inkPhysics

ANSWER BOOK

Cathode rays and the electron

Turning points · Year 13

AQA 3.12.1.1, 3.12.1.2, 3.12.1.3 · CIE 20.3.6 · OCR A 6.3.2(c)

18 questions · 58 marks

NAVY EDITION

SECTION A · Warm-up

A1 A few kilovolts across a low-pressure gas ionises it; positive ions strike the cathode and release electrons (1), which accelerate towards the anode, making the gas glow along their path (1). [2]

A2 Electrons in a heated metal gain enough kinetic energy to escape its surface (1). In air the beam would collide with gas molecules and scatter, so the gun is evacuated (1). [2]

A3 The charge of the particle divided by its mass, e/m for the electron (1). Unit: $C\ kg^{-1}$ (1). [2]

A4 The rays are deflected by a magnetic field, so they are moving charged particles (1). The direction of the deflection shows that the charge is negative (1). [2]

A5 Kinetic energy gained = work done by the pd = eV (1) = $1.60 \times 10^{-19} \times 620 = 9.9 \times 10^{-17}$ J (1). [2]

SECTION B · Standard

B1 [3]
$eV = ½mv^2$, so $v = \sqrt{2(e/m)V}$ (1)
$v = \sqrt{2 \times 1.76 \times 10^{11} \times 3000}$ (1)
$v = 3.25 \times 10^7\ m\ s^{-1}$ (1)

B2 [3]
$v = E/B = 4.2 \times 10^4/(1.5 \times 10^{-3})$ (1)
$v = 2.8 \times 10^7\ m\ s^{-1}$ (1)
The electric force eE and magnetic force Bev are equal and opposite at exactly this speed (1)

B3 [4]
$eV = ½mv^2$ (1)
Rearranging: $e/m = v^2/2V$ (1)
$= (2.8 \times 10^7)^2/(2 \times 2230)$ (1)
$e/m = 1.76 \times 10^{11}\ C\ kg^{-1}$ (1)

B4 [3]
$e/m = 1.60 \times 10^{-19}/(1.67 \times 10^{-27})$ (1)
$e/m = 9.58 \times 10^7\ C\ kg^{-1}$ (1)
Ratio: $1.76 \times 10^{11}/(9.58 \times 10^7) \approx 1837$ (1)

B5 $v = \sqrt{2(e/m)V}$ (1) $= \sqrt{2 \times 1.76 \times 10^{11} \times 730} = 1.60 \times 10^7\ m\ s^{-1}$, about $1.6 \times 10^7\ m\ s^{-1}$ (1). Time = length/speed = $0.060/(1.60 \times 10^7)$ (1) $= 3.7 \times 10^{-9}$ s (1). [4]

B6 $v = \sqrt{(2(e/m)V)} = \sqrt{(2 \times 1.76 \times 10^{11} \times 3200)} = 3.36 \times 10^7$ m s^{-1} (1). $E = V/d = 460/(4.0 \times 10^{-3}) = 1.15 \times 10^5$ V m^{-1} (1). Undeflected means $Bev = eE$, so $B = E/v$ (1) $= 3.4 \times 10^{-3}$ T (1). [4]

B7 m = charge ÷ specific charge (1) $= 1.60 \times 10^{-19}/(4.79 \times 10^7) = 3.34 \times 10^{-27}$ kg (1). This is 2.0 times the hydrogen ion's mass (1), so the ions could be singly charged particles of twice its mass, for example hydrogen molecule ions H_2^+ (or deuterium ions) (1). [4]

SECTION C · Stretch

C1 $V = v^2/(2\ e/m)$ (1) [4]
$= (3.0 \times 10^7)^2/(2 \times 1.76 \times 10^{11})$ (1)
$V = 2557$ V, about 2.6 kV (1)
Beyond a tenth of c, relativistic effects grow: the work done increasingly raises the electron's mass-energy rather than its speed, so $eV = ½mv^2$ over-predicts v (1)

C2 The specific charge was about 1800 times that of the hydrogen ion, the largest previously known (1), and identical whatever cathode metal or gas was used (1). Assuming its charge is comparable to the hydrogen ion's, the particle must be far lighter than the lightest atom, and common to all matter: a universal constituent of atoms (1). [3]

C3 With only a magnetic field, the deflection depends on both the speed and the unknown specific charge (1), so the two cannot be separated (1). Balancing the two fields gives the speed directly as $v = E/B$, independent of e and m, which can then be combined with the accelerating pd (1). [3]

C4 $v = E/B = 3.90 \times 10^4/(1.50 \times 10^{-3}) = 2.60 \times 10^7$ m s^{-1} (1). Specific charge $= v^2/2V$ (1) $= (2.60 \times 10^7)^2/(2 \times 1920) = 1.76 \times 10^{11}$ C kg^{-1} (1). This matches the electron's specific charge, so the beam is consistent with being electrons (1). [4]

C5 Electrons from a heated filament are accelerated from rest through a measured pd V (1). The beam enters an electric field between parallel plates, crossed with a magnetic field at right angles to both the beam and the electric field (1). One field is adjusted until the beam is undeflected, when the electric and magnetic forces balance: $eE = Bev$ (1). The beam speed follows as $v = E/B$ (1). Since $eV = ½mv^2$, the specific charge is $e/m = v^2/2V$ (1). Measured quantities: the accelerating pd, E (from the plate pd and separation) and B (1). [6]

C6 $v = \sqrt{(2(e/m)V)}$, so $v \propto \sqrt{V}$ (1). Doubling the pd therefore raises the speed by a factor $\sqrt{2} \approx 1.4$, not 2 (1). Doubling the speed needs four times the pd: 2000 V (1). [3]