Past-paper walk-through

The Photoelectric Effect ▪ 15.5

eXercise

Questions in this set

- 2024 Q1
- 2018 Q3

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 1

2024 ▪ Q1

In each trial of a photoelectric experiment, a scientist uses a device to shine light of a single frequency on two different metals, 1 and 2. The device can emit light with frequency f_A, f_B, or f_C. Each frequency of light is used to test both metals.
The scientist determines the minimum de Broglie wavelength λ_e of the electrons ejected from the metal in each trial of the experiment. The following table summarizes the results of the experiment. For each trial, the scientist analyzes only the electrons with the minimum de Broglie wavelength.

Trial	Frequency of Light	Metal Tested	λ_e ($\times 10^{-10}$ m)
1	f_A	Metal 1	6.9
2	f_A	Metal 2	9.4
3	f_B	Metal 1	No electrons ejected
4	f_B	Metal 2	No electrons ejected
5	f_C	Metal 1	5.3
6	f_C	Metal 2	6.3

(a) In a coherent, paragraph-length response, **indicate** which frequency, f_A, f_B, or f_C, is greatest and which frequency is least. **Justify** your answer using physics principles.

Question 1

(b) Calculate the maximum kinetic energy of the electrons ejected from Metal 1 in Trial 1. Assume that the momentum p of an ejected electron can be described by the classical definition $p = mv$.

(c) Indicate whether the work function of Metal 1 is greater than, less than, or equal to the work function of Metal 2. **Justify** your answer by referring to the table of results.

Solution 1

(a) Mark scheme

- f_C is greatest and f_B is least. Reasoning: an electron is ejected only if the incident photon's energy ($E = hf$) exceeds the metal's work function. Because no electrons were ejected using f_B, its photon energy (and therefore frequency) must be the least of the three. A photon with greater frequency gives an ejected electron more kinetic energy, and the kinetic energy of an electron is inversely related to its de Broglie wavelength ($\lambda = h/p$, $K = p^2/2m$, so larger λ means smaller K). Because the de Broglie wavelength of electrons ejected by light of frequency f_A is greater than that of electrons ejected by light of frequency f_C, f_A must be less than f_C. Therefore f_C is the greatest frequency, and f_B (which ejects no electrons at all) is the least. Scoring: 1 pt for correctly ranking f_B least and f_C greatest; 1 pt for

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correctly relating photon frequency to photon energy ($E = hf$); 1 pt for indicating that an ejected electron's kinetic energy/speed is inversely related to its de Broglie wavelength; 1 pt for stating that either (i) greater photon energy/frequency gives greater ejected-electron kinetic energy, or (ii) the lowest photon energy/frequency is below the work function/threshold frequency so no electron is ejected; 1 pt for an overall logical, relevant, internally consistent paragraph-length argument.

Solution 1

(b) Mark scheme

- $K = 5 \times 10^{-19}$ J (equivalently about 3 eV). Derivation: the electron's de Broglie wavelength is $\lambda_e = h/p = h/(mv)$, so $v = h/(m\lambda_e)$. Substituting into kinetic energy: $K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2 = \frac{h^2}{2m\lambda_e^2}$. Using $h = 6.63 \times 10^{-34}$ J · s, $m = 9.11 \times 10^{-31}$ kg, and the Trial 1 / Metal 1 de Broglie wavelength $\lambda_e = 6.9 \times 10^{-10}$ m from the data table: $K = \dfrac{(6.63 \times 10^{-34})^2}{2(9.11 \times 10^{-31})(6.9 \times 10^{-10})^2} = 5 \times 10^{-19}$ J. Scoring: 1 pt for either $\lambda_e = h/(mv)$ or $K = p^2/2m$; 1 pt for correctly substituting a λ_e-based (or

Solution 1

numeric) expression for speed/momentum into the kinetic-energy equation; 1 pt for the correct final numeric answer with units (5×10^{-19} J or 3 eV).

Solution 1

(c) Mark scheme

- The work function of Metal 1 is LESS than the work function of Metal 2. Reasoning: when light of the same frequency (same photon energy *hf*) is incident on both metals, the electron ejected from Metal 1 has a smaller de Broglie wavelength than the electron ejected from Metal 2, so the electron ejected from Metal 1 has more kinetic energy. The work function equals the difference between the photon energy and the maximum kinetic energy ($\phi = hf - K_{max}$). Since the photon energy is the same for both metals but K_{max} is larger for Metal 1, the difference (and thus the work function) is smaller for Metal 1. Scoring: 1 pt for correctly indicating Metal 1's work function is less than Metal 2's, with an attempted justification; 1 pt for citing at least two of: the correct relation

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between work function and $hf - K_{max}$; that the incident photon frequency/energy is the same for both metals; that de Broglie wavelength is inversely related to the ejected electron's energy.

Question 3

2018 ▪ Q3

[Diagram: arrows labeled "Light" shine diagonally down onto a rectangular block labeled "Metal"; small circles labeled "Electrons" are shown being emitted upward and diagonally from the metal surface.]

Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

(a)(i) Based on conservation of energy, the relationship between K_e and f is predicted to be $Af = B + K_e$ when $f > f_0$ and $K_e = 0$ when $f \leq f_0$, where A and B are positive constants. A graph of this relationship is shown below. Indicate which aspects of the graph correspond to A and B. Also, explain the physical meaning of A, B, and f_0.

Question 3

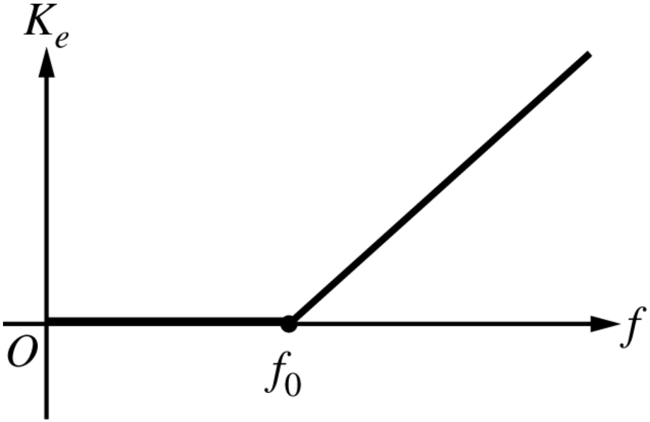
[Graph of K_e (y-axis) vs. f (x-axis); the curve is flat at $K_e = 0$ from the origin O up to f_0 on the x-axis, then rises linearly with positive slope for $f > f_0$.]

(a)(ii) Explain the physical meaning of the horizontal section of the graph between the origin and f_0.

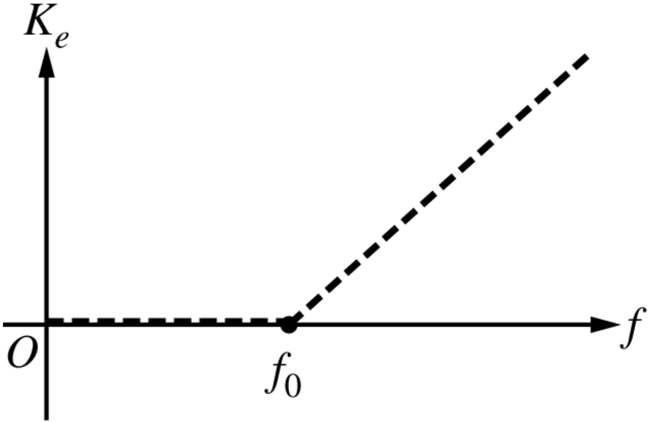
(a)(iii) A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.

[Graph of K_e (y-axis) vs. f (x-axis), with dashed lines showing the flat-then-linear relationship from part (a)(i), flat at $K_e = 0$ from O to f_0 then rising linearly beyond f_0; blank space for the student to sketch a second set of lines for the second metal.]

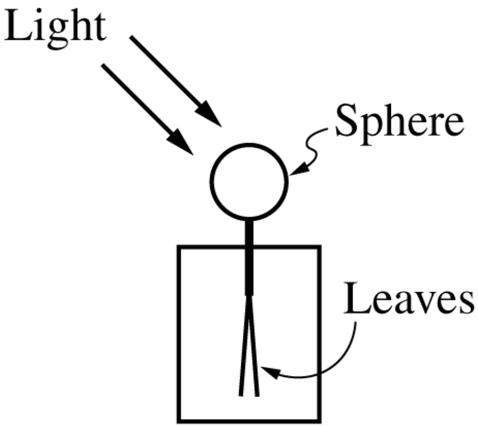
Question 3



Question 3



Question 3



Question 3

2018 ▪ Q3

[Diagram: arrows labeled “Light” shine diagonally down onto a rectangular block labeled “Metal”; small circles labeled “Electrons” are shown being emitted upward and diagonally from the metal surface.]

Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

(b) The figure below shows an electroscope. A sphere is connected by a vertical bar to the leaves, which are thin, light strips of material. The sphere, leaves, and bar are all made of metal. The electroscope initially has a negative charge, so the leaves are separated.

Question 3

[Diagram: arrows labeled “Light” shine diagonally onto a circle labeled “Sphere” at the top of a vertical bar; the bar leads down into a rectangular box containing two thin vertical strips labeled “Leaves”, shown separated/spread apart.]
(b)(i) Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.
(b)(ii) Green light then shines on an identical negatively charged electroscope. No movement of the leaves is observed. Explain why the green light does not make the leaves move, while the UV light does.

Question 3

2018 ▪ Q3

[Diagram: arrows labeled “Light” shine diagonally down onto a rectangular block labeled “Metal”; small circles labeled “Electrons” are shown being emitted upward and diagonally from the metal surface.]

Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

(c) The brightness of the green light is increased until the intensity (power per unit area) is the same as that of the UV light. What aspect of the green light changes when its brightness is increased? Would shining the brighter green light on the electroscope result in movement of the leaves? Explain why or why not.

Solution 3

(a)(i)

Mark scheme

- From $Af = B + K_e$, rearranged as $K_e = Af - B$: A is the slope of the line (the rate of change of K_e with respect to f), and it equals Planck's constant h. B corresponds to the K_e-axis intercept of the line — specifically the line's y-intercept is $-B$; physically B is the work function of the metal, the minimum energy needed to eject an electron. f_0 is the line's f-axis (x) intercept — the minimum (threshold, or cutoff) frequency of light that can eject an electron from the metal.

Solution 3

(a)(ii)

Mark scheme

- The horizontal portion of the graph (from the origin to f_0, where $K_e = 0$) represents frequencies of light whose photon energy is insufficient to eject an electron from the metal, so no photoelectrons are emitted for $f \leq f_0$.

Solution 3

(a)(iii) Mark scheme

- The new line for the second metal should be drawn parallel to the original dashed line (same slope $A = h$, since Planck's constant is unchanged), but shifted horizontally, with its horizontal (zero-K_e) segment extending out to a different threshold frequency f_0' on the f-axis (either before or after the original f_0), and the sloped part beginning at that new intercept. The key difference to explain: the horizontal (f-axis) intercept — the threshold/cutoff frequency f_0 — is different for the second metal because it has a different work function (a different minimum energy needed to eject an electron), so photoelectric emission begins at a different frequency, even though the slope (Planck's constant) is the same for both metals.

Solution 3

(b)

Mark scheme

- This is introductory/context text describing the electroscope figure (a metal sphere connected by a vertical bar to two thin metal leaves, all initially negatively charged so the leaves repel and are spread apart). It poses no question of its own and carries no points — the scored content is in sub-parts (b)(i) and (b)(ii) below.

Solution 3

(b)(i)

Mark scheme

- UV light photons have enough energy (frequency above the metal's threshold frequency) to eject electrons from the electroscope via the photoelectric effect. As electrons leave the electroscope, it becomes less negatively charged (loses some of its excess negative charge), so the electrostatic repulsion between the two leaves decreases, and the leaves move closer together.

Solution 3

(b)(ii)

Mark scheme

- Green light has a lower frequency (and thus lower photon energy, $E = hf$) than UV light. Because the green light's photon energy is below the metal's threshold/cutoff energy (work function), no individual green photon has enough energy to eject an electron from the electroscope, no matter how many green photons arrive — so no charge is removed and the leaves don't move, unlike with UV light.

Solution 3

(c) Mark scheme

- Increasing the brightness (intensity) of the green light at a fixed frequency increases the number of photons striking the electroscope per second (equivalently, in the wave picture, it increases the wave's amplitude) — it does not change the light's frequency, and therefore does not change the energy per photon ($E = hf$). Because each green photon's energy is still below the metal's work function, no single photon can eject an electron no matter how many photons arrive per second, so the brighter green light would still not cause the leaves to move. Full credit requires explaining this via the particle (photon) model of light — that it is the energy of an individual photon, not the total light intensity, that determines whether an electron can be ejected.