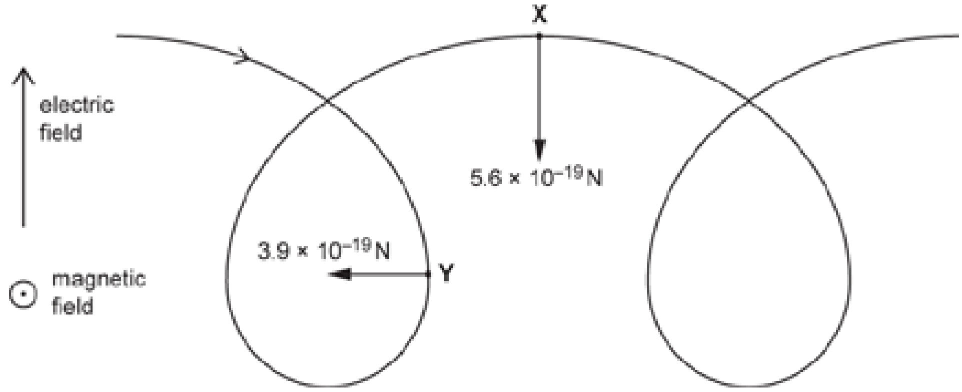
1(a). The figure below shows the path of a proton moving in a region occupied by both an electric field and a magnetic field.

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 $E = 0.90$ N C^{-1}.

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

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

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

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

Show that the magnitude of the constant **electric** force acting on the proton is about 10^{-19} N.

[1]

(b).

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

radius = ... m **[4]**

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

resultant force = ... 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.

[2]

2(a). This question is about lightning.

Sheet lightning occurs when there is an electrical discharge between the upper and lower regions of a thunder cloud.
The upper regions are positive and the lower regions are negative.

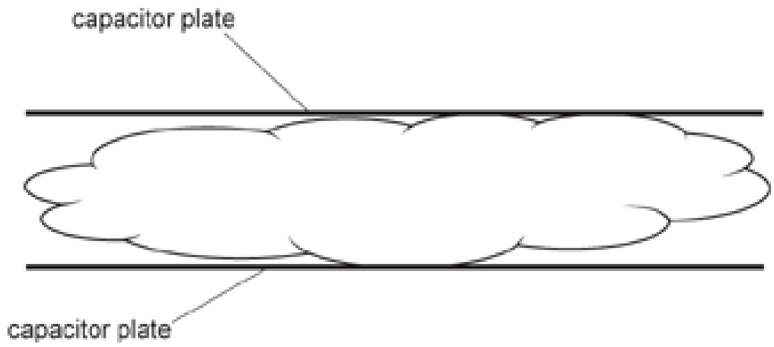
The thunder cloud can be modelled as an ideal parallel plate capacitor with circular horizontal plates.

The data for the capacitor comes from the cloud.

Diameter of cloud	24 km
Distance between upper and lower regions	3.2 km
Electric field strength between the regions	4.0×10^5 V m^{-1}

i. The diagram shows the plates of the model capacitor superimposed on the cloud.

Draw on the diagram to show the electric field lines between capacitor plates.



[2]

ii. Suggest why the actual electric field lines of the cloud would differ from what you have drawn.

[1]

iii. Show that the potential difference (p.d.) V between the plates is about 1×10^9 V.

[1]

iv. Calculate the capacitance C of the model capacitor.

Assume the permittivity of the material of the cloud is the same as the permittivity of free space.

C = ... F **[2]**

v. Calculate the magnitude of the charge Q on one of the plates of the model capacitor.

Q = ... C **[2]**

(b). Fork lightning is an electrical discharge that occurs between the bottom of the cloud and the surface of the Earth.

A cloud has a charge of 155 C and is at a height of 2.0 km.

The surface of the Earth has an electrical potential V of 0 V.

i. Assume the cloud acts as a **point** charge.

Calculate the magnitude of the electrical potential V between the cloud and the surface of the Earth.

V = ... V **[2]**

ii. A fork lightning strike has a duration of 25 ms. The cloud discharges at a constant rate. The cloud is uncharged after the strike.

Calculate the number of electrons reaching the ground in 1.0 ms.

number of electrons in 1.0 ms = ... **[3]**

3. In the Rutherford scattering experiment alpha particles are directed at a gold foil.

Gold nuclei have 79 protons. The distance of closest approach is 47.0 fm.

Which is the best estimate of the work done on an alpha particle as it moves from 53.0 fm to the point of closest approach?

A 10^{-18} J
B 10^{-16} J
C 10^{-15} J
D 10^{-13} J

Your answer ☐ **[1]**

4. The centres of a positron and a helium nucleus are separated by 2 mm.

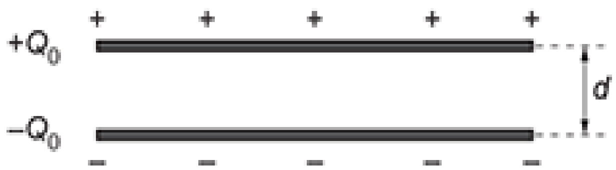
What is the electrostatic force between them?

A 1.15×10^{-28} N
B 2.30×10^{-25} N
C 5.75×10^{-23} N
D 1.15×10^{-22} N

Your answer ☐ **[1]**

5(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 2d.
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

capacitance = ... C_0 **[1]**

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

p.d. = ... V_0 **[1]**

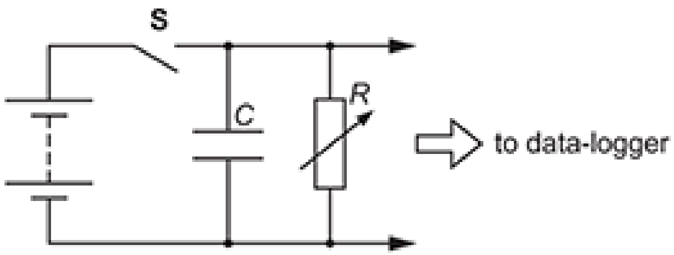
3 energy stored in terms of E_0.

energy = ... E_0 **[1]**

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

[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.

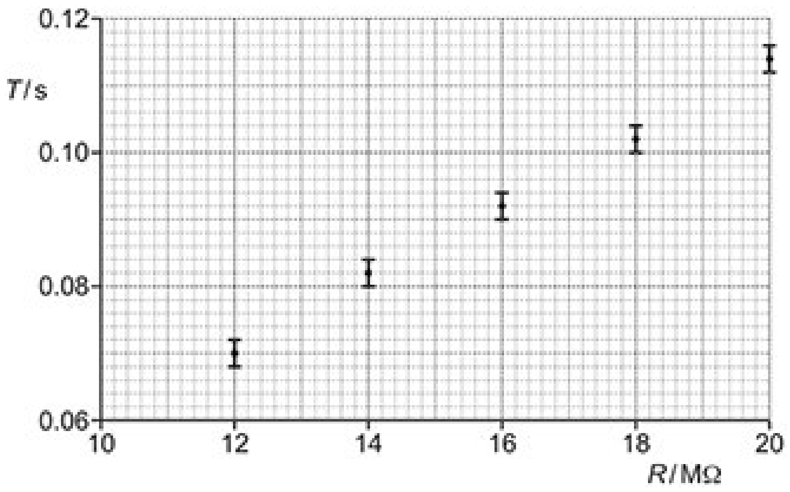
The capacitor is charged fully by closing switch **S**. At time $t = 0$, **S** is opened and the capacitor discharges through the resistor. After $t = T$, the potential difference across the capacitor is halved. The student repeats this for several values of R.

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

Show that the line has gradient = C ln2.

[2]

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



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

1

C = ... F **[3]**

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

2

ε = ... F m^{-1} **[2]**

6(a). The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

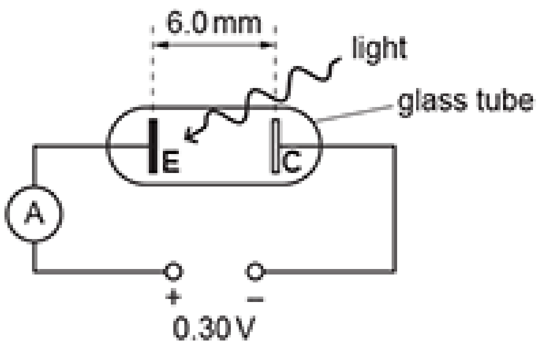


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

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.

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 8.8×10^{12} ms^{-2}.

[3]

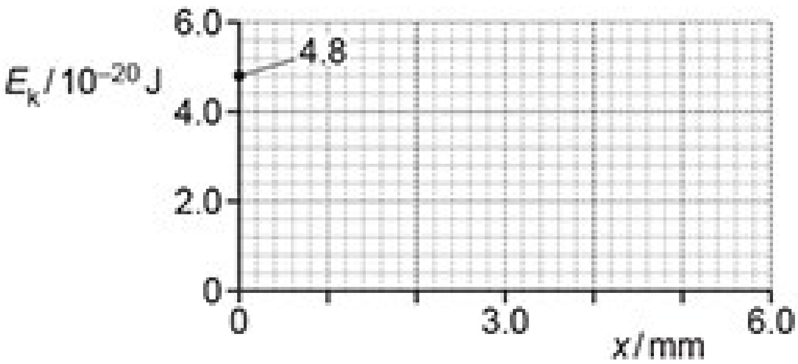
ii. Show that the initial speed of the photoelectron is about 3×10^{5} ms^{-1}.

[2]

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

t = ... s **[2]**

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



[2]

(b). 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**.

[2]

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7. 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.
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 ☐ **[1]**

END OF QUESTION PAPER