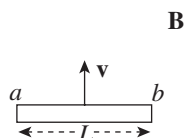


# Chapter 16 Drill

The answers and explanations can be found in Chapter 17.

## Section I: Multiple Choice

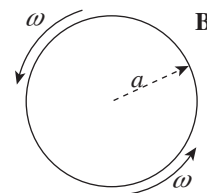
1. A metal rod of length  $L$  is pulled upward with constant velocity  $\mathbf{v}$  through a uniform magnetic field  $\mathbf{B}$  that points out of the plane of the page.



What is the potential difference between points  $a$  and  $b$ ?

- (A) 0
- (B)  $\frac{1}{2}vBL$ , with point  $a$  at the higher potential
- (C)  $\frac{1}{2}vBL$ , with point  $b$  at the higher potential
- (D)  $vBL$ , with point  $a$  at the higher potential
- (E)  $vBL$ , with point  $b$  at the higher potential

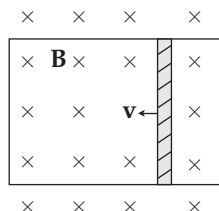
2. A circular disk of radius  $a$  is rotating at a constant angular speed  $\omega$  in a uniform magnetic field,  $\mathbf{B}$ , which is directed out of the plane of the page.



Determine the induced emf between the center of the disk and the rim.

- (A)  $\frac{1}{2}\omega\mathbf{B}a$
- (B)  $\frac{1}{2}\mathbf{B}a$
- (C)  $\frac{1}{2}\omega\mathbf{B}a^2$
- (D)  $\omega\mathbf{B}a^2$
- (E)  $2\pi\omega\mathbf{B}a^2$

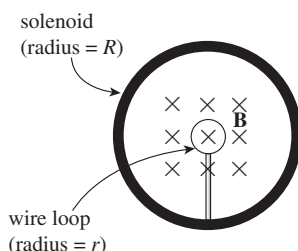
3. A conducting rod of length 0.2 m and resistance  $10\ \Omega$  between its endpoints slides without friction along a U-shaped conductor in a uniform magnetic field  $B$  of magnitude 0.5 T perpendicular to the plane of the conductor, as shown in the diagram below.



If the rod is moving with velocity  $v = 3\text{ m/s}$  to the left, what is the magnitude and direction of the current induced in the rod?

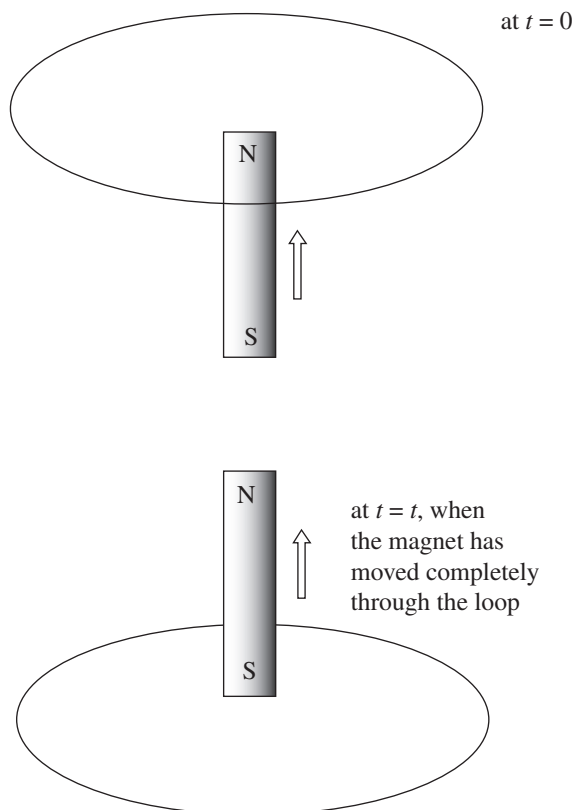
Current	Direction
(A) 0.03 A	down
(B) 0.03 A	up
(C) 0.3 A	down
(D) 0.3 A	up
(E) 3 A	down

4. In the figure below, a small, circular loop of wire (radius  $r$ ) is placed on an insulating stand inside a hollow solenoid of radius  $R$ . The solenoid has  $n$  turns per unit length and carries a current  $I$ . If the current in the solenoid is decreased at a steady rate of  $a$  amps/s, determine the induced emf,  $\mathcal{E}$ , and the direction of the induced current in the loop.



- (A)  $\mathcal{E} = \mu_0 \pi n r^2 a$ ; induced current is clockwise  
 (B)  $\mathcal{E} = \mu_0 \pi n r^2 a$ ; induced current is counterclockwise  
 (C)  $\mathcal{E} = \mu_0 \pi n R^2 a$ ; induced current is clockwise  
 (D)  $\mathcal{E} = \mu_0 \pi n R^2 a$ ; induced current is counterclockwise  
 (E)  $\mathcal{E} = \mu_0 \pi I n R^2 a$ ; induced current is counterclockwise

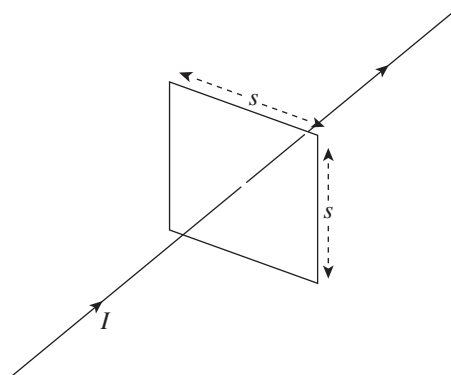
5. In the figure below, a permanent bar magnet is pulled upward with a constant velocity through a loop of wire.



Which of the following best describes the direction(s) of the current induced in the loop (looking down on the loop from above)?

- (A) Always clockwise  
 (B) Always counterclockwise  
 (C) First clockwise, then counterclockwise  
 (D) First counterclockwise, then clockwise  
 (E) No current will be induced in the loop.

6. A square loop of wire (side length =  $s$ ) surrounds a long, straight wire such that the wire passes through the center of the square.



If the current in the wire is  $I$ , determine the current induced in the square loop.

- (A)  $\frac{2\mu_0 Is}{\pi(1+\sqrt{2})}$   
 (B)  $\frac{\mu_0 Is}{\pi\sqrt{2}}$   
 (C)  $\frac{\mu_0 Is}{\pi}$   
 (D)  $\frac{\mu_0 Is\sqrt{2}}{\pi}$   
 (E) 0

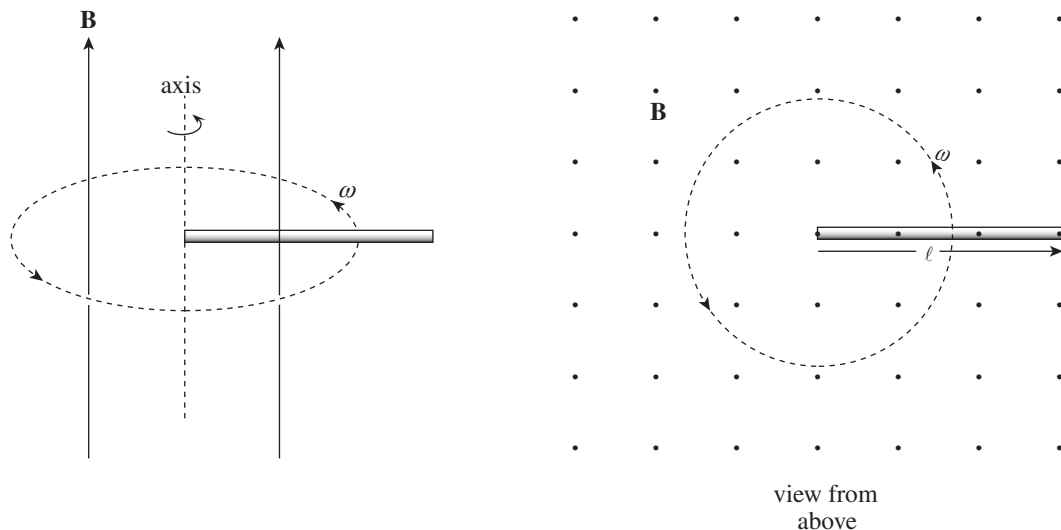
### Questions 7-9

A circuit contains a solenoid of inductance  $L$  in series with a resistor of resistance  $R$  and a battery with terminal voltage  $\mathcal{E}$ . At time  $t = 0$ , a switch is closed and the circuit is completed.

7. How long does it take for the current to reach  $\frac{3}{4}$  of its maximum (steady-state) value?
- (A)  $(\ln 4)(L/R)$   
 (B)  $(\ln \frac{3}{4})(L/R)$   
 (C)  $(\ln \frac{4}{3})(L/R)$   
 (D)  $(\ln \frac{4}{3})(R/L)$   
 (E)  $(\ln 4)(R/L)$
8. When the current reaches its maximum value, how much energy is stored in the magnetic field of the solenoid?
- (A)  $L^2\mathcal{E}^2/(4R^2)$   
 (B)  $L^2\mathcal{E}^2/(2R^2)$   
 (C)  $L\mathcal{E}^2/(4R^2)$   
 (D)  $L\mathcal{E}^2/(2R^2)$   
 (E) 0
9. When the current reaches its maximum value, what is the total magnetic flux through the solenoid?
- (A)  $L\mathcal{E}$   
 (B)  $L\mathcal{E}/R$   
 (C)  $\mathcal{E}/(RL)$   
 (D)  $RL/\mathcal{E}$   
 (E) 0
- 
10. Which one of Maxwell's equations states that a changing electric field produces a magnetic field?
- (A) Gauss's law  
 (B) Gauss's law for magnetism  
 (C) Biot-Savart law  
 (D) Ampere-Maxwell law  
 (E) Faraday's law

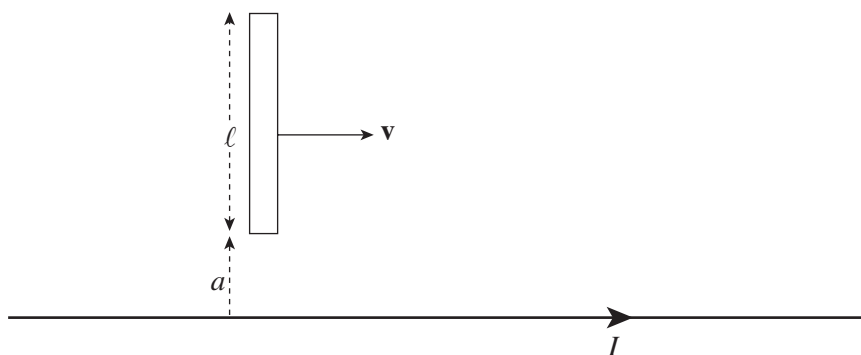
## Section II: Free Response

1. The diagram below shows two views of a metal rod of length  $\ell$  rotating with constant angular speed  $\omega$  about an axis that is in the plane of the page. The rotation takes place in a uniform magnetic field  $\mathbf{B}$  whose direction is parallel to the angular velocity  $\omega$ .



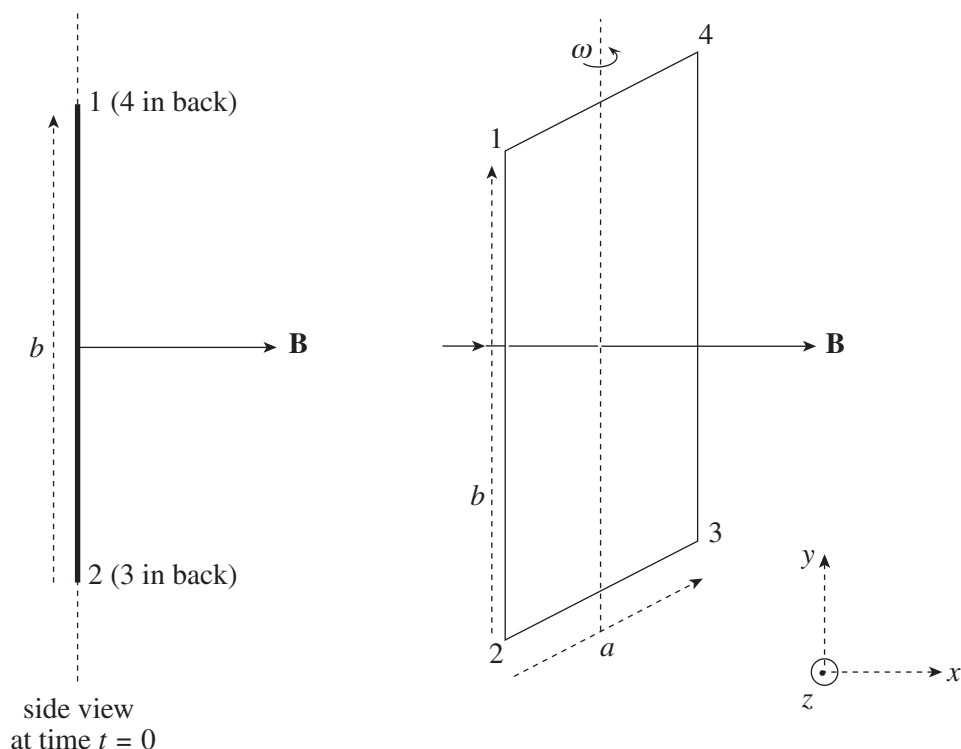
- What is the emf induced between the ends of the rod?
- What is the polarity (+ or –) of the rotating end?

In the following diagram, a metal rod of length  $\ell$  moves with constant velocity  $\mathbf{v}$  parallel to a long, straight wire carrying a steady current  $I$ . The lower end of the rod maintains a distance of  $a$  from the straight wire.



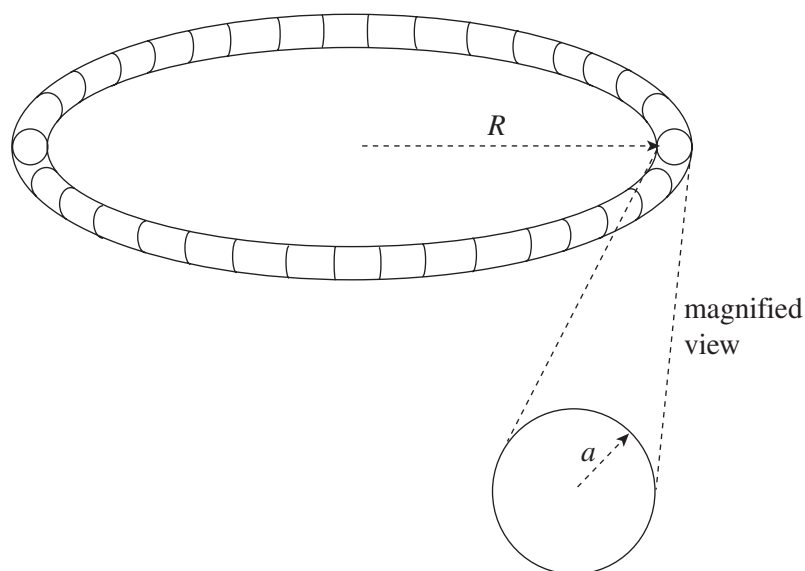
- What is the emf induced between the ends of the rod?
- What is the polarity (+ or –) of the end that is farther from the straight wire?

2. A rectangular loop of wire (side lengths  $a$  and  $b$ ) rotates with constant angular speed  $\omega$  in a uniform magnetic field  $\mathbf{B}$ . At time  $t = 0$ , the plane of the loop is perpendicular to  $\mathbf{B}$ , as shown in the figure on the left. The magnetic field  $\mathbf{B}$  is directed to the right (in the  $+x$  direction), and the rotation axis is the  $y$ -axis (with  $\omega$  in the  $+y$  direction), and the four corners of the loop are labeled 1, 2, 3, and 4. (Express answers in terms of  $a$ ,  $b$ ,  $\omega$ ,  $B$ , and fundamental constants.)



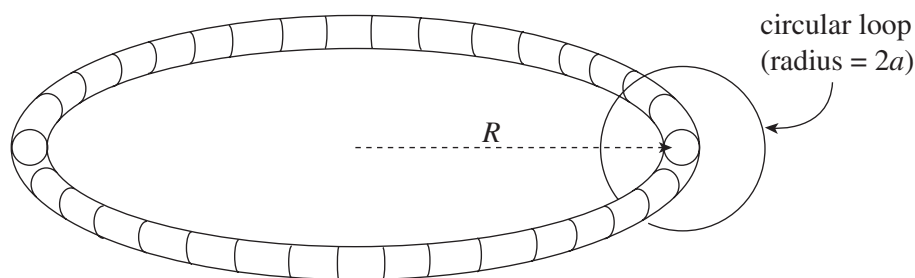
- Find a formula that gives the magnetic flux  $\Phi_B$  through the loop as a function of time,  $t$ .
- Find a formula that gives the emf induced in the loop as a function of time,  $t$ .
- If the total resistance of the loop is  $R$ , what is the current induced in the loop?
- When  $\omega t = \pi/2$ , is the induced current in the loop directed from Point 1 to Point 2 ( $-y$  direction) or from Point 2 to Point 1 ( $+y$  direction)?
- Find the rate at which energy is dissipated (as joule heat) in the wires that comprise the loop, and the amount of energy dissipated per revolution.
- Find the external torque required to keep the loop rotating at the constant angular speed  $\omega$ .

3. The figure below shows a toroidal solenoid of mean radius  $R$  and  $N$  total windings. The cross-sections of the toroid are circles of radius  $a$  (which is much smaller than  $R$ , so variations in the magnetic field strength within the space enclosed by the windings may be neglected).



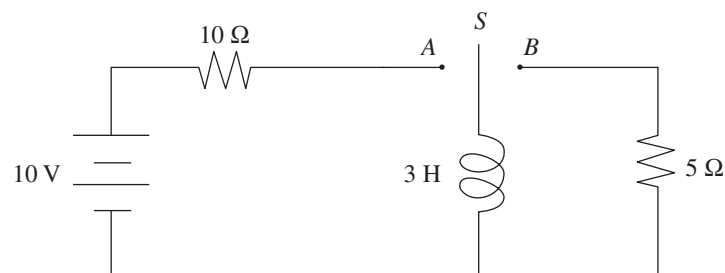
- (a) Use Ampere's law to find the magnetic field strength within the toroid. Write your answer in terms of  $N$ ,  $I$ ,  $R$ , and fundamental constants.

A circular loop of wire of radius  $2a$  is placed around the toroid as shown:



Assume that the current in the toroid is varied sinusoidally according to the equation  $I(t) = I_0 \sin \omega t$ , where  $I_0$  and  $\omega$  are fixed constants.

- (b) Determine the emf induced in the circular wire loop.  
 (c) Determine the electric field induced at the position of the circular wire loop.  
 (d) What is the self-inductance of the toroidal solenoid?



4. A circuit is connected as shown above. The switch  $S$  is initially open. Then it is moved to position  $A$ .

- (a) Determine the current in the circuit immediately after the switch is closed.
- (b) Determine the current in the circuit a long time after the switch is closed.

Some time after the steady state situation has been reached, the switch is moved almost instantaneously from position  $A$  to position  $B$ .

- (c) Determine the current through the  $5\ \Omega$  resistor immediately after the switch has been moved.
- (d) Determine the potential difference across the inductor immediately after the switch has been closed.