2018

AP® CollegeBoard

AP Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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AP® PHYSICS
2018 SCORING GUIDELINES

General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

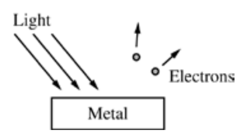
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m}/\text{s}^2$, but the use of $10 \text{ m}/\text{s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 3

12 points total **Distribution of points**

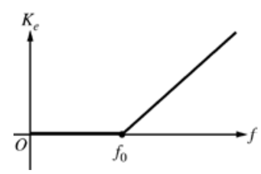


Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

(a)

i. LO 5.B.4.2, SP 1.4, 2.1, 2.2; LO 6.F.3.1, SP 6.4
3 points

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.



For indicating that A represents the slope or the rate of change of K_e as a function of f and equals Planck's constant		1 point
For indicating that -B is the intercept with the K_e axis and equals the minimum energy needed to release an electron from the metal (the work function)		1 point
For indicating that f_0 is the minimum frequency that will release an electron from the metal (the cutoff or threshold frequency)		1 point

ii. LO 6.F.3.1, SP 6.4
1 point

Explain the physical meaning of the horizontal section of the graph between the origin and f_0.

For indicating that the horizontal portion of the graph represents frequencies of light whose energy is insufficient to eject an electron		1 point

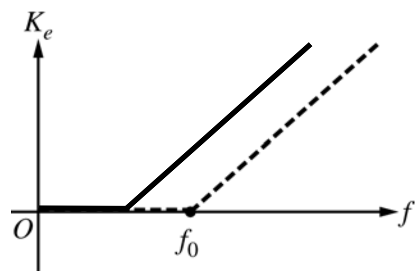
Question 3 (continued)

Distribution of points

(a) (continued)

iii. LO 6.F.3.1, SP 6.4
3 points

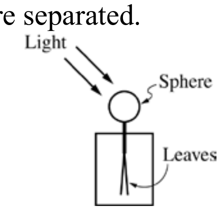
A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



For drawing a line that is parallel to the given line		1 point
For drawing the horizontal intercept on either side of f_0 with the line ending at the horizontal axis (The horizontal segment does not have to be drawn.)		1 point
For indicating that the K_e or f intercept changes because the work function or the frequency at which electrons can be emitted is different		1 point

(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.



i. LO 1.B.1.2, SP 6.4, 7.2, LO 4.E.3.3, SP 6.4; LO 6.F.3.1, SP 6.4
2 points

Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

For indicating that the UV light causes electrons to be ejected from the electroscope		1 point
For indicating that the electroscope becomes less negatively charged, causing the leaves to move closer together		1 point

Question 3 (continued)

Distribution of points

(b) (continued)

ii. LO 6.F.1.1, SP 6.4, 7.2, LO 6.F.3.1, SP 6.4
1 point

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.

For indicating that the green light frequency or energy per photon is too low to eject electrons		1 point

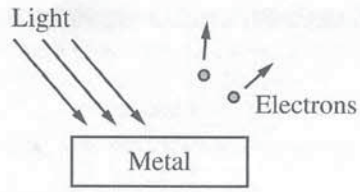
(c) LO 6.F.3.1, SP 6.4
2 points

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.

For indicating that the increase in brightness causes an increase in the number of photons in the beam or increases the amplitude of the wave		1 point
For indicating that the leaves would not separate because the energy per photon or frequency of the light remains the same		1 point
The particle nature of light (photons) must be discussed to receive full credit.		

Learning Objectives (LO)

LO 1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [See Science Practices 6.4, 7.2]
LO 4.E.3.3: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [See Science Practices 1.1, 1.4, 6.4]
LO 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [See Science Practices 1.4, 2.1, 2.2]
LO 6.F.1.1: The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [See Science Practices 6.4, 7.2]
LO 6.F.3.1: The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [See Science Practice 6.4]

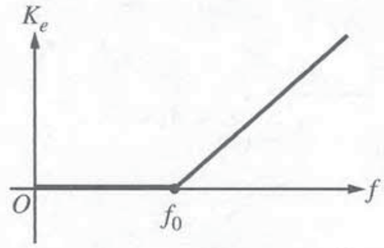


3. (12 points, suggested time 25 minutes)

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 $f \le f_0$, 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.



A is represented by the slope of the graph
B is represented by the y-intercept of the graph

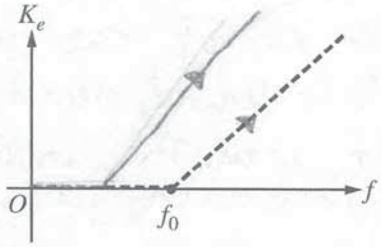
A is equal to planck's constant and determines the energy of a photon given its frequency
B is the work fuction, or amount of energy required to release an electron from the nucleus of one of the metal atoms.
Fo is the minimum frequency required to have enough energy to overcome the work fuction.

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

The horizontal section represents the range of frequencies that don't have enough energy to overcome the work fuction, therefore the electron does not have enough energy to break away from the nucleus. Since the electron is never emmited, Ke cannot be measured.

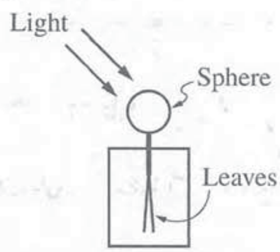
GO ON TO THE NEXT PAGE.

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.



The horizontal section for the graph of a different metal could be different because it could have a lower work fuction.

(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.



i. Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

Due to the photoelectric effect, when light hits the sphere, some electrons in the sphere absorb enough energy from the photons to be emmited. With less total electrons, there is less total negative charge, reducing the repulsive electrostatic force between the leaves, reducing their seperation.

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.

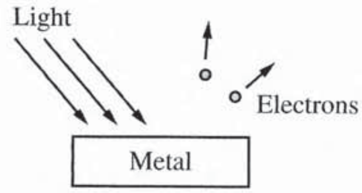
The UV light has a higher frequency than the green light, therefore higher energy. The green light does not give the electrons enough energy to overcome the work function of the metal, or energy required to emmit the electrons. Therefore no charge is lost because no electrons are lost. The UV light has enough energy to overcome the work function.

Question 3 continues on the next page.

GO ON TO THE NEXT PAGE.

(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.

When the brightness of the green light is increased its intensity is increased, meaning more photons are released per unit area. The increase in brightness would not result in movement of the leaves. The change in intensity only changes the amount of photons present and does not change the energy per photon. Each photon would still lack the energy to overcome the work function, meaning no electrons would be released, meaning the leaves wouldn't move.



3. (12 points, suggested time 25 minutes)

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 $f \le f_0$, 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.

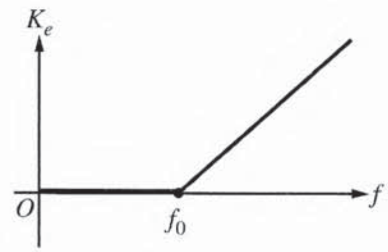
$KE = hf - \cancel{\theta}$

$hf = \theta + KE$

$Af = B + KE$

A corresponds to Planck's constant (4.14 E-15 eV·s)

B corresponds to the work function.



f_0 is the lowest frequency at which electrons are emitted from the metal. fundamental frequency

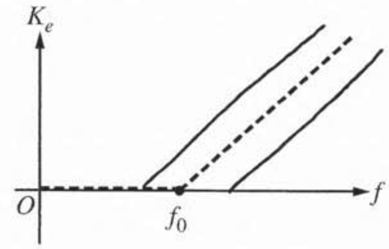
θ (workfunction) is characteristic to the metal, and represents the work required for electrons to be emitted.

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

The physical meaning of the horizontal section of the graph is it is the portion at which there was no KE or electrons emitted from the metal bc the monochromatic light was a $f < f_0$.

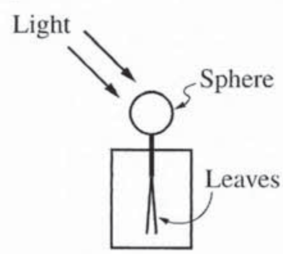
GO ON TO THE NEXT PAGE.

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.



Key difference: the y-intercept or work function (ϕ)
different metal – different work function.

(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.



i. Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

The UV light excites the charges present on the sphere. positive charges are forced down one leaf, and negative charges down the other. This causes an electrostatic force to bring the leaves closer together.

e^- emitted, p^+ take their place, e^- + p^+ attract.

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.

green light does not have a f as high as UV light; therefore, it must've not ~~r~~ reached the threshold f required for the electroscope leaves to move.

e^- not emitted, p^+ can't take their place, e^- + e^- repel.

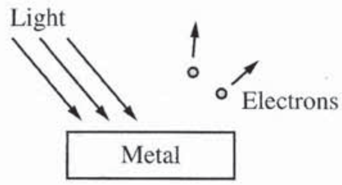
Question 3 continues on the next page.

GO ON TO THE NEXT PAGE.

(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.

When ~~intens~~ brightness is increased the density or the # of green light particles increase.

The brighter green light would still NOT result in movement of the leaves, because the frequency is constant and still insufficient to be able to do so and overcome the work function,



3. (12 points, suggested time 25 minutes)

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.

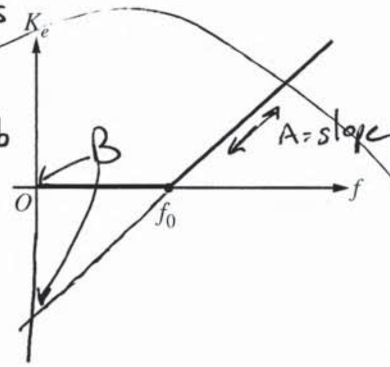
(a)

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 $f \le f_0$, 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.

B is the y-intercept which is at O.

A is the "m" value of y=mx+b so it represents slope.

f_0 represents the threshold frequency that f has to cross before it can translate into Kinetic energy.



~~KE~~
$K_e = Af - B$

If the concept of f_0 wasn't there, the B would intercept at that negative value shown. ~~This doesn't make sense~~

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

Even as the frequency is increasing, there is still no Kinetic energy being produced. If that portion wasn't flat & the graph extended downwards as shown above, it breaks the laws of physics as you can't have low frequency contributing to negative Kinetic energy. The f_0 just serves to say the light isn't adding to electrons energy when $f \le f_0$.

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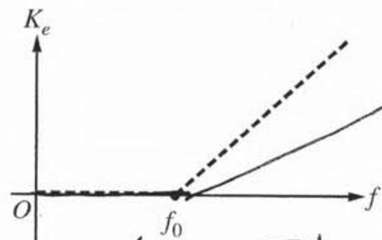
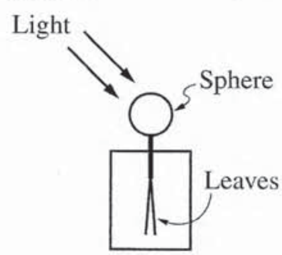
iii. A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



The A value, or slope, is lower. This means that the Ke produced ~~will not be~~ as for the new metal won't be the same as the Ke for the old one at the same frequency. The Ke for the new metal will be less.

(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.



i. Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

UV light has a high frequency. This causes Kinetic Energy to be emitted ~~between the~~ by the electrons that make the leaves lose some charge. This reduces the electrostatic force, enabling the 2 leaves to move closer together.

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.

Green light has far lower frequency than UV light. ~~It~~ One may expect limited movement but instead it produces no movement because $f_{greenlight} \leq f_0$ resulting in no Kinetic Energy gain and ~~loss~~ no loss of electrons.

Question 3 continues on the next page.

(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.

For ~~that~~ brightness to increase, the amplitude of the green light wave increases. This still won't result in the movement of leaves because the increase in amplitude has nothing to do with increase in frequency. ~~If~~ Kinetic energy released is only dependent on frequency. Besides, the light still won't be green if the frequency had increased considerably.

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Question 3

Overview

This question assessed learning objectives 1.B.1.2, 4.E.3.3, 5.B.4.2, 6.F.1.1, and 6.F.3.1.

The responses to this question were expected to demonstrate the following:

- An understanding of the photoelectric effect, both graphical and physical representations, including the following:
  - The concepts of work function, Planck's constant, and threshold frequency.
  - The relationship between the above ideas and the photoelectric equation.
  - The relationship between the photoelectric equation and associated graphs.
- An understanding of the operation of an electroscope.
- An understanding of the properties of light, including the following:
  - The variables that change with intensity.
  - The relationship between visible light and UV on the electromagnetic spectrum.

Sample: P2 Q3 A
Score: 12

This response earned full credit for every part. In parts (a)(i) and (ii), 4 points were earned for showing an understanding of the graph, with its mathematical and physical meaning indicated: A represents the slope of the graph and is equal to Planck's constant, B represents the vertical intercept of the graph and is equal to the work function for the metal, f_0 is equal to the minimum frequency required to release an electron from the metal, and the horizontal portion of the graph represents frequencies of light whose energy is insufficient to eject an electron from the metal. Part (a)(iii) earned 3 points. The response correctly shows a line that is parallel to the given line on the graph, shows the horizontal intercept to the left of f_0 with the line ending at the horizontal axis, and indicates that the horizontal section of the graph of a different metal could be different because it has a different work function. Part (b)(i) earned 2 points. The response indicates that the UV light causes electrons to be ejected from the electroscope, and the electroscope becomes less negatively charged, causing the leaves to move closer together. Part (b)(ii) earned 1 point for indicating that the frequency corresponding to the green light is too low to eject electrons. Part (c) earned 2 points. The response indicates an understanding of the effect of the increase in brightness on the beam, in terms of an increase in the number of photons in the beam. It also indicates that the leaves would not separate because the energy per photon remains the same.

Sample: P2 Q3 B
Score: 7

Part (a)(i) earned 1 point. The response correctly states that f_0 is equal to the minimum frequency required to release an electron from the metal. The response does connect A and B to their physical meanings. However, the quantities are not connected to the graph, which is required to earn each of the associated points. Part (a)(ii) earned no points because it only describes the graph and does not discuss the energy of the light in relation to the ejection of electrons, which is part of the physical meaning of the horizontal section of the graph. Part (a)(iii) earned 3 points. The response correctly shows a line that is parallel to the given line on the graph, has the horizontal intercept on either side of f_0 with the line ending at the horizontal axis, and indicates that the horizontal section of the graph of a different metal could be different because it has a different work function. Part (b)(i) earned no points for an incorrect response, which does not describe how the photoelectric effect results in the motion of the electroscope leaves. Part (b)(ii) earned 1 point for indicating that the frequency corresponding

Question 3 (continued)

to the green light is too low to eject electrons. Part (c) earned 2 points. The response indicates an understanding of the effect of the increase in brightness on the beam, in terms of an increase in the number of photons in the beam. It also indicates that the leaves would not separate because the frequency remains the same.

Sample: P2 Q3 C
Score: 5

In part (a)(i) of this paper, 1 point was earned. The description of f_0 is correct. The variables A and B are connected to their meanings on the graph, slope and horizontal intercept respectively, but not to their physical meanings. Part (a)(ii) earned no points because it only describes the graph and does not discuss the energy of the light in relation to the ejection of electrons, which is part of the physical meaning of the horizontal section of the graph. Part (a)(iii) earned no points. The new slanted line is not parallel to the original line, and the response tries to explain why. The threshold frequency is not clearly different from the original graph, and there is no discussion of a different work function. Part (b)(i) earned 2 points for correctly indicating that the UV light causes electrons to be ejected from the electroscope and how the change in net charge causes the leaves to move closer together. Part (b)(ii) earned 1 point for indicating that the frequency corresponding to the green light is too low to eject electrons. Part (c) earned 1 point. The response correctly describes the relationship between intensity and amplitude and indicates that frequency does not change. It also correctly indicates that the leaves would not move. However, it has no reference to photons, which is required to fully explain the phenomenon.