Worked example

In a cathode-ray tube, electrons leave a cathode (which is negative) and are accelerated for a distance of 4.0 cm by a uniform electric field of electric field strength 1.20×10^5 N C^{-1} (Figure 3). They then pass through a hole in the anode (which is positive) and enter a region in which the electric field strength is zero. Calculate:

(a) the speed of an electron when it reaches the anode

(b) the time it takes to reach the screen of the cathode-ray tube, that is 28 cm from the anode.

Answer

(a) Electric field strength = V/d, therefore $V = 1.20 \times 10^5 \times 0.040 = 4800$ V or 4800 J/C.
The charge on an electron is 1.6×10^{-19} C.
Energy gained = 4800 J/C $\times$ 1.60×10^{-19} C = 7.68×10^{-16} J.
This is the kinetic energy of the electron, that is,
$7.68 \times 10^{-16} = \frac{1}{2} mv^2 = 0.5 \times 9.11 \times 10^{-31} \times v^2$, giving

$$v = \sqrt{\frac{2 \times 7.68 \times 10^{-16}}{9.11 \times 10^{-31}}} = 4.11 \times 10^7 \text{ m s}^{-1}$$

(b) The electron then coasts at constant speed until it reaches the screen.
Time taken = 0.28 m/4.11×10^7 m s^{-1} = 6.8×10^{-9} s.

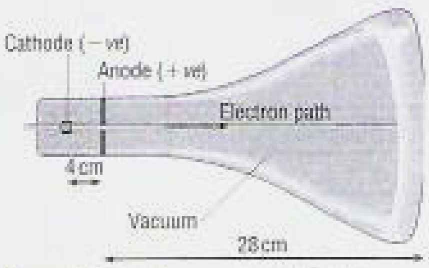

Figure 3 Electrons passing through a cathode-ray tube

Comparison of electric field with gravitational field

The situation described in the previous section has strong similarities with a ball being thrown horizontally in the Earth's gravitational field. The ball has a horizontal velocity unaffected by the downward gravitational force, so (as long as air resistance can be neglected) its horizontal velocity is constant. Its vertical velocity shows a constant downward acceleration. This means that the path followed by a ball in a gravitational field is precisely the same shape as that of a point charge in an electric field.

Other similarities between the fields are given in the table.

	Electric field	Gravitational field
Field symbol	E	g
Force acts on	charge (q)	mass (m)
Field definition	force per unit charge	force per unit mass
Force	$F = Eq$	$F = mg$
Direction of force	in direction of field on positive charge	always in direction of field
Work done (W) in moving distance d	$W = Eqd$	$W = mgd$

Examiner tip

As stated in spread 2.1.1, in electric fields, positive charge experiences a force in the direction of the field and negative charge experiences it in the opposite direction. In a gravitational field, however, there is no such thing as negative mass.

Question

1 Two horizontal parallel metal plates, 1.2×10^{-2} m apart, are connected to a 600 V power supply.

(a) Calculate the electric field strength between the plates.

(b) A tiny sphere of weight 3.3×10^{-14} N has acquired a charge so that it is held in equilibrium midway between the plates by the electric field as shown in Figure 4.

(i) State the magnitude and direction of the electric force on the sphere.

(ii) Calculate the magnitude of the charge on the sphere.

(iii) The voltage between the plates is suddenly doubled. Describe the motion of the sphere.

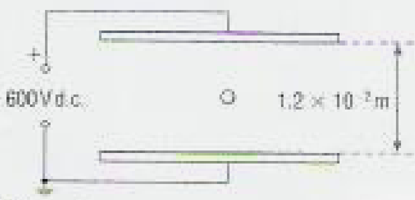

Figure 4