From the 2017 Administration

AP® CollegeBoard

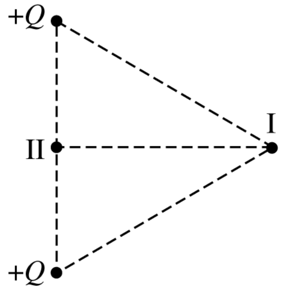
Physics C: Electricity and Magnetism

Practice Exam

PHYSICS C: ELECTRICITY AND MAGNETISM
SECTION I
Time—45 minutes
35 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 then fill in the corresponding circle on the answer sheet.

Questions 1-2



In the figure above, two small spheres, each with charge $+Q$, are fixed in place at the corners of an equilateral triangle. Point I is at the third corner, and point II is midway between the charges.

1. A small particle with charge $+q$, where $q << Q$, is moved from point I to point II at constant speed v by an external force. W_{EXT} is the work done by the external force on the moving charge, and W_{ELEC} is the work done by the electrostatic force. Which of the following correctly identifies the signs of these quantities?

	W_{EXT}	W_{ELEC}
(A)	+	+
(B)	+	−
(C)	−	+
(D)	−	−

(E) None of the above, since the work done by both the external force and the electrostatic force is zero.

2. Which of the following best describes the relationship between the electric potentials V_{I} and V_{II} at points I and II, respectively?

(A) $V_{I} < V_{II}$
(B) $V_{I} = V_{II}$
(C) $V_{I} > V_{II}$
(D) It cannot be determined without knowing the magnitudes of the charges.
(E) It cannot be determined without knowing the distance between points I and II.

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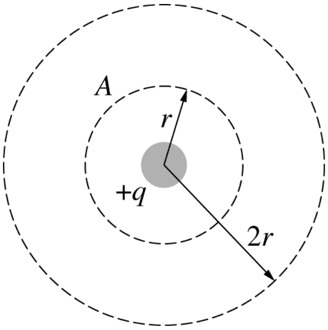
Questions 3-4



A small sphere has a charge $+q$. Spherical Gaussian surfaces A and B are concentric with the sphere, as shown in the figure above. The radii of surfaces A and B are r and $2r$, respectively.

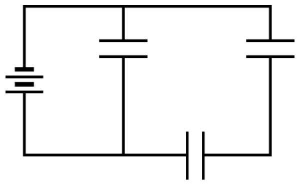
3. The magnitude of the electric flux through A is Φ_A. The magnitude of the electric flux through surface B is Φ_B. The ratio Φ_A/Φ_B is

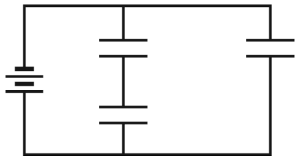
(A) $4/1$
(B) $2/1$
(C) $1/1$
(D) $1/2$
(E) $1/4$

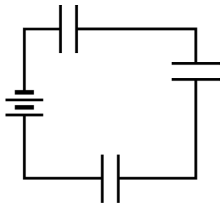
4. The magnitude of the electric field at surface A is E_A. The magnitude of the electric field at surface B is E_B. The ratio E_A/E_B is

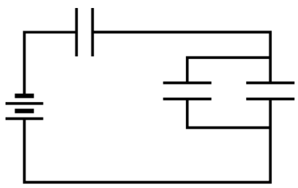
(A) $4/1$
(B) $2/1$
(C) $1/1$
(D) $1/2$
(E) $1/4$

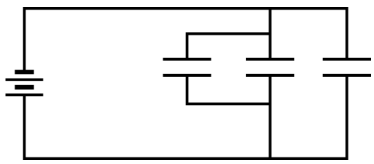
5. Each of the following figures shows three identical capacitors connected to a battery. Which arrangement has the greatest equivalent capacitance?

(A) 

(B) 

(C) 

(D) 

(E) 

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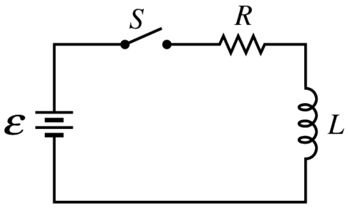
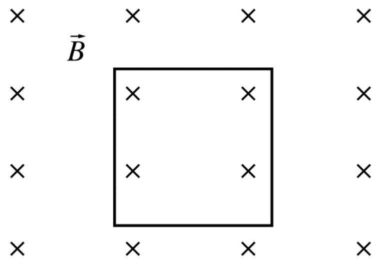
6. A copper wire of length L and diameter D dissipates energy at a rate P_0 when the current in the wire is 10 A. A second copper wire of length L has diameter $2D$. What current in the second wire would dissipate energy at a rate P_0 ?

(A) 2.5 A
(B) 5.0 A
(C) 10 A
(D) 20 A
(E) 40 A



7. Time t is the time it takes the current of an LR circuit with an inductor of inductance L and a resistor of resistance R to reach half of its maximum value. What is the new time if the original inductor is replaced with an inductor of inductance $2L$?

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



8. A loop of wire lies in the plane of the page in a region with a uniform magnetic field $\vec{B}$ directed into the page, as shown in the figure above. In which of the following cases, if any, will an emf be induced in the loop at the moment shown in the figure?

(A) The loop is moving toward the right.
(B) The loop is moving toward the top of the page.
(C) The loop is moving out of the plane of the paper so that the loop's plane remains perpendicular to the magnetic field.
(D) The loop is moving into the plane of the paper so that the loop's plane remains perpendicular to the magnetic field.
(E) An emf cannot be induced in the loop without changing its orientation relative to the magnetic field.

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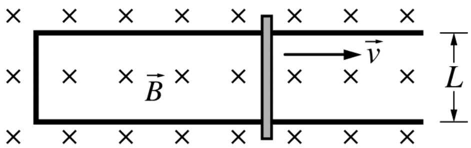

Top View

9. A copper rod of resistance R is in electrical contact with a frictionless U-shaped rail of width L and negligible resistance. The rod is pulled to the right at a constant velocity $\vec{v}$. A magnetic field $\vec{B}$ is directed into the page, as shown in the figure above. Under these conditions, the electric power dissipated in the rod is P. If the velocity of the rod is doubled and the magnetic field strength is reduced by half, the power dissipated in the rod is

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

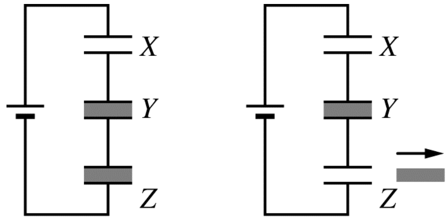

Figure 1 Figure 2

10. Three capacitors are connected in series to an ideal voltage source and charged, as shown in Figure 1 above. The capacitors are identical except that capacitor X has air between its plates, whereas capacitors Y and Z each have a dielectric slab of dielectric constant $\kappa > 1$ between their plates. If the dielectric slab is removed from capacitor Z, as shown in Figure 2, which of the following describes what will happen to the voltage across each capacitor?

	Voltage across Capacitor X	Voltage across Capacitor Y	Voltage across Capacitor Z
(A)	Increases	Increases	Decreases
(B)	Increases	Decreases	Decreases
(C)	Increases	Decreases	Increases
(D)	Decreases	Increases	Decreases
(E)	Decreases	Decreases	Increases

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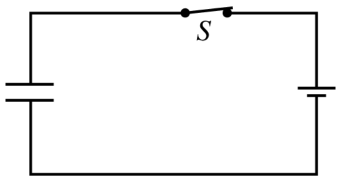
Questions 11-12



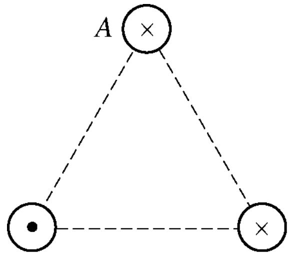
A parallel-plate capacitor connected to a battery is fully charged with the switch S closed, as shown in the circuit above. A slab of dielectric constant $\kappa > 1$ is slowly inserted between the plates of the capacitor.

11. If the switch remains closed when the slab is inserted, what changes, if any, occur?

	Potential Difference Across the Plates	Charge on Positive Plate
(A)	Remains the same	Increases
(B)	Remains the same	Decreases
(C)	Increases	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Remains the same

12. If, instead, the switch is open with the capacitor still fully charged when the slab is inserted, what changes, if any, occur?

	Potential Difference Across the Plates	Charge on Positive Plate
(A)	Remains the same	Increases
(B)	Remains the same	Decreases
(C)	Increases	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Remains the same



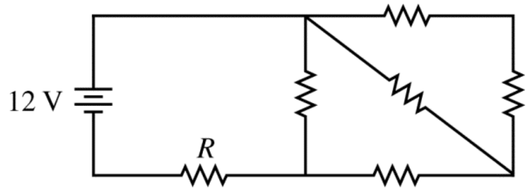
13. Three long wires perpendicular to the page are equidistant from each other, as shown in the cross-sectional view above. Two wires carry current into the page, and the third carries current out of the page. All the currents are equal in magnitude. What is the direction of the net magnetic force on wire A due to the other two wires?

(A) Into the page
(B) Toward the bottom of the page
(C) Toward the top of the page
(D) Toward the left
(E) Toward the right

14. A beam of particles travels at a right angle to a uniform magnetic field. Particles can be separated into different trajectories based on which of the following properties?

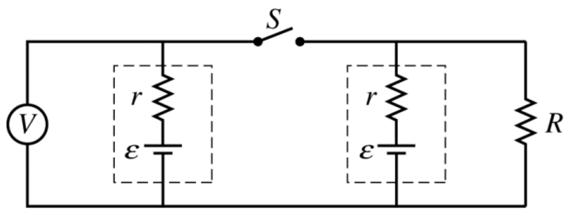
I. The charge of the particle
II. The mass of the particle
III. The velocity of the particle

(A) I only
(B) III only
(C) I and II only
(D) I and III only
(E) I, II and III



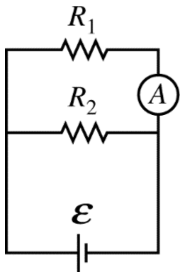
15. Six $2\ \Omega$ resistors are connected to a 12 V battery, as shown in the figure above. What is the current in the resistor labeled R?

(A) 2.6A
(B) 3.7A
(C) 4.0A
(D) 4.3A
(E) 6.0A



16. A resistor of resistance R is connected in a circuit to two identical batteries. The circuit also contains switch S and ideal voltmeter V, as shown in the figure above. The batteries both have an emf $\mathcal{E}$ and internal resistance r. The reading of the voltmeter is noted with the switch in the open position. Which of the following best represents how the voltmeter reading after the switch is closed compares to the reading before the switch is closed?

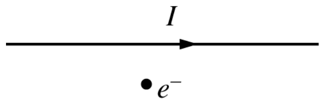
(A) The reading of the voltmeter is the same.
(B) The reading of the voltmeter is higher.
(C) The reading of the voltmeter is lower.
(D) Cannot be determined without knowing the internal resistance of the batteries.
(E) Cannot be determined without knowing the emf of the batteries.



17. In the circuit shown, $R_1 = 6\ \Omega$, $R_2 = 3\ \Omega$, and the emf $\mathcal{E}$ of the battery is 30 V. The reading of the ammeter A is most nearly

(A) 1.6 A
(B) 3.3 A
(C) 5.0 A
(D) 10 A
(E) 15 A

Questions 18-19



An electron is placed near a wire carrying current I, as shown in the figure above, and released from rest. Both the electron and the wire are in the plane of the page.

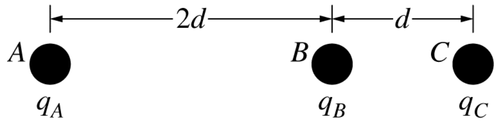
18. Which of the following is true about the direction of the magnetic field produced by the current at the position of the electron?

(A) It is toward the top of the page.
(B) It is toward the bottom of the page.
(C) It is out of the page.
(D) It is into the page.
(E) It has no direction since there is no magnetic field at that point.

19. Which of the following is true about the direction of the initial magnetic force acting on the electron due to the current in the wire?

(A) It is toward the top of the page.
(B) It is toward the bottom of the page.
(C) It is out of the page.
(D) It is into the page.
(E) It has no direction because the magnitude of the initial magnetic force on the electron is zero.

Questions 20-22



Three small spheres, A, B, and C, have charges with magnitudes q_A, q_B, and q_C, respectively. The three spheres are aligned along a straight line, as shown in the figure above. At the instant shown, the net force on sphere A is zero.

20. The ratio q_C/q_B is

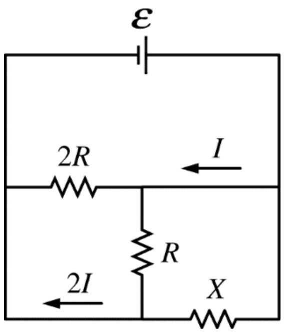
(A) 9/4
(B) 1/1
(C) 4/9
(D) 1/4
(E) 1/9

21. Which of the following statements must be true of the signs of the charges?

(A) Only charges q_A and q_B have the same sign.
(B) Only charges q_A and q_C have the same sign.
(C) Only charges q_B and q_C have the same sign.
(D) Charges q_B and q_C have different signs.
(E) Charges q_A, q_B, and q_C all have the same sign.

22. Which of the following is true about the sign of charge q_A?

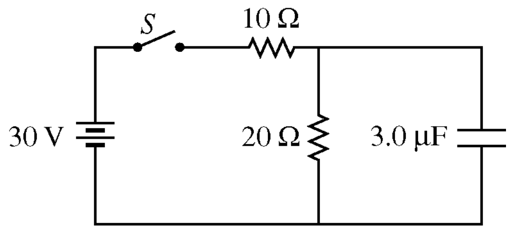
(A) The sign of charge q_A must be the same as that of q_B.
(B) The sign of charge q_A must be the same as that of q_C.
(C) The sign of charge q_A must be the same as that of either q_B or q_C, whichever has the greater magnitude.
(D) The sign of charge q_A must be the same as that of either q_B or q_C, whichever has the lesser magnitude.
(E) It is possible that q_A could be either positive or negative.



23. Three resistors are connected to an ideal battery, as shown in the figure above. The battery has an emf ε . Two of the resistors have known resistances R and $2R$. The third resistor has unknown resistance X. The current in two of the branches is shown. What is the value of the unknown resistance X ?

    (A) $R/5$
    (B) $R/4$
    (C) $R/2$
    (D) R
    (E) $2R$

Questions 24-25



An uncharged $3.0\ \mu F$ capacitor is placed in a circuit with an ideal battery, two resistors, and an open switch *S*, as shown in the figure above. The switch is then closed.

24. What is the current in the $10\ \Omega$ resistor immediately after the switch is closed?

    (A) Zero
    (B) 1.0 A
    (C) 1.5 A
    (D) 3.0 A
    (E) 10 A

25. What is the current in the $20\ \Omega$ resistor a long time after the switch is closed?

    (A) Zero
    (B) 1.0 A
    (C) 1.5 A
    (D) 3.0 A
    (E) 10 A

26. A parallel-plate capacitor connected to an ideal battery has charge $+Q$ on its top plate. The energy stored in the capacitor is U_C. While the capacitor remains connected to the battery, the separation between the two plates is doubled. Which of the following gives the new charge on the top plate and the new energy stored in the capacitor?

	Charge	Potential Energy
(A)	$+2Q$	$2U_C$
(B)	$+2Q$	$U_C/2$
(C)	$+Q$	U_C
(D)	$+Q/2$	$2U_C$
(E)	$+Q/2$	$U_C/2$

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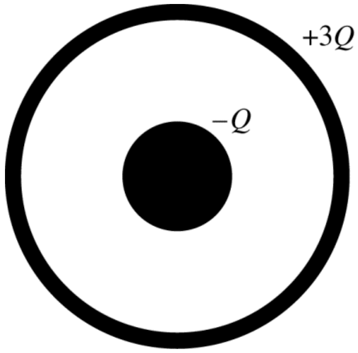
Questions 27-28



A hollow conducting sphere is surrounded by a larger concentric spherical conducting shell, as shown above. The inner sphere has a net charge of $-Q$, and the outer sphere has a net charge of $+3Q$.

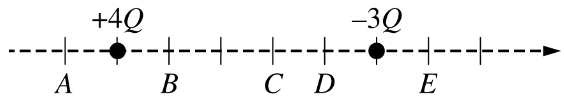
27. What is the net charge on the inner surface of the spherical shell?

(A) $-Q$
(B) 0
(C) $+Q$
(D) $+2Q$
(E) $+3Q$

28. What is the net charge on the outer surface of the spherical shell?

(A) 0
(B) $+Q$
(C) $+2Q$
(D) $+3Q$
(E) $+4Q$

Questions 29-30



Two small spheres are arranged along a line and carry charges of $+4Q$ and $-3Q$, as shown in the figure above. The vertical lines are equally spaced.

29. At which of the labeled points does the electric field point toward the right with the smallest magnitude?

(A) A
(B) B
(C) C
(D) D
(E) E

30. At which of the labeled points does the electric potential have the largest positive value?

(A) A
(B) B
(C) C
(D) D
(E) E

31. Object A and object B are separated by distance d. Object A has charge $+q$, and object B has charge $-2q$. Object A has a force of magnitude F exerted on it by object B. What are the magnitude and direction of the force exerted on object B?

	Magnitude	Direction
(A)	$F/2$	Away from object A
(B)	F	Away from object A
(C)	$2F$	Away from object A
(D)	F	Toward object A
(E)	$2F$	Toward object A

32. A variable voltage source is connected to an inductor of inductance L. The voltage V as a function of time t is given by the equation $V(t) = \beta t^2$, where β is a constant in units of $\mathrm{V/s^2}$. The current in the inductor at time $t = 0$ is zero. Which of the following equations gives the magnitude of the current in the inductor as a function of time?

(A) $I(t) = 0$

(B) $I(t) = \dfrac{2\beta}{L}t$

(C) $I(t) = \dfrac{\beta}{L}t^2$

(D) $I(t) = \dfrac{\beta}{3L}t^3$

(E) $I(t) = \dfrac{\beta}{L}t^2 \sin(\omega t)$

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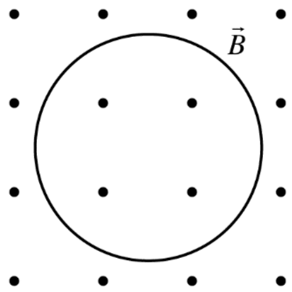


Figure 1

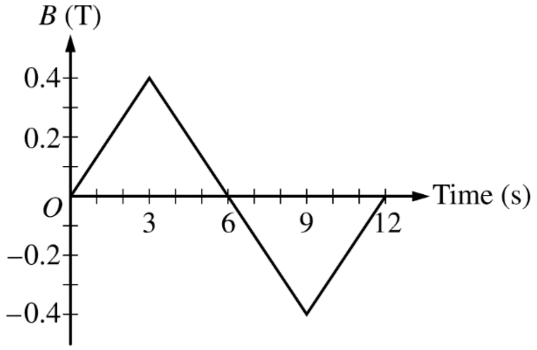
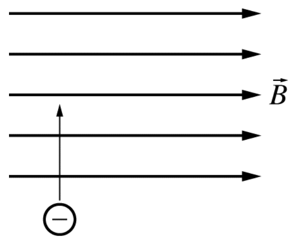


Figure 2

33. A metal wire of resistance 10 Ω is bent into a circular hoop of radius 0.10 meter and placed in a uniform magnetic field, as shown in Figure 1 above. The magnetic field strength B as a function of time is shown in Figure 2, where positive refers to a magnetic field directed out of the page. What are the magnitude and direction of the current induced in the ring at time $t = 6$ s?

	Magnitude	Direction
(A)	3.8 mA	Clockwise
(B)	3.8 mA	Counterclockwise
(C)	0.42 mA	Clockwise
(D)	0.42 mA	Counterclockwise
(E)	0	No direction



34. A negatively charged ion is moving toward the top of the page when it enters a region of space with a uniform magnetic field $\vec{B}$ directed to the right, as shown above. The direction of the force that the magnetic field exerts on the ion is

(A) toward the top of the page
(B) to the right
(C) to the left
(D) out of the page
(E) into the page

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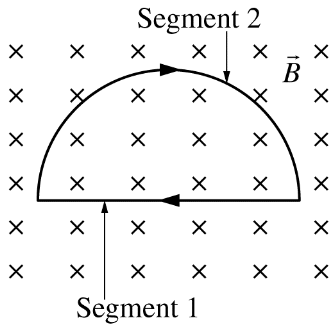


35. A semicircular loop with a clockwise current is placed in a uniform magnetic field that is directed into the page, as shown in the figure above. $\vec{F}_1$ is the net force on segment 1, the straight portion of the loop. $\vec{F}_2$ is the net force on segment 2, the curved portion of the loop. Which of the following correctly indicates the directions and relative magnitudes of the forces $\vec{F}_1$ and $\vec{F}_2$?

	Direction of $\vec{F}_1$	Direction of $\vec{F}_2$	Magnitudes
(A)	Toward the bottom of the page	Toward the top of the page	$\lvert\vec{F}_1\rvert = \lvert\vec{F}_2\rvert$
(B)	Toward the bottom of the page	Toward the top of the page	$\lvert\vec{F}_1\rvert < \lvert\vec{F}_2\rvert$
(C)	Toward the bottom of the page	Toward the top of the page	$\lvert\vec{F}_1\rvert > \lvert\vec{F}_2\rvert$
(D)	Toward the top of the page	Toward the bottom of the page	$\lvert\vec{F}_1\rvert = \lvert\vec{F}_2\rvert$
(E)	Toward the top of the page	Toward the bottom of the page	$\lvert\vec{F}_1\rvert < \lvert\vec{F}_2\rvert$

S T O P

END OF ELECTRICITY AND MAGNETISM SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON ELECTRICITY AND MAGNETISM SECTION I ONLY.

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

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.

1. The electric potential in a region of space as a function of position x is given by the equation $V(x) = \alpha x^2 + \beta x - \gamma$, where $\alpha = 2\ \text{V/m}^2$, $\beta = 7\ \text{V/m}$, and $\gamma = 15\ \text{V}$. All nonelectrical forces are negligible.

(a) An electron starts at rest at $x = 0$ and travels to $x = 20$ m.

i. Calculate the magnitude of the work done on the electron by the electric field during this process.

ii. Calculate the speed of the electron at $x = 20$ m.

(b) Derive an equation for the x-component of the electric field as a function of position x.

(c)

i. On the axes below, sketch a graph of the acceleration of the electron a as a function of position x.

ii. On the axes below, sketch a graph of the kinetic energy of the electron K as a function of position x.

(d) At which of the following locations will an electron that is released from rest move in the negative x direction? Check all that apply.

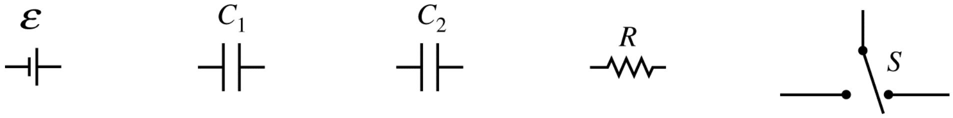
____ $x = -2$ m ____ $x = +1$ m ____ $x = +3$ m

Justify your answer.

(e) A charged object, generating its own electric field given by $E(x) = 7\ \text{V/m}$, is introduced in the region. What is the potential difference from $x = 0$ m to $x = 20$ m caused by the combination of the original electrical potential and the electric field of the charged object?

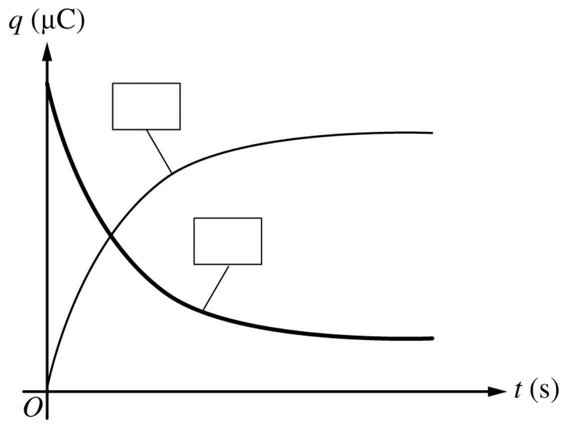
2. A student is to design a circuit using a battery $\mathcal{E}$ with negligible internal resistance, two uncharged capacitors C_1 and C_2, a resistor R, and a switch S. The circuit should be set up so that when the switch is in one position, the battery will only charge capacitor C_1, and when in the second position, capacitor C_1 will discharge through capacitor C_2 and resistor R.

(a) Using the components shown below, draw a circuit diagram that represents a single circuit that will satisfy the criteria outlined above.



The switch S is initially in position to fully charge capacitor C_1. At time $t = 0$, the switch is moved to the second position. The charge as a function of time for both capacitors after the switch is moved is plotted on the graph below.

(b) Label each box to indicate which graph corresponds to C_1 and C_2.



The components of the circuit have the following values: $R = 1000\ \Omega$, $C_1 = 2.0\ \mu F$, $C_2 = 6.0\ \mu F$, $\varepsilon = 12$ V.

(c) Calculate the following for a long time after the switch has been moved to the second position.

i. The charges q_1 and q_2 stored on capacitors C_1 and C_2, respectively

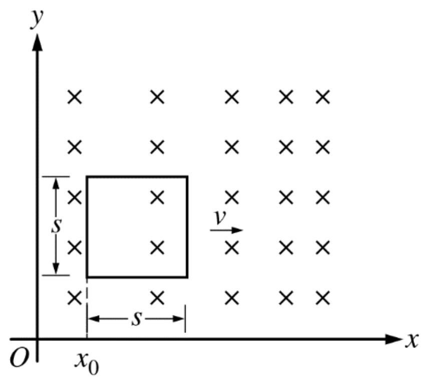
ii. The potential differences V_1 and V_2 across the capacitors C_1 and C_2, respectively

(d) Calculate the total energy dissipated in resistor R during the time capacitor C_1 discharges.

(e)

i. Write, but do NOT solve, a differential equation that could be used to determine the time constant associated with the discharge of C_1.

ii. Calculate the time constant associated with the discharge of C_1.



3. A square loop of conducting wire with resistance R and with sides of length s is located in the xy-plane. The loop is being pushed at constant speed v by an external force of magnitude F_{ext} in the $+x$-direction through a region with a magnetic field that is directed perpendicular to the xy-plane into the page, as shown in the figure above. The magnitude of the magnetic field as a function of position x is given by the equation $B(x) = cx + B_0$, where x is in meters, c is a positive constant in $\mathrm{T/m}$, and B_0 is a positive constant in teslas. The effects of gravity are negligible.

   (a) Derive an expression for the magnetic flux through the loop when the left side of the loop is at position $x = x_0$. Express your answer in terms of s, c, B_0, x_0, and physical constants, as appropriate.

   (b) Derive an expression for the magnitude of the induced current in the loop, if any. Express your answer in terms of R, s, v, c, B_0, x, and physical constants, as appropriate.

(c) Is the induced current in the loop clockwise, counterclockwise, or zero?

____ Clockwise ____ Counterclockwise ____ Zero

Justify your answer.

(d) When the left side of the loop is at position $x = x_0$ and moving with constant speed v, what is the direction of the net magnetic force, if any, on the loop?

____ Toward the top of the page ____ Out of the page ____ Left

____ Toward the bottom of the page ____ Into the page ____ Right

____ Undefined, because the net magnetic force on the loop is zero.

Justify your answer.

(e) Derive an expression for the magnitude of the external force F_{ext} exerted on the loop to keep it moving at a constant speed when the loop is at position $x = x_0$. Express your answer in terms of R, s, v, c, B_0, x_0, and physical constants, as appropriate.

(f) Rank, with 1 being the largest, the magnitude of the magnetic force on the four sides of the loop. If two sides have the same magnetic force, give them the same numerical ranking.

____ Left ______ Right ______ Top ____ Bottom

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**