AP® Physics C: Electricity and Magnetism
2008 Scoring Guidelines

AP® PHYSICS
2008 SCORING GUIDELINES

General Notes About 2008 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 $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ 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)

(i) 2 points

For indicating that the charge on the inner surface of the shell is $-Q$	1 point
For a correct explanation with no incorrect statements	1 point

Examples:

- Applying Gauss's law to a Gaussian surface within the shell gives $Q_{enclosed} = 0$, since the field within a conductor is zero. Therefore the charge on the inner surface of the shell is $-Q$.
- The $+Q$ on the sphere attracts an equal and opposite charge onto the inner surface of the shell. (Equal magnitude could be implied by a statement that earned the first point.)

(ii) 2 points

For indicating that the charge on the outer surface of the shell is $+Q$	1 point
For a correct explanation with no incorrect statements	1 point

Examples:

- Applying Gauss's law to a Gaussian surface outside the shell gives $Q_{enclosed} = +Q$, therefore the sum of the charges on the inner and outer surfaces of the shell must be 0.
- The net charge on the shell is zero. Therefore the charge on the outer surface must be the opposite of the charge on the inner surface because of conservation of charge.

<u>Note</u>: If the correct sign of the charge is given in part i or ii without the magnitude (Q), a correct explanation could receive 1 point.

(b)

(i) 1 point

Since the sphere is a conductor all the charge lies on the outside surface. Applying Gauss's law to any Gaussian surface inside the sphere gives $Q_{enclosed} = 0$.

For a correct answer — 1 point

$E = 0$

(ii) 1 point

For any surface between the sphere and the shell the net enclosed charge is $+Q$.

Applying Gauss's law

$E 4\pi r^2 = Q/\epsilon_0$

For a correct answer — 1 point

$E = Q/4\pi\epsilon_0 r^2$ or $E = kQ/r^2$

Question 1 (continued)

Distribution of points

(b) (continued)

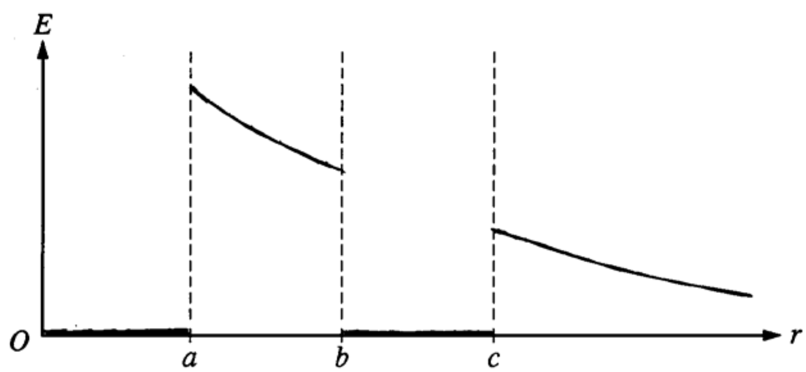
(iii) 1 point

For any surface inside the shell the net enclosed charge is zero.
For a correct answer — 1 point
$E = 0$

(iv) 1 point

For any surface outside the shell the net enclosed charge is $+Q$.
Applying Gauss's law
$E4\pi r^2 = Q/\epsilon_0$
For a correct answer — 1 point
$E = Q/4\pi\epsilon_0 r^2$ or $E = kQ/r^2$

(c) 4 points



For drawing $E = 0$ for $0 \le r \le a$ (must have a line drawn on the axis) — 1 point
For drawing a positive, decreasing, concave up function with $E(b) \ne 0$ for $a \le r \le b$ — 1 point
For drawing $E = 0$ for $b \le r \le c$ (must have a line drawn on the axis) — 1 point
For drawing a positive, decreasing, concave up function with $E(c) < E(b)$ for $r \ge c$ — 1 point

Question 1 (continued)

Distribution of points

(d) 3 points

Note: The intent of the problem was to ask for the speed at a distance of 10*c* instead of the stated 10*r*. Very few students did anything other than treat 10*r* as if it were outside the shell.

For a correct statement of conservation of energy — 1 point

For example, $K + U = 0$

For correct substitution of all variables into a correct relationship (including integration limits of ∞ and 10*r* if integration is used) — 1 point

For example, $\frac{1}{2}m_e v^2 + \frac{Q(-e)}{4\pi\epsilon_0(10r)} = 0$

For a correct solution for the speed — 1 point

$$\frac{1}{2}m_e v^2 = \frac{Qe}{4\pi\epsilon_0(10r)}$$

$$v^2 = \frac{2Qe}{4\pi\epsilon_0 m_e(10r)} = \frac{1}{4\pi\epsilon_0}\frac{Qe}{5m_e r}$$

$$v = \sqrt{\frac{1}{4\pi\epsilon_0}\frac{Qe}{5m_e r}}$$ or equivalent

Note: If a student noted that $10r$ did not define a definite radius, points were awarded as appropriate for attempting a calculation in any region or several regions, or for a clear indication that the solution is region-dependent.

Question 2

15 points total — **Distribution of points**

(a)

(i) 4 points

For calculating the equivalent resistance of the parallel branch — 1 point

$$\frac{1}{R_{resP}} = \frac{1}{(100+50)\ \Omega} + \frac{1}{300\ \Omega} = \frac{3}{300\ \Omega}$$

$R_{resP} = 100\ \Omega$

For calculating the total resistance of the circuit — 1 point

$R_{resT} = R_1 + R_{resP} = 200\ \Omega + 100\ \Omega = 300\ \Omega$

For correctly using the total resistance to compute the current through the battery — 1 point

$I_{resT} = \mathcal{E}/R_{resT} = 1500\ \text{V}/300\ \Omega = 5\ \text{A}$

For correctly using the total current to calculate the voltage across R_2 — 1 point

$V_{1res} = I_{resT}R_1 = (5\ \text{A})(200\ \Omega) = 1000\ \text{V}$

$V_{2res} = \mathcal{E} - V_{1res} = 1500\ \text{V} - 1000\ \text{V}$

$V_{2res} = 500\ \text{V}$

Alternate solution — *Alternate points*

For the correct Kirchhoff junction equation — *1 point*

$I_1 = I_2 + I_3$

For one correct loop equation $(\Sigma V = 0)$ — *1 point*

For a second correct loop equation — *1 point*

$1500\ \text{V} - (200\ \Omega)I_1 - (300\ \Omega)I_2 = 0$

$1500\ \text{V} - (200\ \Omega)I_1 - (150\ \Omega)I_3 = 0$

Using these three equations to solve for I_2

$1500\ \text{V} - (200\ \Omega)I_1 - (300\ \Omega)I_2 = 1500\ \text{V} - (200\ \Omega)I_1 - (150\ \Omega)I_3$

$(300\ \Omega)I_2 = (150\ \Omega)I_3$

$2I_2 = I_3$

$I_1 = I_2 + 2I_2 = 3I_2$

$1500\ \text{V} - (200\ \Omega)3I_2 - (300\ \Omega)I_2 = 0$

$I_2 = 1.67\ \text{A}$

For correctly using the current I_2 *to calculate the voltage across* R_2 — *1 point*

$V_{2res} = (1.67\ \text{A})(300\ \Omega)$

$V_{2res} = 500\ \text{V}$

Question 2 (continued)

Distribution of points

(a) (continued)

(ii) 2 points

For indicating that the current in branch 3 is zero immediately after the switch is closed, either explicitly or by correctly calculating the total resistance at this instant — 1 point

$R_{indT} = R_1 + R_2 = 200\ \Omega + 300\ \Omega = 500\ \Omega$

For correctly using the total resistance to calculate the voltage across resistor R_2 — 1 point

$I_{indT} = \mathcal{E}/R_{indT} = 1500\ \text{V}/500\ \Omega = 3\ \text{A}$

$V_{2ind} = (3\ \text{A})(300\ \Omega) = 900\ \text{V}$

Alternate solution — *Alternate points*

For one correct Kirchhoff equation indicating knowledge that there is no current through resistor R_3 — *1 point*

$1500\ \text{V} - (200\ \Omega)I_{indT} - (300\ \Omega)I_{indT} = 0$

$I_{indT} = 3\ \text{A}$

For correctly using the current to calculate the voltage across resistor R_2 — *1 point*

$V_{2ind} = (3\ \text{A})(300\ \Omega)$

$V_{2ind} = 900\ \text{V}$

(iii) 3 points

For indicating that the voltage across the capacitor is zero immediately after the switch is closed, either explicitly or by correctly calculating the total resistance — 1 point

$$\frac{1}{R_{capP}} = \frac{1}{100\ \Omega} + \frac{1}{300\ \Omega} = \frac{4}{300\ \Omega}$$

$R_{capP} = 75\ \Omega$

$R_{capT} = R_1 + R_{capP} = 200\ \Omega + 75\ \Omega = 275\ \Omega$

For correctly using the total resistance to compute the current through the battery — 1 point

$I_{capT} = \mathcal{E}/R_{capT} = 1500\ \text{V}/275\ \Omega = 5.45\ \text{A}$

For correctly using the total current to compute the voltage across R_2 — 1 point

$V_{2cap} = I_{capT}R_{capP} = (5.45\ \text{A})(75\ \Omega)$

$V_{2cap} = 410\ \text{V}$ (rounded to two significant digits)

Question 2 (continued)

Distribution of points

(a) (continued)

(iii) (continued)

Alternate solution	*Alternate points*
For one correct Kirchhoff equation indicating the current flowing in R_3	*1 point*
For a second correct Kirchhoff equation	*1 point*

$1500\text{ V} - (200\ \Omega)I_1 - (100\ \Omega)I_3 = 0$

$1500\text{ V} - (200\ \Omega)I_1 - (300\ \Omega)I_2 = 0$

Using a Kirchhoff junction equation and solving the three equations for I_2

$I_1 = I_2 + I_3$

$1500\text{ V} - (200\ \Omega)I_1 - (100\ \Omega)I_3 = 1500\text{ V} - (200\ \Omega)I_1 - (300\ \Omega)I_2$

$(100\ \Omega)I_3 = (300\ \Omega)I_2$

$I_3 = 3I_2$

$I_1 = I_2 + 3I_2 = 4I_2$

$1500\text{ V} - (200\ \Omega)4I_2 - (300\ \Omega)I_2 = 0$

$I_2 = 1.36\text{ A}$

For correctly using I_2 *to calculate the voltage across* R_2	*1 point*

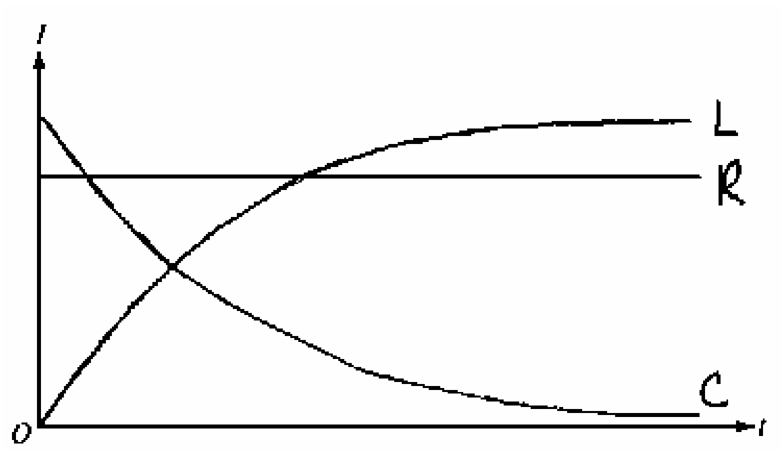
$V_2 = I_2R_2 = (1.36\text{ A})(300\ \Omega)$

$V_2 = 410\text{ V}$ (rounded to two significant digits)

Question 2 (continued)

Distribution of points

(b) 6 points



Resistor graph:

The current is constant with the resistor placed between points *A* and *B*. The resistance of that branch is more than when the capacitor and inductor are placed there, so the current will be less.

For drawing a horizontal line, indicating a constant current — 1 point

For having the value of the resistor graph less than the initial value of the capacitor graph or the steady state value of the inductor graph — 1 point

Inductor graph:

The inductor initially opposes the flow of current, so the initial current in that branch is zero. Eventually, the inductor acts like a wire and does not impede the flow of charge, as the rate of change of current decreases to zero.

For starting the graph at $I_3 = 0$ at time $t = 0$ — 1 point

For a graph that is concave down and asymptotic to the initial current in the capacitor case — 1 point

Capacitor graph:

Initially, the capacitor is uncharged and current is a maximum in the branch containing R_3. As the capacitor charges the current in that branch decreases to zero.

For a finite, nonzero initial value for the current I_3 at $t = 0$ — 1 point

For a graph that is concave up and asymptotic to $I = 0$ — 1 point

Question 3

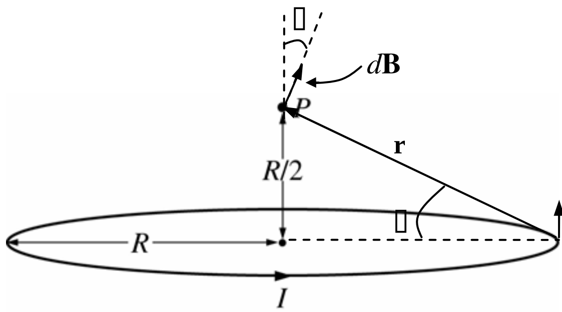
15 points total — **Distribution of points**

(a)

(i) 1 point

For indicating that the magnetic field B_1 at point P is toward the top of the page — 1 point

(ii) 6 points



For using the Biot-Savart law — 1 point

$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\,d\ell \times \mathbf{r}}{r^3}$$

For correctly indicating or applying the fact that $d\ell$ is perpendicular to **r** — 1 point

$$dB = \frac{\mu_0}{4\pi}\frac{I\,d\ell\,r\sin\theta}{r^3} = \frac{\mu_0}{4\pi}\frac{I\,d\ell}{r^2}$$

For recognizing that the net horizontal component will be zero, so that just the vertical components are summed — 1 point

$B_1 = \int dB_{vert} = \int dB\cos\alpha = \int \frac{R}{r}dB$, where α is the elevation angle of the vector **r**

For the correct expression for r — 1 point

$$r = \sqrt{R^2 + \frac{R^2}{4}} = \frac{\sqrt{5}}{2}R$$

$$B_1 = \int \frac{R}{r}dB = \int \frac{R}{r}\frac{\mu_0}{4\pi}\frac{I\,d\ell}{r^2} = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}\int d\ell$$

For the correct calculation of $\int d\ell$ — 1 point

$\int d\ell = \int_0^{2\pi} R\,d\beta = 2\pi R$, where β is the angle around the loop

For a correct final expression — 1 point

$$B_1 = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}\int d\ell = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}2\pi R = \frac{4}{5\sqrt{5}}\frac{\mu_0 I}{R}$$

Question 3 (continued)

Distribution of points

(b) 2 points

For recognizing that B_{net} is the vector sum of the field generated by the first loop and the field generated by the second loop — 1 point

For recognizing that the *B* field from top loop is in the same direction and has the same magnitude as that from the bottom loop — 1 point

$$B_{net} = 2B_1 = \frac{8}{5\sqrt{5}}\frac{\mu_0 I}{R}$$

(c) 2 points

For identifying *B* as B_{net} in a correct expression for magnetic flux — 1 point

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

For correctly substituting the area as s^2 — 1 point

$$\phi = B_{net} s^2$$

(d) 4 points

For using Faraday's law with ϕ identified as magnetic flux — 1 point

$\mathcal{E} = -\dfrac{d\phi}{dt}$ with some work showing understanding of ϕ

For recognizing that there is an angular dependence — 1 point

$$\phi = B_{net} s^2 \cos\theta$$

For correctly relating the angle to the angular velocity — 1 point

$$\phi = B_{net} s^2 \cos\omega t$$

For the correct final expression — 1 point

$$\mathcal{E} = -B_{net}\frac{d}{dt}\left(s^2 \cos\omega t\right) = B_{net} s^2 \omega \sin\omega t$$