AP® Physics C: Electricity and Magnetism
2009 Scoring Guidelines

The College Board

General Notes About 2009 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. 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.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one 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 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 Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m}/\text{s}^2$, but 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.

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)

(i) 3 points

For indicating the field points radially inward — 1 point

$$E_r = -\frac{dV}{dr}$$

For correctly substituting the electric potential for $r < R$ into the equation for the electric field — 1 point

$$E_{inside} = -\frac{dV_{inside}}{dr} = -\frac{d}{dr}\left(\frac{Q_0}{4\pi\epsilon_0 R}\left[-2 + 3\left(\frac{r}{R}\right)^2\right]\right)$$

For correctly taking the derivative of the potential function to determine the magnitude of the electric field — 1 point

$$|E_{inside}| = \frac{Q_0}{4\pi\epsilon_0 R}\left[(3)(2)\left(\frac{r}{R}\right)\left(\frac{1}{R}\right)\right]$$

$$|E_{inside}| = \frac{6Q_0 r}{4\pi\epsilon_0 R^3}$$

(ii) 2 points

For indicating the field points radially outward — 1 point

$$E_r = -\frac{dV}{dr}$$

$$E_{outside} = -\frac{dV_{outside}}{dr} = -\frac{d}{dr}\left(\frac{Q_0}{4\pi\epsilon_0 r}\right)$$

For the correct answer — 1 point

$$|E_{outside}| = \frac{Q_0}{4\pi\epsilon_0 r^2}$$

Question 1 (continued)

Distribution of points

(b)

(i) 3 points

For using Gauss's law — 1 point

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q_{enclosed}}{\epsilon_0}$$

For substituting the correct expression for the flux through a Gaussian sphere — 1 point

$$E 4\pi r^2 = \frac{Q_{enclosed,\ r<R}}{\epsilon_0}$$

$$E_{inside} = \frac{Q_{enclosed,\ r<R}}{4\pi\epsilon_0 r^2}$$

For substituting the appropriate expression for the electric field, consistent with the answer to part (a), including a minus sign — 1 point

$$-\frac{6Q_0 r}{4\pi\epsilon_0 R^3} = \frac{Q_{enclosed,\ r<R}}{4\pi\epsilon_0 r^2}$$

$$Q_{enclosed,\ r<R} = -\frac{6Q_0 r^3}{R^3}$$

(ii) 2 points

From Gauss's law as shown above

$$E = \frac{Q_{enclosed}}{4\pi\epsilon_0 r^2}$$

For correctly substituting the electric field from part (a) into the expression above — 1 point

$$E_{outside} = \frac{Q_0}{4\pi\epsilon_0 r^2} = \frac{Q_{enclosed,\ r>R}}{4\pi\epsilon_0 r^2}$$

$$Q_{enclosed,\ r>R} = Q_0$$

The field points outward, so the charge is positive.

For the correct enclosed charge for $r > R$ — 1 point

$$Q_{enclosed,\ r>R} = +Q_0$$

Question 1 (continued)

Distribution of points

(c) 2 points

There is charge residing on the surface of the sphere.

For indicating that the total enclosed charge equals the charge at the surface plus all the charge inside the sphere — 1 point

$$Q_{enclosed,\ r>R} = Q_{surface} + Q_{enclosed,\ r<R} \text{ when } r=R$$

$$Q_{surface} = Q_{enclosed,\ r>R} - Q_{enclosed,\ r<R} \text{ when } r=R$$

For substituting the correct value of $Q_{enclosed,\ r<R}$ when $r=R$ — 1 point

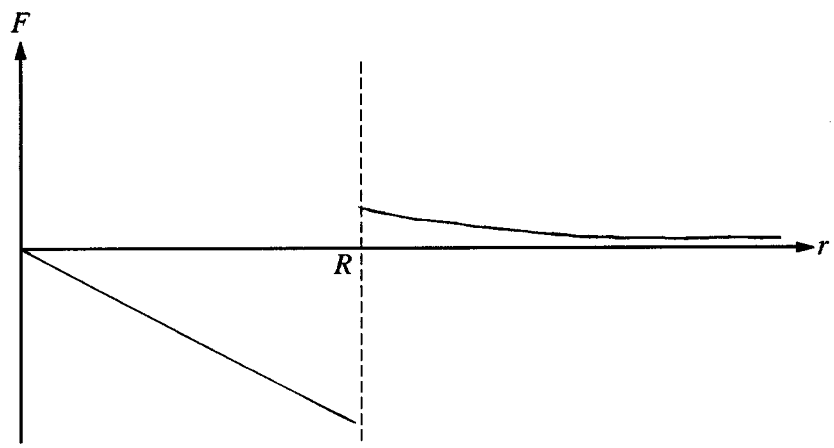
$$Q_{surface} = Q_0 - \left(-\frac{6Q_0R^3}{R^3}\right)$$

$$Q_{surface} = Q_0 - (-6Q_0)$$

$$Q_{surface} = 7Q_0$$

Note: The student could earn 1 point for a correct qualitative description of the charge configuration, even if the surface charge was not calculated.

(d) 3 points



For having the graph for $r < R$ consistent with the answer to part a (i) — 1 point

For having the graph for $r > R$ consistent with the answer to part a (ii), with a finite value at $r = R$ — 1 point

For having a step discontinuity at $r = R$ indicating the presence of charge at the surface (Having both graphs asymptotic to $r = R$ does not constitute the correct discontinuity.) — 1 point

Question 2

15 points total **Distribution of points**

(a) 3 points

For correctly substituting the given values into the expression for resistance — 1 point

$R = \rho\ell/A$

$R = \left(4.5\times10^{-4}\ \Omega\bullet\text{m}\right)(0.080\ \text{m})\big/\left(5.0\times10^{-6}\ \text{m}^2\right) = 7.2\ \Omega$

For correctly combining $V = IR$ and $P = IV$ to get an expression for power in terms of voltage and resistance — 1 point

$P = V^2/R$

$P = (9.0\ \text{V})^2/7.2\ \Omega$

For the correct answer — 1 point

$P = 11\ \text{W}$

Alternate solution: *Alternate Points*

For correctly substituting the given values into the expression for resistance — *1 point*

$R = \rho\ell/A$

$R = \left(4.5\times10^{-4}\ \Omega\bullet\text{m}\right)(0.080\ \text{m})\big/\left(5.0\times10^{-6}\ \text{m}^2\right) = 7.2\ \Omega$

For correctly combining $V = IR$ and $P = IV$ to get an expression for power in terms of current and resistance — *1 point*

$P = I^2R$

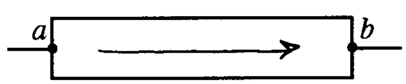
$I = 9.0\ \text{V}/7.2\ \Omega = 1.25\ \text{A}$

$P = (1.25\ \text{A})^2(7.2\ \Omega)$

For the correct answer — *1 point*

$P = 11\ \text{W}$

(b) 3 points



Side View

For an arrow directed from *a* to *b* — 1 point

For correctly indicating that the conventional current is from *a* to *b* OR that the electron current is from *b* to *a* — 1 point

For correctly indicating that the electric field is in the same direction as the conventional current OR in the opposite direction to the electron current — 1 point

Alternate solution: *Alternate Points*

For an arrow directed from a to b — *1 point*

For stating that point a is at a higher potential than point b — *1 point*

For stating that electric field points from higher to lower potential — *1 point*

Note: The third point could be earned for an incorrect field direction consistent with an incorrect current or potential drop direction.

Question 2 (continued)

Distribution of points

(c) 2 points

For recognizing that the electric field is uniform in the bar and stating the relationship between V and E for a uniform field — 1 point

$E = V/\ell$

$E = (9.0\ \text{V})/(0.080\ \text{m})$

For the correct answer — 1 point

$E = 110\ \text{V/m}$

Alternate solution: — *Alternate Points*

$E = \rho J$

For correctly calculating the current density — *1 point*

$J = I/A = 1.25\ \text{A}\big/5.0\times10^{-6}\ \text{m}^2$

$J = 2.5\times10^{5}\ \text{A}\big/\text{m}^2$

$E = J = \left(4.5\times10^{-4}\ \Omega\bullet\text{m}\right)\left(2.5\times10^{5}\ \text{A}\big/\text{m}^2\right)$

For the correct answer — *1 point*

$E = 110\ \text{V/m}$

(d) 2 points

For applying the equation for the magnetic force on a wire with current — 1 point

$F = I\ell B$

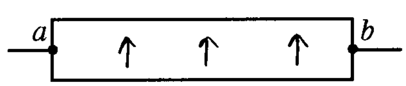
For substituting for current, in terms of either the given quantities or numerical values consistent with previous calculations, for example, the current determined in part (a) — 1 point

Examples: $F = (V/R)\ell B = V\ell B/R$ OR $F = I\ell B$

$F = (9.0\ \text{V})(0.08\ \text{m})(0.25\ \text{T})/(7.2\ \Omega)$ OR $F = (1.25\ \text{A})(0.080\ \text{m})(0.25\ \text{T})$

$F = 0.025\ \text{N}$

(e) 1 point



Side View

For arrows indicating an electric field directed toward the top of the bar — 1 point

Question 2 (continued)

Distribution of points

(f) 3 points

For recognizing that when there is no longer deflection, the electric force is equal and opposite to the magnetic force — 1 point

$F_E = F_B$

For the correct expressions for the electric force and the magnetic force — 1 point

$F_E = qE$

$F_B = qvB$

$qE = qvB$

$E = vB$

For correctly substituting values — 1 point

$E = \left(3.5 \times 10^{-3} \text{ m/s}\right)(0.25 \text{ T})$

$E = 8.8 \times 10^{-4} \text{ V/m}$

Units point

For the correct units on at least two numerical answers — 1 point

Question 3

15 points total | **Distribution of points**

(a) 4 points

Using the expression for the magnitude of the induced emf

$$|\mathcal{E}| = \left| -\frac{d\phi_m}{dt} \right|$$

For recognizing that the area is constant in time — 1 point

$$|\mathcal{E}| = A\left|\frac{dB}{dt}\right|$$

For correctly taking the time derivative of the magnetic field — 1 point

$$\left|\frac{dB}{dt}\right| = \frac{d}{dt}(at+b) = a$$

For a correct expression for the emf — 1 point

For a positive value for the magnitude of the emf — 1 point

$$|\mathcal{E}| = aL^2$$

(b)

(i) 2 points

The resistors are in series, so the total current flows through both of them.

$$I = \frac{\mathcal{E}}{R_{tot}}$$

For correctly calculating the resistance of the two resistors in series — 1 point

$$R_{tot} = \sum R_i = 2R_0$$

For correctly substituting the value of the emf from part (a) — 1 point

$$I = \frac{aL^2}{2R_0}$$

Alternate solution: — *Alternate Points*

$$I_2 = \frac{\mathcal{E}_2}{R_2}$$

The resistors have equal resistance, so the emf across each is half the total emf.

For correctly substituting the emf across bulb 2, consistent with the answer to part (a) — *1 point*

$$I_2 = \frac{\left(aL^2/2\right)}{R_2}$$

For correctly substituting the resistance of bulb 2 — *1 point*

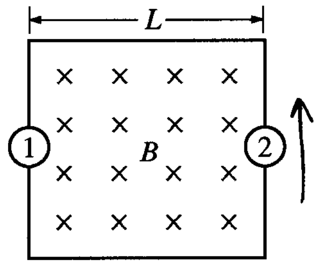
$$I_2 = \frac{\left(aL^2/2\right)}{R_0} = \frac{aL^2}{2R_0}$$

Question 3 (continued)

Distribution of points

(b) (continued)

(ii) 1 point



For indicating that current flows upward in bulb 2 or counterclockwise around the loop — 1 point

(c) 2 points

$P_1 = I_1 V_1 = I_1^2 R_1 = V_1^2 / R_1$

For substituting one correct value into one of the above expressions — 1 point

For substituting a second correct value in the chosen expression — 1 point

$$P = \left(\frac{aL^2}{2R_0}\right)\left(\frac{aL^2}{2}\right) \quad \text{OR} \quad P = \left(\frac{aL^2}{2R_0}\right)^2 R_0 \quad \text{OR} \quad P = \left(\frac{aL^2}{2}\right)^2 \Big/ R_0$$

$$P = a^2 L^4 / 4R_0$$

(d) 4 points

For indicating that bulb 1 is brighter — 1 point

For any indication that the emf is the same as in the original circuit (since there is no flux through the added loop) — 1 point

For stating that adding a bulb in parallel with bulb 2 decreases the overall resistance of the circuit — 1 point

For stating that decreasing the overall resistance increases the overall current, which is equal to the current in bulb 1 — 1 point

(e) 2 points

For indicating that bulb 1 is the same brightness as in the original circuit — 1 point

For a complete and correct justification — 1 point

Examples:

Since each loop has half the area, each has half the original emf. But each also has half the resistance. This means the current and thus the power in bulb 1 is the same.

The two loops are essentially identical. Separately, the flux through each loop would create an emf that is counterclockwise. Since these emfs are in opposite directions in the central wire, the net effect is that there is no emf in that wire. Therefore the situation is equivalent to the original one.