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 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 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 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 $Q_{\text{enclosed}} = 0$, 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 $Q_{\text{enclosed}} = +Q$, 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 $Q_{\text{enclosed}} = 0$.

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

$E4\pi r^2 = Q/\epsilon_0$

For a correct answer — 1 point

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

Question 1 (continued)

Distribution of points

(b) (continued)

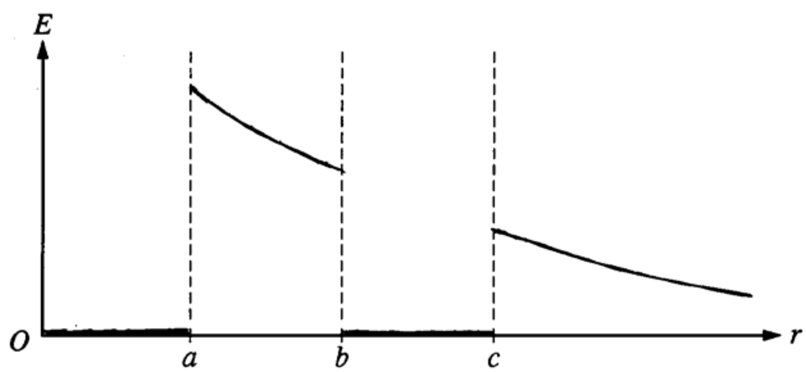
(iii) 1 point

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 $E(b) \neq 0$ 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.

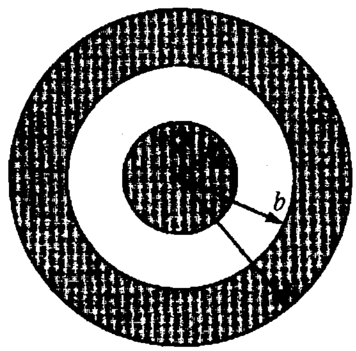
PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



E&M. 1.

A metal sphere of radius a contains a charge $+Q$ and is surrounded by an uncharged, concentric, metallic shell of inner radius b and outer radius c, as shown above. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the induced charge on each of the following and explain your reasoning in each case.

i. The inner surface of the metallic shell

$-Q$

The electric field within the metallic shell must be zero at equilibrium. If we apply Gauss's law with a spherical shell ($b<r<c$) centered at the center of the sphere, the only way this can occur is if the net charge inside is zero.

ii. The outer surface of the metallic shell

$+Q$

Initially the metallic shell is uncharged.
Since the inner surface now has a $-Q$ charge, by the conservation of charge the outer surface must have a $+Q$ charge.

GO ON TO THE NEXT PAGE.

(b) Determine expressions for the magnitude of the electric field E as a function of r, the distance from the center of the inner sphere, in each of the following regions.

i. $r < a$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0} = 0$$

(charge on surface for metal sphere)

$$E = 0$$

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ii. $a < r < b$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

$$E(4\pi r^2) = \frac{Q}{\varepsilon_0} \qquad E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

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iii. $b < r < c$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0} = 0$$

(inside a conductor)

$$E = 0$$

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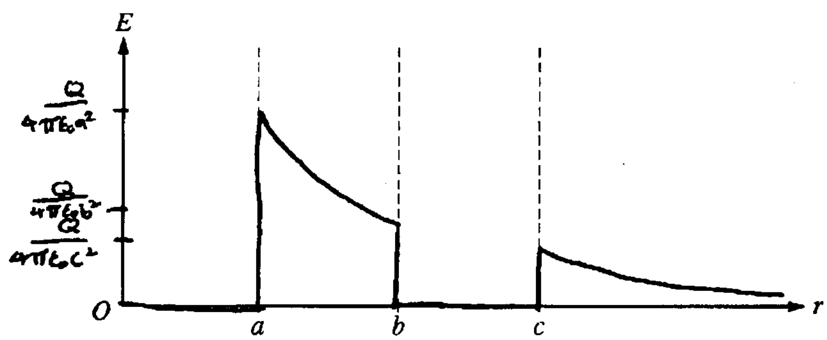
iv. $c < r$

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

$$E(4\pi r^2) = \frac{Q}{\varepsilon_0} \qquad E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

(c) On the axes below, sketch a graph of E as a function of r.



(d) An electron of mass m_e carrying a charge $-e$ is released from rest at a very large distance from the spheres. Derive an expression for the speed of the particle at a distance $10r$ from the center of the spheres.

Assuming $10r > c$

$$V_{10r} - V_{\infty} = -\int_{\infty}^{10r} \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\,dr$$

$$V_{10r} - 0 = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}\Big|_{\infty}^{10r}$$

$$V_{10r} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{10r} = \frac{Q}{40\pi\varepsilon_0 r}$$

$$\Delta U = qV = \frac{Qe}{40\pi\varepsilon_0 r} = \frac{1}{2}m_e v^2$$

$$v^2 = \frac{Qe}{20\pi\varepsilon_0 m_e r}$$

$$v = \sqrt{\frac{Qe}{20\pi\varepsilon_0 m_e r}}$$

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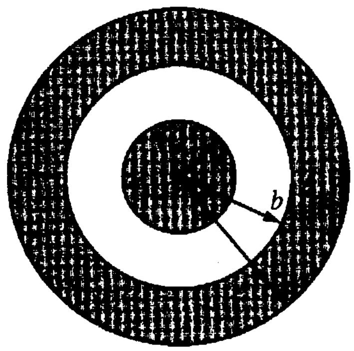


E&M. 1.

A metal sphere of radius a contains a charge $+Q$ and is surrounded by an uncharged, concentric, metallic shell of inner radius b and outer radius c, as shown above. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the induced charge on each of the following and explain your reasoning in each case.

i. The inner surface of the metallic shell

$-Q$ the electrons in the outer shell are attracted to the inner surface by the positive charges on the sphere.

ii. The outer surface of the metallic shell

$+Q$ the electrons that were pulled inward leave excess positive charges on the outside of the shell, giving it a positive charge.

GO ON TO THE NEXT PAGE.

(b) Determine expressions for the magnitude of the electric field E as a function of r, the distance from the center of the inner sphere, in each of the following regions.

i. $r < a$

$\cancel{E=0}$ $E = \frac{4\pi k r^+ Q}{3}$

ii. $a < r < b$

$E = \frac{k^+ Q}{r^2}$

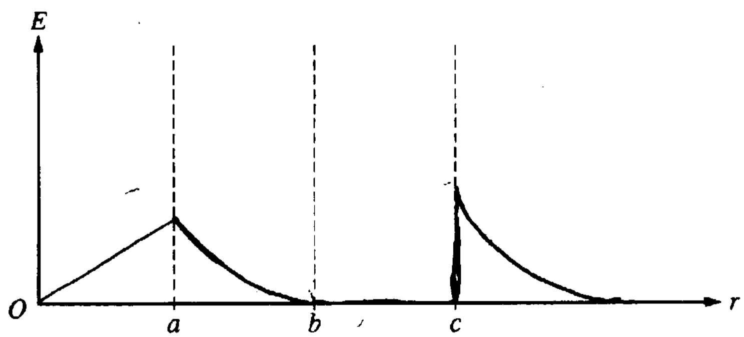
iii. $b < r < c$

$\cancel{E=k=0}$ $E = 0$

iv. $c < r$

$E = \frac{k^+ Q}{r^2}$

(c) On the axes below, sketch a graph of E as a function of r.



(d) An electron of mass m_e carrying a charge $-e$ is released from rest at a very large distance from the spheres. Derive an expression for the speed of the particle at a distance $10r$ from the center of the spheres.

$F = \frac{kQ^- e}{100r^2} = ma \quad a = \frac{-kQe}{100 m_e r^2}$ $\cancel{\int \frac{kQe}{100}}$

$V = \int \frac{-kQe}{100r^2} dr = \frac{-kQe}{100} \int \frac{1}{r^2} dr = \frac{kQe}{100r}$

$V = \frac{kQe}{100r} = \frac{1.44 \cdot 10^{-11} \cdot Q}{r}$

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SECTION II
Time—45 minutes
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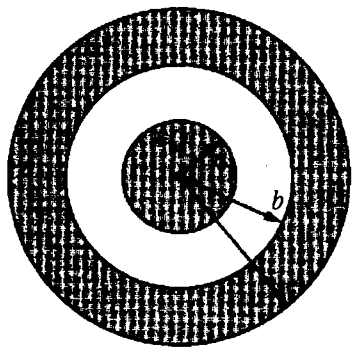


E&M. 1.

A metal sphere of radius a contains a charge $+Q$ and is surrounded by an uncharged, concentric, metallic shell of inner radius b and outer radius c, as shown above. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the induced charge on each of the following and explain your reasoning in each case.

i. The inner surface of the metallic shell

0, there is no induced charge on the inner surface because it is already charged to Q.

ii. The outer surface of the metallic shell

−Q, the outer surface produces a "shield" of charge to counter the force it is experiencing from the inner surface.

GO ON TO THE NEXT PAGE.

(b) Determine expressions for the magnitude of the electric field E as a function of r, the distance from the center of the inner sphere, in each of the following regions.

i. $r < a$ $\quad \int_0^a E\, dA = \frac{Q}{\varepsilon_0} = 0$

ii. $a < r < b$ $\quad \int_a^b E\, dA = \frac{Q}{\varepsilon_0}$

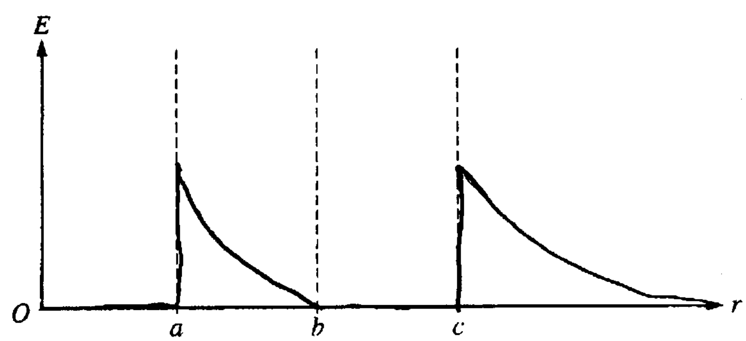
$E(2\pi b - 2\pi a) = \frac{Q}{\varepsilon_0}$ $\quad 2\pi E(b-a) = \frac{Q}{\varepsilon_0}$ $\quad E = \frac{Q}{2\pi\varepsilon_0(b-a)}$

iii. $b < r < c$ $\quad \int_b^c E\, dA = \frac{Q}{\varepsilon_0} = 0$

iv. $c < r$ $\quad \int_c^\infty E\, dA = \frac{Q}{\varepsilon_0}$

$E = \frac{Q}{2\pi\varepsilon_0}\left(\frac{1}{(c)} - \frac{1}{\infty}\right)$

(c) On the axes below, sketch a graph of E as a function of r.



(d) An electron of mass m_e carrying a charge $-e$ is released from rest at a very large distance from the spheres. Derive an expression for the speed of the particle at a distance $10r$ from the center of the spheres.

$F = \frac{k q_1 q_2}{r^2}$

Question 1

Overview

The first three parts of this question assessed students' understanding of electrostatics, specifically Gauss's law, as applied to conductors. Students were first asked to determine and give explanations for the values of the charges on various conductor surfaces. They were then asked to determine and sketch the electric field in various regions. The final part of this question assessed students' ability to apply conservation of energy to find the speed of a charged particle that had been released from rest at a very large distance from the conductors.

Sample: CE1A
Score: 15

This student explicitly shows use of Gauss's law in part (b) and provides a complete and well-organized solution in part (d).

Sample: CE1B
Score: 8

Part (a) earned full credit. The first answer in part (b) is incorrect, so only 3 points were earned for that part. Part (c) earned 1 point for the correct third segment. The first curved segment goes to zero, and the second one does not start below the final value of the first. Part (d) uses an incorrect approach, so no points were earned.

Sample: CE1C
Score: 4

No points were earned in part (a). It appears the student might have been thinking about the inner and outer metallic surfaces adjacent to the space between the conductors instead of the surfaces of the shell. Parts (b) and (c) earned 2 points each for the regions where the field is zero. No points were earned in part (d).