

SECTION I, ELECTRICITY AND MAGNETISM

36. E

The equivalent capacitance of capacitors connected in parallel is the sum of each capacitor. Therefore: $C_{eq} = 3 + 3 + 3 = 9 \mu\text{F}$.

37. B

Using the equation $P = IV$, we see current and voltage are inversely proportional if power is held constant. Since the voltage in the question doubled, the current must be halved.

38. E

The flux is proportional to the number of field lines that pass through the surface of the sphere. Since the background electric field E is uniform, every background field line that enters the sphere also exits the sphere. Therefore, it has no contribution to the flux. The field lines from the $+2Q$ charge will radiate outward and every field line that exists due to the $+2Q$ will pass through the sphere, regardless of R . Therefore, the flux only depends on the value of Q . This is in accordance with Gauss's law.

39. D

The potential difference can be calculated using the equation that relates the potential difference to the electric field, $\Delta V = -\int E \cdot dr$. The limits of the integration will be from 0 to 5, because the radius is 5 for the point (3, 4).

$$\begin{aligned}\Delta V &= -\int_0^5 (-6r^2 + 4r + 3) dr \\ \Delta V &= -(-2r^3 + 2r^2 + 3r) \Big|_0^5 \\ \Delta V &= -(-250 + 50 + 15) = 185 \text{ V}\end{aligned}$$

40. C

Determine the direction of the force on the charge using the right-hand rule. Consider the leftmost point of the circle. The force must be toward the center of the circle, to the right, and the magnetic field is out of the page, so the velocity must be up. This indicates the particle is moving clockwise. However, the right-hand rule gives the direction for a positive charge. Since the actual charge moving is negative, the direction should be reversed. Thus, the negative charge is moving counterclockwise. The force on the charge is $F = qvB$, and use Newton's Second Law to solve for the acceleration as shown below.

$$\begin{aligned}\sum F &= ma \\ qvB &= ma \\ a &= \frac{qvB}{m}\end{aligned}$$

Choice (C) has these two pieces of information correct.

41. D

For a particle traveling in uniform circular motion, $2\pi r = vT$ because the particle travels one revolution in one period. The period is the inverse of the frequency. Applying this information and solving for f is shown below.

$$2\pi r = \frac{v}{f}$$

$$f = \frac{v}{2\pi r}$$

42. **C**

The energy stored in a capacitor is given by the equations $U_c = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$. Select the last part of the equation because the charge, in millicoulombs, and the capacitance, in microfarads, are given. The solution is shown below

$$U_c = \frac{(6 \times 10^{-3})^2}{2(30 \times 10^{-6})} = 0.6 \text{ J}$$

43. **D**

The electric field is uniform in between the plates, so the force and the acceleration are constant. Relating the potential difference to the electric field gives us $\Delta V = -Ex$, where x is the separation of the plates. The definition of the electric field is the force divided by the charge. Use these two pieces of information and Newton's Second Law to solve for the acceleration in terms of V .

$$E = \frac{F}{q}$$

$$\frac{V}{x} = \frac{F}{q}$$

$$\frac{Vq}{x} = ma$$

$$\frac{Vq}{mx} = a$$

This shows the acceleration is directly proportional to the potential difference V .

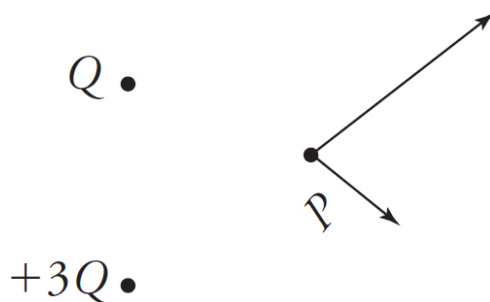
44. **E**

Ampere's law is $\oint B \cdot ds = \mu_0 I$. For an ideal solenoid the magnetic field is uniform and directed along the central axis within the solenoid and zero outside. In this case, only segment bc contributes to the integral because ad is outside the solenoid where the field is zero and ab and cd are perpendicular to the field, so the dot product of those segments with B is zero. The number of times the current will pass through our path is equal to the number of coils in the solenoid. This gives us the equation $B(x) = \mu_0 NI$.

45. **E**

The electric field will radiate outward from both $+3Q$ and $+Q$, and the field due to the $+3Q$ charge will be greater because point P is the same distance for both charges. This

vector diagram is shown below. The resultant will be in the $+x$ and $+y$ directions.



46. **E**

The electric potential can be calculated using the equation $V = \sum \frac{kQ}{r}$. Because there are only positive charges, the electric potential due to each charge will be positive, so the sum cannot be zero.

47. **B**

When the switch S is opened, the equivalent resistance, R_{eq} , of the parallel circuit increases. This results in the increase of the R_{eq} of the entire circuit. When the R_{eq} of the entire circuit increases, the total current, I , must decrease. This is because the total potential difference, V , is constant. The decrease in total I results in a decrease in the V across the $54\ \Omega$ resistor. Since the total V has not changed, while the V across the $54\ \Omega$ has decreased, the V across the $10\ \Omega$ resistor must increase. This results in an increase in the current through the $10\ \Omega$ resistor.

The current is not doubled, though, because that would require the V across the $10\ \Omega$ resistor to have doubled. This would only have occurred if the V across the $54\ \Omega$ resistor had halved. That would have required the circuit's current to have halved as well. This would have occurred only if the $10\ \Omega$ had a much greater resistance.

48. **A**

The equation for the resistance of a wire is $R = \frac{\rho L}{A}$, and $A = \pi r^2$. If the length is twice as long, the wire will have twice the resistance and if the radius is half, the wire will have 4 times the resistance per unit length because the radius is squared in the equation.

Conceptually this makes sense also because the charge is trying to flow through a cross-sectional area one-fourth as large. These two factors mean the total resistance is 8 times the resistance of wire Y.

49. **C**

For the region $0 < r < R$ the electric potential is constant. For the potential to be constant, the electric field must be zero because $E = -\frac{dV}{dr}$.

50. **E**

The force between two parallel wires is given by the equation $F_B = \frac{\mu_0 \ell I_1 I_2}{2\pi x}$, where x is the distance between the wires and ℓ is the length of the wires. Therefore, if the currents are halved the force will be one-fourth the original value.

51. **A**

The area of the square is given by $A = \ell^2 = k^2 t^4$. Use Faraday's law to determine the induced emf as shown below. Since the question asks for the magnitude of the emf, it is not necessary to include the negative sign in your answer.

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{d(BA)}{dt} = -B\frac{dA}{dt}$$

$$\varepsilon = -B\frac{d}{dt}(k^2 t^4)$$

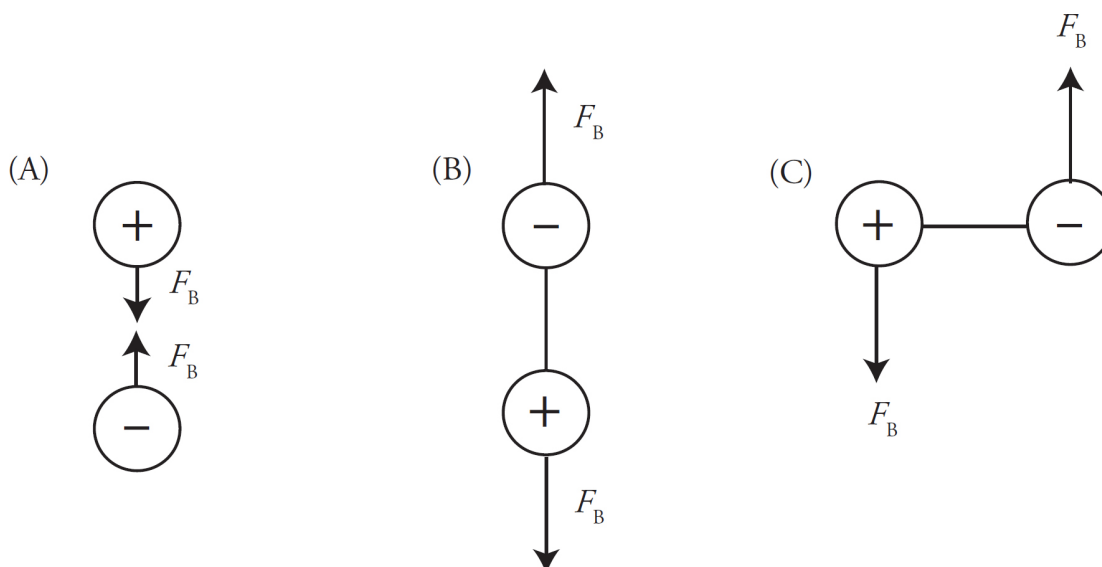
$$\varepsilon = |-4Bk^2 t^3|$$

52. **D**

The potential difference around the loop must be zero according to Kirchhoff's loop rule. The current in the circuit is going counterclockwise if the battery is being charged by the 120 V outlet. A counterclockwise loop starting right below the 120 V outlet will produce the following, $120 - \varepsilon - (3)(30) = 0$. Therefore, $\varepsilon = 30$ V.

53. **C**

Use the right hand rule on each half of the dipole. For each answer choice, the resulting magnetic forces would be



From these figures, we can see that all three would have 0 net force, but (C) is the only one that will rotate due to a net torque.

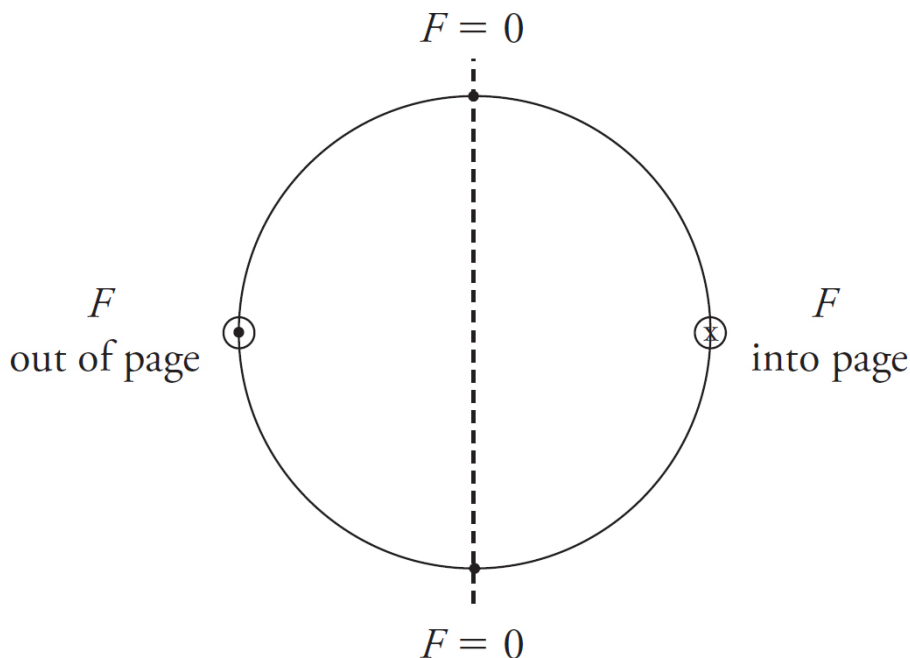
54. **C**

The magnetic field through the loop decreases when the magnet is pulled away. To oppose the change in the flux through the loop, the loop will induce its own current that creates a magnetic field to the right. This will cause the loop to be attracted to the magnet

with a force to the left (again to oppose the change in flux). Choice (C) combines these two pieces of information correctly.

55. **A**

Use the right-hand rule to determine the force on each part of the loop. A diagram is shown below with the forces indicated. These forces would produce a torque that causes the loop to rotate about the indicated axis. This would cause the loop to rotate as shown in (A).



56. **C**

First, find the equivalent resistance of the entire circuit.

$$\begin{aligned} R_{2+3} &= R_2 + R_3 \\ &= 8 \, \Omega + 16 \, \Omega = 24 \, \Omega \end{aligned}$$

$$\begin{aligned} \frac{1}{R_{2+3+4}} &= \frac{1}{R_{2+3}} + \frac{1}{R_4} \\ &= \frac{1}{24 \, \Omega} + \frac{1}{6 \, \Omega} = \frac{5}{24 \, \Omega} \end{aligned}$$

$$R_{2+3+4} = \frac{24}{5} \, \Omega$$

$$\begin{aligned} R_{1+2+3+4} &= R_1 + R_{2+3+4} \\ &= 4 \, \Omega + \frac{5}{24} \, \Omega = \frac{44}{5} \, \Omega \end{aligned}$$

Then use Ohm's law to solve for current.

$$V = IR$$

$$I = V/R$$

$$= (10 \text{ V}) / \left(\frac{44}{5} \Omega \right) = \frac{25}{22} \text{ A}$$

57. **A**

The strength of each charge's contribution to the electric field at the center of the square is the same for each charge because they are each the same distance away from the center. The electric field due to each one radiates outward from the charge (not outward from the center). The field created by each is cancelled by the field from the charge diagonal from it, so the total field is zero.

58. **A**

The work done will be equal to the change in electric potential energy. The electric potential is the algebraic sum of the potential due to each one, $V = \sum \frac{kQ}{r}$. Therefore, the total electric potential in the center is $V = \frac{4kQ}{\ell}$ because they are all positive and the same distance ℓ from the center. The electric potential far away is zero, so $\Delta V = V$ at the center. Now relate the potential difference to the potential energy and solve for ΔV .

$$\begin{aligned}\Delta V &= \frac{\Delta U}{Q} \\ \Delta V(3Q) &= \Delta U \\ \frac{4kQ}{\ell}(3Q) &= \Delta U \\ \frac{12kQ^2}{\ell} &= \Delta U\end{aligned}$$

59. **B**

The strength of the electric field is given by $E = -\frac{dV}{dx}$. Therefore, the closer the equipotential lines are the greater the strength of the electric field. *B* is the point where the equipotential lines have the greatest density, so (B) is correct.

60. **A**

The equation relating the electric field to potential difference is $E = -\frac{dV}{dx}$. The negative sign indicates that the electric field points toward decreasing electric potential. The electric field is also perpendicular to equipotential lines. Therefore, (A) indicates the correct direction for the field at point *D*.

61. **E**

If a negative charge were released from the -10 V equipotential line it would want to travel to a higher potential, so when it goes to the 20 V line it must be losing electric potential energy. This means the answer should be negative: eliminate (A), (B), and (C). We can also use the definition of electric potential to solve for the value of ΔU .

$$\Delta V = \frac{\Delta U}{q}$$

$$(30\text{ V})(-3\text{ }\mu\text{C}) = \Delta U$$

$$-90\text{ }\mu\text{J} = \Delta U$$

62. **D**

Maxwell's equations relates electric and magnetic fields. A changing electric field would create a changing electric flux, which in turn would induce a magnetic field. This is Ampere–Maxwell's law, which is (D).

63. **B**

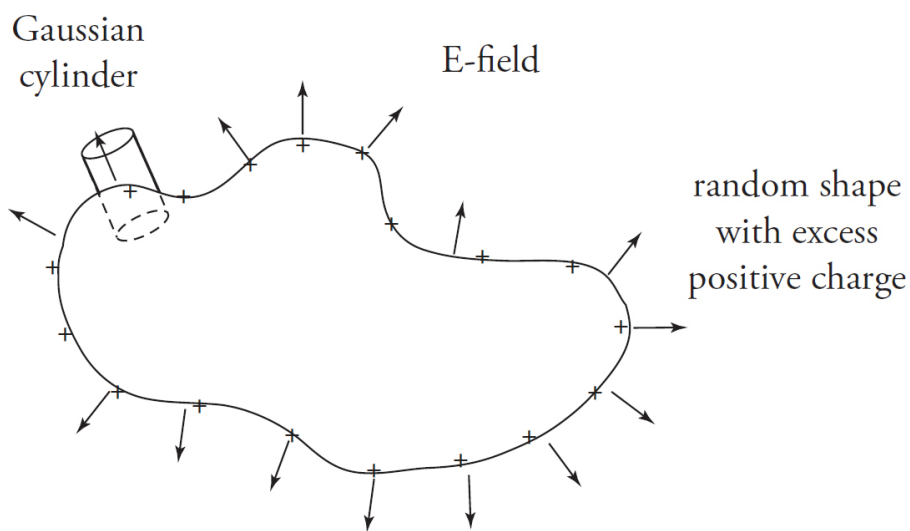
For this circuit, R would change how long the capacitor took to get charged, but would not alter the capacitance or the charge on the plates. Therefore any answer that changes R will not be correct, so (A), (C), and (E) can be eliminated. The capacitance of a parallel plate capacitor can be increased by increasing the dielectric constant K , increasing the area of the plates A , or decreasing the distance between the plates d . If we increase V , more charge will be stored on the capacitor. Therefore, (D) would certainly increase the charge stored and can be eliminated. Choice (B) is correct because decreasing d would increase the capacitance and we could decrease V such that less charge would be stored on the capacitor even though the capacitance increased. Furthermore, $Q = CV$, so V must decrease when C increases in order for Q to decrease.

64. **B**

Use the right-hand rule to determine the direction of the magnetic field due to each wire. The magnetic fields due to F and G cancel because the one due to F is out of the page at point P and the one due to G is into the page at point P . The field due to wire H is out of the page, so (B) is the answer.

65. **D**

For a solid, metal object the electric field inside is equal to zero. The electric field outside the object will not be zero because some excess charge is contained on the object and Gauss's law can be applied to show that Q_{in} would generate an electric field. This information eliminates (A) and (B). The surface of a conductor is an equipotential, so (E) is not correct. The strength of the electric field should decrease as the distance away from the center increases, so (C) is not correct. Choice (D) is correct, and we can apply Gauss's law as shown below to the odd-shaped figure as indicated. The Q_{in} will be equal to the surface charge density at the location times the area of the endcap of the Gaussian cylinder. This is only true very close to the surface of the object so that the Gaussian cylinder is perpendicular to the surface.



$$\oint E \cdot dA = \frac{Q_{in}}{\epsilon_0}$$

$$EA = \frac{\sigma A}{\epsilon_0}$$

$$E = \frac{\sigma}{\epsilon_0}$$

66. **E**

Because the switch is closed after being open for a long time, the inductor will not have to oppose any change in current from the resistors in the circuit. Therefore, the potential difference will be 12 V, or (E).

67. **D**

After the switch has been closed a long time the inductor acts like a wire, and the switch shorts out the $2\ \Omega$ resistor. Use Ohm's law to solve for the current through the $4\ \Omega$ resistor, as follows:

$$\Delta V = IR$$

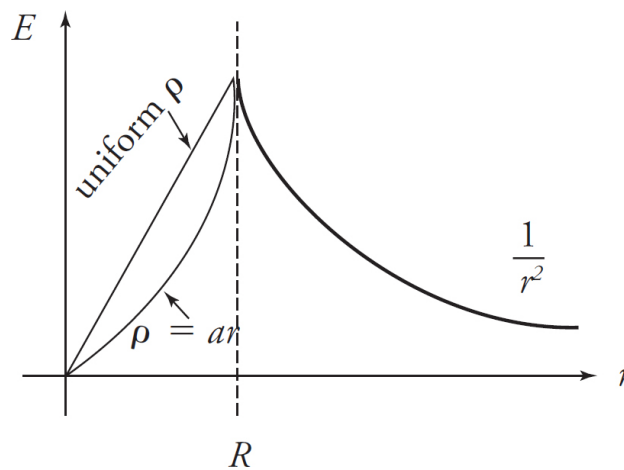
$$12 = I(4)$$

$$I = 3\text{ A}$$

68. **E**

The electric field will decrease as $\frac{1}{r^2}$ when $r > R$. This eliminates (A), (B), and (C).

When ρ is constant for a spherical charge distribution, the electric field strength varies linearly with r for $r < R$. Therefore, if ρ increases with r , as in this problem, more charge is being contained as r increases. This will make the electric field increase less rapidly than if ρ were constant. Therefore, (E) is correct. The general shapes of E vs. r for a uniform ρ and our problem are shown below. This sketch assumes the total charge is equal for both.



69. **B**

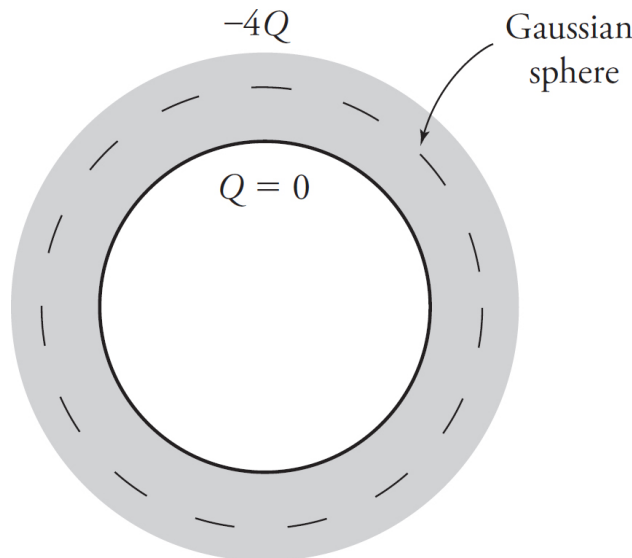
For Figure II, the electrons in the finger are attracted to the rod and will go from the finger into the electroscope. Therefore, (B) is correct.

70. **C**

This is essentially a Hall's voltage question. Use the left-hand rule to determine the direction of the magnetic force on the electrons traveling to the left in the diagram. The force is downward, which means the potential at X will be positive and the potential at Y will be negative. Therefore, (C) is correct.

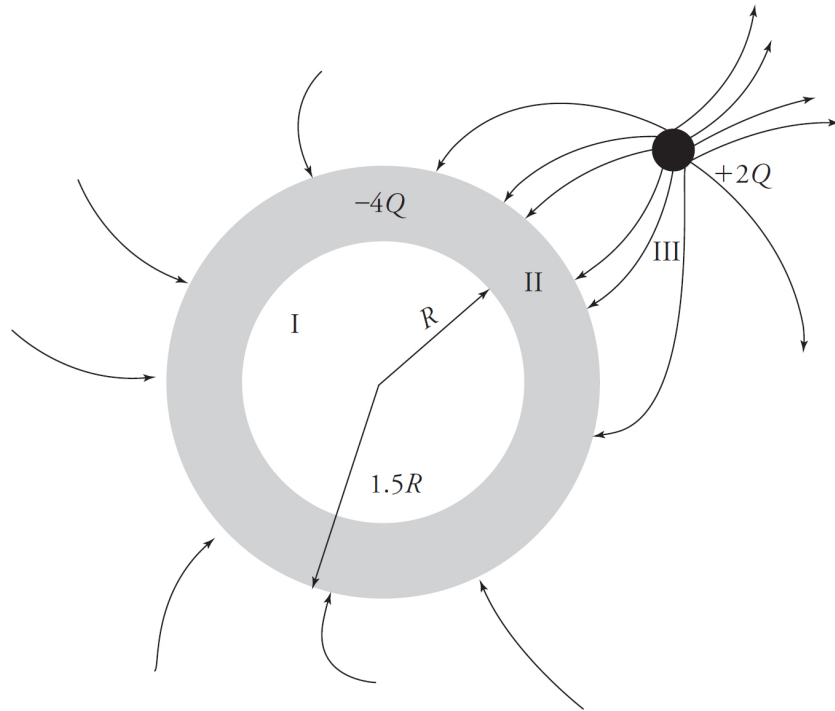
SECTION II, ELECTRICITY AND MAGNETISM

1. (a) (i) Consider the Gaussian sphere as shown just below. Since the electric field is zero inside a conductor, the charge enclosed must be zero. Therefore the charge on the inner surface is zero. This leaves the $-4Q$ charge on the outer surface, as shown below.



- (ii) The electric field inside a conductor at equilibrium is always zero, so the electric field in region II is zero. Field lines originate on positive charges and end on negative charges. Since there is no excess charge on the inner surface of the sphere or within region I, the electric field in region I is also zero. The electric field in region III is shown below. The electric field lines will originate at the $+2Q$ charge and terminate at the outer surface of the spherical shell because the outer surface will have a charge of $-4Q$. Some of the $-4Q$ charge will be closer to the $+2Q$ charge, but that still leaves an excess of negative

charge around the rest of the outer surface of the shell, so the field lines should be ending on the outer surface. All field lines need to be perpendicular to the surface of the shell.



- (b) Use Gauss's law for each of the radii. The surface area of the Gaussian sphere is $4\pi r^2$, so $\oint dA = 4\pi r^2$. Also substitute $\frac{1}{4\pi\epsilon_0} = k$ to simplify the expression.

(i)

$$\begin{aligned}\oint E \cdot dA &= \frac{q_{in}}{\epsilon_0} \\ E(4\pi r^2) &= \frac{(+2Q)}{\epsilon_0} \\ E &= \frac{1}{4\pi r^2} \left(\frac{+2Q}{\epsilon_0} \right) \\ E &= \frac{2kQ}{r^2}\end{aligned}$$

(ii) $E = 0$, within a conductor.

(iii)

$$\begin{aligned}\oint E \cdot dA &= \frac{q_{in}}{\epsilon_0} \\ E(4\pi r^2) &= \frac{(+2Q - 4Q)}{\epsilon_0} \\ E &= \frac{1}{4\pi r^2} \left(\frac{-2Q}{\epsilon_0} \right) \\ E &= \frac{-2kQ}{r^2}\end{aligned}$$

- (c) The potential difference can be calculated using the equation $\Delta V = -\int E \cdot dr$ as shown below.

$$\Delta V = -\int_{\infty}^{1.5R} \left(\frac{-2kQ}{r^2} \right) dr$$

$$\Delta V = \frac{-2kQ}{r} \Big|_{\infty}^{1.5R}$$

$$\Delta V = \frac{-2kQ}{1.5R} - 0$$

$$\Delta V = \frac{-4kQ}{3R}$$

2. (a) When the switch is first moved to position *A* the $50 \mu\text{F}$ capacitor is acting like a wire because it does not oppose the current when it is uncharged. The current through the 20Ω resistor is the same as the entire left side of the circuit because it is a series circuit. Use Ohm's law to solve for the current.

$$V = IR$$

$$30\text{V} = I(10 \Omega + 20 \Omega)$$

$$I = 1.0 \text{ A}$$

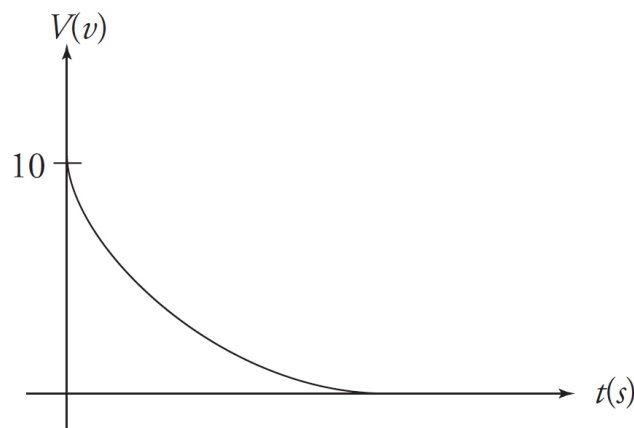
- (b) The initial voltage across the 10Ω resistor can be calculated using Ohm's law.

$$V = IR$$

$$V = (1 \text{ A})(10 \Omega)$$

$$V = 10 \text{ V}$$

For an RC circuit the voltage across the resistor will decrease exponentially because the current decreases exponentially as the capacitor is charging. The sketch of the voltage is shown below.



- (c) When the switch is in position *A*, the capacitor will continue being charged until the voltage across the $50 \mu\text{F}$ becomes 30 V , which will happen after a long time. When the switch is moved to position *B*, the $20 \mu\text{F}$ capacitor acts like a wire because it is uncharged. Use Ohm's law to solve for the current through the 15Ω resistor immediately after the switch is moved to position *B*.

$$V = IR$$

$$30 \text{ V} = I(15 \Omega)$$

$$I = 2 \text{ A}$$

- (d) The total charge stored on the $50 \mu\text{F}$ capacitor when the switch is at position *A* can be calculated using the equation

$$C = \frac{Q}{V}$$

$$50 \mu\text{F} = \frac{Q}{30 \text{ V}}$$

$$Q = 1,500 \mu\text{C}$$

When the switch is moved to position *B*, this charge will distribute between the two capacitors until the system reaches equilibrium. The voltage across each capacitor will be the same when the system is in equilibrium. Use this information and the fact that $\Delta V = \frac{Q}{C}$ for a capacitor. Let q be the charge on the $20 \mu\text{F}$ capacitor, which means $1,500 - q$ is the charge on the $50 \mu\text{F}$ capacitor.

$$\frac{1,500 - q}{50} = \frac{q}{20}$$

$$30,000 - 20q = 50q$$

$$30,000 = 70q$$

$$q = 429 \mu\text{C}$$

3. (a) The magnetic flux is the dot product of the magnetic field and area vector that the magnetic field goes through. For this problem the area goes out to a radius d because the field does not go out to the radius of the loop.

$$\Phi_B = \mathbf{B} \cdot \mathbf{A}$$

$$\Phi_B = B_o \cdot \pi d^2$$

- (b) Use Faraday's law to determine the induced emf. We will ignore the negative sign in the final answer because we only need the magnitude of the emf.

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

$$\varepsilon = -\pi d^2 \frac{d}{dt}(B_o t^2)$$

$$\varepsilon = -\pi d^2 (2B_o t)$$

$$\varepsilon = -2B_o \pi d^2 t$$

$$|\varepsilon| = 2B_o \pi d^2 t$$

- (c) Lenz's law states that the induced emf will produce a magnetic field to oppose the change in the external magnetic field. The external magnetic field going into the page is increasing with time, so to oppose the change in the external magnetic field, the induced current in the loop will create a magnetic field out of the page. To do this, the induced current must be counterclockwise.
- (d) Power is the rate at which energy is dissipated. Power for a circuit is given by the equations $P = IV = \frac{V^2}{R} = I^2 R$. We will use $\frac{V^2}{R}$ for power since we know the voltage and the resistance.

$$P=\frac{dE}{dt}$$

$$\frac{V^2}{R}dt=dE$$

$$\int_0^{t_1}\frac{V^2}{R}dt=E$$

$$\int_0^{t_1}\frac{(2B_o\pi d^2t)^2}{R}dt=E$$

$$\frac{4B_o^2\pi^2d^4t_1^3}{3R}=E$$

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