2024

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 1

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 1: Paragraph-Length Response — 10 points

(a)

For indicating that f_B is least and f_C is greatest — **1 point**

For correctly relating the frequency of a photon to the energy of the photon — **1 point**

For indicating that the kinetic energy or speed of an ejected electron is inversely related to the de Broglie wavelength of the electron — **1 point**

For indicating **one** of the following: — **1 point**

- That a greater photon energy or frequency results in a greater kinetic energy for an ejected electron
- That the lowest photon energy or frequency is below the work function or threshold frequency which results in no ejected electron

For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response — **1 point**

Example Response

An electron will be ejected if the incident photon has an energy greater than the work function of the metal. Because no electrons were ejected using f_B, the corresponding photon energy, and, therefore, frequency must be the least. A photon with greater frequency will result in an ejected electron with more kinetic energy; the kinetic energy of an electron is inversely related to the de Broglie wavelength of the electron. Because the de Broglie wavelength of electrons ejected by light of frequency f_A is greater than those ejected by light of frequency f_C, f_A must be less than f_C. Therefore, f_C is the greatest.

Total for part (a) 5 points

(b) For **one** of the following: **1 point**

- Correctly relating electron de Broglie wavelength to a correct expression that includes h, m, and v
- Relating kinetic energy to a correct expression that includes momentum and mass

Example Responses

$\lambda_e = \frac{h}{mv}$

OR

$K = \frac{p^2}{2m}$

For correctly substituting an algebraic expression in terms of λ_e for the electron speed or momentum into a relevant equation for kinetic energy **1 point**

Scoring Note: This point can be earned for substituting a numerical value for electron speed or momentum into a relevant equation for kinetic energy.

Example Responses

$K = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2$ **OR** $K = \frac{\left(\frac{h}{\lambda_e}\right)^2}{2m}$

For a correct answer with units **1 point**

Example Response

$K = 5 \times 10^{-19}\ \text{J}$

Example Solution

$\lambda_e = \frac{h}{p} = \frac{h}{mv}$

$v = \frac{h}{m\lambda_e}$

$K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda_e}\right)^2$

$K = \frac{h^2}{2m\lambda_e^2}$

$K = \frac{\left(6.63 \times 10^{-34}\ \text{J} \cdot \text{s}\right)^2}{2\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(6.9 \times 10^{-10}\ \text{m}\right)^2} = 5 \times 10^{-19}\ \text{J}$

Scoring Note: An answer of $3\ \text{eV}$ also earns the final point.

Total for part (b) 3 points

(c) For indicating that the work function of Metal 1 is less than the work function of Metal 2 with an attempt at a relevant justification **1 point**

For indicating at least **two** of the following: **1 point**

- The correct relationship between the work function and the difference between hf and $K_{\max}$
- The frequency or energy of the incident photons is the same
- The de Broglie wavelength is inversely related to the energy of the ejected electrons

Example Response

The work function of Metal 1 is less than the work function of Metal 2. When light of the same frequency is incident on both metals, the electron ejected by Metal 1 has a smaller de Broglie wavelength than that of Metal 2, so an electron ejected from Metal 1 has more kinetic energy. The work function is the difference between the photon energy and the maximum kinetic energy. Since the photon energy is the same but the maximum kinetic energy is larger for Metal 1, the difference between the energies, and thus the work function, is smaller for Metal 1.

Total for part (c) 2 points

Total for question 1 10 points

Question 1

Begin your response to **QUESTION 1** on this page.

PHYSICS 2

SECTION II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

1. (10 points, suggested time 20 minutes)

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

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Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 1

Continue your response to **QUESTION 1** on this page.

(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.

f_C is greatest and f_B is least. According to the photoelectric equation $K_{max} = hf - \phi$, where hf is the energy of incident light and ϕ is the work function of metal, when the kinetic energy is greater, frequency is greater. Since there's no electrons ejected by light f_B, the energy hf is less than ϕ, indicating that the frequency of B is also smallest. Because $K = \frac{1}{2}mv^2$ and $\lambda = \frac{h}{p} = \frac{h}{mv}$, when wavelength is greater, velocity is smaller, resulting in a smaller kinetic energy. Therefore, since λ_e on metal 1 with light f_A is greater than f_C, $f_C > f_A$.

(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 $p = mv$.

$K_{max} = \frac{1}{2}mv^2$

$= \frac{1}{2} \cdot 9.11 \times 10^{-31} \cdot v^2$

$= \frac{1}{2} \cdot 9.11 \times 10^{-31} \cdot (0.11 \times 10^{-3})^2$

$= 5.07 \times 10^{-39}$ m/s

$\lambda = \frac{h}{p} = \frac{h}{mv}$

$6.9 = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \cdot v}$

$v = 0.11 \times 10^{-3}$

(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.

Since in trial 1 and 2, λ_e of metal 1 is smaller than in metal 2, $K_1 > K_2$. Since the incident light is same, hf is the same, and because $K = hf - \phi$, ϕ of metal 1 is smaller than metal 2.

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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 $\downarrow_P$
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$\lambda = \frac{h}{p}$ $E = hf$ $\frac{hc}{\lambda} = E$

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Question 1

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(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.

$f_C > f_A > f_B$

Greater frequency means more energy. More energy means more momentum for the electrons Since $\lambda = \frac{h}{p}$ if they gain more momentum ther wavelength will be smaller. f_B is the smallest because it did not provide enough energy to release an electron.

(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 $p = mv$.

$K_{max} = hf - \phi$

$\lambda = \frac{h}{p}$

$6.9 \cdot 10^{-10} = \frac{4.14 \cdot 10^{-15}}{(9.11 \cdot 10^{-31})v}$

$v = \frac{4.14 \cdot 10^{-15}}{(9.11 \cdot 10^{-31})(6.9 \cdot 10^{-10})}$

$v = 6.586 \cdot 10^{24}$

$K = \frac{1}{2}mv^2$

$K = 1.976 \cdot (10^{9})$ J

(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.

The work function for metal 2 is greater because the wavelengths released are greater. Greater λ means less p which comes from $K_{max} = hf - \phi$. Since hf is the same then less p and K_{max} comes from a greater work function

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Question 1

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(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.

f_a is the greatest frequency as it produced the largest de Broglie wavelengths. For both Metal 1 & Metal 2 f_a resulted in a larger de Broglie wavelength than f_c. In turn, f_B was the least frequency as it did not even meet the minimum de Broglie wavelength necessary to record data.

(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 $p = mv$.

$K = \frac{1}{2}mv^2$ $\quad \sqrt{\frac{2K}{m} = v^2}$

$p = mv$ $\quad p = m\sqrt{\frac{2K}{m}}$

(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.

The work function of Metal 1 is less than Metal 2. This can be seen from the results in the table as the de Broglie wavelength for metal 1 was less in both trials.

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Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Relate the frequency of a photon to the energy of the photon.
- Relate the kinetic energy or speed of an electron to the de Broglie wavelength of the electron.
- Relate the energy of an incident photon to the energy of an electron ejected from a metal sample.
- Analyze the photoelectric effect to compare the kinetic energy of ejected electrons when the energy of incident photons exceeds the work function.
- Analyze the photoelectric effect to determine if electrons will be ejected when the energy of incident photons does not exceed the work function.
- Calculate the kinetic energy of electrons from a given de Broglie wavelength by analyzing the relationship between λ_e and p or v *and* the relationship between K and p or v.
- Analyze $K_{\max} = hf - \phi$ to relate the energy of the incident photons and the kinetic energy of ejected electrons to the work function of different materials.

Sample: 1A
Score: 9

Part (a) earned 5 points. The first point was earned for indicating that f_B is the least and f_C is the greatest. The second point was earned for correctly relating the frequency of a photon to the energy of a photon. The third point was earned for correctly indicating that the kinetic energy of an electron is inversely related to the wavelength of the electron. The fourth point was earned for indicating that the lowest frequency photon results in no ejected electron due to an energy or frequency below the metal's work function or threshold frequency. The fifth point was earned for addressing the question asked in a logical, relevant, and internally consistent paragraph-length response. Part (b) earned 2 points. The first point was earned for correctly relating the electron's de Broglie wavelength to h, m, and v to determine the speed of the electron. The second point was earned for correctly substituting the numerical value for the speed into a relevant equation for kinetic energy. The third point was not earned because the answer includes an incorrect value. Part (c) earned 2 points. The first point was earned for correctly indicating the work function of Metal 1 is less than the work function of Metal 2, with an attempt at a relevant justification. The second point was earned for stating the correct relationship between the work function and the difference between hf and maximum kinetic energy. In addition, the response indicates that the wavelength of the electron from Metal 1 is smaller, and the kinetic energy is larger, which indicates that the de Broglie wavelength is inversely related to the energy of the ejected electron.

Sample: 1B
Score: 7

Part (a) earned 3 points. The first point was earned for correctly indicating that f_B is the least and f_C is the greatest. The second point was not earned because the response indicates that greater frequency means more energy but does not clearly indicate whether the energy is referring to the energy of the photons or to the energy of the ejected electrons. The third point was earned for indicating that the wavelength of the electron is inversely related to the momentum but does not directly relate the wavelength to the speed or kinetic energy of the electron. However, the response does relate energy to momentum, in addition to the inverse relationship between wavelength and momentum, thus correctly relating electron wavelength and electron energy. The fourth point was not earned because the response indicates that the lowest frequency photon results in no ejected electron but does not explicitly indicate that the frequency is below the work function or a threshold frequency. The fifth point was earned for addressing the question asked in a logical, relevant, and internally consistent paragraph-length response.

Question 1 (continued)

Part (b) earned 2 points. The first point was earned for correctly relating the electron's de Broglie wavelength to h, m, and v. The second point was earned for correctly substituting a numerical value for the speed into a relevant equation for kinetic energy. The third point was not earned because the answer includes an incorrect value. Part (c) earned 2 points. The first point was earned for correctly indicating the work function of Metal 2 is greater than the work function of Metal 1 and including a relevant justification. The second point was earned for indicating the frequency and energy hf of the incident photons is the same and indicates the correct relationship between the work function and the difference between hf and maximum kinetic energy.

Sample: 1C
Score: 3

Part (a) earned 1 point. The first point was not earned because, although the response correctly indicates that f_B is the least it incorrectly indicates that f_A is the greatest. The second point was not earned for not explicitly relating the frequency of a photon to the energy of a photon. The third point was not earned for not stating the inverse relationship between kinetic energy or speed of an electron and the wavelength of the electron. The fourth point was not earned because the response does not indicate that a greater photon energy results in greater electron energy and does not indicate that a smaller photon energy (less than the work function) or frequency (less than threshold frequency) results in no ejected electron. The fifth point was earned for addressing the question asked in a logical, relevant, and internally consistent paragraph-length response. Part (b) earned 1 point for correctly relating the kinetic energy to p and m. The second point was not earned for not correctly substituting an algebraic expression, in terms of wavelength, for the momentum and speed of the electron. The third point was not earned for not having a correct answer with units. Part (c) earned 1 point for correctly indicating that the work function of Metal 1 is less than the work function of Metal 2 with an attempt at a relevant justification. The second point was not earned for not including a correct relationship between the work function and the difference between hf and maximum kinetic energy, not indicating the frequency or energy of the incident photons is the same and by not indicating the de Broglie wavelength is inversely related to the energy of the ejected electron.