Unit 20 · Electrons

ANSWER KEY · FOR TEACHERS

Full marks 34

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. quantized
2. terminal velocity
3. viscous drag
4. X-rays
5. parabola
6. specific charge
7. velocity selector
8. electron volt

K · 4

Each carries 0.5 mark.

2 Label the diagram

1. drop
2. atomizer
3. W_2 X-rays
4. water jacket

K · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** 9.4×10^6 m/s — A · 1

$\frac{1}{2}mv^2 = eV$, so $v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 250}{9.1 \times 10^{-31}}} = 9.4 \times 10^6$ m/s.

ii. **b.** 2.4×10^{-19} C — U · 1

Charge comes only in whole numbers of $e = 1.6 \times 10^{-19}$ C. 2.4×10^{-19} C is 1.5e, so no drop can carry it.

iii. **c.** 1.5×10^7 m/s — A · 1

They go straight when eE = evB: $v = E/B = 3.0 \times 10^4 \div 2.0 \times 10^{-3} = 1.5 \times 10^7$ m/s.

iv. **c.** a parabola — K · 1

Its horizontal speed stays the same and it has a constant acceleration towards the positive plate, as a ball thrown sideways under gravity: $y = kx^2$, a parabola.

v. **b.** 1.6×10^{-19} J — K · 1

1 eV is the energy gained by an electron moving through 1 V: $eV = 1.6 \times 10^{-19}$ C $\times$ 1 V $= 1.6 \times 10^{-19}$ J.

4 Short answers

a. MARKING SCHEME — U · 2

- ✓ The drag grows with speed.
- ✓ When drag + upthrust = weight, the net force is zero: a terminal velocity.

b. MARKING SCHEME — U · 2

- ✓ No field, so no force, outside the plates.
- ✓ It goes on in a straight line along the tangent at the exit.

c. MARKING SCHEME — U · 2

- ✓ A larger e/m for a similar charge means a much smaller mass.
- ✓ So they are far lighter than an atom: particles inside atoms (electrons).

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5 Long answer

ANSWER U · 4

The field gives a constant force eE across the plates and no force along them, so the electron keeps its speed v along the plates: x = vt, t = x/v. Across, it starts with no velocity and has a constant acceleration a = eE/m, so $y = \frac{1}{2}at^2 = \frac{1}{2}\frac{eE}{m}\left(\frac{x}{v}\right)^2 = \frac{eE}{2mv^2}x^2$. With e, E, m and v constant this is y = kx^2, a parabola; the deflection after x is $\frac{eEx^2}{2mv^2}$.

MARKING SCHEME

- ✓ Constant speed along the plates: t = x/v.
- ✓ Constant acceleration a = eE/m across them.
- ✓ $y = \frac{1}{2}at^2 = eEx^2/(2mv^2)$.
- ✓ $y = kx^2$: a parabola.

6 Numerical problems

a. **ANSWER** A · 3

$m = \frac{4}{3}\pi r^3\rho = \frac{4}{3}\pi(1.5\times10^{-6})^3\times900 = 1.27\times10^{-14}$ kg, so mg = 1.25×10^{-13} N.

Held still: qE = mg, with E = V/d: $q = \frac{mgd}{V} = \frac{1.25\times10^{-13}\times0.0080}{1560} = \mathbf{6.4\times10^{-19}\ C}$, which is 6.4 ÷ 1.6 = **4 electrons**.

MARKING SCHEME

- ✓ The drop's mass (or weight) 1.25×10^{-13} N.
- ✓ q = mgd/V = 6.4×10^{-19} C.
- ✓ 4 electrons.

b. **ANSWER** A · 4

i. $a = \frac{eV}{md} = \frac{1.6\times10^{-19}\times100}{9.1\times10^{-31}\times0.020} = \mathbf{8.8\times10^{14}\ m/s^2}$.

ii. t = 0.040 ÷ 2.0×10^{7} = $\mathbf{2.0\times10^{-9}\ s}$.

iii. y = ½at^2 = ½ × 8.8×10^{14} × $(2.0\times10^{-9})^2$ = **1.8 mm**. That is less than the 10 mm of room on each side, so they **do** leave the plates.

iv. tan θ = at/v = $8.8\times10^{14}\times2.0\times10^{-9}\div2.0\times10^{7}$ = 0.088, so θ = **5.0**°.

MARKING SCHEME

- ✓ a = 8.8×10^{14} m/s^2.
- ✓ t = 2.0×10^{-9} s.
- ✓ y = 1.8 mm, less than 10 mm, so they leave.
- ✓ θ = 5.0°.

c. **ANSWER** A · 3

$v = \sqrt{2(e/m)V_a} = \sqrt{2\times1.76\times10^{11}\times2000} = \mathbf{2.65\times10^{7}\ m/s}$.

E = 600 ÷ 0.010 = 6.0×10^{4} V/m; undeflected when v = E/B: $B = \frac{6.0\times10^{4}}{2.65\times10^{7}} = \mathbf{2.3\times10^{-3}\ T}$.

MARKING SCHEME

- ✓ v = 2.65×10^{7} m/s.
- ✓ E = 6.0×10^{4} V/m.
- ✓ B = 2.3 mT.

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7 Think

ANSWER HA · 3

For a drop held still, $qV/d = mg$, so $q \propto 1/V$ with the same drop: the charge rose in the ratio 2400 : 1600 = 3 : 2. With 2 electrons at first it now has **3**. A steady temperature keeps the air still (no convection currents carrying the drop) and keeps the air's viscosity and the oil's density the same during the measurements.

MARKING SCHEME

- ✓ $q \propto 1/V$ for the same drop, so the charge rose by 3/2.
- ✓ 3 electrons now.
- ✓ Steady temperature: no air currents, and the viscosity stays the same.

8 Activity: Charging an electroscope in steps (Activity 20.1)

(not marked)

WHAT STUDENTS SHOULD FIND

The leaves open a little more at each touch of the comb and close a little at each touch of the key: the charge changes in steps, one step per touch. But each touch moves thousands of millions of electrons, a different number each time, so it is only a model of charge arriving in packets; a single electron's charge is far too small to see this way. Millikan's tiny drops, carrying a few electrons, are the proof.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	8	11	12	3	**34**

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