# A-Level Physics

## The Discovery of Photoelectricity

### Mark Scheme

**Time available: 62 minutes**
**Marks available: 52 marks**

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## Mark schemes

**1.** (a) Electromagnetic/EM radiation ✓

Spectrum with peak depending on temperature (of emitter alone). ✓

*If no other mark awarded, allow 1 mark for (EM) radiation given off by perfect absorber /emitter.*

*Condone light for radiation*

**2**

(b) (Description of ultraviolet catastrophe)

*If no other mark awarded, 1 mark can be given for idea that there is 'no peak'.*

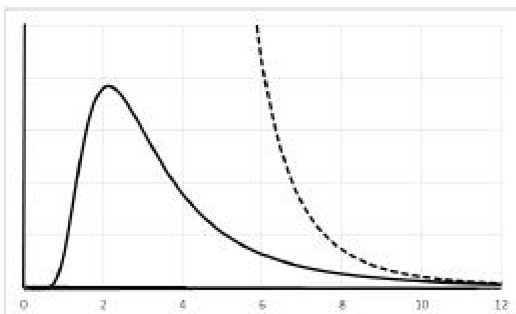
**1**

Intensity similar at long wavelengths, ✓

(But rather than peak) theory predicts intensity increases at shorter wavelengths/infinite at very short wavelengths✓

*Allow correct line on graph for either for 1 mark*

*But some correct description needed for both*




*Condone any line that goes to infinity at short wavelengths for MP2.*

**1**

(c) EM radiation emitted in quanta ✓

Energy of quantum is related to a single frequency **OR**

E = hf, where h is Planck's constant. ✓

*Do not condone photon or packet for quanta in MP1*

**2**

(d) The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

| Mark | Criteria |
|---|---|
| 6 | All 3 areas covered with at least two aspects of photoelectric effect covered in some detail.<br>6 marks can be awarded even if there is an error and/or parts of one aspect missing. |
| 5 | A fair attempt to analyse all 3 areas. If there are several errors or missing parts then 5 marks should be awarded. |
| 4 | Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error. |
| 3 | One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion. |
| 2 | Only one area discussed, or makes a partial attempt at two areas. |
| 1 | None of the three areas covered without significant error. |
| 0 | No relevant analysis. |

The following statements are likely to be present.

**A main outcomes of experiments.**

No photoelectric emission if incident light below threshold frequency

Photoelectric emission is instantaneous/occurs as soon as light is incident on metal surface

(Photoelectrons have a range of KE from zero to max value, depending on type of metal and frequency of incident light.

Number of photoelectrons per second is proportional to intensity of incident radiation)

**B problems of classical wave theory**

Intensity of wave (brightness of light) should determine whether photoelectron emitted/KE of photoelectron OR light of any frequency should cause emission.

Wave energy spread over surface should mean time needed to for electrons to accumulate enough energy to be
emitted/lower intensity the longer the time.

**C Aspects of Einstein's theory**

Light is made of photons

Photoelectrons due to one photon interacting with one electron in surface of metal.

Minimum energy (work function of metal) needed for electron to be emitted related to a threshold frequency by $\varphi = hf_o$

Remaining energy of photon ($hf-hf_o$) becomes (max) KE of photoelectron.

Brighter source means more photons (per second) and therefore more photoelectrons (per second).

**6**

**[12]**

**2.** (a) **Marks awarded for this answer will be determined by the Quality of Written Communication (QWC) as well as the standard of the scientific response. Examiners should apply a 'best-fit' approach to the marking.**

**Level 3 (5—6 marks)**
Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below:
- argument is well structured with minimum repetition or irrelevant points
- accurate and clear expression of ideas with only minor errors in the use of technical terms, spelling and punctuation and grammar

**Level 2 (3—4 marks)**
Answer has some omissions but is generally supported by some of the relevant points below:
- the argument shows some attempt at structure
- the ideas are expressed with reasonable clarity but with a few errors in the use of technical terms, spelling, punctuation and grammar

**Level 1 (1—2 marks)**
Answer is largely incomplete. It may contain valid points which are not clearly linked to an argument structure.
Unstructured answer
Errors in the use of technical terms, spelling, punctuation and grammar or lack of fluency

**Level 0 Nothing of relevance**

**examples of possible points in the response**

**Observations**

- Initially ammeter record current
- as pd increases the current decreases
- eventually current becomes 0

**Emissions**

- Photons / light cause emission of electrons
- Emitted electrons have KE (if photon energy > work function
- pd tends to stop emitted electrons reaching the electrode / anode (**not** stop electrons being emitted)
- Recognises that the electrode is negative w.r.t. the cathode or vice versa
- Recognises that there are a range of electron KEs
- Explains why there is a range of KEs
- Electrons with low energy stopped (first) so current decreases

**Stopping potential**

- The potential between the electrodes when the current = 0
- The potential that prevents electrons reaching the anode / electrode
- Stopping potential depends on maximum electron KE

**Application of Einstein equation**

- Use of $E_{k(max)} = hf - \varphi$
- Defines terms
- Explain / identifies that stopping potential × electron charge = atoms / molecules / electrons $V_s e = E_{k(max)}$

***extra information***

***5-6*** *will address 3 aspects well or all 4 with minor omissions in coherent response*

***3-4*** *will address three of the points with significant omissions or eg give good response to 2 parts*

***1-2*** *may give brief but relevant comments on*

- *the emission*
- *what is meant by stopping potential*
- *Some attempt to apply Equation*

***0*** *makes no relevant comment*

**6**

(b) (i) Kinetic energy of emitted electrons = $0.24 \times 1.6 \times 10^{-19}$ **or** $0.38 \times 10^{-19}$(J) seen ✓

energy of photon incident = $6.63 \times 10^{-34} \times 3 \times 10^{8} / 490 \times 10^{-9}$ or $4.06 \times 10^{-19}$(J) seen ✓

Work function = $3.68 \times 10^{-19}$ (J) ✓

Or

energy of photon incident = $6.63 \times 10^{-34} \times 3 \times 10^{8} / 490 \times 10^{-9} = 4.06 \times 10^{-19}$(J) ✓

(energy of photon incident = 2.54 eV so) work function = 2.30 eV ✓

Work function = 3.7 (3.68) $\times 10^{-19}$ (J) ✓

*Must see all values substituted to get the mark by substitution*

**3**

(ii) No of electrons emitted = $6.1 \times 10^{-6}$/ their photon energy(1.5(1.48) $\times 10^{13}$ if correct) ✓

Current = Their electron number $\times 1.6 \times 10^{-19}$ (2.4(2.37) μA if correct) ✓

*Allow for first mark only*

*$6.16 \times 10^{-6}$/work function*

*($1.65 \times 10^{13}$)*

*Allow ecf for incorrect calculation of photon energy from (b))(i) or first step*

**2**

**[11]**

**3.** (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 $\varphi$ = 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 = $\varphi / h$
(or y-intercept = $-\varphi / e$ ) ✓

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

**3 max**

(c) $hf = \dfrac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{418 \times 10^{-9}} = 4.76 \times 10^{-19}$ 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]**

**4.** (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 ($= hf = \dfrac{hc}{\lambda} = \dfrac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{590 \times 10^{-9}}$)

$= 3.37 \times 10^{-19}$ 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]**

**5.** (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)**

(= $2.9 \times 10^{14}$ (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]**