AP® Physics C: Electricity and Magnetism
2010 Scoring Guidelines

The College Board

AP® PHYSICS
2010 SCORING GUIDELINES

General Notes

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

2. 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 — for example, a speed faster than the speed of light in vacuum.

3. 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 contains the application of that equation to the problem but the student does not write the basic equation, 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 AP Physics Exam equation sheets. 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 Course Description*.

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

5. 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

15 points total **Distribution of points**

(a) 3 points

For indicating that the potential at point B ranks 1 (has the highest potential)	1 point
For indicating that the potentials at points A and C are equal and rank 2	1 point
For a correct justification	1 point

Example: Compared to points A and C, point B is closer to most, and possibly all, points along the charge distribution. Since potential varies inversely with distance, point B has the highest potential. Points A and C have the same potential by symmetry.

(b) 2 points

For any indication of correct qualitative reasoning about the potential for this particular geometry — 1 point

Example: All points on the arc are a distance R from point P. Since potential is a scalar quantity, the potential will be the same as that of a point charge with charge Q located a distance R away.

For a correct answer — 1 point

$V = kQ/R$

Alternate solution — *Alternate points*

For indicating the potential is obtained by integrating the contributions from each part of the charge distribution — *1 point*

$$V = \int \frac{kdq}{r} \quad \text{where} \quad dq = \lambda r\, d\theta = \frac{Q}{r(\pi/2)} r\, d\theta = \frac{2Q}{\pi} d\theta$$

Noting that $r = R$ *for the entire distribution, the integral becomes:*

$$V = \frac{2kQ}{\pi R} \int_0^{\pi/2} d\theta$$

For a correct answer — *1 point*

$V = kQ/R$

(c) 4 points

For an indication that mechanical energy is conserved — 1 point

$U_i + K_i = U_f + K_f$

For correct substitution of potential energies — 1 point

$U_f = 0$

$U_i = qV$

For substituting the potential at P from part (b) — 1 point

$q(kQ/R) = K_f$

For substituting correctly for the kinetic energy and solving for the velocity — 1 point

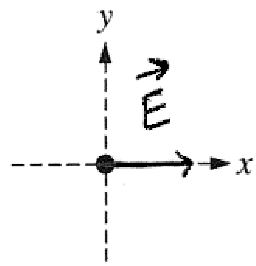
$q(kQ/R) = (1/2)mv^2$

$v = \sqrt{2kqQ/mR}$

Question 1 (continued)

Distribution of points

(d) 1 point



For a vector drawn in the correct direction — horizontally to the right — 1 point

(e) 5 points

For any indication that the net electric field is the integral of all of the horizontal components from each part of the charge — 1 point

$|\boldsymbol{E}| = E_x = \int dE_x$

For correctly using cosine in computing the x-component — 1 point

$|\boldsymbol{E}| = \int dE\cos\theta = \int \frac{k\,dQ}{R^2}\cos\theta$

For changing variables to integrate with respect to θ — 1 point

$dq = \frac{2Q}{\pi}d\theta$

For correct limits of integration — 1 point

$|\boldsymbol{E}| = \int_{-\pi/4}^{\pi/4} \frac{2kQ}{\pi R^2}\cos\theta\,d\theta$ (or equivalent limits such as $\frac{3\pi}{4}$ and $\frac{5\pi}{4}$)

$|E| = \frac{2kQ}{\pi R^2}\sin\theta\Big|_{-\pi/4}^{\pi/4}$

For a correct answer — 1 point

$|\boldsymbol{E}| = \frac{2\sqrt{2}\,kQ}{\pi R^2}$

Question 2

15 points total	**Distribution of points**
(a) 2 points	
For correctly stating that there is no current in the steady state $I = 0\text{ A}$	2 points
(b) 2 points	
$Q = CV$	
For correct substitution of capacitance into the equation above $Q = (10\ \mu\text{F})(30\text{ V})$	1 point
For a correct numerical answer with units $Q = 300\ \mu\text{C}$	1 point
(c) 3 points	
$U = \frac{1}{2}CV^2$	
For substitution of the correct capacitance (in units of μF or F) into the correct expression for energy	1 point
For substitution of the battery voltage into the correct expression for energy $U = \frac{1}{2}(5\ \mu\text{F})(30\text{ V})^2$	1 point
For correct units on a numerical answer $U = 2250\ \mu\text{J}$	1 point
(d) 2 points	
For recognizing the two resistors are now in series and correctly calculating the equivalent resistance $R_T = 20\ \Omega + 40\ \Omega = 60\ \Omega$ $V = IR$ $I = V/R$	1 point
For substitution of the correct voltage and the calculated equivalent resistance into Ohm's law $I = 30\text{ V}/60\ \Omega$ $I = 0.5\text{ A}$	1 point

Question 2 (continued)

Distribution of points

(e) 3 points

For recognizing that the voltage across the $5.0\ \mu\text{F}$ capacitor is the same as that for the $40\ \Omega$ resistor and calculating that voltage — 1 point

$V_{40\ \Omega} = (0.5\ \text{A})(40\ \Omega) = 20\ \text{V}$

$Q = CV$

For correctly substituting the value of the capacitance into the above equation — 1 point

$Q = (5.0\ \mu\text{F})(20\ \text{V})$

For the correct answer — 1 point

$Q = 100\ \mu\text{C}$

Alternate solution — *Alternate points*

For correctly applying the loop equation to the loop that includes the $5.0\ \mu\text{F}$ capacitor, the $20\ \Omega$ resistor and the $30\ \text{V}$ battery — *1 point*

$$V - IR - \frac{Q}{C} = 0$$

$Q = (C)(V - IR)$

For correctly substituting the current and the resistances — *1 point*

$Q = (5.0\ \mu\text{F})[(30\ \text{V}) - (0.5\ \text{A})(20\ \Omega)]$

For the correct answer — *1 point*

$Q = 100\ \mu\text{C}$

(f) 3 points

$P = I^2R$

For correct substitution of the total current from part (d) and the resistance into the above equation for power (or substituting correct values into $P = V^2/R$ or $P = IV$) — 1 point

$P = (0.5\ \text{A})^2(40\ \Omega) = 10\ \text{W}$

For correctly substituting the power into an equation for energy — 1 point

For correctly substituting the time in seconds into an equation for energy — 1 point

$E = Pt$

$E = (10\ \text{W})(60\ \text{s})$

$E = 600\ \text{J}$

Note: If time is not substituted using seconds, the units on the final answer must be consistent with the substitution.

Question 3

15 points total | **Distribution of points**

(a) 4 points

For a correct indication that the current in the loop is in the counterclockwise direction	1 point
For indicating that the magnetic field through the loop is directed out of the page (which can be done on the diagram)	1 point
For indicating that the current in the wire is decreasing, either explicitly or by indicating a decrease in field or flux through the loop	1 point
For indicating that the direction of the induced current is such as to oppose the change in flux	1 point

Example: The flux due to current I is out of the plane of the page (by the right-hand rule) and is decreasing with time. The induced current will be in the direction that will produce a compensating flux (by Lenz's law). Again using a right-hand rule, the current must be counterclockwise.

(b) 2 points

For a correct indication that the brightness of the lightbulb remains the same	1 point
For a correct justification	1 point

Example: The field and the flux both vary linearly with time. The emf, which is the time derivative of the flux, must then be constant. Since the power output of the lightbulb depends only on the emf and resistance (which are both constant), the power must be constant.

(c) 2 points

$$\oint \mathbf{B} \cdot d\ell = \mu_0 I$$

$$B 2\pi r = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B = \left.\frac{\mu_0 I}{2\pi r}\right|_{t=0}$$

For the correct answer — 2 points

$$B = \frac{\mu_0 I_0}{2\pi r}$$

One point partial credit could be earned for either correctly applying Ampere's law and leaving the result in terms of I, or obtaining an incorrect expression for B in terms of I_0.

Question 3 (continued)

Distribution of points

(d) 4 points

$\phi = \int \mathbf{B} \cdot d\mathbf{A}$

For correctly substituting the expression for B as a function of r into the flux equation — 1 point

$\phi = \int \left(\dfrac{\mu_0 I}{2\pi r} \right) dA$

For correctly recognizing that $dA = b\ dr$ — 1 point

$\phi = \int \left(\dfrac{\mu_0 I}{2\pi r} \right) b\ dr$

For correctly integrating with respect to r — 1 point

$$\phi = \frac{\mu_0 I b}{2\pi} \int_d^{d+a} \frac{dr}{r}$$

$$\phi = \frac{\mu_0 I b}{2\pi} \ln(r) \Big|_d^{d+a}$$

$$\phi = \frac{\mu_0 I b}{2\pi} \ln\left(\frac{d+a}{d} \right)$$

For correctly substituting the current as a function of time — 1 point

$$\phi = \frac{\mu_0 (I_0 - Kt) b}{2\pi} \ln\left(\frac{d+a}{d} \right)$$

(e) 3 points

$P = V^2 / R$ (which can be derived from $P = I^2 R$ and $V = IR$)

For recognizing that the voltage across the bulb is the induced emf in the loop, and using that emf in the above expression for power — 1 point

$P = \mathcal{E}^2 / R$, where $\mathcal{E} = -d\phi/dt$

For correctly substituting the flux from part (d) into the above equation for emf — 1 point

$$\mathcal{E} = -\frac{d}{dt}\left[\frac{\mu_0 b (I_0 - Kt)}{2\pi} \ln\left(\frac{d+a}{d} \right) \right]$$

For correctly taking the derivative (with respect to time) of the flux — 1 point

$$\mathcal{E} = -\frac{\mu_0 b}{2\pi} \ln\left(\frac{d+a}{d} \right) \left[\frac{d}{dt} (I_0 - Kt) \right]$$

$$\mathcal{E} = -\frac{\mu_0 b}{2\pi} \ln\left(\frac{d+a}{d} \right) (-K)$$

$$P = \frac{\mathcal{E}^2}{R} = \frac{1}{R} \left[\frac{\mu_0 b K}{2\pi} \ln\left(\frac{d+a}{d} \right) \right]^2$$

Note: If $P = I\mathcal{E}$ is used with the expression for the current in the long wire (rather than the loop) being substituted for I, the last 2 points for correctly determining the emf could still be earned.