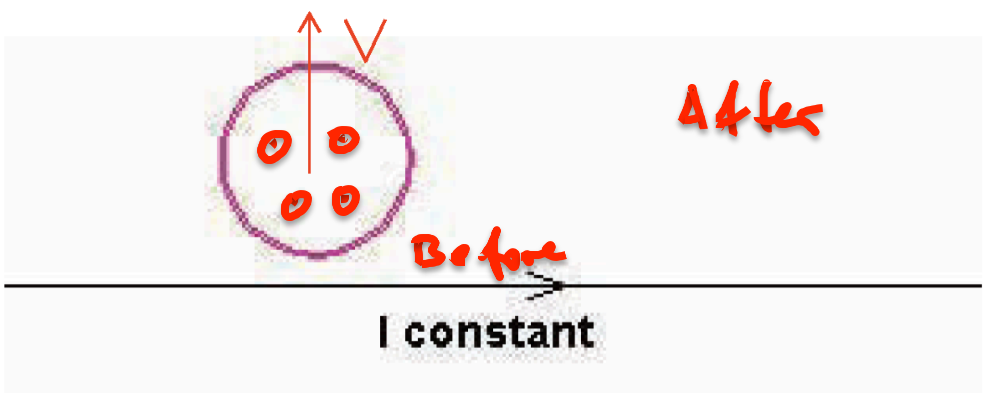
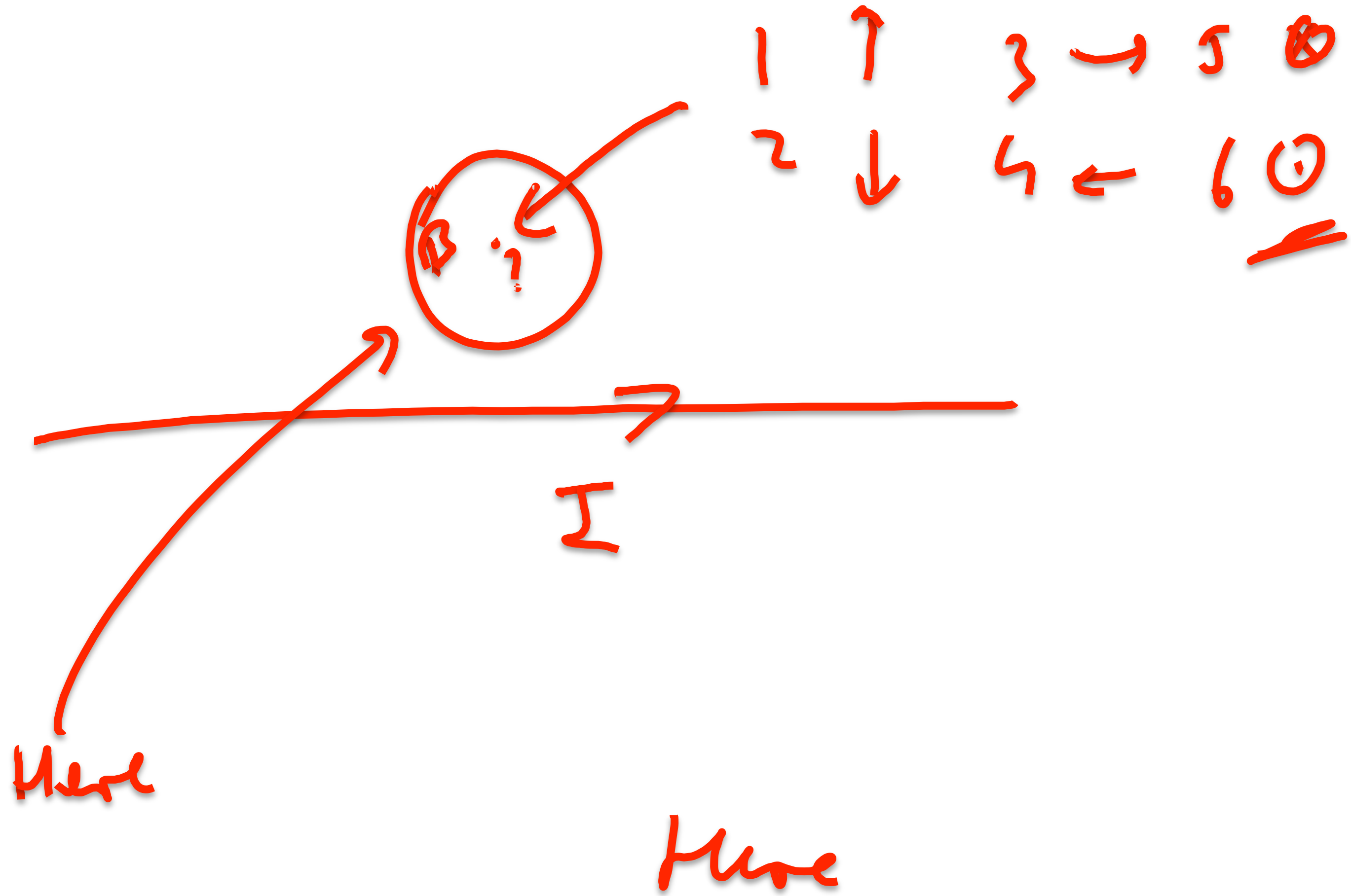
Lenz's Law example

A wire loop is located near a long straight current-carrying wire. The current in the wire is directed to the right.

With the current held constant in the long straight wire, the loop is moved up, away from the wire. In what direction is the induced current in the loop?

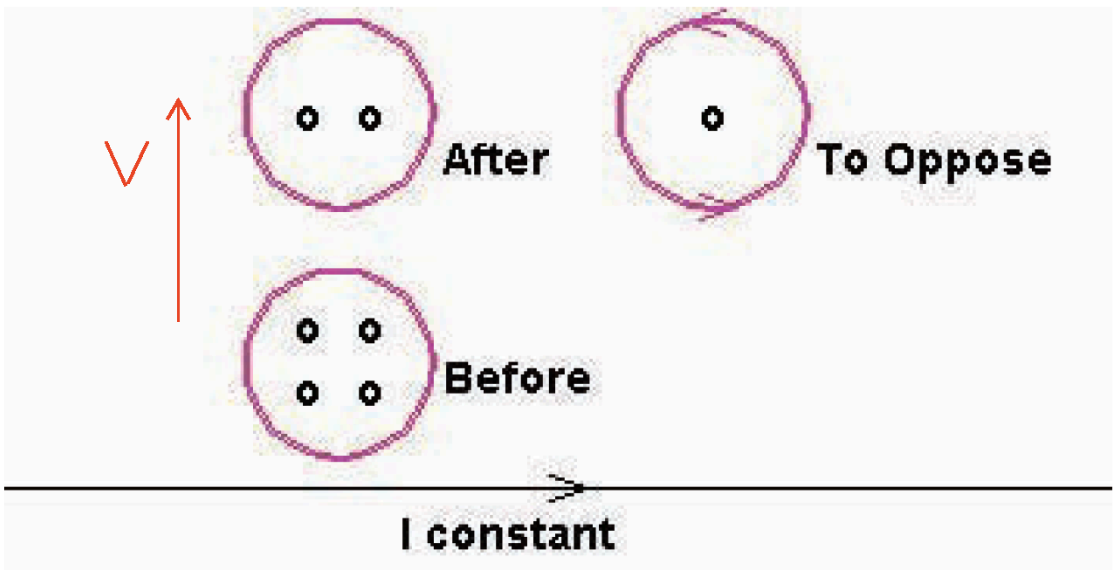
1. The induced current is clockwise.
2. The induced current is counter-clockwise.
3. There is no induced current.

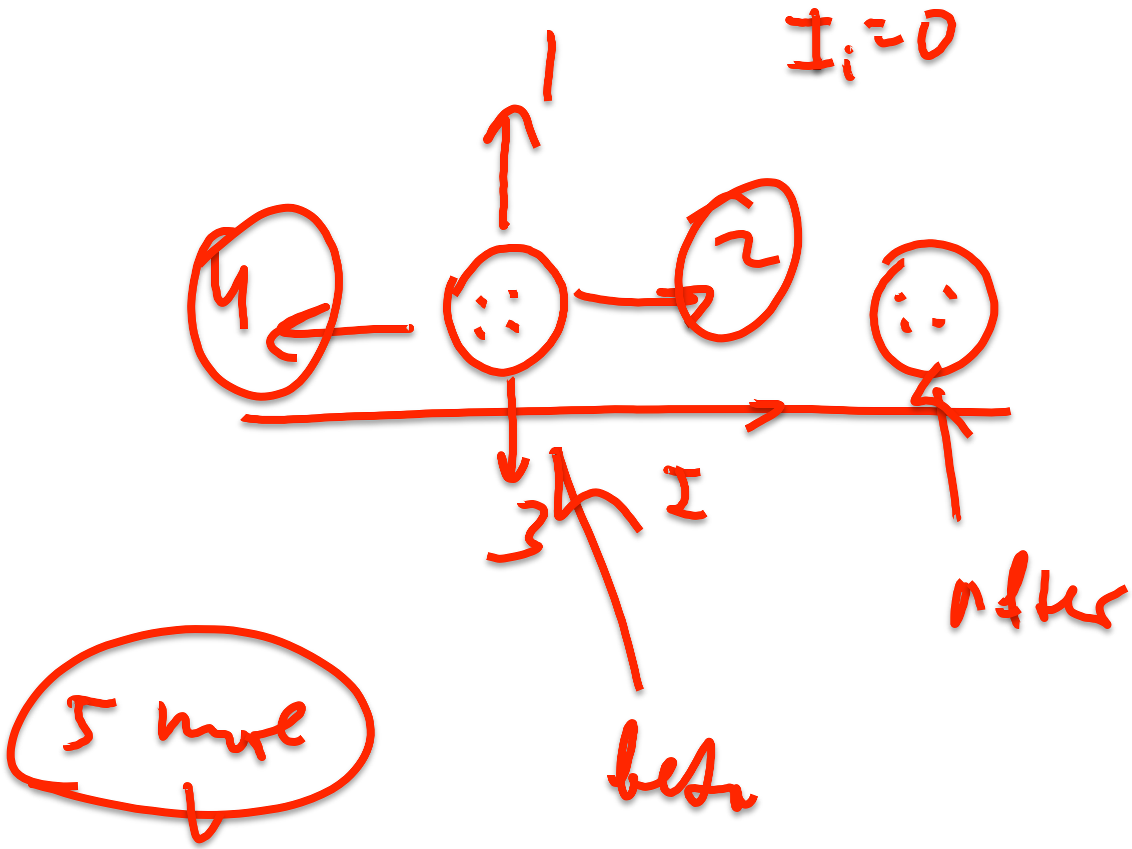



1 ↑ 3 → 5 ⊗
2 ↓ 4 ← 6 ⊙
B
I
Here
Here

Lenz's Law example

The flux through the loop decreases, so the loop tries to add field lines that are directed out of the page to oppose the change. The induced current must go counter-clockwise to produced the required field.




I_i=0
1
2
3
4
I
before
after
5 more

Lenz's Law example

With the current in the long straight wire, the loop is parallel to the wire. If the current in the wire is increasing, in what direction is the induced current in the loop?

1. The induced current is clockwise.
2. The induced current is counter-clockwise.
3. There is no induced current.

Lenz's Law example

With the current in the long straight wire, the loop is parallel to the wire. If the current in the wire is increasing, in what direction is the induced current in the loop?

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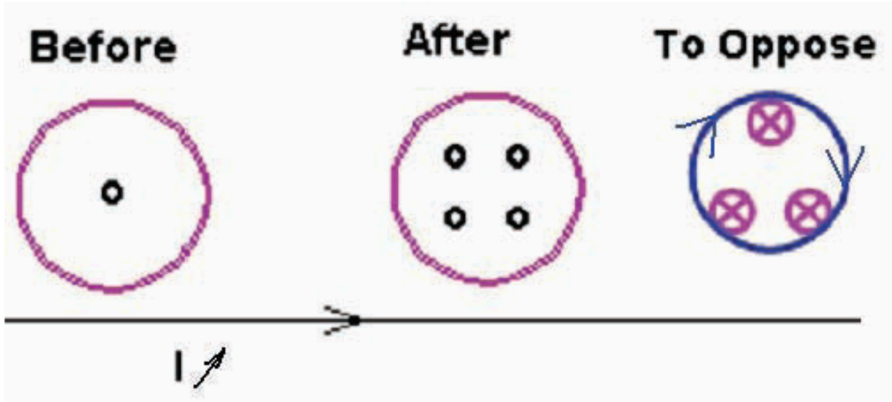
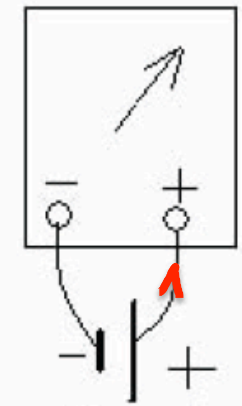
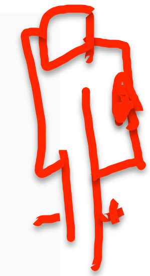


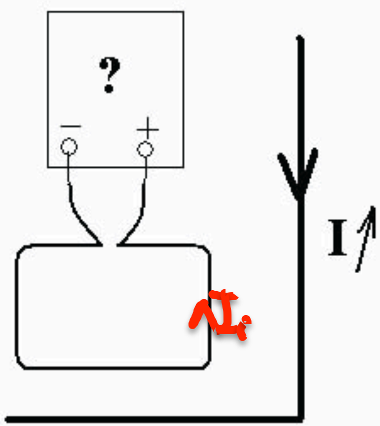
When a galvanometer is connected as shown in picture 1, the needle deflects to the right. Note that the galvanometer needle points straight up when no current passes through the galvanometer, and it would deflect to the left if we reversed the battery in picture 1.



pic. 1



Picture 2 shows a wire with an increasing current in it and a loop of wire connected to the galvanometer.



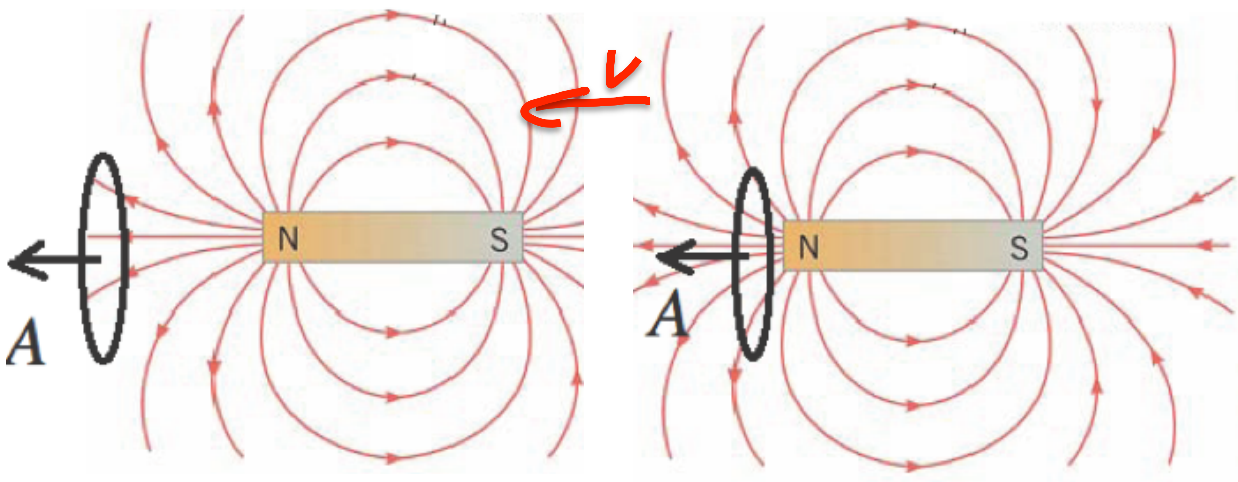
pic. 2

In which direction is the needle of the galvanometer deflected in picture 2?

1. to the left

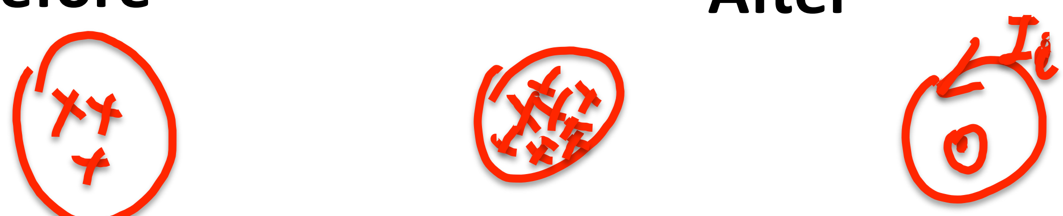
2. to the right

A moving magnet and a loop connected to a galvanometer (1)

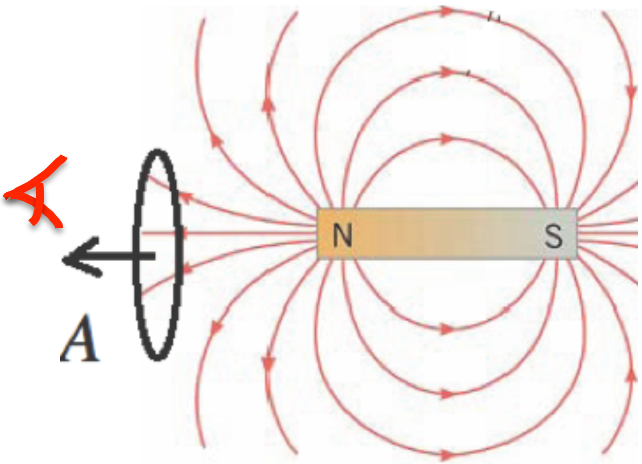


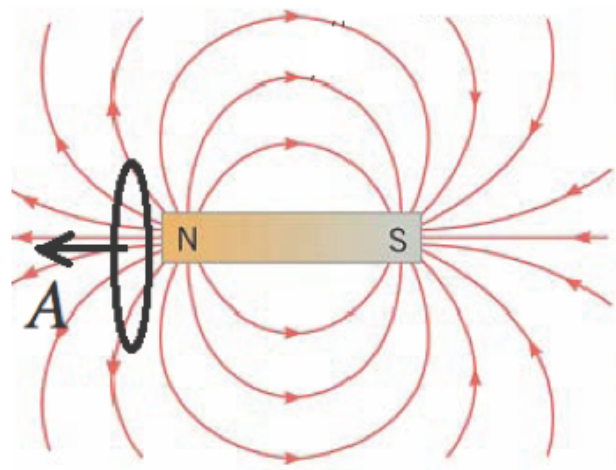
(where is the observer?)

Before **After** **To oppose**



A moving magnet and a loop connected to a galvanometer (1)





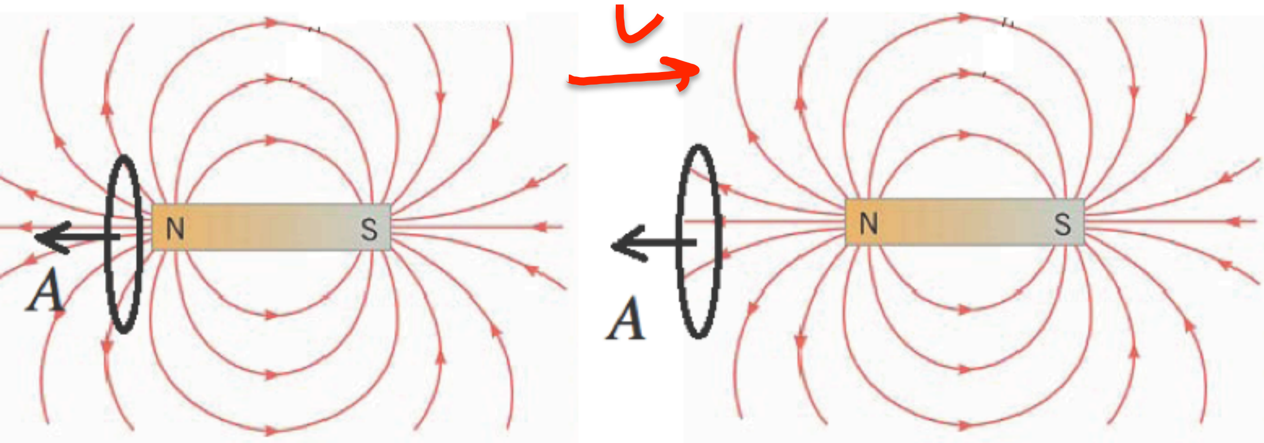
(where is the observer?)

Before

After

To oppose

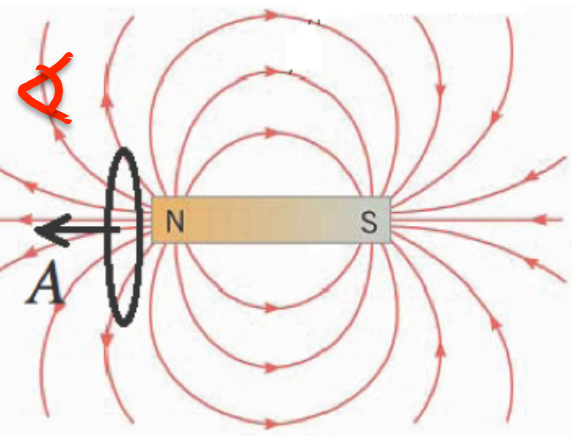
A moving magnet and a loop connected to a galvanometer (2)

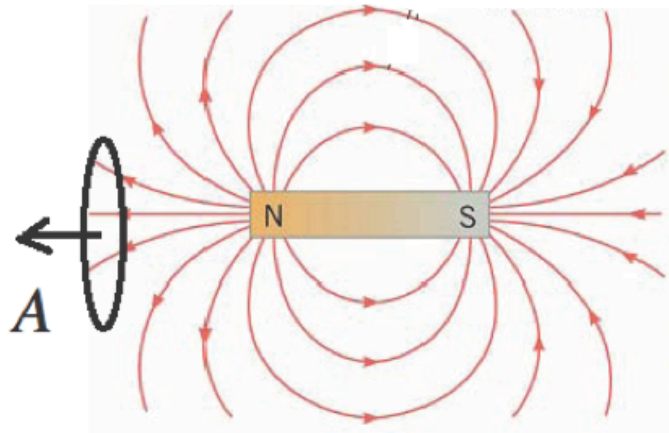


(where is the observer?)

Before **After** **To oppose**

A moving magnet and a loop connected to a galvanometer (2)



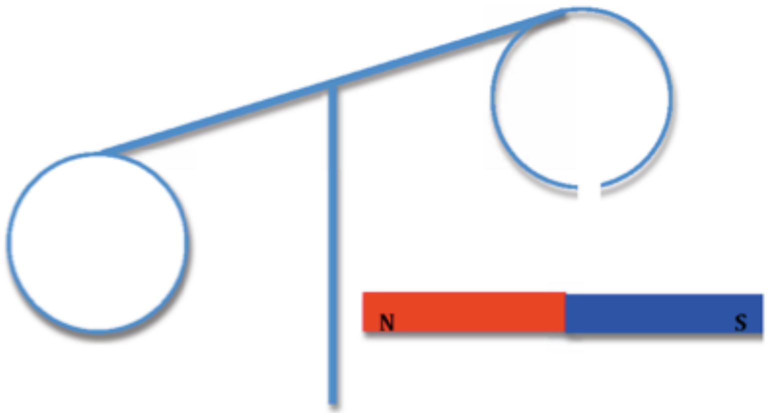


(where is the observer?)

Before

After

To oppose

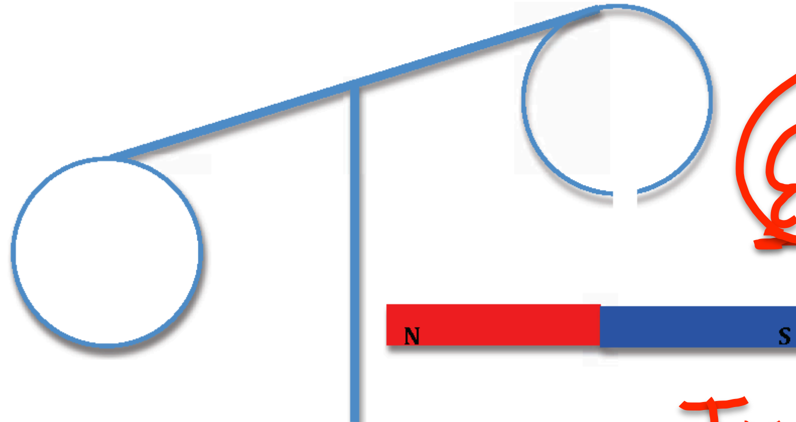


When we move a magnet – which has N (S) poll closer to the loop - toward to (away from) the loop, the loop is

1. not moving
2. attracted by the magnet
3. repelled by the magnet

What will happen when we close the switch?

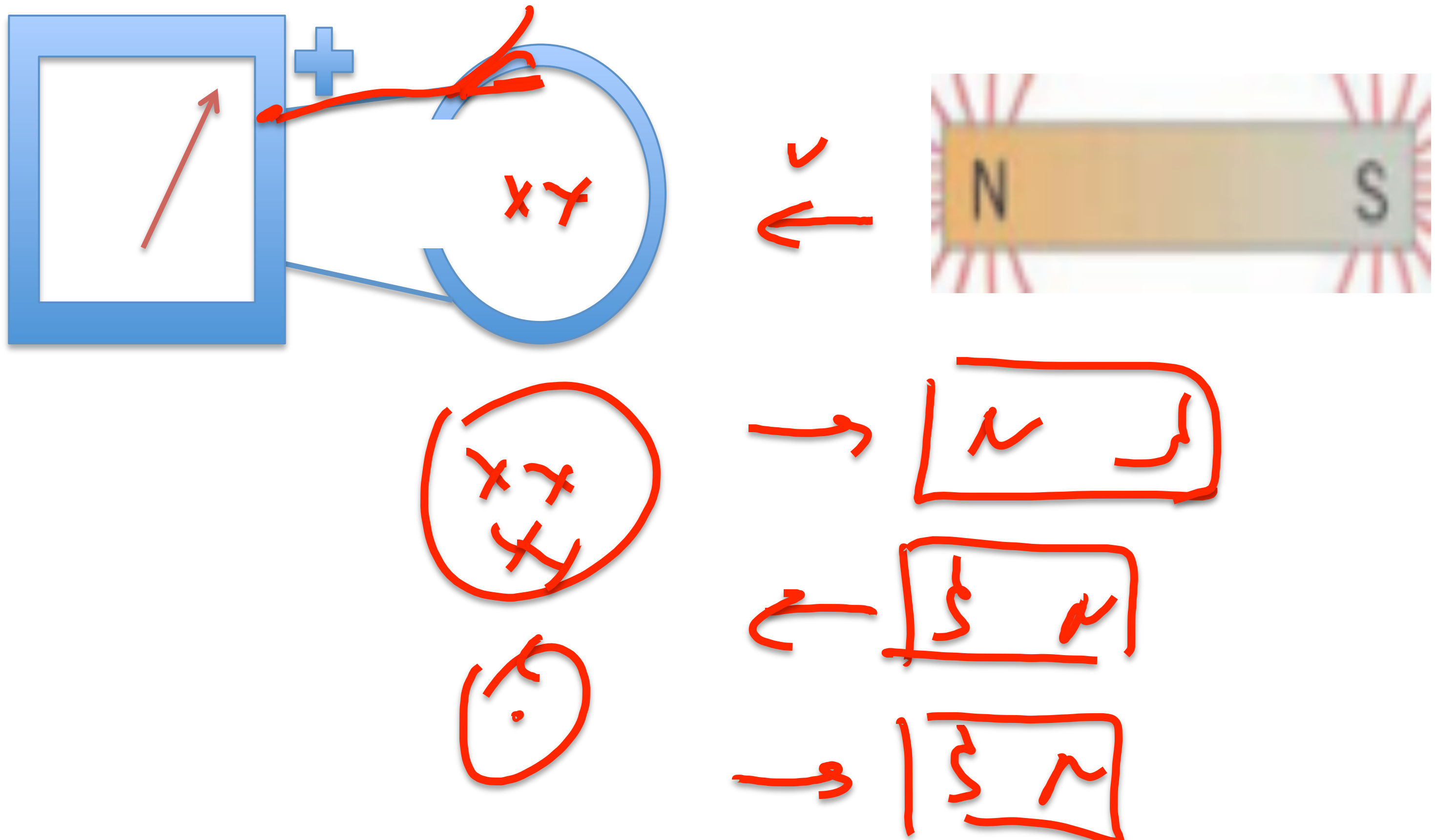
1. **nothing**
2. **the ring jumps**



If we will be moving the magnet into the loops

1. they both move
2. only the completed one moves
3. only the cut one moves
4. none of the loops moves

A moving magnet and a loop connected to a galvanometer



Lenz's Law

Lenz's Law: A changing magnetic flux induces a response that ***tends to oppose the change***.

external $\qquad$ E $\qquad$ induced

$|\Delta\Phi/\Delta t| \rightarrow \varepsilon \rightarrow I = \varepsilon\, /R \rightarrow B \rightarrow \Delta\Phi$ <u>opposite</u>

The change can be made, but the coil or loop tries to oppose the change while the change is taking place. This tendency to oppose is why there is a minus sign in Faraday's Law.

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} \qquad |\varepsilon| = \left|N\frac{\Delta\Phi}{\Delta t}\right|$$

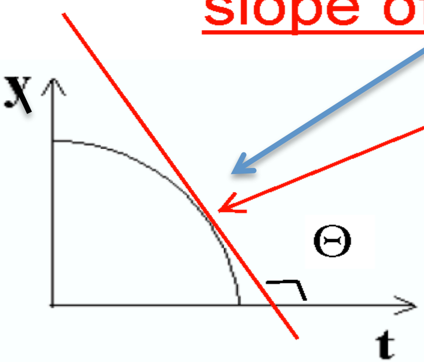
Review!

Instantaneous velocity

average velocity $= \dfrac{\text{net displacement}}{\text{total time}}$, or, $\bar{v} = \dfrac{\Delta \vec{x}}{\Delta t}$

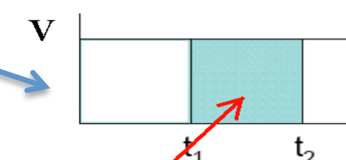
instantaneous velocity = $\vec{v} = \lim_{\Delta t \to 0} \dfrac{\Delta \vec{x}}{\Delta t}$

This is an intimidating definition. It's often easier, and more intuitive, to find instantaneous velocity from the slope of the tangent of a position vs. time graph.



$v = \tan(\Theta)$

$\Delta x = v * \Delta t$



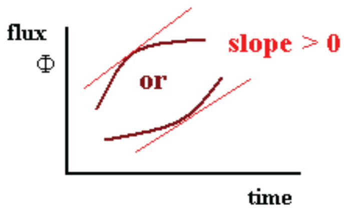
"displacement = area under velocity vs. time graph"

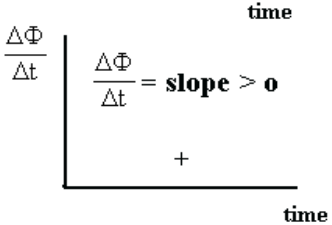
Flux, change in the flux and the induced current

We can divide the graphs into four typical parts.

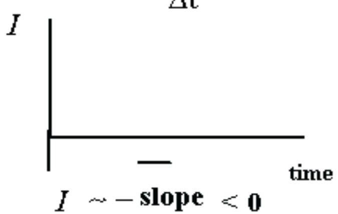
The actual behavior of the function depends on the situation, but there are some similarities as such:

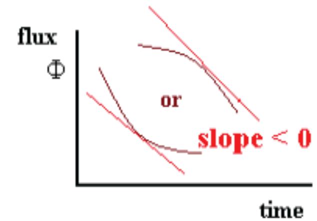
$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

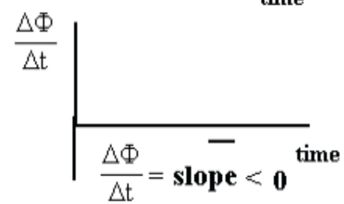




$$I = \varepsilon / R = (-N\frac{\Delta\Phi}{\Delta t}) / R \sim -\text{slope}$$







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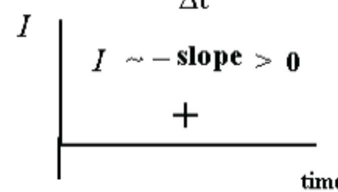
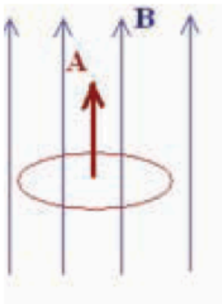


Same |slope| => same |I|

Work together!

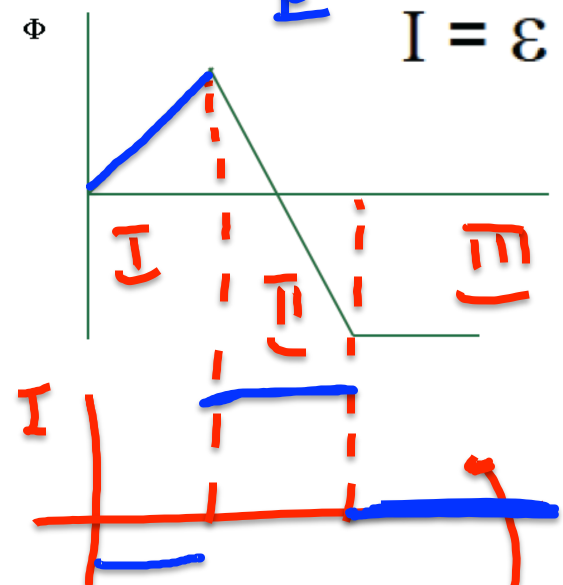
$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

$$I = \varepsilon / R$$

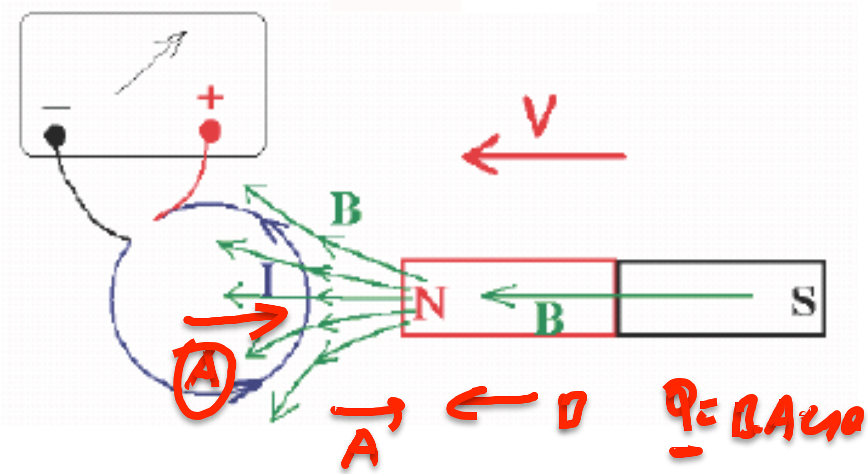


A loop is in magnetic field.

The magnetic flux Φ through the loop is presented by the graph on the right.

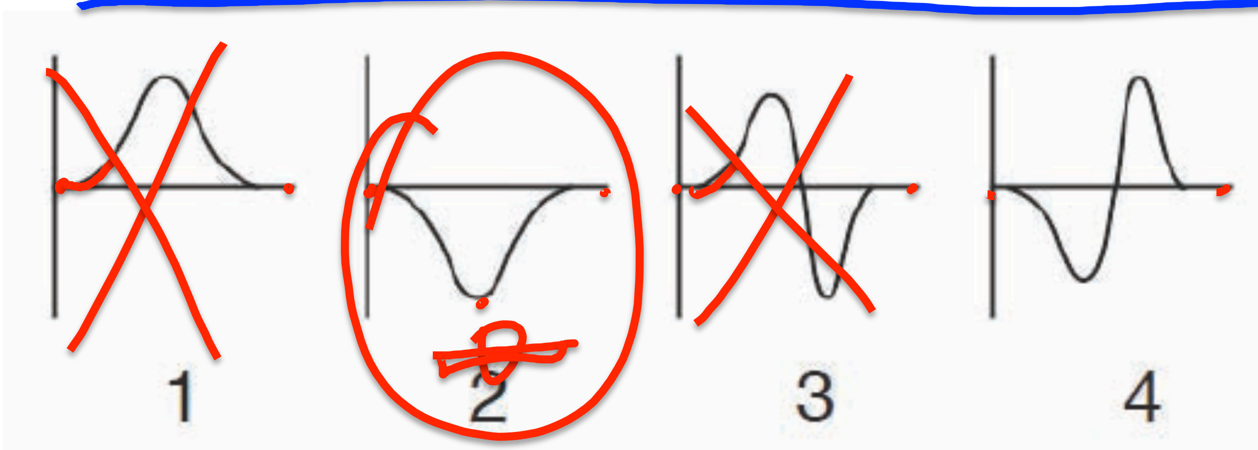


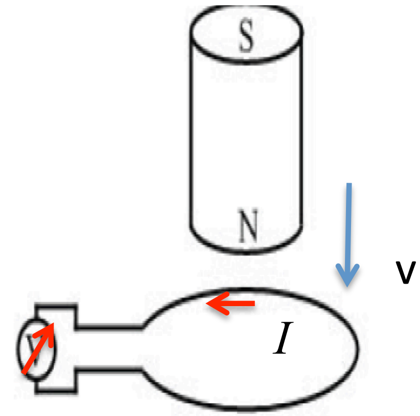
Sketch the graph for the current induced in the loop vs. time.



In our experiment with the area vector pointing out of the page, which of the graphs below represents the flux in the loop as a function of time?

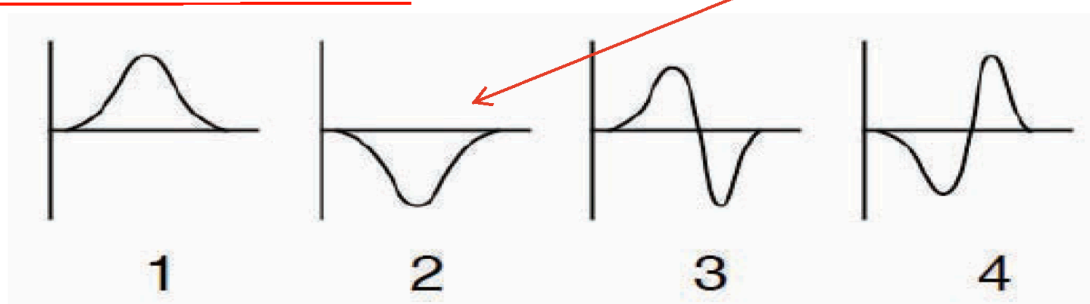
We set positive direction of the induced current as shown.

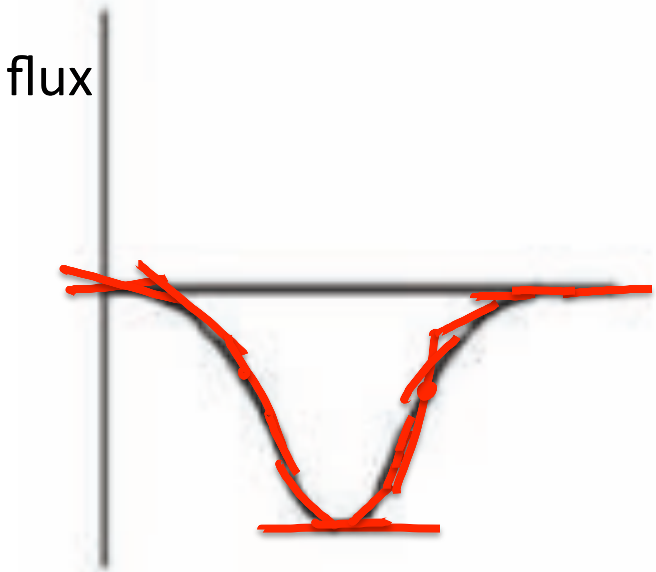




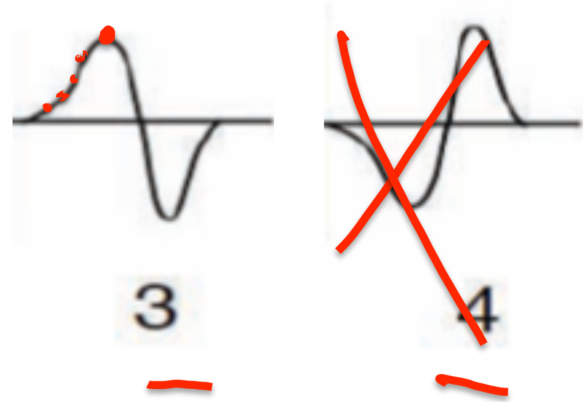
a magnet is dropped from rest. As shown in the diagram, the north pole of the magnet is at the bottom of the magnet and the south pole is at the top. The magnet accelerates down, passing through the center of a loop of wire connected to a voltmeter. Assume that the magnet is always oriented as shown in the diagram, with the south pole at the top of the magnet and the north pole at the bottom.

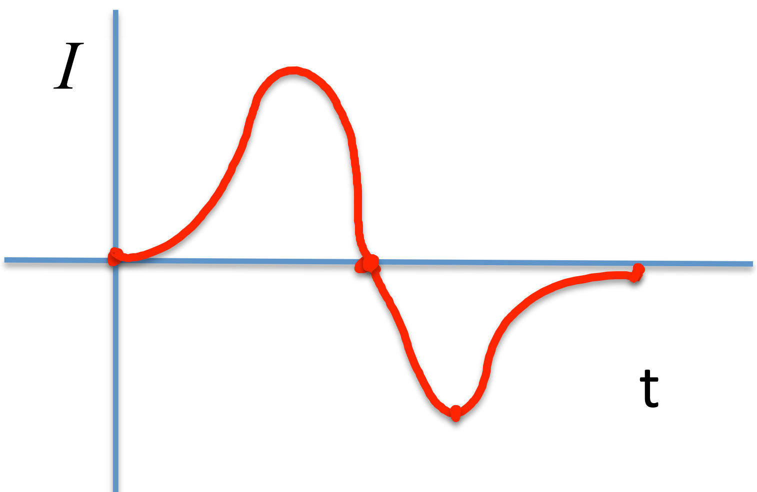
Let us define *positive* flux as coming from magnetic field lines that are directed *up* through the loop (recall the graph for the flux!). Which of the graphs below that best represents the graph of **induced EMF** as a function of time for the magnet passing through the loop.





$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} \qquad I = \varepsilon / R$$





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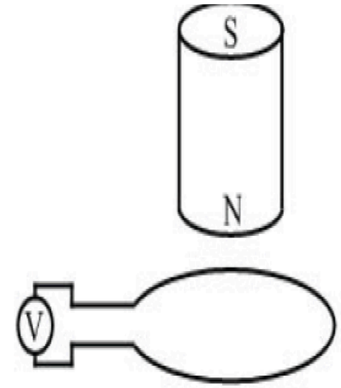
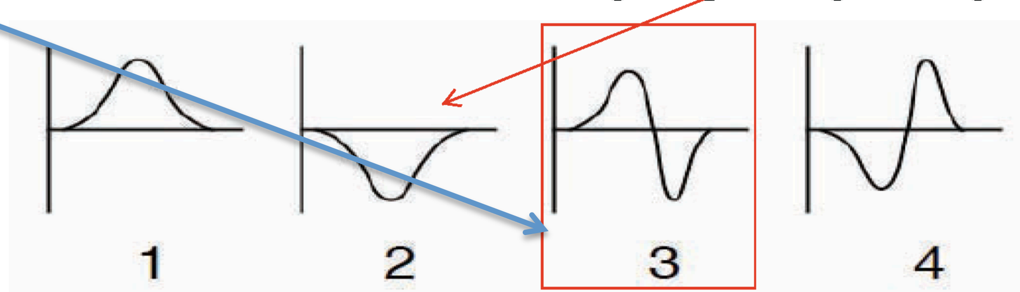
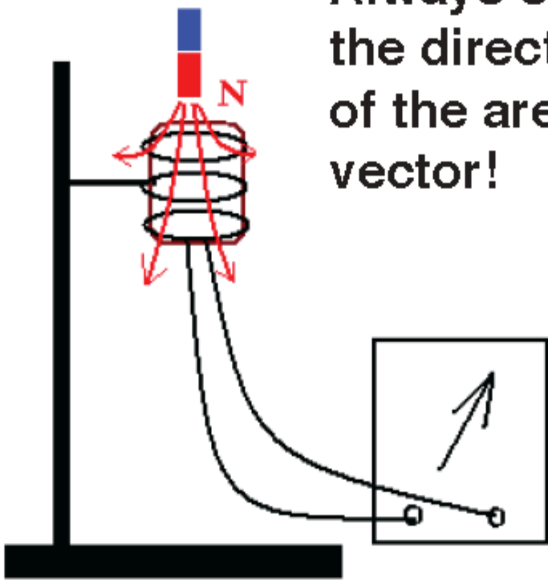


Let us define *positive* flux as coming from magnetic field lines that are directed *up* through the loop (recall the graph for the flux!). Which of the graphs below that best represents the graph of **induced EMF** as a function of time for the magnet passing through the loop.



An experiment

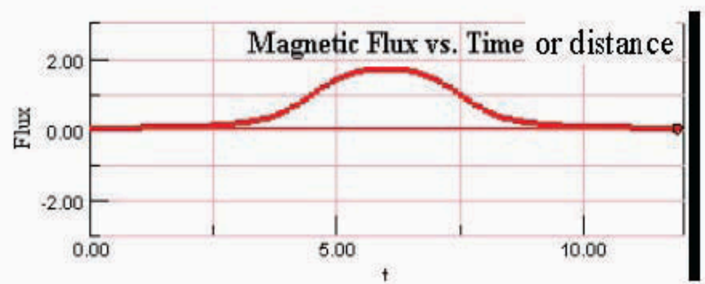


Always state the direction of the area vector!

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

$$I = \frac{\varepsilon}{R}$$

$$\Phi_B = BA\cos\theta$$



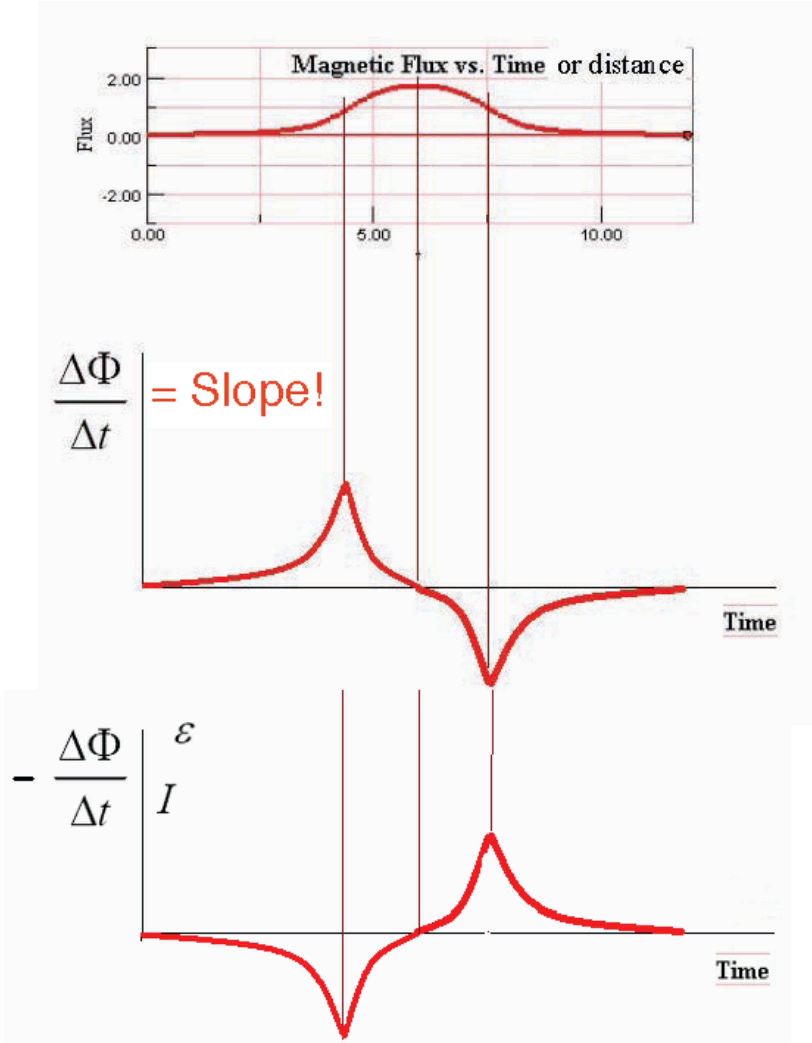
$\Phi > 0$

for

our choice for the area vector for the coil

If we want the flux to be positive in this experiment, we have to point area vector down!

Flux, change in the flux and the induced current



$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

$$I = \frac{\varepsilon}{R}$$

(theses are sketches, not graphs!)

A falling magnet accelerates!

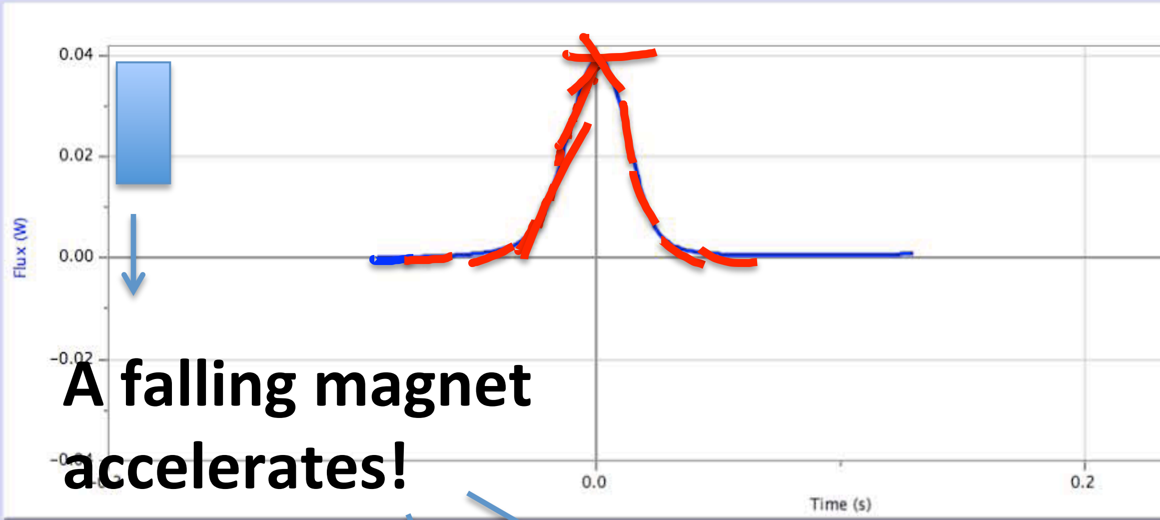
$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t}$$

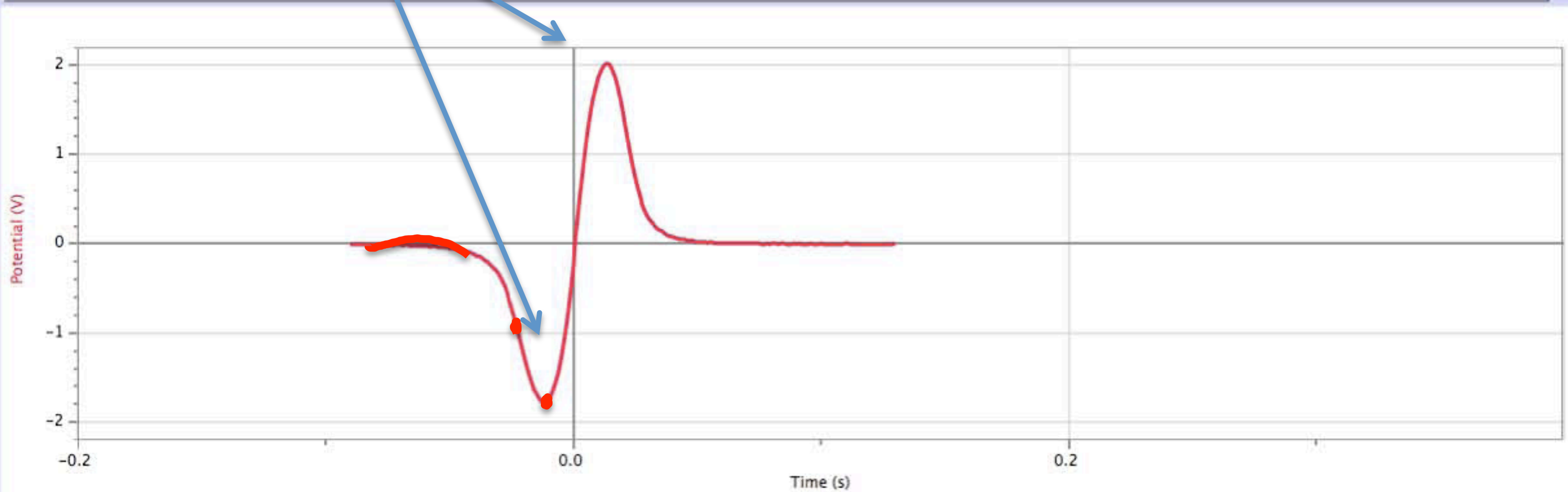
$$I = \frac{\mathcal{E}}{R}$$

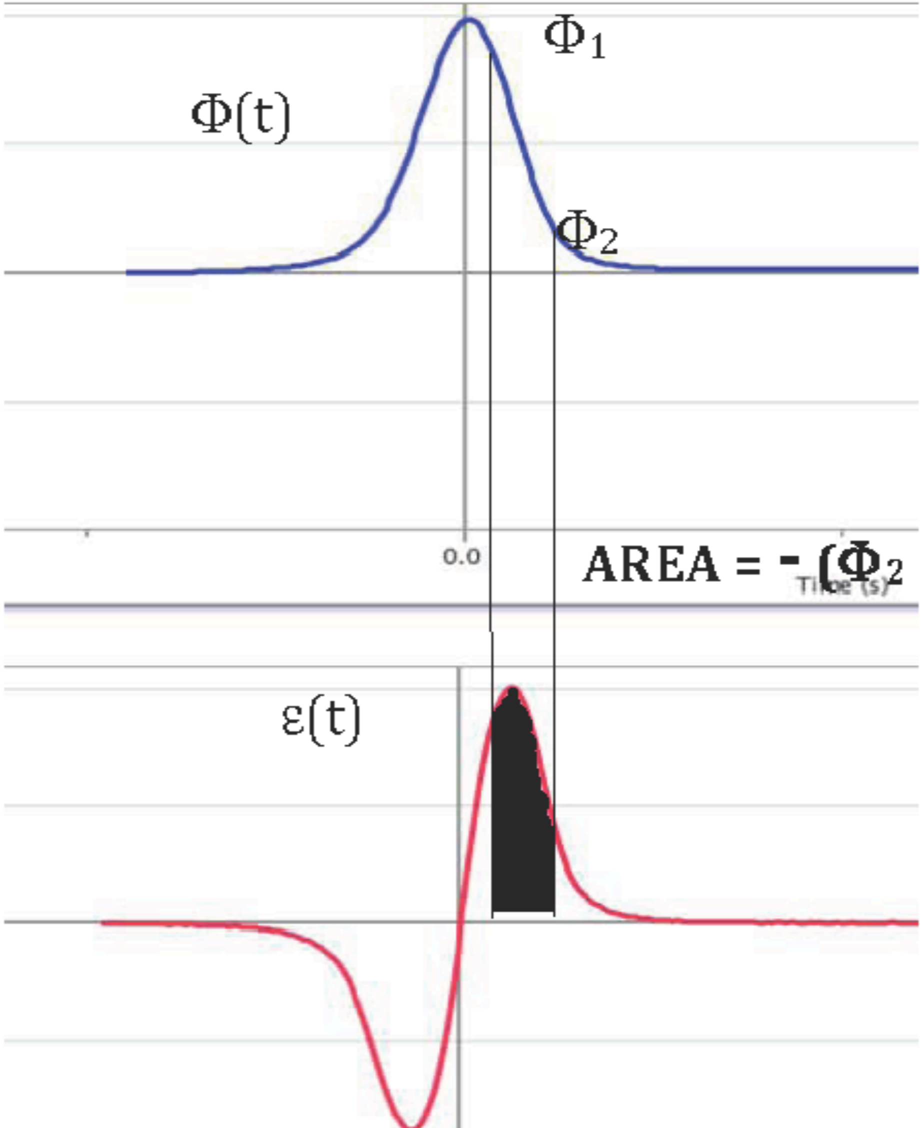
	Latest	
	Time (s)	Potential (V)
1	-0.090	-0.004
2	-0.089	-0.004
3	-0.088	-0.014
4	-0.087	-0.004
5	-0.086	-0.004
6	-0.085	-0.009
7	-0.084	-0.014
8	-0.083	-0.009
9	-0.082	-0.009
10	-0.081	-0.014
11	-0.080	-0.014
12	-0.079	-0.009
13	-0.078	-0.014
14	-0.077	-0.014
15	-0.076	-0.014
16	-0.075	-0.014
17	-0.074	-0.014
18	-0.073	-0.019
19	-0.072	-0.014
20	-0.071	-0.014
21	-0.070	-0.014
22	-0.069	-0.019
23	-0.068	-0.014
24	-0.067	-0.014
25	-0.066	-0.019
26	-0.065	-0.023
27	-0.064	-0.019
28	-0.063	-0.023
29	-0.062	-0.023
30	-0.061	-0.023
31	-0.060	-0.023
32	-0.059	-0.028

Potential

V







Analogy!!

$v = \frac{\Delta x}{\Delta t}$ => v is represented by the slope of X(T) graph, and Δx equals the AREA on v(t) graph.

AREA = - (Φ_2 - Φ_1)

$\varepsilon = -\frac{\Delta \Phi}{\Delta t}$ $(\Phi = N \bullet \Phi_{single\_loop})$

ε is represented by the slope of $-\Phi(t)$ graph, and $\Delta\Phi$ equals the AREA on $-\varepsilon(t)$ graph.

Faraday's Law

A loop of wire, in the plane of the page, has an area of 0.5 m^2 and a resistance of R = 0.1 Ω. There is a uniform magnetic field of B = 1.0 T passing through the loop into the page. the magnetic field is reduced steadily from 1.0 T to 0 over a 10 second period What is the value of the induced current in the loop?

$$\Phi = B\,A\cos\theta \qquad I = \frac{\varepsilon}{R}$$

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

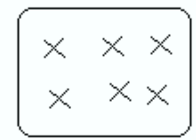
1. 0.1 A
2. 0.5 A
3. 1 A

Faraday's Law

$A = 0.5 \text{ m}^2$ $R = 0.1\ \Omega$ $B_i = 1.0 \text{ T}$

The magnetic field is reduced steadily from 1.0 T to 0 over a 10 second period.

$$\left|\frac{\Delta B}{\Delta t}\right| = \left|\frac{-1.0 \text{ T}}{10 \text{ s}}\right| = 0.1 \text{ T/s}$$



First, apply Faraday's law to find the induced emf (voltage):

$$|\varepsilon| = \left|-N\frac{\Delta\Phi}{\Delta t}\right| = N\frac{|\Delta(BA\cos\theta)|}{\Delta t} = NA\cos\theta\frac{|\Delta B|}{\Delta t}$$

$$= 1 \times (0.5 \text{ m}^2) \times 1 \times (0.1 \text{ T/s}) = 0.05 \text{ V}$$

$$I = \frac{\varepsilon}{R} = \frac{0.05 \text{ V}}{0.1\ \Omega} = 0.5 \text{ A}$$

$I = \frac{Q}{t}$

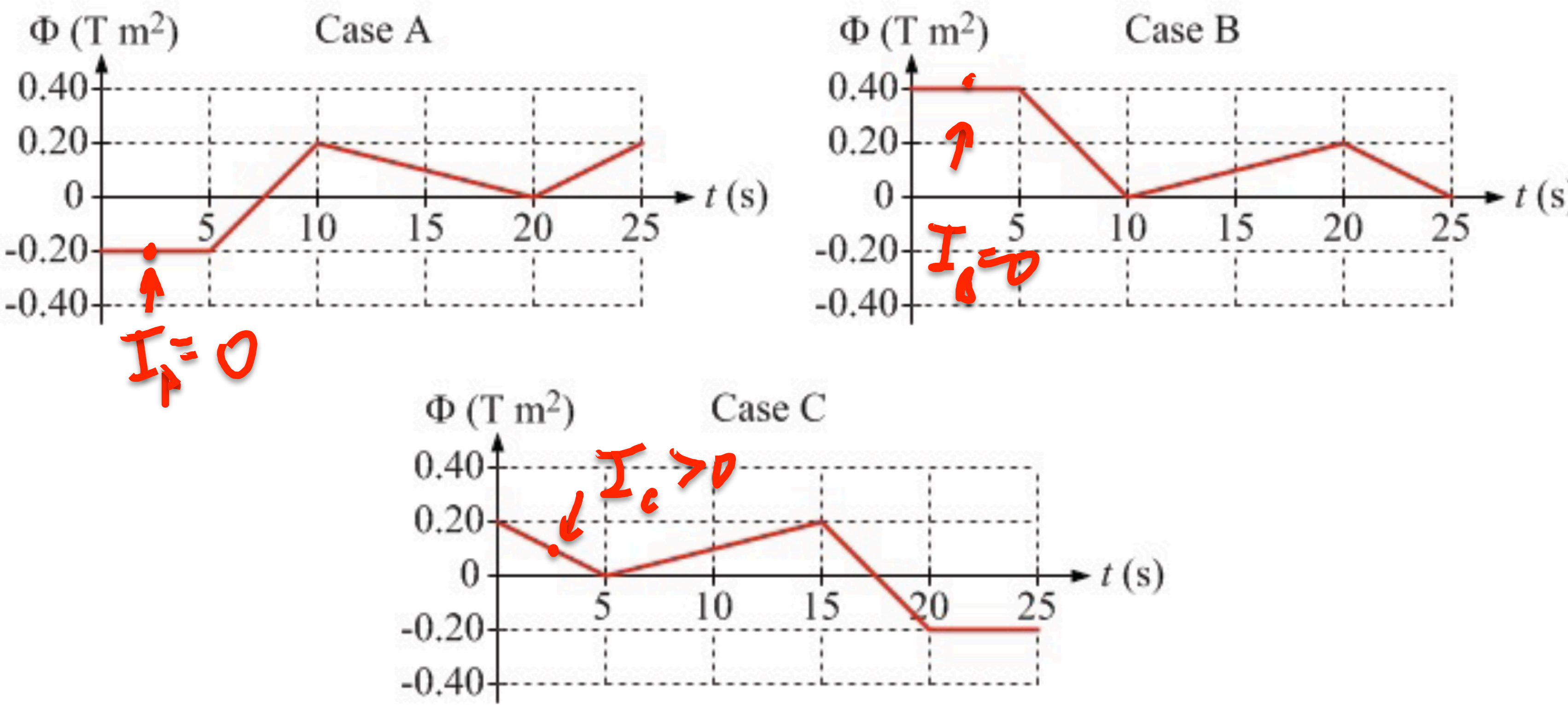
$Q = I \cdot t = 5c$

$$\Delta \Phi = \Phi_1 - \Phi_i =$$

$$= B_1 A_1 \cos\theta_1 - B_i A_i \cos\theta_i =$$

$$= B_1 \underbrace{A \cos\theta} - B_i \underbrace{A \cos\theta} =$$

$$= (B_1 - B_i) \cdot A \cdot \cos\theta = \underline{\Delta B \cdot A \cdot \cos\theta}$$



At t = 3 s, which has the largest magnitude of the induced current?

A.

B.

C.

Assume counterclockwise direction of the current when it has a positive value.

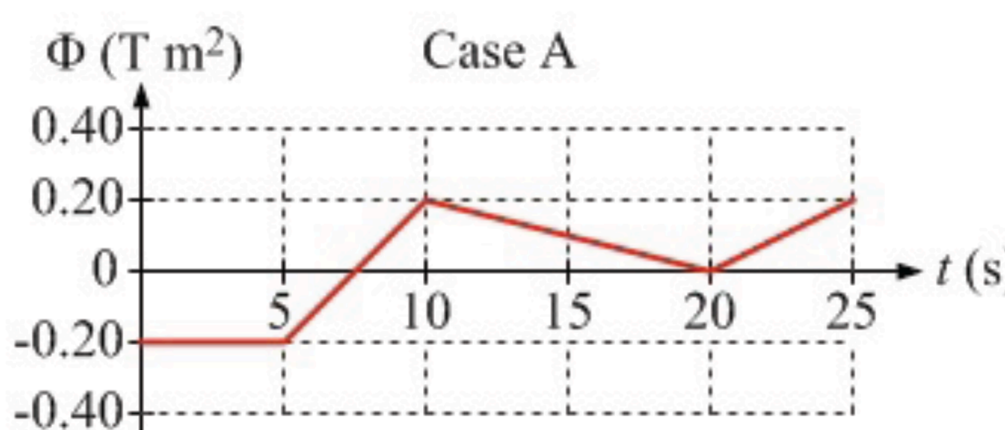
At t = 8 s, for case A, what is the direction of the induced current?

1. clockwise

2. counterclockwise

What about cases B and C?

At which times is the induced current clockwise?



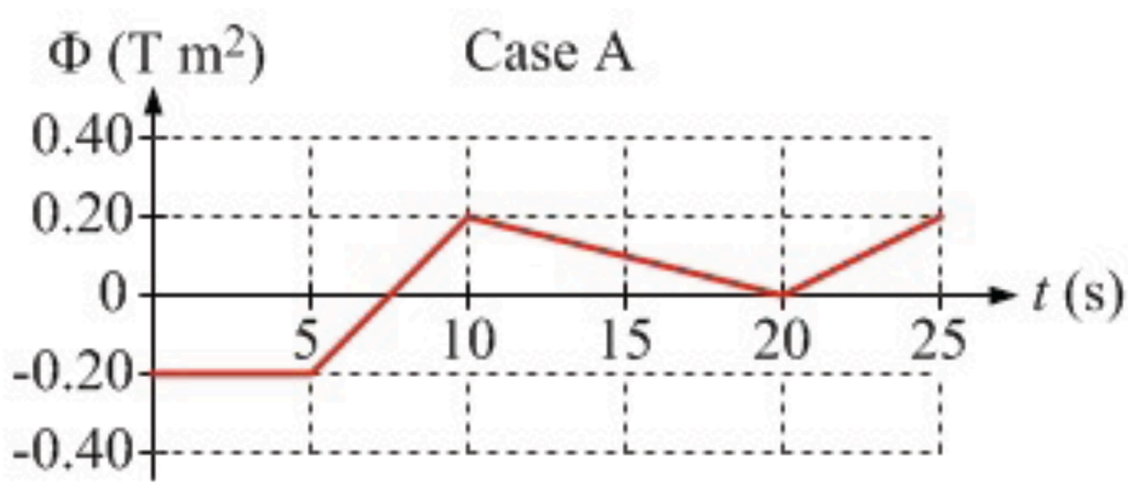
A flat coil of wire, consisting of 30 circular loops, with a total resistance of 20.0 ohms,

For case A, find the magnitude of the induced current at t = 8 s.

1. 0.12 A

2. 1.2 A

3. 12 A



For case A, find the magnitude of the induced current at t = 8 s.

A flat coil of wire, consisting of 30 circular loops, with a total resistance of 20.0 ohms,

Get the slope off the graph:

$$\frac{\Delta\Phi}{\Delta t} = \frac{0.4\ \mathrm{T\ m^2}}{5.0\ \mathrm{s}} = 0.08\ \mathrm{T\ m^2/s}$$

at t=6
1. $I_6 > 0.12$ A
2. $I_6 = 0.12$ A
3. $I_6 < 0.12$ A

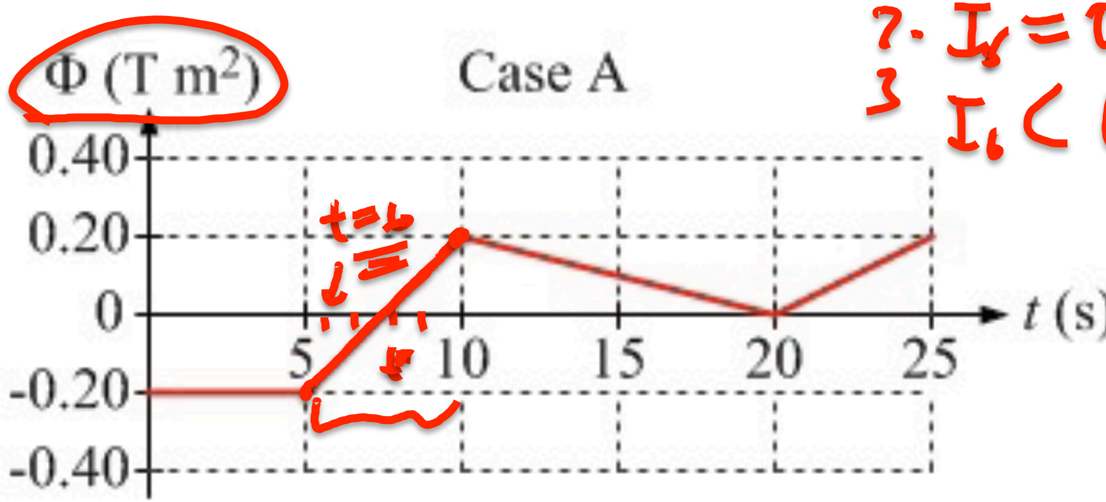
$$|\varepsilon| = \left| -N\frac{\Delta\Phi}{\Delta t} \right|$$

$$= 30 \times 0.08\ \mathrm{T\ m^2/s}$$

$$= 2.4\ \mathrm{V}$$

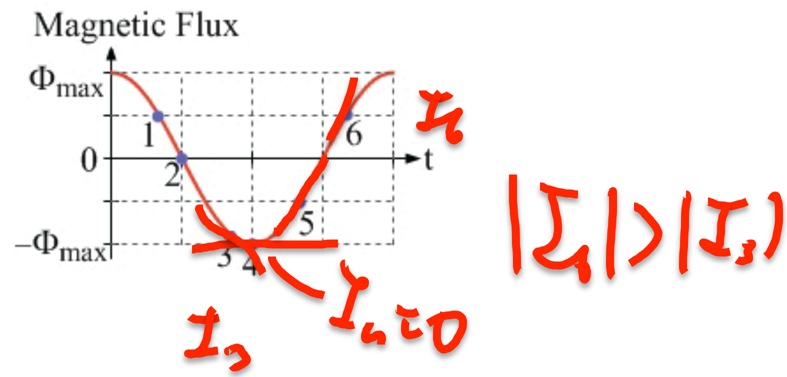
$$|I| = \frac{|\varepsilon|}{R}$$

$$= \frac{2.4\ \mathrm{V}}{20\ \Omega} = 0.12\ \mathrm{A}$$



What about other cases and instants?

The graph shows the magnetic flux, as a function of time, through a conducting loop that is at rest. Note that the graph has the shape of a cosine graph.



(a) At which of the six points is the magnitude of the magnetic flux through the loop largest?

(b) At which of the six points is the magnitude of the induced emf largest?

(c) If the induced current in the loop is directed clockwise at the instant corresponding to point 5, at which of the other five points is the induced current also directed clockwise?

(d) At which of the other five points does the induced emf have the same magnitude as it does at the instant corresponding to point 5?

(e) Rank, from largest to smallest, the magnitude of the induced emf at points 2, 3, and 4.