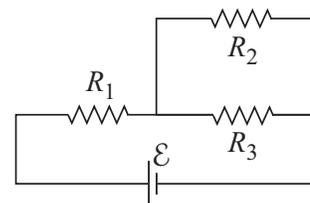


Answer 1 is correct for all problems.

1. In the figure, $\mathcal{E} = 18.0 \text{ V}$, $R_1 = 2.0 \text{ k}\Omega$, $R_2 = 6.0 \text{ k}\Omega$, and $R_3 = 12.0 \text{ k}\Omega$. What is the power dissipated in R_2 , in mW?

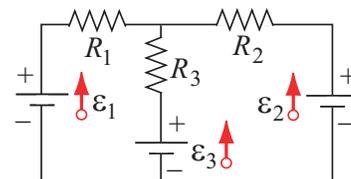
- (1) 24
(2) 56
(3) 74
(4) 12
(5) 35



The equivalent resistance of this circuit is $6.0 \text{ k}\Omega$. So the current that flows through R_1 is 3.0 mA , which splits into two at the junction to R_2 and R_3 in proportion to the inverse ratio of the two resistances. 2.0 mA and 1.0 mA will flow, respectively, through R_2 and R_3 . The power dissipated in R_2 is therefore $(2.0 \text{ mA})^2(6.0 \text{ k}\Omega) = 24 \text{ mW}$.

2. In the figure, $\mathcal{E}_1 = 3.0 \text{ V}$ and $\mathcal{E}_2 = \mathcal{E}_3 = 1.5 \text{ V}$. All the resistors are $2.0 \text{ k}\Omega$. What is the magnitude of the current flowing through resistor 3, in mA?

- (1) 0.25
(2) 0.40
(3) 0.10
(4) 0.050
(5) 0.025



Let i_1 be the current that flows through R_1 from left to right, and i_2 the current that flows through R_2 from right to left. Then $i_1 + i_2$ flows down R_3 . Loop rule gives $\mathcal{E}_1 - i_1 R_1 - (i_1 + i_2) R_3 - \mathcal{E}_3 = 0$ and $\mathcal{E}_2 - i_2 R_2 - (i_1 + i_2) R_3 - \mathcal{E}_3 = 0$ for the two small loops. Solving these equations for i_1 and i_2 , after substituting values for \mathcal{E} 's and R 's, gives $i_1 = 0.50 \text{ mA}$ and $i_2 = -0.25 \text{ mA}$. So $i_1 + i_2 = 0.25 \text{ mA}$.

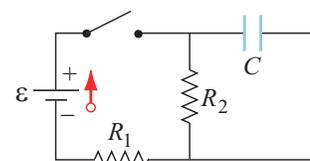
3. A capacitor with an initial potential difference of 15 V is discharged through a resistor when a switch between them is closed at $t = 0$. At $t = 1.0 \text{ s}$, the potential difference across the capacitor is 1.5 V . What is the potential difference across the capacitor at $t = 2.0 \text{ s}$?

- (1) 150 mV (2) 120 mV (3) 0 (4) 90 mV (5) 30 mV

The potential difference, V , across the capacitor decays exponentially. The exponential function $\exp(x)$ changes by the same factor over a given interval Δx at any x . In the present case, where the argument x is $-t/\tau$, the potential difference changes by a factor of 10 in the first 1 s. It must therefore change by another factor of 10 in the next 1 s. So 150 mV is the right answer. Algebraically, $1.5 = 15 \exp(-1.0/\tau)$ and $V = 15 \exp(-2.0/\tau)$. Rewriting the first equation as $\exp(-1.0/\tau) = 1.5/15$ and substituting it into the second equation gives $V = 15(1.5/15)^2$, which is 0.15 (V) .

4. In the figure, $\mathcal{E} = 6.0 \text{ V}$, $C = 150 \mu\text{F}$, $R_1 = 1.0 \text{ k}\Omega$, and $R_2 = 2.0 \text{ k}\Omega$. At $t = 0$ the switch is closed. After a long enough time for the capacitor to become fully charged, what will be its final charge, in coulombs?

- (1) 6.0×10^{-4} (2) 9.0×10^{-4} (3) 1.5×10^{-1} (4) 3.0×10^{-1} (5) 2.5×10^{-2}



After the wait, current no more flows into or out of the capacitor, so the currents through R_2 and R_1 are the same. As a result, the potential difference across R_2 is $\mathcal{E} R_2 / (R_1 + R_2)$, which is 4.0 V . This is also the potential difference across the capacitor, which is in parallel with R_2 . The charge on the capacitor is $(4.0 \text{ V})(150 \mu\text{F}) = 600 \mu\text{C}$.

5. A horizontal power line carries a current of 3.0 kA from north to south. Earth's magnetic field of magnitude $60 \mu\text{T}$ is directed toward the north and is inclined downward from horizontal at an angle of 30° . What is the magnitude of the magnetic force, per unit length, on the power line?

(1) 0.090 N/m (2) 0.18 N/m (3) 0 (4) 0.062 N/m (5) 0.034 N/m

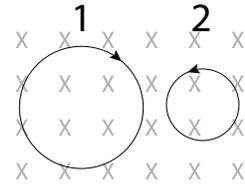
(3.0 kA)($60 \mu\text{T}$) $\sin(30^\circ)$, or $\sin(150^\circ)$ if you will. This is $90\text{e-}3$ N/m.

6. In the above problem, what is the direction of the force?

(1) east (2) west (3) up (4) down (5) none of the others

Sketch the arrangement viewed from a direction most convenient for you. For instance, viewed from east, the current flows from left (south) to right (north) and the magnetic field lines point slightly downward. The right-hand rule tells that the direction of the magnetic force is out of the page — east.

7. A uniform magnetic field is going into the plane of the page. Two charged particles move in circles in the plane of the page, as shown in the figure. The particles have the same speed and the same magnitude of charge, $|q|$, but they move in the opposite directions, as indicated by arrows. Which of the following is true about the charge of particle 1, q_1 , and the masses, m_1 of particle 1 and m_2 of particle 2?



(1) $q_1 < 0, m_1 > m_2$ (2) $q_1 < 0, m_1 < m_2$ (3) $q_1 > 0, m_1 > m_2$ (4) $q_1 > 0, m_1 < m_2$ (5) $q_1 > 0, m_1 = m_2$

If q_1 is positive, the force on particle 1 would be outward, pointing away from the center of the circular orbit. This is a wrong direction, so q_1 must be negative. For the second part of the problem, $F = ma$ and $F = qvB$ (here all symbols stand for magnitudes; signs, if any, are all dropped). Equating the two gives $ma = qvB$. For a circular motion, $v^2 = ar$. Therefore, $mv/r = qB$. The orbit of particle 1 has a larger r ; therefore the particle has a larger m .

8. A circular loop of radius 0.1 m, carrying a current of 0.2 A, is placed in a uniform magnetic field of 0.8 T. What is the work required to flip the loop from its lowest-energy orientation to its highest-energy orientation?

(1) 10 mJ (2) 0.16 J (3) 20 mJ (4) 80 mJ (5) 0

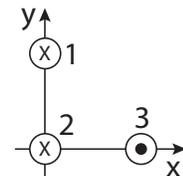
The magnetic dipole moment of the loop is $\mu = 0.2(\pi(0.1)^2) \text{ Am}^2$. The work required is $2\mu B = 2(0.2\pi 0.1^2)(0.8) = 1.0\text{e-}2$ J.

9. A proton traveling at 23 m/s in the $+y$ direction enters a region of space in which there is a uniform electric field of 41 N/C pointing in the $-x$ direction. To keep the proton moving on a straight line without deflection, how large a magnetic field (in tesla) must be applied and what is its direction?

(1) 1.8, $+z$ direction (2) 1.8, $+x$ direction (3) 940, $+z$ direction (4) 940, $-y$ direction (5) 940, $+x$ direction

The force due to the electric field is in the $-x$ direction. To cancel this with a magnetic force, the magnetic field must be in the $+z$ direction, according to the right-hand rule. $F = qE = qvB$, hence $B = E/v = 41/23 = 1.8$ T.

10. Three long straight wires run perpendicular to the plane of the page and carry currents in the directions indicated in the figure. Wire 1 passes the y axis of the plane at $y = 2.0$ m, wire 2 goes through the origin, and wire 3 passes the x axis at $x = 2.0$ m. If the magnitudes of the currents in wires 1, 2, and 3 are $i_1 = 1.0$ A, $i_2 = 2.0$ A, and $i_3 = 3.0$ A, respectively, what is the magnitude of the force per unit length on wire 2 due to the other two wires?



(1) 6.3×10^{-7} N/m (2) 8.0×10^{-7} N/m (3) 5.1×10^{-7} N/m (4) 4.0×10^{-7} N/m (5) 2.7×10^{-7} N/m

The magnetic field due to wire 1 is in the $-x$ direction; the field due to wire 2 is in the $-y$ direction and three times as large. The magnitude of the total field is therefore $\sqrt{1^2 + 3^2}\mu_0(1.0)/(2\pi(2.0))$. Multiplying this with i_2 gives the force per length.

11. To create a magnetic field of 2.0 T inside a solenoid of length 50 cm and radius 1.0 cm, how many windings are required if the current in the wire is 100 A?

(1) 8,000 (2) 1,600 (3) 16,000 (4) 80,000 (5) 160,000

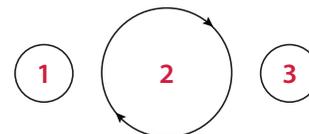
Use the formula for an ideal solenoid, $B = \mu_0 i N / \ell$, as an approximation. Solve this for N and substitute values.

12. A uniform current flows through a straight wire with circular cross section of radius R . At what distance from the center of the wire is the magnitude of the magnetic field one half of the magnetic field at the surface of the wire?

(1) $R/2$ and $2R$ (2) $R/2$ and $\sqrt{2}R$ (3) only $2R$ (4) only $\sqrt{2}R$ (5) only $4R$

As can be found by using Ampere's law, the magnetic field in the wire is proportional to the radial distance from the center, and the field outside is inversely proportional to the distance. So the field reaches the specified value at two distances, $R/2$ and $2R$.

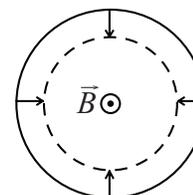
13. Three circular loops of conductors are placed on the page, as shown in the figure. The current in the large loop, loop 2, is in the clockwise direction and increasing. What is the direction of the induced current in loop 1 and in loop 3, respectively?



- (1) clockwise, clockwise
 (2) clockwise, counterclockwise
 (3) counterclockwise, counterclockwise
 (4) counterclockwise, clockwise
 (5) no induced current

Outside loop 2, the field points out of the page. To oppose the increase of this field inside either of the smaller loops, the induced current in it flows in the direction that creates a field (inside the loop) pointing into the page. According to the right-hand rule, that direction is clockwise.

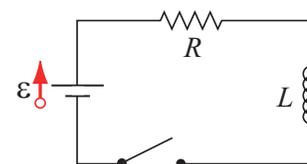
14. A circular conducting loop is placed in a uniform 1.0-tesla magnetic field pointing out of the page, as shown. If the loop suddenly contracts from its initial radius of 0.3 m with a radial velocity of $dr/dt = -0.2$ m/s, what is the magnitude and direction of the induced current immediately after the loop starts contracting? Assume that the resistance of the loop, 0.1Ω , is not affected by the contraction.



(1) 3.8 A counterclockwise (2) 3.8 A clockwise (3) 1.9 A counterclockwise (4) 1.9 A clockwise (5) 0

The area of the loop changes at the rate $(2\pi r)dr/dt$, which causes an emf of $d\Phi/dt = B(2\pi r)dr/dt$, which in turn drives an induced current, $i = \bar{B}(2\pi r)(dr/dt)/R$. Substituting values into the equation gives 3.8 A, ignoring a negative sign. The direction of the current is to oppose the decrease in Φ — to produce a magnetic field pointing out of the page. That direction is counterclockwise.

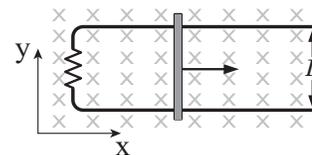
15. In the RL circuit shown, the component values are $R = 5.0 \Omega$, $L = 10.0$ mH, and $\mathcal{E} = 9.0$ V. If the switch is closed at $t = 0$, what is the magnitude of the self-induced emf in the inductor at 3.0 ms?



(1) 2.0 V (2) 12.0 V (3) 9.0 V (4) 5.0 V (5) 0

At $t = 0$, immediately after the switch is closed, the magnitude of the self-induced emf, \mathcal{E}_L , is the same as the source's emf \mathcal{E} . In the opposite limit of $t = \infty$, \mathcal{E}_L approaches zero. As these two limits help you to recall, $\mathcal{E}_L = \mathcal{E} \exp(-t/\tau)$, where $\tau = L/R$. Substitute values into the equation to find $\mathcal{E}_L = 2.0$ V.

16. The figure shows a rod that is forced to move at constant speed $v = 2.0$ m/s along the horizontal rails, which are separated by distance $L = 10$ cm. The rod, rails, and connecting resistor at the left form a conducting loop. The resistor has a resistance $R = 0.5 \Omega$; the rest of the loop has negligible resistance. The entire apparatus is placed in a uniform 0.80 T magnetic field pointing into the page. What is the direction (the $+y$ or $-y$ direction) and value of the induced current *through the resistor*?



- (1) $-y$, 0.32 A (2) $+y$, 0.32 A (3) $-y$, 32 A (4) $+y$, 32 A (5) no current

The area of the loop changes at the rate Ldx/dt , which is Lv . This causes the emf $d\Phi/dt = B(Lv)$, which in turn drives the induced current $i = BLv/R$. Substituting values into the equation gives $i = 0.32$ A. In this problem, the magnetic flux in the loop increases with time. To oppose that change, the current flows in the direction that produces a magnetic field pointing out of the page. That direction is counterclockwise, which is in the $-y$ direction through the resistor.

17. A capacitor in an LC oscillator has a maximum potential difference of 17 V and a maximum energy of $160 \mu\text{J}$. When the capacitor has a potential difference of 5 V, what is the energy stored in the magnetic field of the inductor, in μJ ?

- (1) 146 (2) 113 (3) 80 (4) 56 (5) 31

Considering an instant at which all the energy is stored in the capacitor, you find the relation $160 = C(17)^2/2$, where the left-hand side is in μJ and C in a proper unit. Similarly, when the potential difference across the capacitor is 5 V, the energy stored in the capacitor is $U_C = C(5)^2/2$. Taking the ratio of the two equations gives $U_C/160 = (5/17)^2$, which gives $U_C = 14$. This is in μJ because the value 160 is in μJ . Subtracting $14 \mu\text{J}$ from the total energy of the oscillator, $160 \mu\text{J}$, gives the answer.

18. An alternating emf with an amplitude of 10 V and a frequency (not angular frequency!) of 60 Hz is applied across a $300 \mu\text{F}$ capacitor. What is the amplitude of the current through the emf source?

- (1) 1.1 A (2) 65 A (3) 3.3 kA (4) 27 mA (5) 3.0 mA

The amplitude I of the current is \mathcal{E}_m/X_C , where the reactance X_C is $1/(\omega_d C)$. Converting the frequency to an angular frequency and substituting values into the formula gives the answer.

19. Consider an RLC circuit with driving emf amplitude $\mathcal{E}_m = 12$ V, resistance $R = 4.0 \Omega$, inductance $L = 20$ mH, and capacitance $C = 120 \mu\text{F}$. Find the amplitude of the potential difference across the resistor *at resonance*.

- (1) 12 V (2) 3.0 V (3) 60 V (4) 240 V (5) 600 V

At resonance, the potential difference across the inductor and the potential difference across the capacitor completely cancel out. (Note that the phasors for these potential differences always point in opposite directions and, at resonance, their lengths are the same.) So the potential difference across the resistor is the same as the driving emf \mathcal{E} . The amplitudes of the two quantities are also the same.

20. An ideal transformer provides an output emf whose magnitude is 7 V and frequency 60 Hz, when the amplitude of the input is 175 V. If there are 700 primary windings around the transformer core, what is the number of secondary windings?

- (1) 28 (2) 76 (3) 175 (4) 240 (5) 700

Use the formula $V_s/V_p = N_s/N_p$.