Solutions to past paper questions on Syllabus dot point 9.4.1

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2001 Exam

Question 2

A. Using the right hand rule.

2002 Exam

Question 13

C. The electrons are deflected up towards the positive plate.

Question 25

(a)

$$\begin{aligned} E &= \frac{V}{d} \\ &= \frac{1000\,\mathrm{V}}{5 \times 10^{-3}\,\mathrm{m}} \\ &= 2 \times 10^{5}\,\mathrm{Vm}^{-1} \end{aligned}$$

(b)

$$\begin{aligned} F &= |q|\,E \\ &= \left|-1.6 \times 10^{-19}\,\mathrm{C}\right| \times 2 \times 10^{5}\,\mathrm{Vm}^{-1} \\ &= 3.2 \times 10^{-14}\,\mathrm{N} \end{aligned}$$

(c)

Notes: As the electric field deflects the electrons up, the magnetic field should apply a force to cancel this. By the right hand rule (and taking into account that the electrons have a negative charge) this means the magnetic field should be into the page.

Answer:

$$\begin{aligned} \sum F &= 0 \\ qE - qvB &= 0 \\ B &= \frac{E}{v} \\ &= \frac{2 \times 10^5 \,\text{Vm}^{-1}}{3 \times 10^6 \,\text{ms}^{-1}} \\ &= 6.67 \times 10^{-2}\,\text{T} \end{aligned}$$

$\vec{B} = 6.67 \times 10^{-2}\,\text{T}$ into the page.

2003 Exam

Question 12

D. The maltese cross casts a shadow at the end of the cathode ray tube, demonstrating that cathode rays (electrons in a vacuum) move in straight lines.

Question 24

Notes: Thomson performed two separate experiments to determine the ratio $\frac{e}{m}$ (a copy of his original paper can be found here). The more straightforward to describe for our purposes in the HSC consisted of two steps, which must both be discussed for full marks. The markers preferred answers which utilised equations and clear diagrams. Below is a diagram taken from the book "Flash of the Cathode rays" by Per F. Dahl (IOP publishing, 1997) that can be used, however note that a pair of coils (not shown) were also mounted either side of the parallel plates to produce the magnetic field used in the experiment.

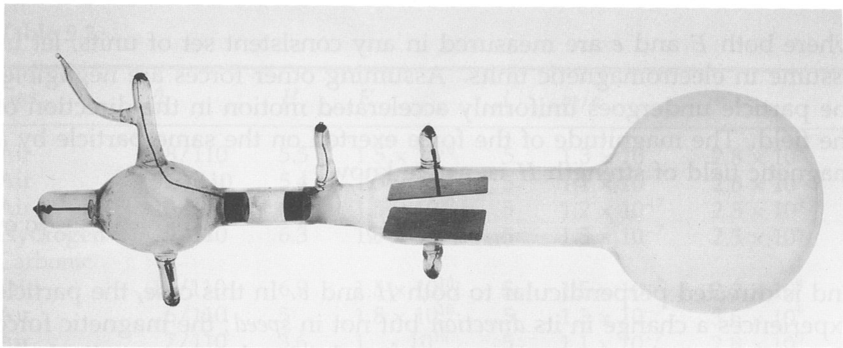


Figure 9.6. *Thomson's e/m tube of October 1897, employing crossed electric and magnetic fields.*

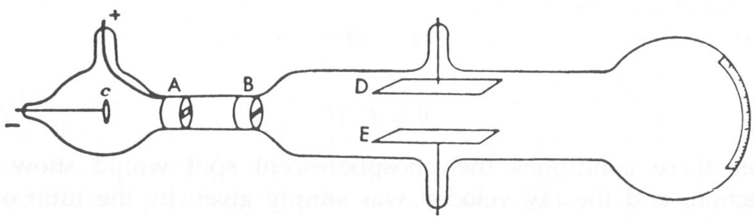


Figure 9.7. *A schematic rendering of Thomson's crossed-field tube of October 1897. The slotted plug A is the anode, c is the cathode, and D and E are the electric deflection plates.*

Answer:
Thomson's experiment consisted of two steps.

1. Determing the velocity of the rays using equal and opposite electric and magnetic forces to produce zero deflection of the beam. Then as , $qvB = qE$, we have $v = \frac{E}{B}$.

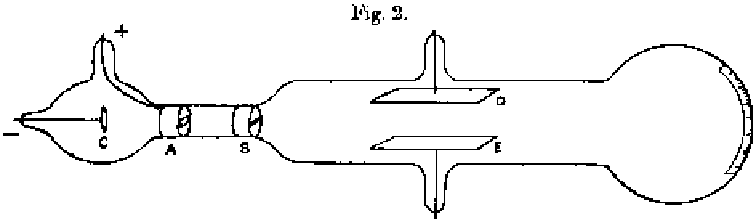
2. Secondly, the radius of curvature of the beam under the influence of

the magnetic field alone was used to determine $\frac{q}{m}$ via:

$$\begin{aligned} qvB &= \frac{mv^2}{r} \\ \frac{q}{m} &= \frac{v}{Br} \\ &= \frac{E}{B^2 r} \end{aligned}$$

(substituting in the result for velocity we obtained in the first step). Fig. 2 below is a sketch of the apparatus (note that there were also two coils either side of the parallel plates to produce the magnetic field).

Fig. 2.



Question 27

Notes: This question is not ideally worded. As a magnetic field always produces a force which is perpendicular to the direction of the velocity of the charge it can only change the direction a charge is moving, but not its speed. It can never therefore be used to 'accelerate an electron to near the speed of light'. Rather, in a particle accelerator, electric fields are used to accelerate the electron by changing its speed, while magnetic fields are used to guide the particle around the desired path.

Answer:

In a particle accelerator magnetic fields provide the centripetal force required to guide charges along a desired path. For $|v| \ll c$ the magnitude or the required B field is

$$\begin{aligned} |q|\, vB &= \frac{m_e v^2}{r} \\ B &= \frac{m_0 v}{|q|\, r} \end{aligned}$$

where m_0 is the rest mass of an electron. At speeds which are a significant fraction of c, then mass dilation must be accounted for in determining the required magnitude of the magnetic field

$$B = \frac{m_v v}{|q|\, r}$$

where

$$m_v = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

2004 Exam

Question 12

B. The varying patterns are obtained at different gas pressures.

2005 Exam

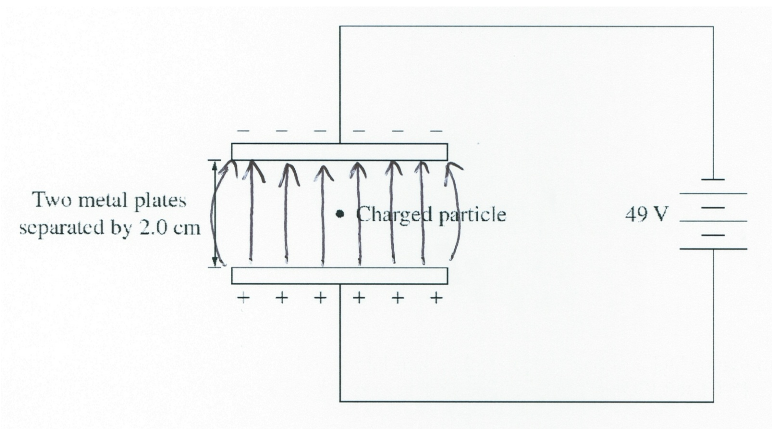
Question 11

The answer given in the markers notes for this question is B.

Notes: The momentum of the electrons is insufficient to rotate the paddle wheel in this piece of apparatus. Thomson was able to demonstrate that the wheel actually turns as a result of the radiometric effect ("Flash of the cathode rays", Per. F. Dahl, IOP publishing, 1997, pg. 73), with electrons rather than light rays providing the source of heat. Nonetheless, it is sometimes stated that the rotation of the paddle wheel demonstrates that cathode rays carry momentum and this experiment is thus cited as evidence in favour of the particle hypothesis. The markers at the board of studies seem to be seeking this answer.

Question 26

(a)



(b)

$$\begin{aligned} E &= \frac{\Delta V}{d} \\ &= \frac{49\,\mathrm{V}}{0.02\,\mathrm{m}} \\ &= 0.245\,\mathrm{Vm^{-1}} \\ &= 0.25\,\mathrm{Vm^{-1}}\,(2\,\mathrm{s.f.}) \end{aligned}$$

(c)

Let up be the +ve direction. Then if $a = 0$

$$\begin{aligned} \sum \vec{F} &= 0 \\ q\vec{E} + m\vec{g} &= 0 \\ q &= -\frac{(-9.8\,\mathrm{ms^{-2}}) \times (9.6 \times 10^{-6}\,\mathrm{kg})}{0.245\,\mathrm{Vm^{-1}}} \\ &= 3.84 \times 10^{-4}\,\mathrm{C} \\ &= 3.8 \times 10^{-4}\,\mathrm{C}\,(2\,\mathrm{s.f.}) \end{aligned}$$

q is a positive charge with magnitude 3.8×10^{-4} C.

Question 27

(a)

$$\begin{aligned} \frac{mv^2}{r} &= |q|\,vB \\ mv &= |q|\,rB \\ p &= |q|\,rB \end{aligned}$$

(b)

$$\begin{aligned} m &= \frac{|q|\,rB}{v} \\ &= \frac{(1.602 \times 10^{-19}\,\mathrm{C}) \times (0.350\,\mathrm{m}) \times (1.82\,\mathrm{T})}{(6.0 \times 10^{7}\,\mathrm{ms^{-1}})} \\ &= 1.701 \times 10^{-27}\,\mathrm{kg} \\ &= 1.7 \times 10^{-27}\,\mathrm{kg}\,(2\,\mathrm{s.f.}) \end{aligned}$$

(c)

$$\begin{aligned}
m_v &= \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} \\
m_0 &= m_v\sqrt{1-\frac{v^2}{c^2}} \\
&= \left(1.701\times10^{-27}\,\mathrm{kg}\right)\times\sqrt{1-\left(\frac{6.0\times10^{7}\,\mathrm{ms^{-1}}}{3.0\times10^{8}\,\mathrm{ms^{-1}}}\right)^2} \\
&= \left(1.701\times10^{-27}\,\mathrm{kg}\right)\times\sqrt{1-0.2^2} \\
&= 1.67\times10^{-27}\,\mathrm{kg}
\end{aligned}$$

2006 Exam

Question 12

C. The force is independent of the component of the charge's velocity that is parallel to the magnetic field.

Question 14

C.

$$\begin{aligned}
E &= \frac{\Delta V}{d} \\
&= \frac{50\,\mathrm{V}}{0.01\,\mathrm{m}} \\
&= 5000\,\mathrm{Vm^{-1}}
\end{aligned}$$

For double the electric field we need

$$10000\,\mathrm{Vm^{-1}} = \frac{100\,\mathrm{V}}{0.01\,\mathrm{m}} = \frac{50\,\mathrm{V}}{0.005\,\mathrm{m}}$$

Both B and C yield the correct value for the electric field strength. However, parallel plate capacitors are always made out of conductors so that the time it takes current to flow onto the plates of the capacitor to establish the electric field is minimised. Thus C is 'more' correct.

Question 25

(a)

The purpose of the deflecting plates is to bend the beam of electrons in a direction perpendicular to the plates. The is achieved by a force due to an electric field $\vec{F} = q\vec{E}$, which is established by the application of a voltage between the plates.

The role of the cathode (the negative electode) is to provide a source or 'emitter' of electrons which are then accelerated towards the anode (positive electrode) by the application of a large voltage between them. A hole in the anode allows the beam of electrons to pass through and collide with the far wall of the cathode ray tube.

(b)

$$
\begin{aligned}
m_v &= \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} \\
&= \frac{(9.11 \times 10^{-31}\,\mathrm{kg})}{\sqrt{1-0.6^2}} \\
&= 1.14 \times 10^{-30}\,\mathrm{kg}
\end{aligned}
$$

(c)

$$
\begin{aligned}
l_v &= l_0\sqrt{1-\frac{v^2}{c^2}} \\
l_0 &= \frac{l_v}{\sqrt{1-\frac{v^2}{c^2}}} \\
&= \frac{0.24\,\mathrm{m}}{\sqrt{1-0.6^2}} \\
&= 0.3\,\mathrm{m}
\end{aligned}
$$

Question 27

Notes: Electromagnetic (EM) radiation is produced whenever electric charges accelerate. When electrons hit the end of the cathode ray tube they are rapidly decelerated, producing high energy EM radiation (X-rays).

(a)

Using a highly evacuated cathode ray tube with parallel plates between which a voltage was applied, J.J. Thomson later observed that cathode rays are in fact deflected by electric fields. This, taken together with earlier observation that cathode rays are also deflected by magnetic fields was conclusive in establishing their identity as a stream of charged particles.

(b)

X-rays, which can cause intracellular damage, are produced when cathode rays (fast moving electrons) are rapidly decelerated by hitting the glass at the end of the cathode ray tube. To minimise the risk associated with exposure students should stand at least a metre from the end of the cathode ray tube.

2007 Exam

Question 11

D.

$$\begin{aligned} E &= \frac{\Delta V}{d} \\ &= \frac{10^2\,\mathrm{V}}{10^{-3}\,\mathrm{m}} \\ &= 10^5\,\mathrm{Vm^{-1}} \end{aligned}$$

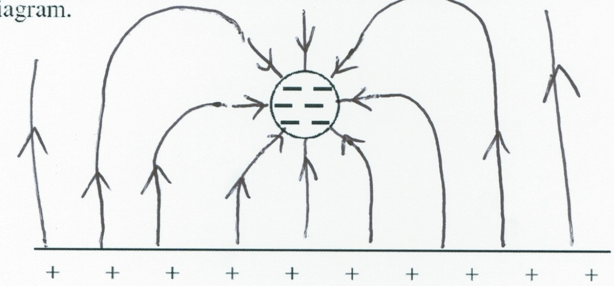
Question 13

C. Determine the direction of the field around the wire due to the current by the right hand 'grip' rule. Then use the right hand 'push' rule to determine the direction of the motion of the electron given the direction of the field and the direction of the force.

Question 24

(a) A negatively charged cylinder is fixed in position near a positively charged plate as shown in the cross-section. **1**

Sketch the electric field lines between the cylinder and the plate on the cross-section diagram.



(b)

$$
\begin{aligned}
F &= ma \\
&= \left(10^{-30}\,\mathrm{kg}\right) \times \left(7.0 \times 10^{21}\,\mathrm{ms^{-2}}\right) \\
&= 7.0 \times 10^{-9}\,\mathrm{N}
\end{aligned}
$$

$$
\begin{aligned}
F &= qE \\
E &= \frac{7.0 \times 10^{-9}\,\mathrm{N}}{6 \times 10^{-12}\,\mathrm{C}} \\
&= 1167\,\mathrm{NC^{-1}} \\
&= 1.2 \times 10^{3}\,\mathrm{NC^{-1}}\ (2s.f.)
\end{aligned}
$$

2008 Exam

Question 11

D.

$$
\begin{aligned}
\frac{mv^2}{r} &= |q|\,vBr \\
r &= \frac{mv}{|q|\,B} \\
&= \frac{(9.11 \times 10^{-31}\,\mathrm{kg}) \times (8.0 \times 10^{6}\,\mathrm{ms^{-1}})}{(1.6 \times 10^{-19}\,\mathrm{C}) \times (2.1 \times 10^{-2}\,\mathrm{T})} \\
&= 2.2 \times 10^{-3}\,\mathrm{m}
\end{aligned}
$$

Note that the velocity and magnetic field vectors are always perpendicular, i.e. $\theta = 90°$.

Question 12

B. Thomson's observation of deflection by electric fields was a conclusive confirmation of the particle hypothesis.

Question 23

(a)

The force on the electron is down

(b)

$$\begin{aligned} F &= qvB \\ &= \left(1.6 \times 10^{-19}\,\mathrm{C}\right) \times \left(2 \times 10^{6}\,\mathrm{ms^{-1}}\right) \times (0.001\,\mathrm{T}) \\ &= 3.2 \times 10^{-16}\,\mathrm{N} \end{aligned}$$

(c)

Thomson adjusted the strength of the electric and magnetic fields until there was no deflection of the beam of electrons. The allowed him to calculate the velocity of the electrons via

$$\begin{aligned} qE &= qvB \\ v &= \frac{E}{B} \end{aligned}$$

Then, by measuring the radius of the path of the electron beam under the influence of the magnetic field alone, he determined the charge to mass ratio of the electrons via

$$\begin{aligned} \frac{mv^2}{r} &= qvB \\ \frac{q}{m} &= \frac{v}{rB} \\ &= \frac{E}{rB^2} \end{aligned}$$

2009 Exam

Question 15

A. The electric field strength between parallel charged plates is constant.

Question 19

(a)

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

and

$$\begin{aligned} F &= qE \\ &= \frac{qV}{d} \\ &= \frac{(1.6 \times 10^{-19}\,\mathrm{C}) \times (100\,\mathrm{V})}{(0.1\,\mathrm{m})} \\ &= 1.6 \times 10^{-16}\,\mathrm{N} \end{aligned}$$

As the electric field points directly up, the force on the electron is directly down at all points between the plates.

(b)

As the force and so the acceleration is constant, we can use projectile motion equations. The time of flight is determined by the initial vertical velocity. We also need to determine the velocity via $F = ma$. Note that the answer provided by the BOS is only the time to reach the maximum height, not the total time of flight as required by the question.

$$\begin{aligned} u_y &= v \sin\theta \\ &= \left(6 \times 10^{6}\,\mathrm{ms}^{-1}\right) \times \sin 60 \\ &= 5.196 \times 10^{6}\,\mathrm{ms}^{-1} \end{aligned}$$

$$\begin{aligned} a &= \frac{F}{m} \\ &= \frac{1.6 \times 10^{-16}\,\mathrm{N}}{9.11 \times 10^{-31}\,\mathrm{kg}} \\ &= 1.76 \times 10^{14}\,\mathrm{ms}^{-2} \end{aligned}$$

$$\begin{aligned}
\Delta y &= u_y t + \frac{1}{2}at^2 \\
0 &= t\left(u_y + \frac{1}{2}at\right) \\
t &= 0, -\frac{2u_y}{a}
\end{aligned}$$

The time of flight is therefore

$$\begin{aligned}
t &= \left(\frac{2 \times 5.196 \times 10^6\,\mathrm{ms}^{-1}}{1.76 \times 10^{14}\,\mathrm{ms}^{-2}}\right) \\
&= 5.9 \times 10^{-8}\,\mathrm{s}
\end{aligned}$$

Question 25

(a)

The charge on the particle travelling from left to right is negative and that on the particle travelling right to left is positive. The two charges are equal in magnitude.

(b)

$$\begin{aligned}
\frac{mv^2}{r} &= qvB \\
B &= \frac{mv}{qr} \\
&= \frac{(1.67 \times 10^{-27}\,\mathrm{kg}) \times (1 \times 10^7\,\mathrm{ms}^{-1})}{(1.6 \times 10^{-19}\,\mathrm{C}) \times (4.2\,\mathrm{m})} \\
&= 2.485 \times 10^{-2}\,\mathrm{T} \\
&= 2.5 \times 10^{-2}\,\mathrm{T}(2s.f.)
\end{aligned}$$

2010 HSC Physics Exam

Question 15

B.

$$\begin{aligned}\frac{mv^2}{r} &= qvB \\ r &= \frac{mv}{qB}\end{aligned}$$

If $B_{new} = 2B$ then

$$\begin{aligned}r_{new} &= \frac{mv}{qB_{new}} \\ &= \frac{mv}{q2B} \\ &= \frac{r}{2}\end{aligned}$$

Question 16

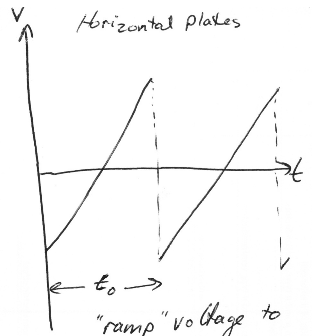
A. By the right hand rule.

Question 17

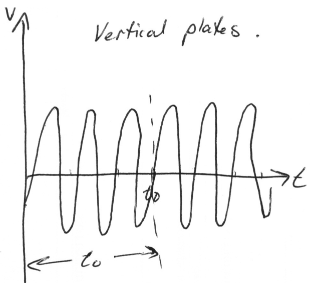
D. The electric and magnetic fields must be perpendicular to provide equal and opposite forces on the electron beam.

Question 29

Two sets of deflection plates are used. One is used to scan the beam horizontally across the screen at a rate set by the time constant. The other set deflects the electron beam vertically in proportion to the voltage (the signal) applied to the plates. In the case of the pattern displayed on the screen in the question, the voltage applied to the vertical deflection plates varies sinusoidally with time.



"ramp" voltage to move ~~curve~~ beam from left to right at a const. rate.
t_0 = time constant, which is length of signal shown on screen.



"signal" voltage in eg. given there are 3 λ per time constant t_0