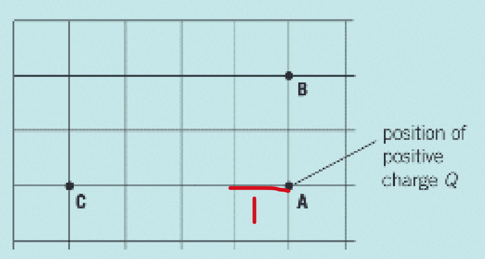
1, 2, 5

Practice questions

1 a Define *electric field strength* at a point in space. *(1 mark)*

b Figure 1 shows an evenly spaced grid.



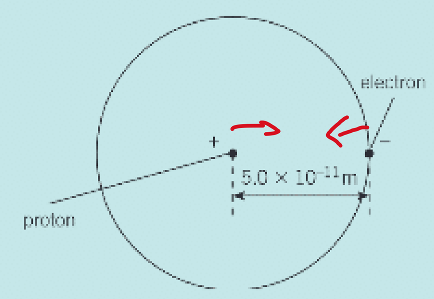
▲ Figure 1

A, **B**, and **C** are points on a grid. A positive charge Q is placed on the grid at point **A**. The magnitude of the electric field strength at point **B** due to the charge Q is $8.0 \times 10^5\,NC^{-1}$.

(i) Apart from the magnitude of the electric field strengths, state another difference between the electric field at points **B** and **C**. *(1 mark)*

(ii) Determine the magnitude of the electric field strength at point **C**. *(2 marks)*

c The simplest atom is that of hydrogen with one proton and one electron, see Figure 2.



▲ Figure 2

The mean separation between the proton and the electron is shown in Figure 2.

(i) Calculate the magnitude of the electrical force F_E acting on the electron. *(3 marks)*

(ii) The gravitational force F_G acting on the electron due to the proton is very small compared with the electrical force F_E it experiences.

Calculate the ratio $\frac{F_E}{F_G}$. *(2 marks)*

(iii) A simplified model of the hydrogen atom suggests that the de Broglie wavelength of the electron is four times the mean separation between the proton and the electron shown in Figure 2.

Estimate

1 the momentum p of the electron *(3 marks)*

2 the kinetic energy E_k of the electron. *(3 marks)*

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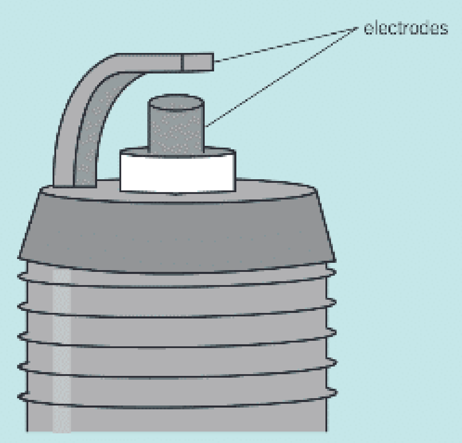
2 Figure 3 shows a close-up of the two electrodes of a spark plug.



▲ Figure 3

The electrodes may be considered as two parallel plates. The electric field strength between the electrodes is almost uniform.

a Define electric field strength. *(1 mark)*

b The separation between the electrodes is 1.3 mm. An electric spark is produced when the electric field strength is $3.0 \times 10^6\,Vm^{-1}$.

(i) Estimate the potential difference V between the electrodes when the spark is produced. *(2 marks)*

(ii) The electric spark lasts for 4.0×10^{-2} s and produces an average current of 2.7×10^{-9} A.

1 Calculate the charge transferred between the electrodes. *(2 marks)*

2 Calculate the number of electrons transferred between the electrodes. *(1 mark)*

(iii) Estimate the total energy transferred by the electrons in **(ii)**. *(2 marks)*

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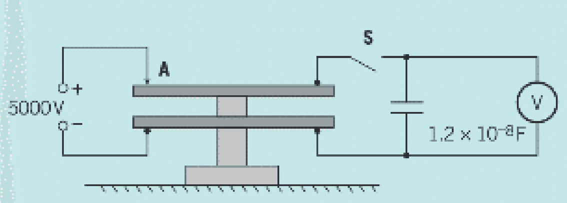
3 Figure 4 shows two parallel metal plates which act as a capacitor supported above a bench on an insulating rod which passes through the centre of each plate.



▲ Figure 4

a The capacitor is charged by touching the upper plate momentarily with a wire **A** connected to the positive terminal of a 5000 V power supply. The capacitance C of the plates is 1.2×10^{-11} F. Calculate the charge Q_0 on the plates. Give a suitable unit for your answer. *(3 marks)*

b The charge on the plates leaks away slowly through the insulating rod, which has an effective resistance R of $1.2 \times 10^{15}\,\Omega$.

(i) Show that the time constant for the plates to discharge through the rod is about 1.5×10^4 s. *(1 mark)*

(ii) Show that the initial value of the leakage current is about 4×10^{-12} A. *(1 mark)*

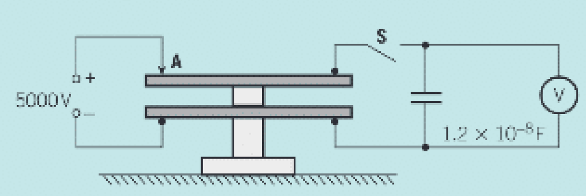
(iii) Suppose that the plates continue to discharge at the constant rate calculated in **(ii)**. Show that the charge Q_0 would leak away in a time equal to the time constant. *(2 marks)*

(iv) Using the equation for the charge Q at time t

$Q = Q_0 e^{-\frac{t}{RC}}$

Show that, in practice, the plates only lose about $\frac{2}{3}$ of their charge in a time equal to one time constant. *(2 marks)*

c The plates are recharged to 5000 V by touching the upper plate momentarily with wire **A**. Switch **S** is then closed so that the plates are connected in parallel to an uncharged capacitor of capacitance 1.2×10^{-8} F and a voltmeter as shown in Figure 5.



▲ Figure 5

(i) The charged and the uncharged capacitor act as two capacitors in parallel. The total charge Q_0 is shared instantly between the two capacitors. Explain why the charge left on the plates is $\frac{Q_0}{1000}$. *(3 marks)*

(ii) Hence or otherwise calculate the initial reading V on the voltmeter. *(2 marks)*

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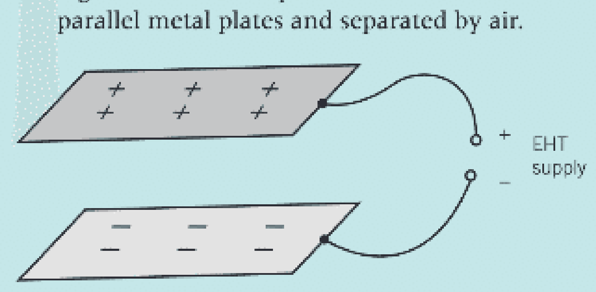
4 Figure 6 shows a capacitor made from two parallel metal plates and separated by air.



▲ Figure 6

a On a copy of Figure 6, draw electric field lines to show the electric field pattern between the plates. *(2 marks)*

b The separation between the capacitor plates is 2.0 cm and each plate has a surface area of 81 cm². The plates are connected to a 4.0 kV supply. A student disconnects the supply from and measures the charge stored on one of the plates using a coulombmeter. The reading on the coulombmeter is 14.0 ± 0.5 nC.

(i) Calculate the permittivity of free space ε_0 from these results. Include the absolute uncertainty in your answer. *(5 marks)*

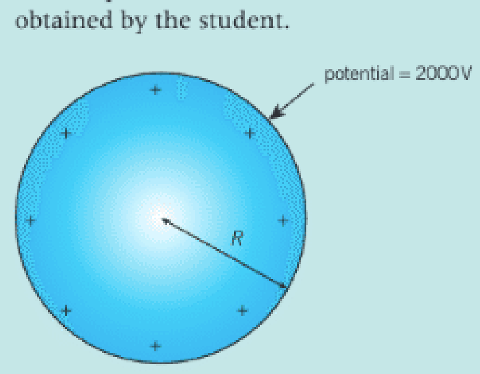
(ii) Discuss whether or not the value of ε_0 in **(b)(i)** is accurate. *(2 marks)*

c Qualitatively explain the effect on the charge stored by the capacitor in **(b)** when a thick sheet of plastic is inserted in the space between the capacitor plates. *(2 marks)*

5 a Define *electric potential* at a point in space around a charged object. *(1 mark)*

b An isolated metal sphere is charged using a high-voltage supply. Discuss the factors that affect the charge stored on the surface of the sphere. *(2 marks)*

c A student is investigating the charge Q stored by a metal sphere of radius r. The sphere is always charged to a potential of 2.0 kV, see Figure 7. A coulombmeter is used to determine the charge stored on the sphere. Table 1 shows the results obtained by the student.



▲ Figure 7

▼ Table 1

r / cm	Q / 10^{-9} C
5.0	11.0
7.3	16.1
9.1	20.0
11.6	25.5
15.0	33.0

(i) Plot a graph of Q against r and draw a line of best fit. *(3 marks)*

(ii) Use your graph to determine the permittivity of free space. *(4 marks)*

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1 a) ~~The force experienced per unit positive charge within a field~~ NC^{-1}

b) i) The direction in which a positive charge would move from these points

ii) $\boxed{E = \frac{kQ}{r^2}} = \frac{Q}{4\pi\varepsilon_0 r^2}$

$\rightarrow E = \frac{8.99 \times 10^9 \times \cancel{8 \times 10^5}}{}$ Q

$\boxed{E \propto \frac{1}{r^2}}$

$E = \frac{m}{r^2}$

$Er^2 = m$

$8 \times 10^5 \times 2^2 = E_c \times 4^2$

$2 \times 10^5\,NC^{-1} = E_e$

c) i) $F = Eq$ ✓

$\boxed{F = \frac{kQq}{r^2}}$

$F = \frac{(8.99 \times 10^9)(1.6 \times 10^{-19})^2}{(5 \times 10^{-11})^2}$

$F = 9.2 \times 10^{-8}\,N$

ii) $F_g = \frac{GMm}{r^2}$

$F_g = \frac{(6.67 \times 10^{-11})(1.67 \times 10^{-27})(9.11 \times 10^{-31})}{(5 \times 10^{-11})^2}$

$F_g = 4 \times 10^{-47}\,N$

$\frac{9.2 \times 10^{-8}}{4 \times 10^{-47}} = 2.3 \times 10^{39}$

iii) 1) $4 \times 5 \times 10^{-11} = 2 \times 10^{-10}$

$E = hf$

$2 \times 10^{-10} = \frac{h}{p}$

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

$\frac{6.63 \times 10^{-34}}{2 \times 10^{-10}} = p$

$\lambda \propto \frac{1}{p}$

$p = 3.32 \times 10^{-24}\,kgms^{-1}$

2) $Ke = \frac{1}{2}mv^2$

$v = \frac{3.32 \times 10^{-24}}{9.11 \times 10^{-31}} = 3.64 \times 10^6$

$= \frac{1}{2}(9.11 \times 10^{-31})(3.64 \times 10^6)^2$

$= 6 \times 10^{-18}\,J$

2 a) The force experienced per unit positive charge within a field

b) i) $E = \frac{V}{d}$

$E = \frac{V}{d}$

$\cancel{E = \frac{3 \times 10^6}{1.3 \times 10^{-3}}}$

$V = Ed$

$E = \cancel{2.3 \times 10^9}\,V$ $V = 3{,}900$ ✓

ii) 1) $Q = I \times t$

$Q = 2.7 \times 10^{-9} \times 4 \times 10^{-2}$

$Q = 1.08 \times 10^{-10}\,C$

2) $\frac{1.08 \times 10^{-10}}{1.6 \times 10^{-19}} = 6.75 \times 10^8$ electrons

iii) $V = \frac{W}{Q}$

$3900 = \frac{W}{1.08 \times 10^{-10}}$

$W = 4.21 \times 10^{-7}\,J$