InkPhysics

ANSWER BOOK

Millikan's oil drop experiment

Turning points · Year 13

AQA 3.12.1.4

18 questions · 54 marks

NAVY EDITION

SECTION A · Warm-up

A1 $QV/d = mg$ (1): Q the droplet's charge, V the pd across the plates, d their separation, m the droplet's mass. The electric force exactly supports the weight (1). [2]

A2 $F = 6\pi\eta rv$ (1), for a small sphere moving slowly through a fluid of viscosity η, so that the flow around the sphere is laminar (1). [2]

A3 Every measured charge was a whole-number multiple of 1.6×10^{-19} C and never anything in between (1): electric charge is quantised, in units of the electronic charge e (1). [2]

A4 By friction, as the spray breaks up on leaving the atomiser (1). [1]

A5 The electric force on the droplet must act upwards, to balance the weight (1). The field between the plates points downwards, away from the positive upper plate, so the droplet's charge must be negative (1). [2]

SECTION B · Standard

B1 $Q = (\text{weight} \times d)/V = 1.632 \times 10^{-14} \times 6.0 \times 10^{-3}/612$ (1) [3]
$Q = 1.6 \times 10^{-19}$ C (1)
Exactly one electron's worth, e itself (1)

B2 At terminal speed $6\pi\eta rv = (4/3)\pi r^3\rho g$ (1) [4]
$r = \sqrt{(9\eta v/2\rho g)} = 1.1 \times 10^{-6}$ m (1)
$m = (4/3)\pi r^3\rho$ (1)
$m = 4.4 \times 10^{-15}$ kg (1)

B3 $V = mgd/Q$ (1) [3]
$V = 4.4 \times 10^{-15} \times 9.81 \times 5.0 \times 10^{-3}/(3.2 \times 10^{-19})$ (1)
$V = 675$ V (1)

B4 The balance condition contains the droplet's mass, which is far too small to weigh directly (1). The terminal speed of the free fall, through Stokes' law, gives the radius (1); the radius gives the mass, and only then can the balance equation yield the charge (1). [3]

B5 A water droplet would evaporate during the measurement (1), so its mass and radius would change while it was being timed, and the balance and terminal-speed equations would no longer describe the same droplet (1). [2]

B6 $m = (4/3)\pi r^3\rho$ (1) $= (4/3)\pi \times (1.2 \times 10^{-6})^3 \times 880 = 6.37 \times 10^{-15}$ kg, about 6.4×10^{-15} kg (1). Stationary: $QE = mg$, so $E = mg/Q$ with $Q = 3e = 4.80 \times 10^{-19}$ C (1). $E = 6.37 \times 10^{-15} \times 9.81/(4.80 \times 10^{-19}) = 1.3 \times 10^5$ V m^{-1} (1). [4]

B7 In the balance condition $QV/d = mg$, the mass, g and the separation are unchanged, so $V \propto 1/Q$ (1). The charge falls from 3e to 2e (1), so the pd must rise by the factor 3/2: 440 × 3/2 = 660 V (1). [3]

B8 With the electric force removed the weight is unbalanced, so the droplet accelerates downwards (1). As it speeds up, the viscous drag $6\pi\eta rv$ grows with speed (1), until the drag equals the weight and the droplet then falls at a constant terminal speed (1). [3]

SECTION C · Stretch

C1 Dividing by 1.6×10^{-19} C gives exactly 2, 3 and 5 (1): each charge is a whole multiple of one shared unit (1) and none falls between (1). The implied quantum is $e = 1.6 \times 10^{-19}$ C (1). [4]

C2 $m = e \div (e/m)$ (1) [3]
$m = 1.60 \times 10^{-19}/(1.76 \times 10^{11})$ (1)
$m = 9.09 \times 10^{-31}$ kg (1)

C3 $4.0 \times 10^{-19}/(1.6 \times 10^{-19}) = 2.5$, not a whole number (1). Charge only occurs in whole multiples of e, so a non-integer result indicates an experimental or arithmetic error (1). [2]

C4 $r = \sqrt{(9\eta v/2\rho g)} = 1.19 \times 10^{-6}$ m (1). $m = (4/3)\pi r^3\rho = 6.15 \times 10^{-15}$ kg (1). Balance: $Q = mgd/V$ (1) $= 6.15 \times 10^{-15} \times 9.81 \times 6.0 \times 10^{-3}/755 = 4.8 \times 10^{-19}$ C (1). $Q/e = 3.0$, so the droplet carries three electrons' worth of charge (1). [5]

C5 Charged oil droplets are sprayed between horizontal parallel plates and one is watched through a microscope (1). The pd is adjusted until the droplet hangs stationary, when the electric force balances the weight: $QV/d = mg$ (1). With the field off, the droplet falls at terminal speed, where Stokes' drag equals the weight: $6\pi\eta rv = (4/3)\pi r^3\rho g$ (1). The measured terminal speed gives the radius, hence the mass, which the balance equation converts into the charge Q (1). Repeated over many droplets, every measured charge is a whole-number multiple of 1.6×10^{-19} C, with none in between (1). So charge is quantised: it exists only in integral multiples of the electronic charge e (1). [6]