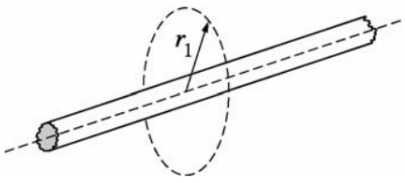
**PHYSICS C: ELECTRICITY AND MAGNETISM**
**Section I**
**Time–45 minutes**
**30 Questions**

**Directions:** Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

1. An electric field is produced by the very long, uniformly charged rod drawn below. If the strength of the electric field is $E_1$ at a distance $r_1$ from the axis of the rod, at what distance from the axis is the field strength $E_1/4$?




(A) $r_1/4$
(B) $r_1/2$
(C) $2r_1$
(D) $4r_1$
(E) $16r_1$

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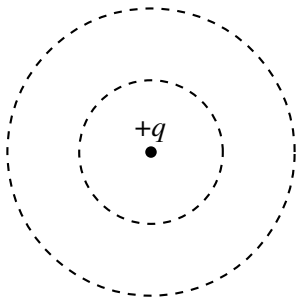
**Question 2–3**




Two concentric spherical surfaces are drawn around an isolated positive charge $+q$ located at their center, as shown above. The inner surface has a radius that is $1/2$ that of the outer surface.

2. If the total electric flux passing through the inner surface is $\phi$, what is the total electric flux passing through the outer surface?

(A) $\phi/4$
(B) $\phi/2$
(C) $\phi$
(D) $2\phi$
(E) $4\phi$

3. If the electric field strength at the inner surface is $E$, what is the electric field strength at the outer surface?

(A) $E/4$
(B) $E/2$
(C) $E$
(D) $2E$
(E) $4E$

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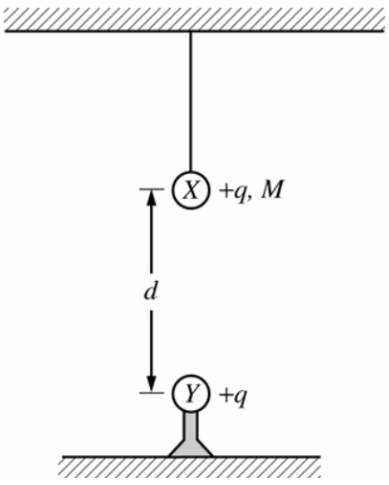
4. Sphere $X$ of mass $M$ and charge $+q$ hangs from a string as shown below. Sphere $Y$ has an equal charge $+q$ and is fixed in place a distance $d$ directly below sphere $X$. If sphere $X$ is in equilibrium, the tension in the string is most nearly




(A) $Mg$
(B) $Mg + \frac{kq}{d}$
(C) $Mg - \frac{kq}{d}$
(D) $Mg + \frac{kq^2}{d^2}$
(E) $Mg - \frac{kq^2}{d^2}$

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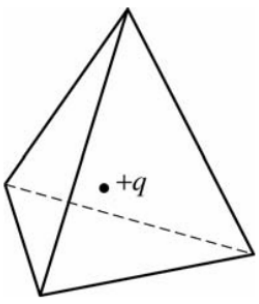
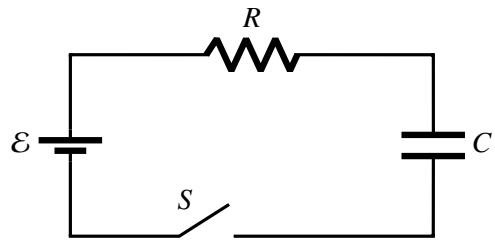
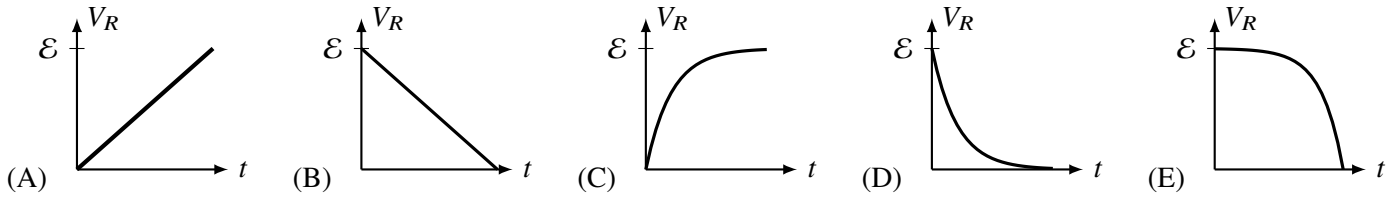
5. A charge $+q$ is placed at the center of a tetrahedron whose faces are all equilateral triangles, as shown below. What is the flux of the electric field through one face of the tetrahedron?




(A) 0
(B) $q/\epsilon_0$
(C) $q/4\epsilon_0$
(D) $4\epsilon_0 q$
(E) The flux through one face cannot be determined from the information given.




6. The capacitor $C$ in the circuit shown above is initially uncharged. The switch $S$ is then closed. Which of the following best represents the voltage $V_R$ across the resistor $R$ as a function of time $t$?

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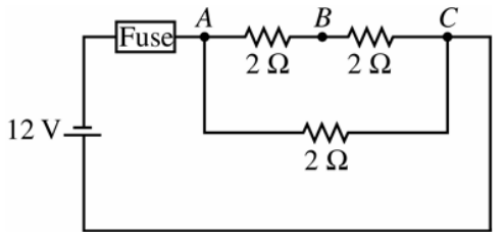
**Question 7–8**




An electric circuit consists of a 12 V battery, an ideal 10 A fuse, and three 2 Ω resistors connected as shown above.

7. What would be the reading on a voltmeter connected across points $A$ and $C$?

   (A) 12 V
   (B) 6 V
   (C) 3 V
   (D) 2 V
   (E) 0 V, since the fuse would break the circuit

8. What would be the reading on an ammeter inserted at point $B$?

   (A) 9 A
   (B) 6 A
   (C) 3 A
   (D) 2 A
   (E) 0 A, since the fuse would break the circuit

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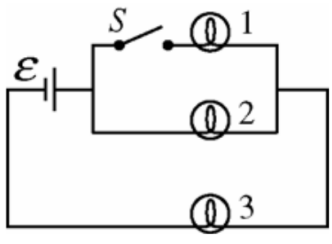


9. The three light bulbs in the circuit below are identical, and the battery has zero internal resistance. When switch $S$ is closed to cause bulb 1 to light, which of the other two bulbs increase(s) in brightness?

   (A) Neither bulb
   (B) Bulb 2 only
   (C) Bulb 3 only
   (D) Both bulbs
   (E) It cannot be determined without knowing the emf of the battery.

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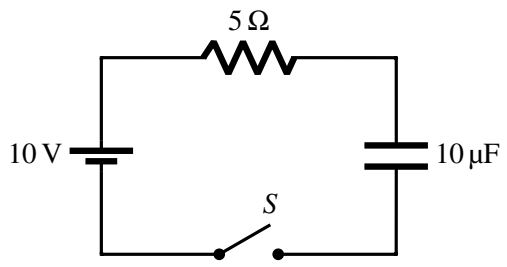
10. A length of wire of resistance $R$ is connected across a battery with zero internal resistance. The wire is then cut in half and the two halves are connected in parallel. When the combination is reconnected across the battery, what happens to the resultant power dissipated and the current drawn from the battery?

| | Power | Current |
|---|---|---|
| (A) | No change | No change |
| (B) | Doubles | Doubles |
| (C) | Quadruples | Doubles |
| (D) | Doubles | Quadruples |
| (E) | Quadruples | Quadruples |

11. In the circuit shown below, the 10 μF capacitor is initially uncharged. After the switch $S$ has been closed for a long time, how much energy is stored in the capacitor?




(A) 0 μJ
(B) 100 μJ
(C) 250 μJ
(D) 500 μJ
(E) 1000 μJ

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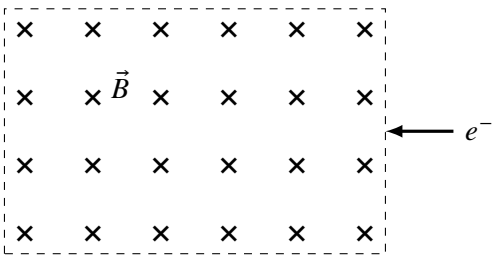
12. An electron $e^-$ moving in the plane of the page is injected into a uniform magnetic field $\vec{B}$ that is perpendicular to the page, as shown below. Upon entering the field, the electron takes a path that is




(A) straight through the field
(B) clockwise, circular, and in the plane of the page
(C) counterclockwise, circular, and in the plane of the page
(D) circular and curved out of the page
(E) circular and curved into the page

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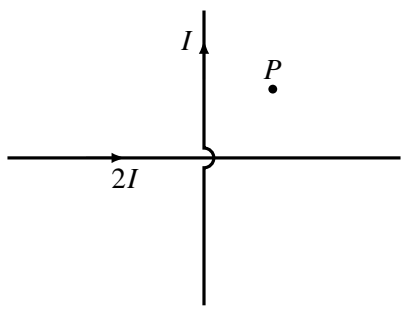


13. In the figure above, two long, straight, insulated wires at right angles in the plane of the page carry currents of $I$ and $2I$, as shown. What is the direction of the magnetic field at point $P$, which is equidistant from the wires and coplanar with them?

(A) Into the page
(B) Out of the page
(C) ↘
(D) ↖
(E) ↗

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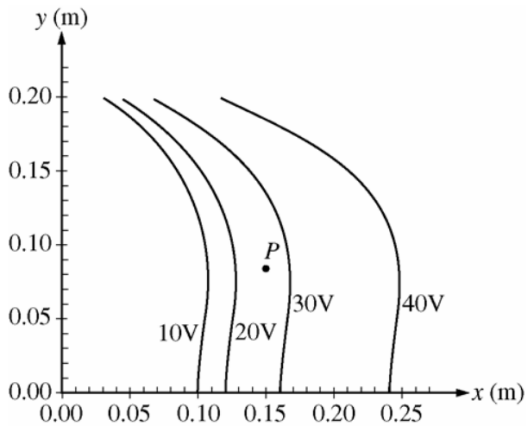
**Questions 14–15**




A fixed charge distribution produces the equipotential lines shown in the figure above.

14. Which of the following expressions best represents the magnitude of the electric field at point $P$?

(A) $\frac{10\text{ V}}{0.14\text{ m}}$
(B) $\frac{10\text{ V}}{0.04\text{ m}}$
(C) $\frac{25\text{ V}}{0.14\text{ m}}$
(D) $\frac{25\text{ V}}{0.04\text{ m}}$
(E) $\frac{40\text{ V}}{0.25\text{ m}}$

15. The direction of the electric field at point $P$ is most nearly

(A) toward the left
(B) toward the right
(C) toward the bottom of the page
(D) toward the top of the page
(E) perpendicular to the plane of the page

16. A helium nucleus (charge $+2q$ and mass $4m$) and a lithium nucleus (charge $+3q$ and mass $7m$) are accelerated through the same electric potential difference, $V_0$. What is the ratio of their resultant kinetic energies, $\frac{K_{\text{Li}}}{K_{\text{He}}}$?

(A) $\frac{2}{3}$
(B) $\frac{6}{7}$
(C) $1$
(D) $\frac{7}{6}$
(E) $\frac{3}{2}$

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17. The electric potential in the $xy$-plane in a certain region of space is given by $V(x, y) = 6x^2y - 2y^3$, where $x$ and $y$ are in meters and $V$ is in volts. What is the magnitude of the $y$-component of the electric field at the point $(-1, 2)$?

(A) $0\,\text{V/m}$
(B) $4\,\text{V/m}$
(C) $18\,\text{V/m}$
(D) $24\,\text{V/m}$
(E) $30\,\text{V/m}$

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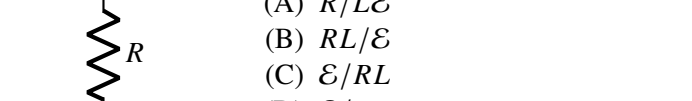


18. Two protons and an electron are assembled along a line, as shown below. The distance between the electron and each proton is $a$. What is the work done by an external force in assembling this configuration of charges?

(A) $-2\frac{ke^2}{a}$
(B) $-\frac{3}{2}\frac{ke^2}{a}$
(C) $\frac{1}{2}\frac{ke^2}{a}$
(D) $\frac{3}{2}\frac{ke^2}{a}$
(E) $3\frac{ke^2}{a}$

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**Questions 19–20**

A cloud contains spherical drops of water of radius $R$ and charge $Q$. Assume the drops are far apart.

19. The electric field $E_0$ and potential $V_0$ at the surface of each drop is given by which of the following?

| | $E_0$ | $V_0$ |
|---|---|---|
| (A) | $0$ | $0$ |
| (B) | $\frac{kQ}{R}$ | $\frac{kQ}{R^2}$ |
| (C) | $\frac{kQ}{R^2}$ | $\frac{kQ}{R}$ |
| (D) | $0$ | $\frac{kQ}{R}$ |
| (E) | $\frac{kQ}{R}$ | $0$ |

20. If two droplets happen to combine into a single larger droplet, the new potential $V$ at the surface of the larger droplet is most nearly equal to

(A) $3V_0$
(B) $2V_0$
(C) $\frac{2}{2^{1/3}}V_0$
(D) $2^{1/3}V_0$
(E) $V_0$

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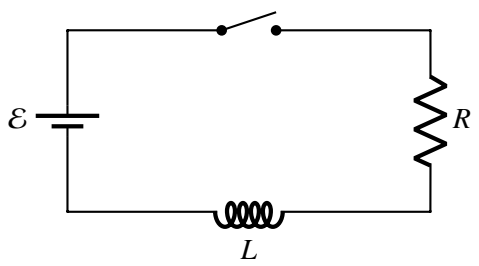
21. An inductor of inductance $L$ is connected in series with a resistor of resistance $R$, a battery of emf $\mathcal{E}$, and a switch, as shown above. When the switch is closed, the current $I$ in the circuit increases with time, approaching the value $I_{\text{max}}$. What is $I_{\text{max}}$?




(A) $R/L\mathcal{E}$
(B) $RL/\mathcal{E}$
(C) $\mathcal{E}/RL$
(D) $\mathcal{E}/R$
(E) $L\mathcal{E}$

**Questions 22–23**

An emf of 20 V is induced around a metal ring by increasing a uniform magnetic field at a constant rate from zero to a final magnitude of $1.0 \times 10^{-2}$ T throughout the region enclosed by the ring. The field direction is perpendicular to the plane of the ring.

22. If the area enclosed by the ring is $4.0 \times 10^{-3}$ m$^2$, what is the time interval during which the field is increased?

(A) 2.0 μs
(B) 5.0 μs
(C) 10 μs
(D) 20 μs
(E) 50 μs

23. If the electrical resistance of the ring is 500 Ω, what is the rate at which energy is dissipated in the ring as the field is increased?

(A) 0.040 W
(B) 0.80 W
(C) 1.25 W
(D) 25 W
(E) $1.0 \times 10^4$ W

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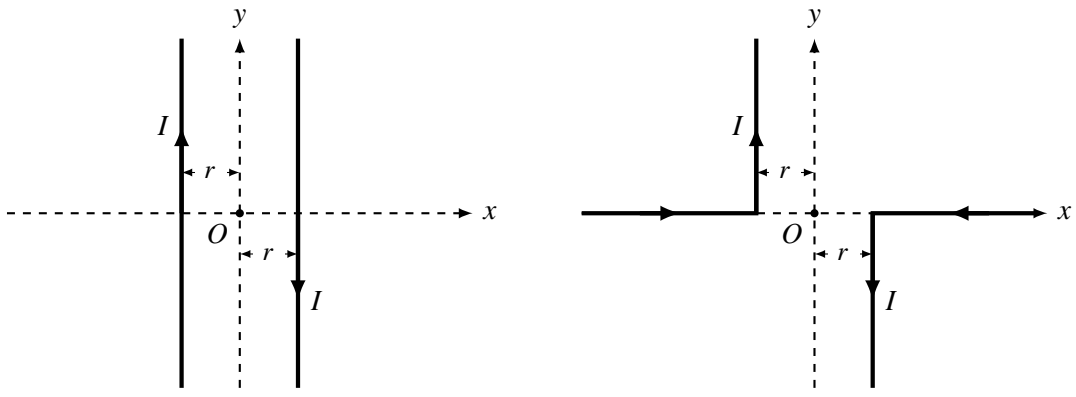


24. Two long, straight wires are parallel to and equidistant from the $y$-axis, as shown above left. Each carries current $I$ in opposite directions, resulting in a magnetic field of magnitude $B_0$ at the origin. If the wires are each bent into right angles and placed as shown above right, what is the magnitude of the magnetic field $B$ at the origin?

(A) Zero
(B) Between zero and $B_0/2$
(C) $B_0/2$
(D) Between $B_0/2$ and $B_0$
(E) $B_0$

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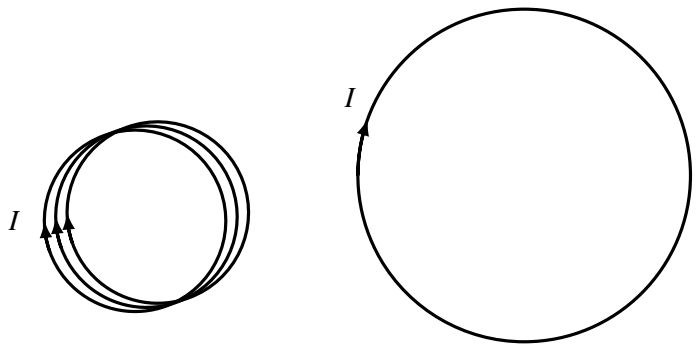
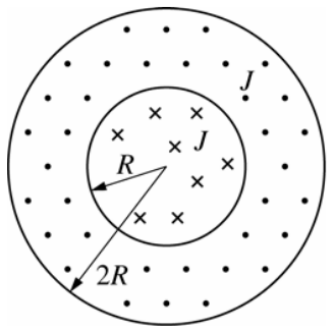



Loop $X$ Loop $Y$

25. A length of wire carrying a steady clockwise current $I$ is bent to form the triple circular loop $X$ above. An identical length of the same wire is bent less tightly to form the single loop $Y$ of larger radius, which carries the same current $I$. The ratio of the magnetic field strength at the center of loop $Y$ to the magnetic field strength at the center of loop $X$ is

(A) 1/9
(B) 1/3
(C) 1
(D) 3
(E) 9




26. The diagram above shows the cross section of a long cable that has an inner wire of radius $R$ surrounded by a conducting sheath of outer radius $2R$. The wire and the sheath carry currents in opposite directions but with the same uniform current density $J$. What is the magnitude of the magnetic field at the surface of the outer conductor?

(A) Zero
(B) $\frac{1}{4}\mu_0 RJ$
(C) $\frac{1}{2}\mu_0 RJ$
(D) $\frac{3}{4}\mu_0 RJ$
(E) $\mu_0 RJ$

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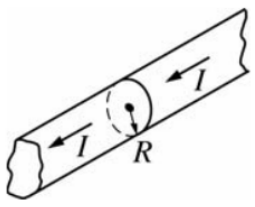
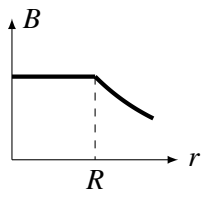
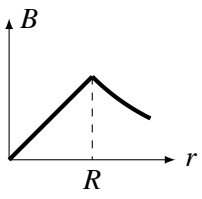
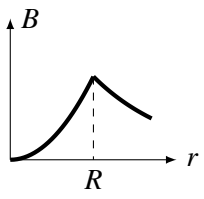
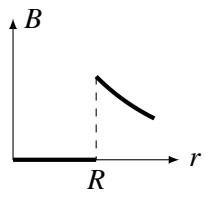


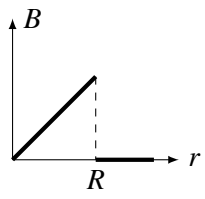

27. A long wire of radius $R$ carries a current $I$, as shown above, with a current density $J = ar$ that increases linearly with the distance $r$ from the center of the wire. Which of the following graphs best represents the magnitude of the magnetic field $B$ as a function $r$?

(A) 


(B) 


(C) 


(D) 


(E) 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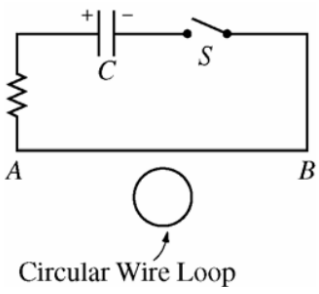


28. In the circuit drawn above, the switch $S$ is initially open, and the capacitor $C$ is charged with the polarity indicated. The switch is then closed, and the capacitor begins discharging through the resistor. Which of the following is true of the current that is subsequently induced in the circular wire loop near the long, straight wire $AB$?

(A) It is counterclockwise and constant.
(B) It is counterclockwise and increases with time.
(C) It is counterclockwise and decreases with time.
(D) It is clockwise and increases with time.
(E) It is clockwise and decreases with time

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29. Which of the following statements contradicts one of Maxwell's equations?

(A) A changing magnetic field produces an electric field.
(B) A changing electric field produces a magnetic field.
(C) The net magnetic flux through a closed surface depends on the current inside.
(D) The net electric flux through a closed surface depends on the charge inside.
(E) The electric field due to an isolated stationary point charge is inversely proportional to the square of the distance from the charge.

30. A student building a circuit wishes to increase the frequency of an oscillator consisting of a capacitor of capacitance $C$ and an inductor of inductance $L$. Which of the following would accomplish this objective?

I. Increase $L$
II. Increase $C$
III. Decrease $L$
IV. Decrease $C$

(A) I only
(B) I or II
(C) I or IV
(D) II or III
(E) III or IV