

M1.(a) emitted electrons have a range of speeds ✓

(electrostatic) force acting on electrons emitted from surface increases OR pull / attraction on electrons from surface increases ✓

microammeter reading due to electrons reaching T (moving round circuit) ✓

(microammeter reading decreases because) electrons unable to reach T due to increasing force(or insufficient k_e or too much work needed) ✓

Alternative for last point ; (microammeter reading decreases because) fewer electrons can reach T as pd increases,

3 max

- (b) (i) Graph ; straight line with a positive gradient ✓
intercept on + x-axis (or on – y-axis if drawn) ✓
Need to see 1st point to get the 2nd point

2

- (ii) $E_{K(max)} = eV_s$ (or $E_{K(max)}$ proportional to V_s) ✓

$$\text{gives } eV_s = hf - \phi$$

where hf = photon energy

and ϕ = work function of metal ✓

Alt for 2nd mark; recognition that

$$V_s = \frac{hf}{e} - \frac{\phi}{e}$$

where ϕ = work function of metal so this is equation for st line (or $y = mx + c$)

Graph of V_s against f is a straight line with gradient h/e ✓

and x-intercept = ϕ/h (or y-intercept = $-\phi/e$) ✓

Accept either of last 2 marks if shown on the graph clearly

3 max

(c) $hf = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{418 \times 10^{-9}} = 4.76 \times 10^{-19} \text{ J } \checkmark$

Accept sub or ans for marks 1 and 2

$$E_{K(\max)} = eV_s = 1.6 \times 10^{-19} \times 1.92 = 3.07 \times 10^{-19} \text{ J } \checkmark$$

(Ans in J; allow 1.7 or 1.66* or 1.70 in place of 1.69)

$$\begin{aligned} \phi &= hf - E_{K(\max)} \text{ (or } 4.76 \times 10^{-19} - 3.07 \times 10^{-19}) \\ &= 1.69 \times 10^{-19} \checkmark \text{ J } \checkmark \text{ (or } 1.06 \text{ eV)} \end{aligned}$$

(Ans in eV ; allow 1.1 or 1.04*)
*arises from rounding 3.07 to 3.1)

4
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M2. (a) (i) work done (due to stopping potential V) = eV (1)

$$\begin{aligned} E_{K\max} &= \text{work done due to stopping potential} \\ &= (1.6 \times 10^{-19} \times 0.35) = 5.6 \times 10^{-20} \text{ J (1)} \end{aligned}$$

2

(ii) (rearranging $hf = \phi + E_{K\max}$) gives $\phi = hf - E_{K\max}$ (1)

$$\begin{aligned} \text{photon energy (} = hf = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{590 \times 10^{-9}} \text{)} \\ = 3.37 \times 10^{-19} \text{ J (1)} \end{aligned}$$

$$\phi = hf - E_{K\max} = 3.37 \times 10^{-19} - 5.6 \times 10^{-20} = 2.8(1) \times 10^{-19} \text{ J (1)}$$

3

(b) (i) photons have the same energy (as in a)) (1)

when a (conduction) electron in the metal absorbs a photon, it gains all the energy of the photon (1)

work function (of Y) is the minimum energy needed by an electron to escape (1)

work function of Y is greater than the energy gained by an electron (so electron cannot escape) (1)

max 2

(ii) wave theory predicts that incident light (of any frequency) would cause photoelectric emission (from any metal) (1)

and any **one** of the following points

wave theory could not explain why light below a certain frequency (or below a threshold frequency) could not cause photoelectric emission (1)

or this (threshold) frequency is characteristic of the metal (or depends on the metal) (1)

or wave theory could not explain the instantaneous emission of photoelectrons (1)

2

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- M3.** (a) light consists of photons (1)
an electron in the metal absorbs a photon (1)
an electron needs a minimum amount of energy to escape (1)
a blue photon has more energy than a red photon (1)
 $hf > \phi$ for blue photon, $< \phi$ for red photon (1)

Max 4

- (b) every electron would gain sufficient energy from the waves in time (1)
no matter what the frequency/colour/wavelength of the light is (1)

2

[6]

- M4.(a)** (i) an electron requires 1.2 eV of energy to escape from the metal (surface) (1)

(ii) (use of $\phi = hf_0$ gives) $f_0 \left(= \frac{\phi}{h} \right) = \frac{1.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}}$ (1)

(= 2.9×10^{14} (Hz))

(use of $c = f_0 \lambda_0$ gives) $\lambda_0 \left(= \frac{c}{f_0} \right) = \frac{3.0 \times 10^8}{2.9 \times 10^{14}} = 1.0 \times 10^{-6} \text{ m}$ (1)

(allow C.E. for value of f_0 , if f_0 calculated)

3

- (b) (i) energy of a (light) photon = hf (1)
a blue photon has more energy than a red photon (1)
[or has higher frequency if first mark awarded]
an electron (at the metal surface) absorbs a photon (1)
an electron needs a certain amount of energy to escape from the metal (1)
[or frequency > threshold frequency if 1st and 3rd marks awarded]
a blue photon gives an electron enough energy to escape,
whereas a red photon does not (1)
- (ii) classical wave theory predicted that all wavelengths / colours / frequencies of light should cause electrons to be emitted (1)
classical wave theory was rejected in favour of the photon theory (1)

max 5

[8]

- M5.(a)** (i) $hf =$ photon energy (1)
- (ii) $\phi =$ **minimum** energy to eject electron from metal surface (1)
- (iii) $E_k =$ **maximum** kinetic energy of a photoelectron (1)

3

- (b) (i) no photoelectrons are emitted (1)
- (ii) wave theory predicts photoelectrons will be emitted with red light (or at any frequency) (1)
- (iii) one photon absorbed by one electron (1)
electron emitted from metal if photon energy [or hf] > ϕ (or not if < ϕ) (1)
red light photon energy < ϕ (1)

max 3

(c) $\phi = \frac{hc}{\lambda}$ (1) k.e._{max} (1)

$$\phi = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{3.00 \times 10^{-7}} - 3.26 \times 10^{-19} \text{ (1)}$$

$$\phi = 3.4 \times 10^{-19} \text{ J (1)}$$

2

[8]