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 ke 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) ✓

gives $eV_s = hf - \varphi$

where hf = photon energy
and φ = work function of metal ✓

Alt for 2nd mark; recognition that

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

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 = $-\varphi / e$) ✓

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

3 max

(c) $$hf = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{418\times10^{-9}} = 4.76\times10^{-19}\text{ J}$$ ✓

Accept sub or ans for marks1 and 2

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

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

$\varphi = hf - E_{K(max)}$ (or $4.76 \times 10^{-19} - 3.07 \times 10^{-19}$)
$= 1.69 \times 10^{-19}$ ✓ J ✓ (or 1.06 eV)

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

4

[12]

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

E_{Kmax} = work done due to stopping potential
$= (1.6 \times 10^{-19} \times 0.35) = 5.6 \times 10^{-20}$ J **(1)**

2

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

photon energy (= hf = $\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{590 \times 10^{-9}}$)

$= 3.37 \times 10^{-19}$ J **(1)**

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

[9]

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) $\lambda_0 \left(= \frac{c}{f_0}\right) = \frac{3.0 \times 10^{8}}{2.9 \times 10^{14}} = 1.0 \times 10^{-6}$ 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) ϕ = ***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)***

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

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

2

[8]