2018

AP® CollegeBoard

AP Physics 2: Algebra-Based

Scoring Guidelines

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.

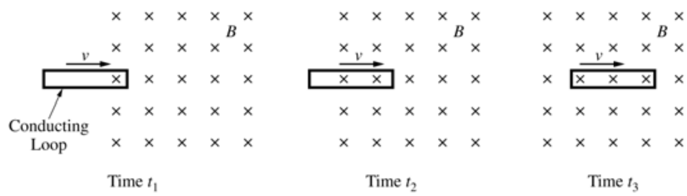
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 $g = 9.8 \text{ m/s}^2$, but the use of 10 m/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 1

10 points total **Distribution of points**



The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

(a) LO 2.D.1.1, SP 2.2; LO 4.E.2.1, SP 6.4
5 points

In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

For indicating that the currents at t_1 and t_2 have equal nonzero magnitudes and are in the same direction		1 point
For indicating that there is no current at t_3		1 point
For correctly indicating that the currents depend on the change in flux through the loop or the forces on the charges moving in the field		1 point
For correctly identifying the direction of the current as counter-clockwise and either explaining that the direction of the current generates a magnetic field that opposes the change in flux <u>or</u> analyzing the force on the charge carriers in each segment of the loop		1 point
For an on-topic response that has sufficient paragraph structure, as described in the published requirements for the paragraph length response		1 point

(b)

The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.

Question 1 (continued)

Distribution of points

(b) (continued)

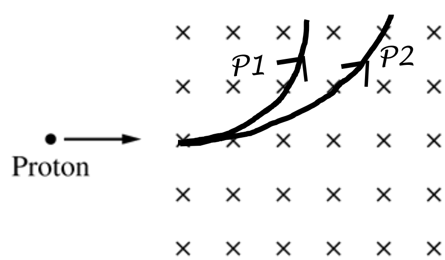
i. LO 2.D.1.1, SP 2.2
1 point

Calculate the magnitude of the force on the proton as it enters the field.

For correct substitutions into a correct expression and correct units on the final answer		1 point
$F = qvB$		
$F = \left(1.6 \times 10^{-19}\ \text{C}\right)\left(3.0 \times 10^{5}\ \text{m/s}\right)(0.03\ \text{T})$		
$F = 1.4 \times 10^{-15}\ \text{N}$		

ii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4; LO 3.C.3.1, SP 1.4
1 point

On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



For drawing a curved arc through the field, curved upward where the proton enters		1 point
Anything greater than a semi-circle or a path that does not reach the edge of the field does not earn credit. Any path after exiting the field is ignored.		

iii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4
1 point

A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

For drawing a path with a larger radius that is consistent with answer to (b)(ii)		1 point

Question 1 (continued)

Distribution of points

(b) (continued)

iv. LO 2.C.1.1, SP 6.4; LO 2.C.1.2, SP 2.2; LO 3.B.2.1, SP 1.4, 2.2
2 points

Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

For indicating a direction of the electric field that is consistent with the response to (b)(ii)		1 point
Given the correct response to (b)(ii) illustrated above, the electric field must be directed in the *-y* direction (or toward the bottom of the page)		
For equating the electric and magnetic forces and substituting into the correct expression using values consistent with the response to (b)(i)		1 point
$qE = qvB$ (Implicitly equating the calculated magnetic force to the electric force is acceptable.)		
$E = vB$		
$E = \left(3.0 \times 10^5 \text{ m/s}\right)(0.03 \text{ T})$		
$E = 9000 \text{ N/C}$		

Learning Objectives (LO)

LO 2.C.1.1: The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation. [See Science Practices 6.4, 7.2]

LO 2.C.1.2: The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. [See Science Practice 2.2]

LO 2.D.1.1: The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See Science Practice 2.2]

LO 3.B.1.4: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]

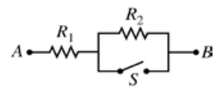
LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]

LO 3.C.3.1: The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [See Science Practice 1.4]

LO 4.E.2.1: The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [See Science Practice 6.4]

Question 2

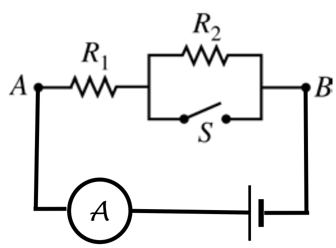
12 points total **Distribution of points**



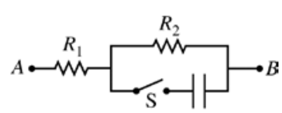
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) LO 4.E.5.3, SP 2.2, 4.2, 5.1; LO 5.B.9.5, SP 6.4; LO 5.C.3.4, SP 6.4
4 points

Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.



For a diagram with an ammeter and battery in series with the resistor combination		1 point
For indicating that the current should be measured with the switch closed and open		1 point
For correctly indicating that with the switch closed $R_1 = V/I_1$		1 point
For correctly indicating that with the switch open $R_2 = (V/I_2) - R_1$		1 point



A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

Question 2 (continued)

Distribution of points

(b)

i. LO 4.E.5.2, SP 6.1, 6.4; LO 5.B.9.5, SP 6.4; LO 5.C.3.7, SP 1.4
3 points

Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

For indicating that the current through resistor 1 immediately after the switch is closed is greater than the current a long time after the switch is closed		1 point
For indicating that the current through resistor 2 is zero immediately after the switch is closed and nonzero a long time after the switch is closed		1 point
For indicating that the current through the switch is nonzero immediately after the switch is closed and zero a long time after the switch is closed		1 point

ii. LO 4.E.5.1, SP 2.2, 6.4
2 points

Calculate the values of R_1 and R_2.

For using the correct value of current and correctly calculating R_1		1 point
$9\ \text{V} = (0.9\ \text{A})R_1$		
$R_1 = 10\ \Omega$		
For using the correct value of current and correctly calculating R_2, consistent with the calculated value of R_1		1 point
$9\ \text{V} = (0.3\ \text{A})(R_1 + R_2) = (0.3\ \text{A})(10\ \Omega + R_2)$		
$R_2 = 20\ \Omega$		

iii. LO 4.E.5.1, SP 2.2; LO 5.B.9.6, SP 2.2, LO 5.C.3.7, SP 1.4, 2.2
1 point

Determine the potential difference across the capacitor a long time after the switch is closed.

For correctly calculating the potential difference across the capacitor, including correct units, consistent with part (b)(ii)		1 point
$V_C = V_{\text{battery}} - V_{\text{resistor 1}} = 9\ \text{V} - (0.3\ \text{A})(10\ \Omega)$		
$V_C = 6\ \text{V}$		

Question 2 (continued)

Distribution of points

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) LO 5.B.9.7, SP 5.3
2 points

How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

For correctly explaining that the third group's measured current is smaller		1 point
For correctly indicating that the third group's value of R_1 is higher than the second group's or the resistance they will determine is actually $R_1 + r$		1 point

Learning Objectives (LO)

LO 4.E.5.1: The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 2.2, 6.4]

LO 4.E.5.2: The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 6.1, 6.4]

LO 4.E.5.3: The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [See Science Practices 2.2, 4.2, 5.1]

LO 5.B.9.5: The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See Science Practice 6.4]

LO 5.B.9.6: The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]

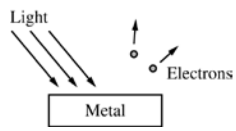
LO 5.B.9.7: The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [See Science Practices 4.1, 4.2, 5.1, 5.3]

LO 5.C.3.4: The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. [See Science Practices 6.4, 7.2]

LO 5.C.3.7: The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [See Science Practice 1.4, 2.2]

Question 3

12 points total **Distribution of points**

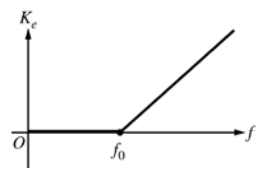


Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

(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 $f \le f_0$, 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.



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

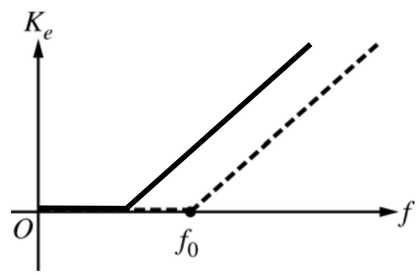
Question 3 (continued)

Distribution of points

(a) (continued)

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

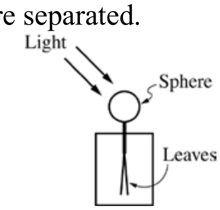
A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



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]

Question 4

10 points total — **Distribution of points**

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b. The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel}. The boat owners want to be able to carry as many beams as possible.

(a) LO 1.E.1.2, SP 6.4; LO 3.B.2.1, SP 1.1, 1.4, 2.2; LO 5.B.10.1, SP 2.2
4 points

Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

For equating the correct forces acting on the boat-steel system: gravity (weight) and the buoyant force		1 point
For correctly calculating the weight of the boat-steel system		1 point
$W_{system} = (M_b + N_{steel}\rho_{steel}V_{steel})g$, where N is the number of steel beams (must clearly use mass of boat)		
For correctly calculating the buoyant force		1 point
$F_b = \rho_{water}gV_b$		
For algebraic manipulation of the equations to get an expression for the number of beams consistent with the equations for weight and buoyant force		1 point
$(M_b + N\rho_{steel}V_{steel})g = \rho_{water}gV_b$		
$N = (\rho_{water}V_b - M_b)/\rho_{steel}V_{steel}$		

(b) LO 6.C.1.1, SP 6.4, 7.2; LO 6.E.1.1, SP 6.4, 7.2; LO 6.E.3.3, SP 6.4, 7.2
4 points

The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

The constructive interference is between light reflected from the air-oil interface and light reflected from the oil-water interface.		
For indicating that the green appearance is the result of interference of light from two waves		1 point
For indicating that there is a phase shift due to one of the reflections		1 point
For indicating that the wavelength of the light is different in air and oil		1 point
For indicating that there is a path-length difference of the light reflected from the two surfaces		1 point

Question 4 (continued)

Distribution of points

(c) LO 5.F.1.1, SP 2.2, 7.2
2 points

Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

For an attempting to apply the principle of continuity		1 point
$A_{wide}v_{wide} = A_{narrow}v_{narrow}$		
$(60 \text{ m})(\text{depth})(5 \text{ km/hr}) = (30 \text{ m})(\text{depth})(v_{narrow})$		
For correctly calculating the speed		1 point
$v_{narrow} = 10 \text{ km/hr}$		

Learning Objectives (LO)

LO 1.E.1.2: The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [See Science Practices 4.1, 6.4]
LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]
LO 5.B.10.1: The student is able to use Bernoulli's equation to make calculations related to a moving fluid. [See Science Practice 2.2]
LO 5.F.1.1: The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [See Science Practices 2.1, 2.2, 7.2]
LO 6.C.1.1: The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [See Science Practices 6.4, 7.2]
LO 6.E.1.1: The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [See Science Practices 6.4, 7.2]
LO 6.E.3.3: The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [See Science Practices 6.4, 7.2]