Past-paper walk-through

Photoelectric effect ▪ 22.2

eXercise

Questions in this set

- 9702/44 N25 Q9 ▪ 8 marks
- 9702/42 J25 Q9 ▪ 8 marks
- 9702/41 N24 Q8 ▪ 9 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 9

9702/44 N25 ▪ Q9 ▪ 8 marks

(a) State what is meant by the photoelectric effect. **[2]**

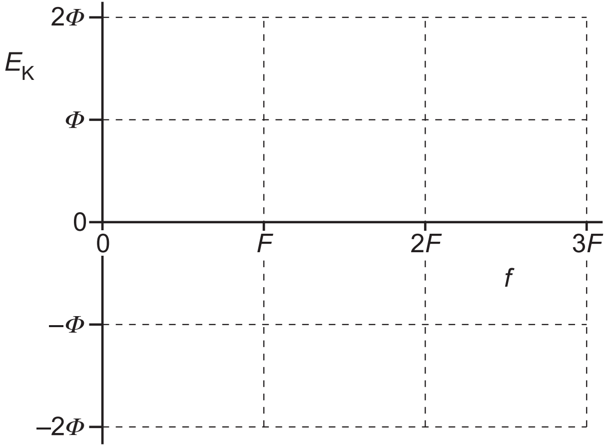
(b)(i) the threshold frequency of metal Y **[1]**

(b)(ii) the Planck constant. **[1]**

(c) The maximum kinetic energy E_K of photoelectrons is determined for each of the plates in (b) for different frequencies f of incident radiation.

On Fig. 9.1, sketch the variation of E_K with f for each plate. Label your lines X and Y to identify which line relates to which plate. **[4]**

Question 9



Solution 9

(a)

Mark scheme

- emission of electrons (from a metal surface) **M1**
- when electromagnetic radiation is incident (on surface) **A1**

Solution 9

(b)(i)

Mark scheme

- threshold frequency $= 2F$ **A1**

(b)(ii)

Mark scheme

- Planck constant $= \Phi \;/\; F$ **A1**

Solution 9

(c) Worked steps

Einstein's equation, $E_\mathsf{K} = hf - \Phi$, is the graph: a straight line of gradient h whose intercept is the work function.

- Draw **two straight lines with positive gradient**, and draw them **only where $E_\mathsf{K} > 0$** — below the threshold no electrons are emitted at all, so there is no line to draw there.
- Each line starts on the frequency axis at its own **threshold frequency**: X at $(F, 0)$ and Y at its larger threshold, further right.
- The two lines are **parallel**: the gradient is Planck's constant, the same for every metal. That is the mark this question is really about — different metals shift the line along, they do not tilt it.

Solution 9

Mark scheme

- two diagonal straight lines with positive gradient in the positive EK region only, starting at non-zero values of f **B1**
- line labelled X passing through (F, 0) and line labelled Y passing through (2F,0) and extending to 3F or $+2\Phi$ **B1**
- two diagonal straight lines with equal gradients **B1**
- X line extrapolates back to (0, $-\Phi$) and Y line extrapolates back to (0, -2Φ) **B1**

Question 9

9702/42 J25 ▪ Q9 ▪ 8 marks

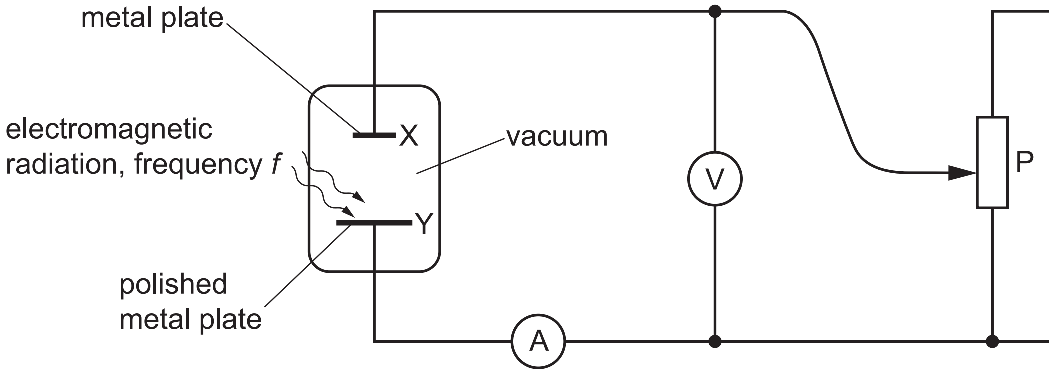
(a) State what is meant by the photoelectric effect. **[2]**

(b)(i) Explain, with reference to photons, why V_S depends on the frequency of the incident electromagnetic radiation. **[3]**

(b)(ii) State **three** quantitative conclusions that can be drawn from the results in Fig. 9.2 and Fig. 9.3. Use the space for any working.

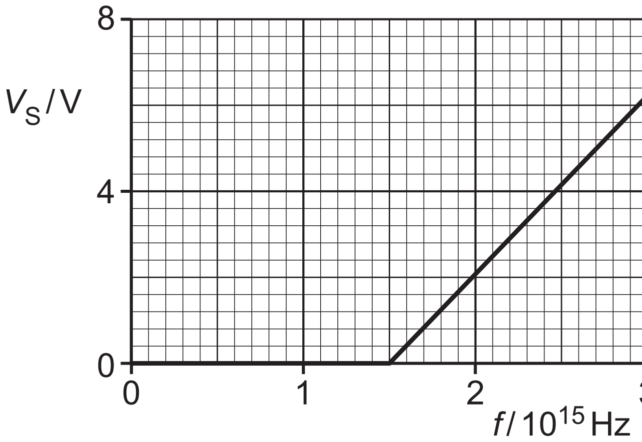
1. 2. 3. **[3]**

Question 9

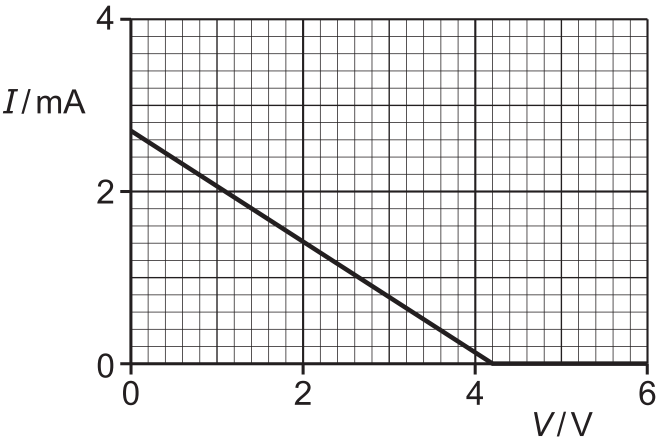


metal plate
electromagnetic
radiation, frequency *f*
polished
metal plate
X
Y
vacuum
V
A
P

Question 9



Question 9



Solution 9

(a)

Mark scheme

- emission of electrons (from a metal surface) **B1**
- when electromagnetic radiation is incident (on surface / electrons) **B1**

Solution 9

(b)(i)

Mark scheme

- current falls to zero when applied voltage equals energy per unit charge of emitted electrons **B1**
- energy of photon depends on frequency **B1**
- maximum energy of electron depends on energy of photon **B1**

Solution 9

(b)(ii) Worked steps

The word that matters is **quantitative** — each conclusion has to be a number read off, or calculated from, the graphs. Three that follow directly:

- **Threshold frequency**: the intercept where the maximum kinetic energy first becomes positive, $f_0 = 1.5 \times 10^{15}$ Hz.
- **Threshold wavelength**: convert it with $c = f\lambda$, $\lambda_0 = \dfrac{3.00 \times 10^8}{1.5 \times 10^{15}} = 2.0 \times 10^{-7}$ m.
- **Work function**: the minimum energy to release an electron, $\Phi = hf_0 = 6.63 \times 10^{-34} \times 1.5 \times 10^{15} = 9.9 \times 10^{-19}$ J, which is $\dfrac{9.9 \times 10^{-19}}{1.60 \times 10^{-19}} = 6.2$ eV.

Solution 9

All three come from the same intercept, which is why the question gives three marks for what looks like one reading: you are being asked to convert it two different ways and to say what each conversion means.

Use the space for working — the second and third conclusions are calculations, and a bare number with no substitution risks the mark. And keep the units on: a frequency in hertz, a wavelength in metres, a work function in joules or electronvolts.

A qualitative statement such as "the kinetic energy increases with frequency" earns nothing here, however true. The question asked for numbers. **Mark scheme**

- Any three points from:
- - threshold frequency = 1.5×1015 Hz

Solution 9

- - threshold wavelength = 2.0 × 10–7 m
- - work function = 6.2 eV (or 9.9 × 10–19 J)
- - Planck constant = 6.6 × 10–34 J s (not 6.63 × 10–34 J s)
- - number per unit time (of photons / electrons) = 1.7 × 1016 s–1 (in stage 1)
- - power of incident radiation = 0.028 W (in stage 1) **B3**

Question 8

9702/41 N24 ▪ Q8 ▪ 9 marks

A polished sheet of magnesium in a vacuum emits electrons when it is illuminated by ultraviolet radiation.

(a) State the name of this phenomenon. **[1]**

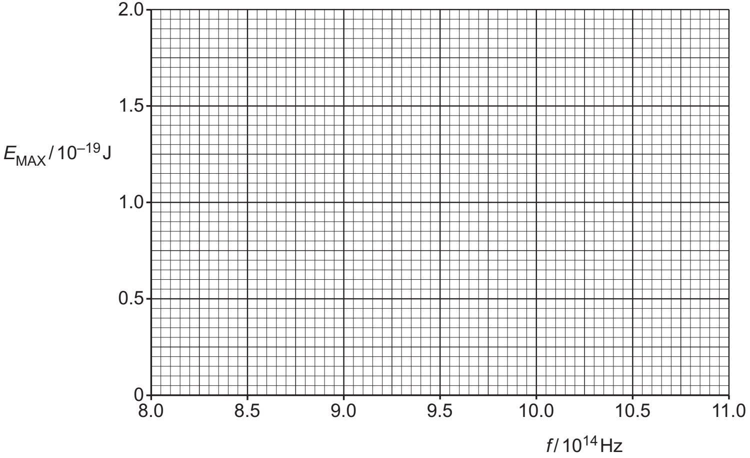
(b)(i) Calculate the work function energy of magnesium. **[2]**

(b)(ii) For ultraviolet radiation with a frequency of 11×10^{14} Hz, calculate the maximum speed of the emitted electrons. **[3]**

(c) The frequency *f* of the ultraviolet radiation incident on the magnesium sheet is varied between 8.0×10^{14} Hz and 11×10^{14} Hz.

On Fig. 8.1, sketch the variation with *f* of the maximum kinetic energy E_{MAX} of the emitted electrons. Use the space below for any working that you need. **[3]**

Question 8



Solution 8

(a)

Mark scheme

- photoelectric effect

Solution 8

(b)(i) Worked steps

Know. The **threshold frequency** is the lowest frequency that just releases an electron. At that frequency the whole photon energy is spent freeing the electron, with nothing left over as kinetic energy, so the work function is hf_0.
Equation. $\Phi = hf_0$.
Substitute. $\Phi = (6.63 \times 10^{-34})(8.8 \times 10^{14})$, reading the threshold frequency off the graph.
Answer. $\Phi = 5.8 \times 10^{-19}$ J.

Solution 8

Check. The answer is asked for in **joules**, so no conversion to electronvolts is wanted. As a check, 5.8×10^{-19} J is 3.6 eV, which is a sensible work function for a metal.

Mark scheme

- $E = hf$
- work function $= 6.63 \times 10^{-34} \times 8.8 \times 10^{14}$
- $= 5.8 \times 10^{-19}$ J

Solution 8

(b)(ii) Worked steps

Know. Einstein's photoelectric equation splits the photon's energy in two: some frees the electron, the rest becomes kinetic energy. The **maximum** speed goes with the electrons that needed only the minimum energy to escape.

Equation. $hf = \Phi + \frac{1}{2}mv_{\mathrm{MAX}}^2$.

Substitute. $(6.63 \times 10^{-34})(11 \times 10^{14}) = (5.8 \times 10^{-19}) + \frac{1}{2}(9.11 \times 10^{-31})v_{\mathrm{MAX}}^2$.

Solution 8

Rearrange. $\frac{1}{2}mv_{\mathsf{MAX}}^2 = 7.29 \times 10^{-19} - 5.8 \times 10^{-19} = 1.46 \times 10^{-19}$ J.
Answer. $v_{\mathsf{MAX}} = 5.7 \times 10^5$ m s^{-1}.

Solution 8

Check. Subtract the work function **before** taking the square root, and remember the $\frac{1}{2}$. Using the whole photon energy as kinetic energy gives 1.3×10^6 m s^{-1}, more than twice too large.

Mark scheme

- $hf = \Phi + \frac{1}{2}mv_{\mathsf{MAX}}^2$
- $6.63 \times 10^{-34} \times 11 \times 10^{14} = (5.8 \times 10^{-19}) + (\frac{1}{2} \times 9.11 \times 10^{-31} \times v_{\mathsf{MAX}}^2)$
- $v_{\mathsf{MAX}} = 5.7 \times 10^5$ m s^{-1}

Solution 8

(c) Worked steps

Know. Rearranging the photoelectric equation gives $E_{\mathsf{MAX}} = hf - \Phi$: a straight line of gradient h that crosses the frequency axis at the threshold.
Below threshold. From $f = 8.0 \times 10^{14}$ to 8.8×10^{14} Hz no electrons are emitted at all, so draw $E_{\mathsf{MAX}} = 0$ along the axis.
Above threshold. From $f = 8.8 \times 10^{14}$ Hz onwards, a **single straight line** with a positive gradient.
One point to fix it. At $f = 11 \times 10^{14}$ Hz the answer to (b)(ii) gives $E_{\mathsf{MAX}} = 1.45 \times 10^{-19}$ J, so the line must pass through $(11,\ 1.45)$ on the printed axes.

Solution 8

Check. The graph is a straight line, not a curve, and it stays flat at zero below the threshold rather than going negative. That flat section is the part of the photoelectric effect that wave theory could not explain, which is why the question asks for it.

Mark scheme

- E_{MAX} shown as zero from $f = 8.0$ to 8.8 and non-zero from $f = 8.8$ to 11
- all non-zero E_{MAX} shown as a single straight line with a positive gradient
- line passing through $(11, 1.45)$