Photoelectric Effect Answers

1. (a) The following equation describes the release of electrons from a metal surface illuminated by electromagnetic radiation.

$$hf = k.e._{\text{max}} + \phi$$

Explain briefly what you understand by each of the terms in the equation.

hf **Energy of a photon (1)**

$k.e._{\text{max}}$ **Kinetic energy of emitted electron/equivalent (1)**

ϕ **Energy to release electron from surface / equivalent (1)**

(3 marks)

(b) Calculate the momentum p of an electron travelling in a vacuum at 5% of the speed of light.

p = mv **(1)**

= 9.11×10^{-31} kg × 0.05 × 3×10^{8} m s^{-1} (1)
(no ecf for incorrect mass)

p **= 1.37×10^{-23} N s/kg m s^{-1} (1) Unit penalty**

(3 marks)

What is the de Broglie wavelength of electrons travelling at this speed?

$\lambda = \dfrac{6.63 \times 10^{34}}{1.37 \times 10^{-23}}$ **ecf (b) (1)**

λ **= 4.84×10^{-11} m Unit penalty (1)**

(2 marks)

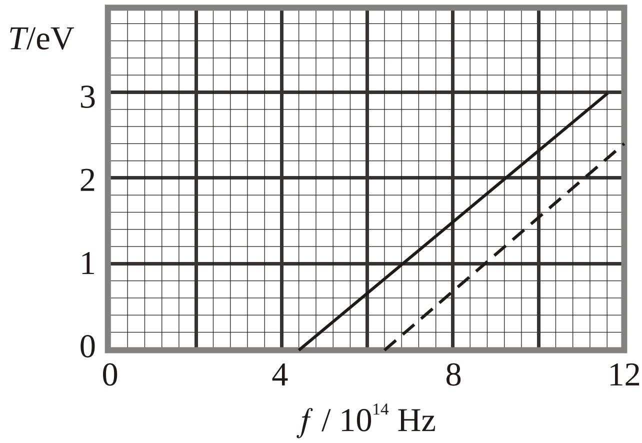
Why are electrons of this wavelength useful for studying the structure of molecules?

λ </similar to size / spacing atoms / molecules (1)

Diffraction occurs (1)

(2 marks)
[Total 10 marks]

2. The graph shows how the maximum kinetic energy T of photoelectrons emitted from the surface of sodium metal varies with the frequency f of the incident radiation.



A parallel line (1)
starting at a higher frequency (1)

Why are no photoelectrons emitted at frequencies below 4.4×10^{14} Hz?

Photon energy too small/less than ϕ (1)

(1 mark)

Calculate the work function ϕ of sodium in eV.

If using $\phi = hf - T$

then a valid pair of points (1)

with both points in the same units (1)

OR

If using $hf_o = \phi$

with $f_o = 4.4 \times 10^{14}$ Hz (1)

Work function = 1.8 eV (1)

(3 marks)

Explain how the graph supports the photoelectric equation $hf = T + \phi$

$T = hf - \phi$ is similar to $y = mx + c$ (1)

Straight line shows T/f relationship (1)

Negative intercept T axis shows ϕ (1)

Any two

(2 marks)

How could the graph be used to find a value for the Planck constant?

From the gradient (1)

(not necessary to mention conversion factor)

(1 mark)

Add a line to the graph to show the maximum kinetic energy of the photoelectrons emitted from a metal which has a greater work function than sodium. (See graph.)

(2 marks)
[Total 9 marks]

3. Experiments on the photoelectric effect show that

- the kinetic energy of photoelectrons released depends upon the frequency of the incident light and not on its intensity,
- light below a certain threshold frequency cannot release photoelectrons.

How do these conclusions support a particle theory but not a wave theory of light?

Particle theory: E = *hf* implied packets/photons (1)

One photon releases one electron giving it k.e. (1)

Increase f ⇒ greater k.e. electrons (1)

Lower f; finally ke = O ie no electrons released Waves (1)

Energy depends on intensity / (amplitude)^2 (1)

More intense light should give greater k.e–NOT SEEN (1)

More intense light gives more electrons but no change in maximum kinetic energy (1)

Waves continuous ∴ when enough are absorbed electrons should be released–NOT SEEN (1)

(6 marks)

Calculate the threshold wavelength for a metal surface which has a work function of 6.2 eV.

6.2eV × 1.6 × 10^{-19} C (1)

Use of $\lambda = \frac{hc}{E}$ **(1)**

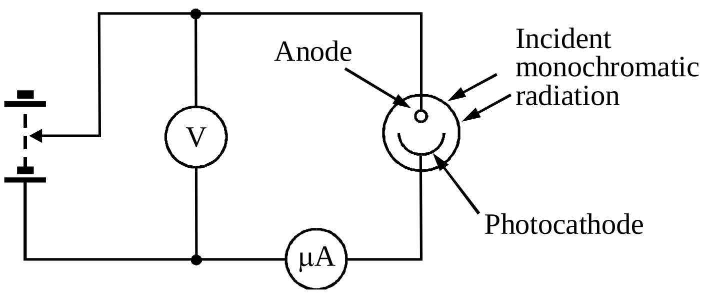
Threshold wavelength = **2.0 × 10^{-7} m (1)**

To which part of the electromagnetic spectrum does this wavelength belong?

UV ecf their λ (1)

(4 marks)
[Total 10 marks]

4. The diagram shows monochromatic light falling on a photocell.



As the reverse potential difference between the anode and cathode is increased, the current measured by the microammeter decreases. When the potential difference reaches a value V_s, called the stopping potential, the current is zero.

Explain these observations.

Photons release e^- at photocathode; e^- travel to anode making a current (1)

Photon energy > work function of photocathode (1)

OR All energy of <u>A</u> photon goes to <u>an</u> electron (1)

Electrons released with a <u>range</u> of kinetic energies (1)

So smaller kinetic energy electrons stopped at lower pds (1)

PD opposes kinetic energy of these electrons (1)

V_S supplies enough energy to stop electrons with kinetic energy max (1)

(MAX 5 marks)
(5 marks)

What would be the effect on the stopping potential of

(i) increasing only the intensity of the incident radiation,
No effect (1)

(ii) increasing only the frequency of the incident radiation?
Increases stopping potential (1)

(2 marks)
[Total 7 marks]

5. Particle theory:

One photon releases one electron giving it kinetic energy **(1)**

Increase $f \rightarrow$ greater k.e. electrons **(1)**

Lower f finally k.e. = 0 i.e. no electrons released **(1)**

Waves:
More intense light should give greater k.e.**(1)**

More intense light gives more electrons but no change in maximum kinetic energy **(1)**

Waves continuous $\therefore$ when enough are absorbed electrons should be released **(1)** Max 5

Quality of written communication 1

Line parallel to existing line
to left of existing line 2

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6. <u>Calculation:</u>

$E = hc/\lambda$ [seen or implied] **(1)**
physically correct substitutions **(1)**
$\div 1.6 \times 10^{-19}$ eV J^{-1} **(1)**
5.78 eV **(1)** 4

<u>Maximum kinetic energy:</u>
3.52 eV [ecf but not if –ve.] **(1)**

Stopping potential:
3.52 V [Allow e.c.f., but not signs] **(1)** 2

Annotated graph:
Position of S **(1)**
Cuts V axis between origin and existing graph **(1)**
Similar shape [*I* levels off up/below existing line] **(1)** 3

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7. Photoelectric effect

(a) Explanation:

Particle theory: one photon (interacts with) one electron **(1)**

Wave theory allows energy to 'build up', i.e. time delay **(1)** 2

(b) Explanation:

Particle theory: *f* too low then not enough energy (is released by photon to knock out an electron) **(1)**

Wave theory: Any frequency beam will produce enough energy (to release an electron, i.e. should emit whatever the frequency) **(1)** 2

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8. Planck constant
Realise that h is the gradient
Correct attempt to find gradient [but ignore unit errors here]
$h = (6.3 \text{ to } 6.9) \times 10^{-34}$ J s [No **bald** answers] 3

Work function
Use of hf_0 / use intercept on T axis/use of $\phi = hf - T$ **(1)**
$\phi = (3.4 \text{ to } 3.9) \times 10^{-19}$ J [-1 if –ve] [2.1 to 2.4 eV] **(1)** 2

Stopping potential
$T = 2.3 \times 10^{-19}$ //Use of $T = hf - \phi$ **(1)**
Use of V = their energy $\div 1.6 \times 10^{-19}$ **(1)**
$V = 1.44$ V // $V = 1.1 - 1.8$ V [ignore –ve sign] [ecf h] **(1)** 3

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