Solutions

Each answer shows the steps, then the **result**.

2.1

- the **minimum** energy needed
- to remove an electron from the surface of the metal
- "the energy needed to free an electron" without "minimum" or "surface" earns one mark only

2.2

- one photon gives all of its energy to one electron, so a single photon must supply the whole work function energy by itself
- the energy of a photon is hf, which depends on the frequency alone
- below the threshold frequency $hf < \Phi$, so no single photon is enough; making the light brighter sends **more** photons, each one still too weak, so still no emission

2.3

(a)

- **unchanged**
- the electron's kinetic energy comes from one photon, and the photon energy hf has not changed: $\frac{1}{2}mv_{\max}^2 = hf - \Phi$

(b)

- **doubled**
- twice the intensity means twice as many photons arriving per second, so twice as many electrons released per second

2.4

- a wave model predicts a **delay**, because a faint wave would deliver energy slowly and the electron would have to absorb it over a long time before it had Φ
- in the photon model the energy arrives in whole packets, not as a trickle
- so the very first photon to arrive can free an electron at once, however few photons per second there are

3.1 B

- doubling the intensity doubles the number of photons per second, not the energy of each one
- so each electron is unchanged (ruling out **C** and **D**) but there are twice as many per second (ruling out **A**)

3.2

(a)

$$E = hf = 6.63 \times 10^{-34} \times 7.5 \times 10^{14} = 4.97 \times 10^{-19} \text{ J}$$

$$E = \frac{4.97 \times 10^{-19}}{1.60 \times 10^{-19}} = \mathbf{3.11} \text{ eV} \approx 3.1 \text{ eV}$$

(b)

$$\tfrac{1}{2}mv_{\text{max}}^2 = hf - \Phi = 3.11 - 2.1 = 1.01 \text{ eV}$$

$$= 1.01 \times 1.60 \times 10^{-19} = \mathbf{1.6 \times 10^{-19}} \text{ J}$$

(c)

- $eV_\text{s} = \frac{1}{2}mv_{\text{max}}^2 = 1.01$ eV, so $V_\text{s} = \mathbf{1.0}$ V

(d)

- the stopping potential is **unchanged**
- $eV_\text{s} = hf - \Phi$ depends only on the frequency and the metal, and neither has changed; halving the intensity halves the current, not the energy of each electron

3.3

(a)

- the fastest electron is just stopped by the reverse p.d., so $eV_\text{s} = \frac{1}{2}mv_{\text{max}}^2$
- substituting into $hf = \Phi + \frac{1}{2}mv_{\text{max}}^2$ gives $eV_\text{s} = hf - \Phi$

(b)

- the **gradient** is the **Planck constant** h
- the intercept on the energy axis is $-\Phi$, so its magnitude is the **work function energy**

(c)

- the line crosses the frequency axis where $eV_\text{s} = 0$, so there $hf_0 = \Phi$

$$\Phi = 6.6 \times 10^{-34} \times 5.5 \times 10^{14} = 3.63 \times 10^{-19} \text{ J}$$

$$\Phi = \frac{3.63 \times 10^{-19}}{1.60 \times 10^{-19}} = \mathbf{2.3} \text{ eV}$$

(d) any **two** of:

- the gradient is the **same**, because the gradient is h and that is a constant of nature
- the line crosses the frequency axis at a **higher** threshold frequency, i.e. it is shifted to the right
- the intercept on the energy axis is **more negative**, since it is $-\Phi$
- the two lines are therefore parallel

(e)

- a photon of frequency f has to pay the work function energy Φ before any kinetic energy is left, so at $f = 0$ the line would sit at $-\Phi$, not at zero – there is no emission at all until f reaches f_0