If you move away from a wire with a current, so that new distance from the wire is 4r, where r is the original distance, what happens to the magnitude of the magnetic field generated by the wire, comparing to the value at the original point?

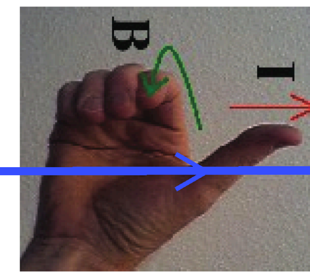
1. B doubles
2. B quadruples
3. B getting 16 times stronger
4. B halves
5. B getting 4 times weaker
6. B getting 16 times weaker
7. B does not change

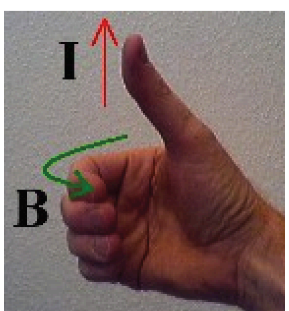
A wire with a current creates a magnetic field around it!

What do you think would be the direction of the magnetic field of this wire here?

⊙ Out of the page!

I





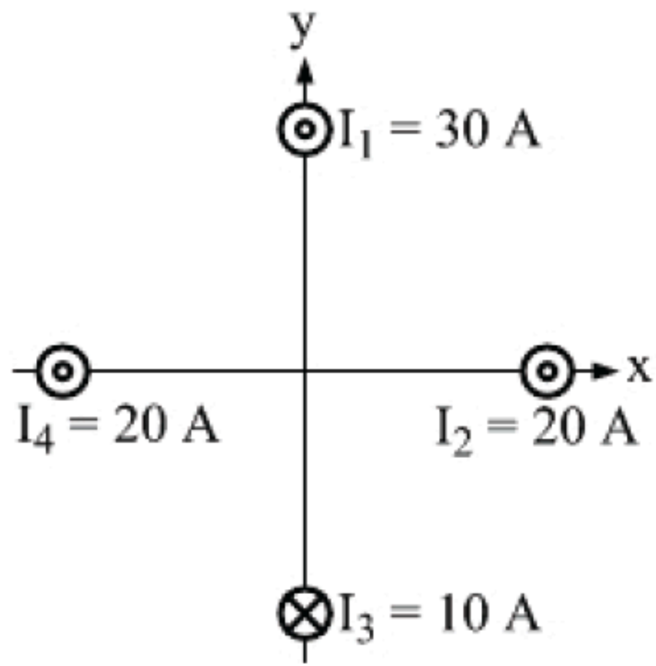
$\oplus B$ Into the page!

$$B = \frac{\mu_0 I}{2\pi r}$$

The net magnetic field

In which direction is the net magnetic field at the origin in the situation shown below? All the wires are the same distance from the origin.

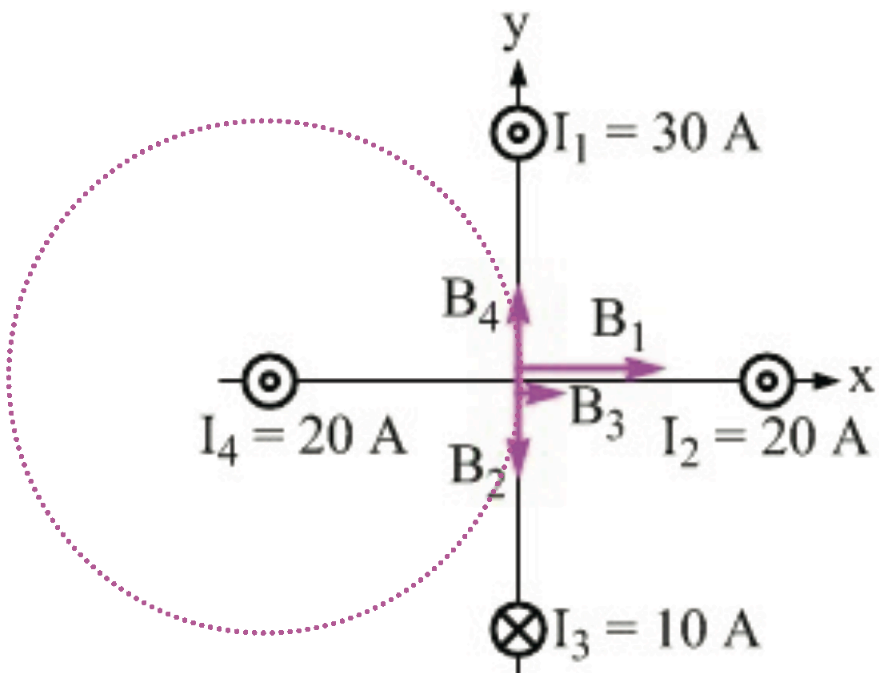
1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net field is zero



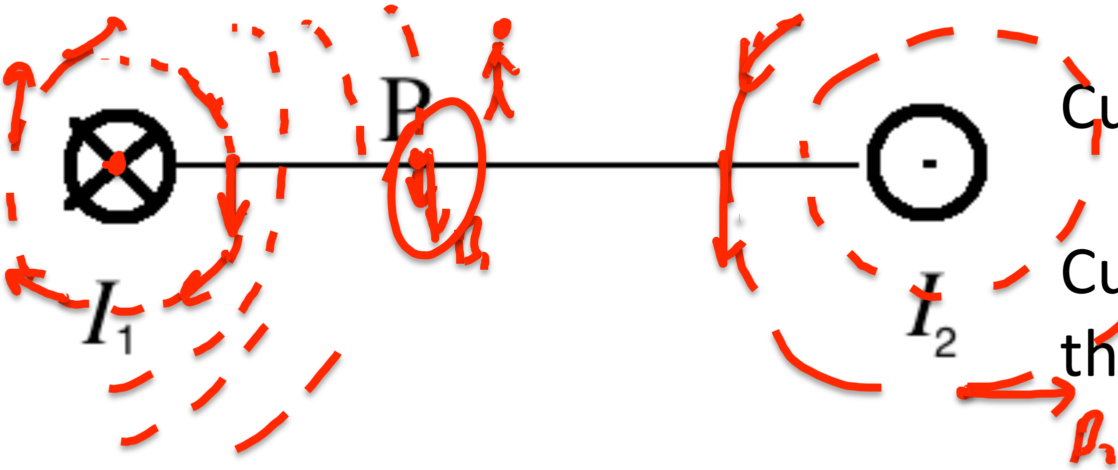
The net magnetic field

We add the individual fields to find the net field, which is directed right.

$$B = \frac{\mu_0 I}{2\pi r}$$



$$If \quad \frac{\mu_0}{2\pi r} \quad => B_{net} = \ldots$$



Current I_1 is into the screen;

Current I_2 is out of the screen;

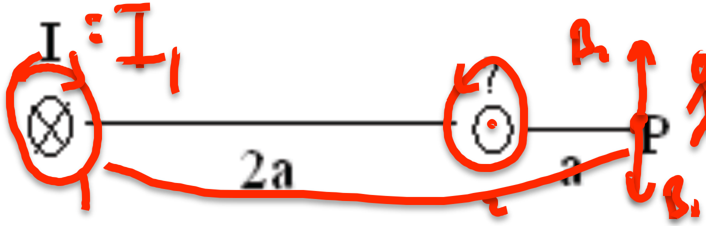
Can net magnetic field at point P be 0?

$$B = \frac{\mu_0 I}{2\pi r}$$

1. Yes

2. No

3. Maybe if currents have correct values.



Two wires carry a current. What current (2I, 3I or etc.) should be carried by the second wire to make the net magnetic field at the point P be zero? What should be the direction of that current?

$r_1 = 3a$

$r_2 = a$

$B_{net} = 0 \qquad \vec{B}_1 + \vec{B}_2 = 0$

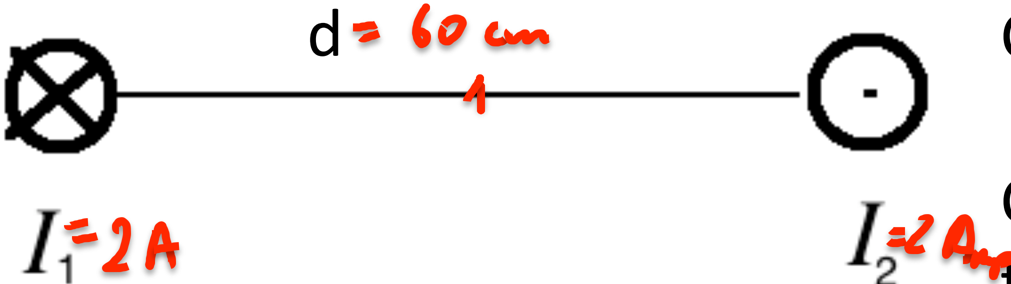
$$B = \frac{\mu_0 I}{2\pi r}$$

$|B_1| = |B_2|$

$I_2 = ?$

$$\frac{\mu_0}{2\pi}\frac{I_1}{r_1} = \frac{\mu_0}{2\pi}\frac{I_2}{r_2} \Rightarrow \frac{I}{3a} = \frac{I_2}{a} \Rightarrow I_2 = \frac{I}{3}$$

1. left
2. right
3. up
4. down
5. into
6 out



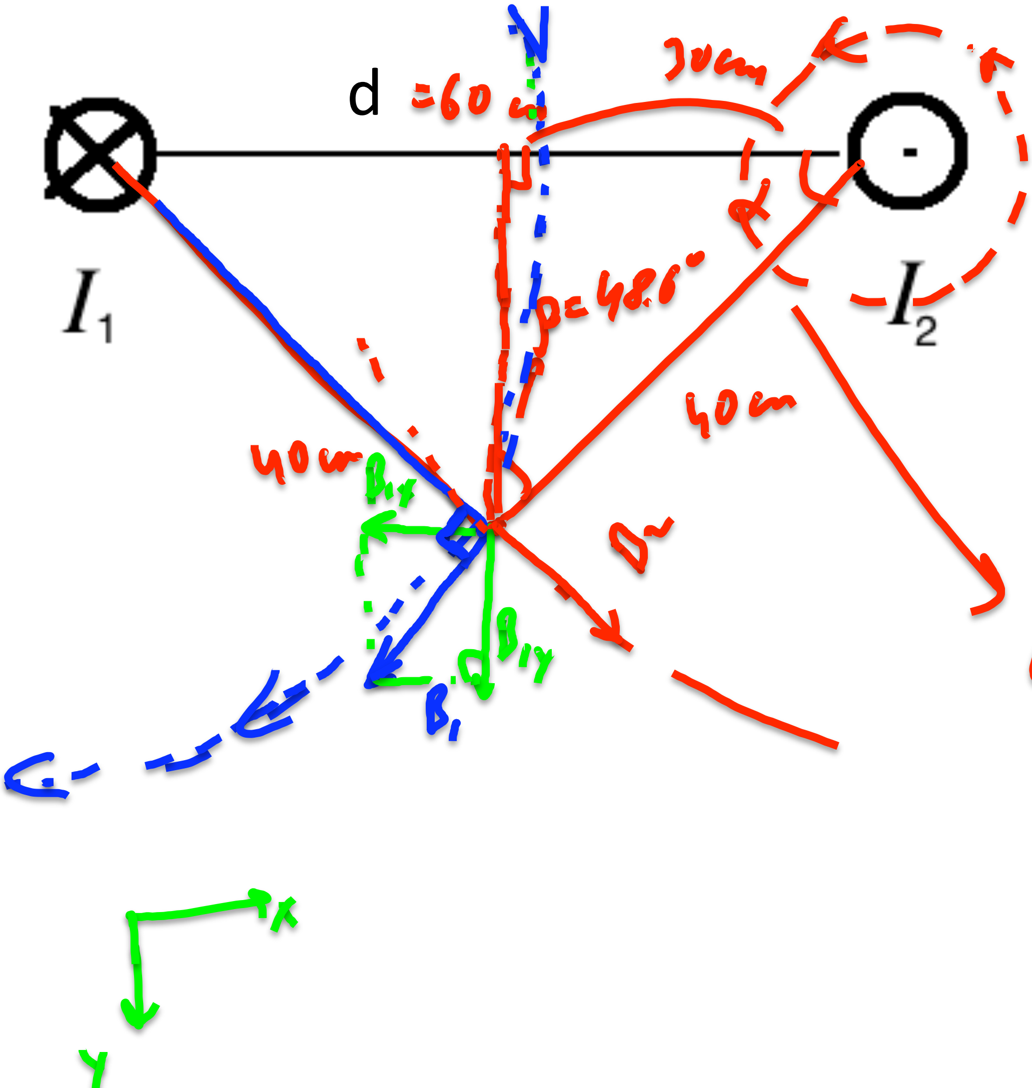
Current I_1 is into the screen;

Current I_2 is out of the screen;

$$B = \frac{\mu_0 I}{2\pi r}$$

$I_1 = I_2 =$ 2 Amp; d = 60 cm.

Find the net magnetic field at a point which is 40 cm from each wire.



$$B = \frac{\mu_0 I}{2\pi r}$$

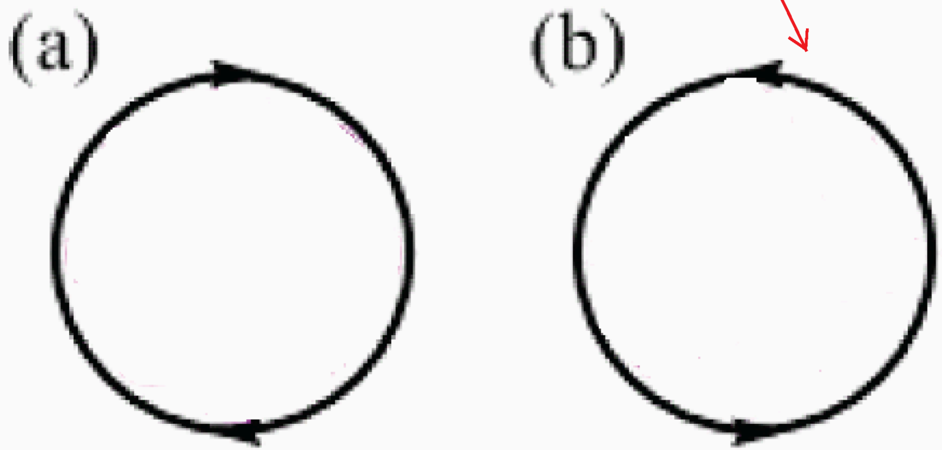
$I_1 = I_2 = 2$ Amp;
d = 60 cm;
$r_1 = r_2 = 40$ cm.

$\cos\alpha = \frac{30\,cm}{40\,cm} = 0.75$

$\alpha = \cos^{-1} 0.75 =$

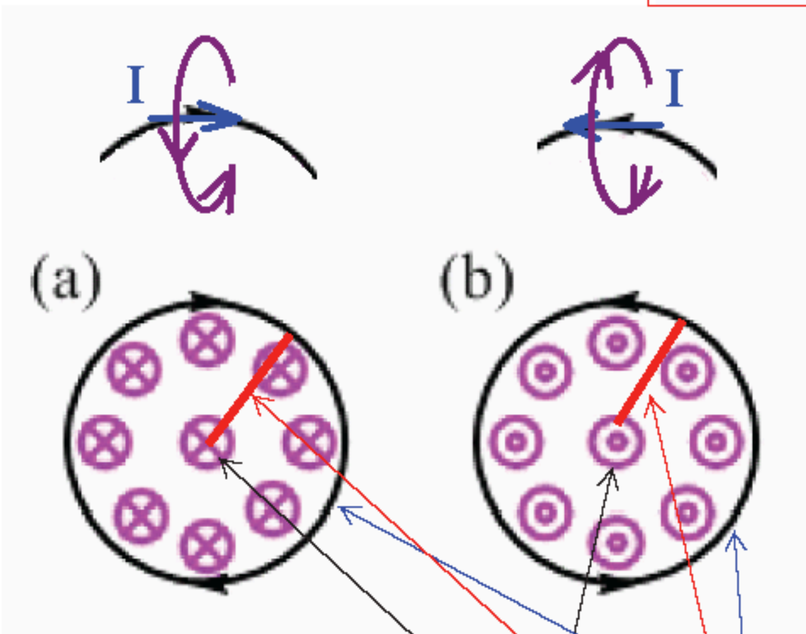
$= 41.4°$

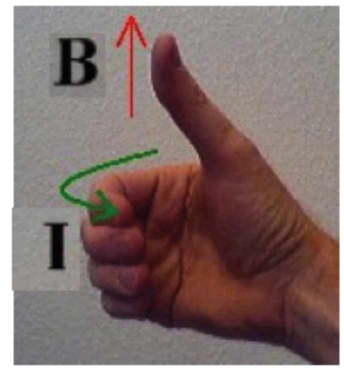
In which direction is the magnetic field inside a loop if the loop has a counter-clockwise current? What if the current is clockwise?



1. left
2. right
3. up
4. down
5. into
6 out

At the center of the loop $|B| = \dfrac{\mu_0 I}{2R}$





At the center of the loop $|B| = \dfrac{\mu_0 I}{2R}$

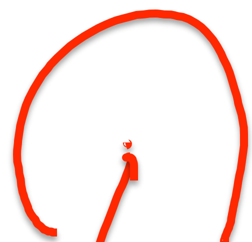
The wire shown in picture carries a current of 80A. Find the field at point P.

1. 0.94 mT **2. 9.4 mT**

3. none of the above

$$|B| = \frac{\mu_0 I}{2R}$$

$$B = \frac{\mu_0 I}{2\pi r}$$



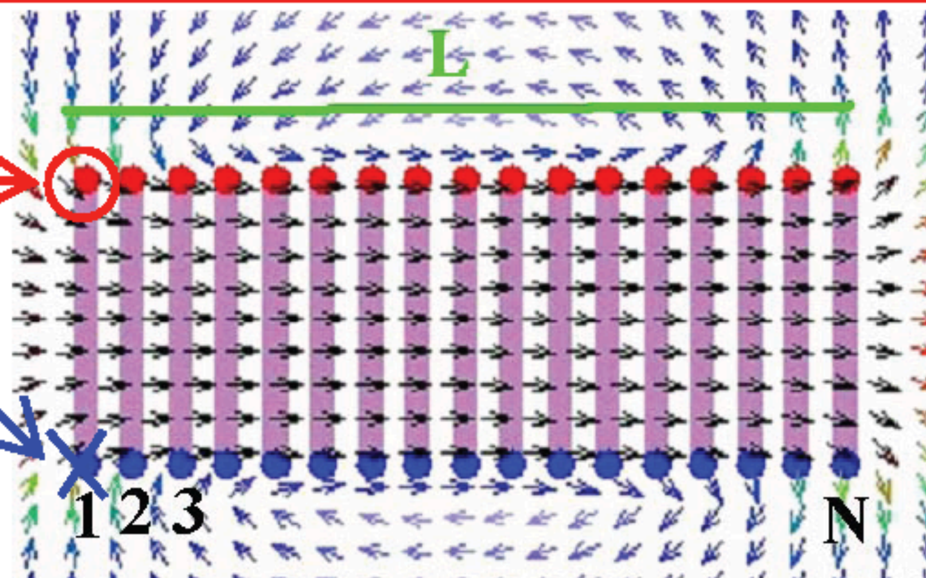
$$\frac{3}{4} \cdot \frac{\mu_0 I}{2R}$$

The field from a solenoid

A solenoid is simply a coil of wire with a current going through it. It's basically a bunch of loops stacked up. Inside the coil, the field is very uniform (not to mention essentially identical to the field from a bar magnet).

For a solenoid of length *L*, current I, and total number of turns *N*, the magnetic field inside the solenoid is given by:

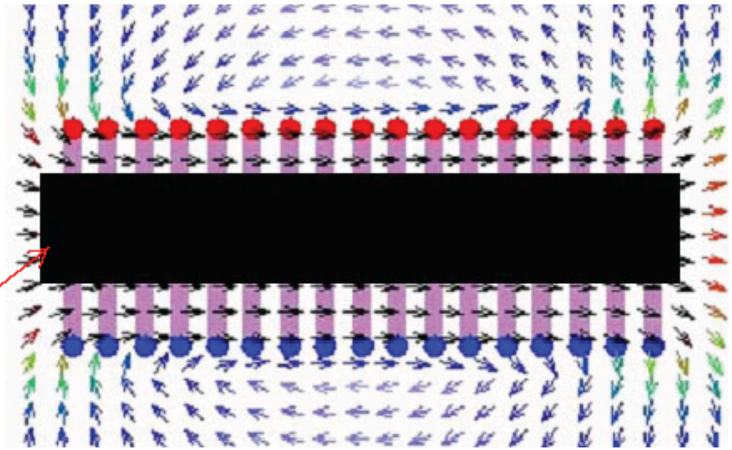
$$B = \frac{\mu_0 N I}{L}$$



$$N/L = n$$

The field from a solenoid

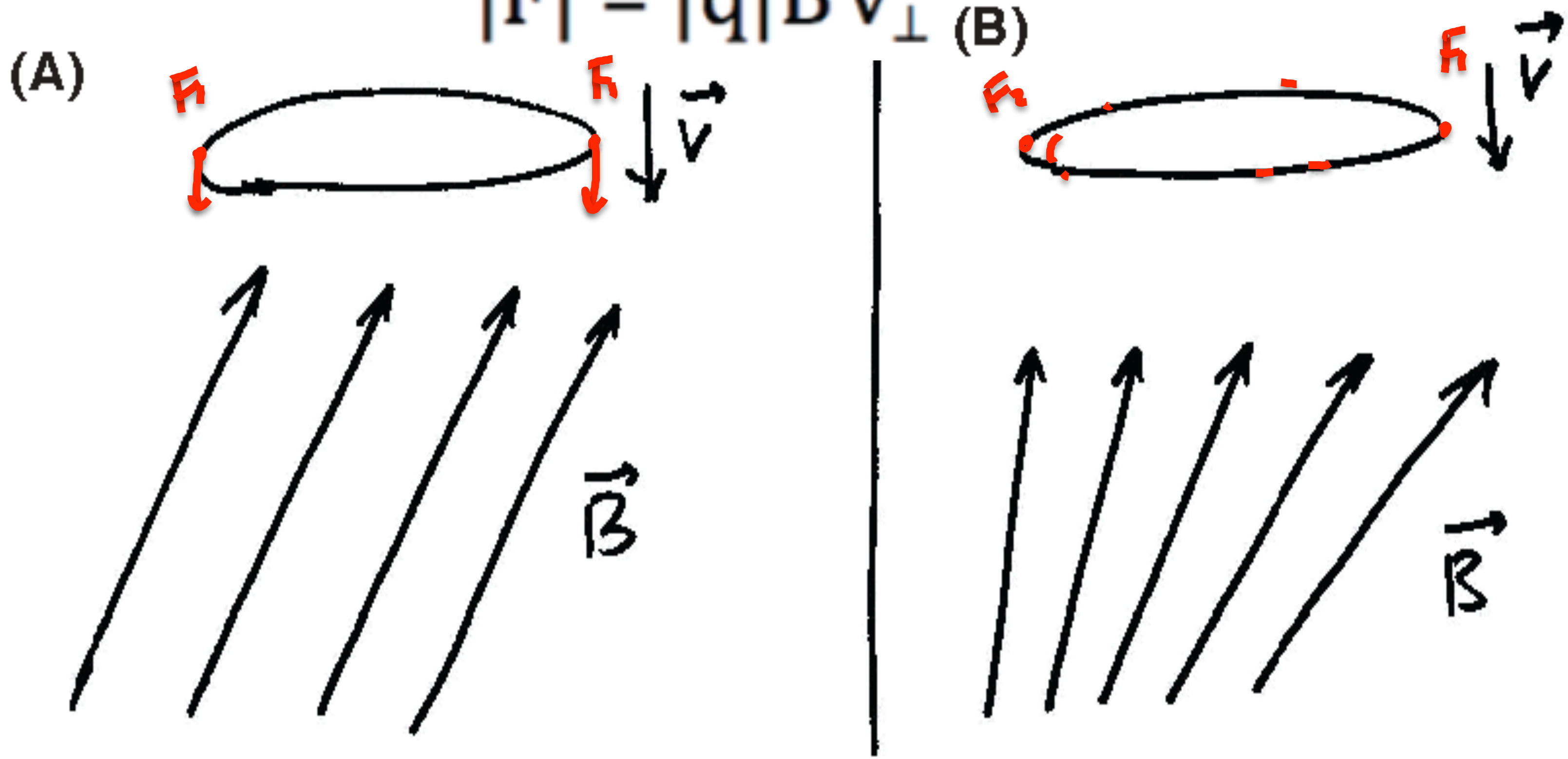
$$B = \mu_0 n I$$



$$B = \mu_0 \mu n I$$

If we put a piece of ferromagnetic material (a core made of iron or steel) inside the solenoid, we can magnify the magnetic field by a large factor μ (like 1000 or so). (permeability)

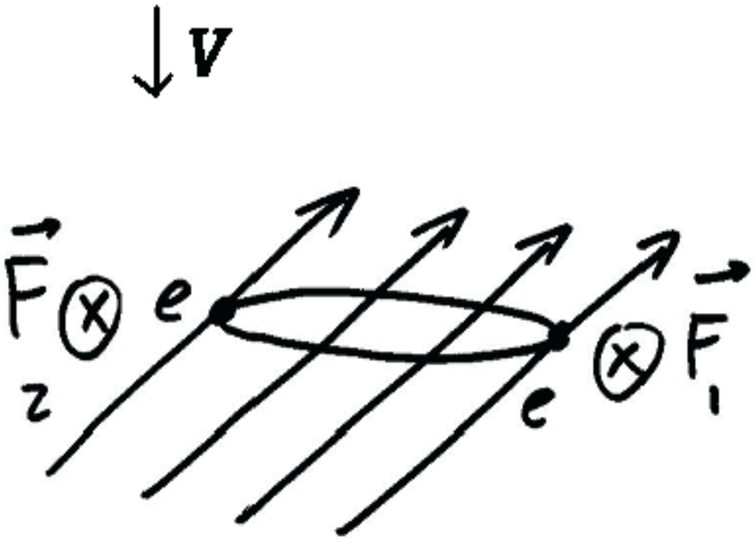
$$|F| = |q| B v_{\perp}$$

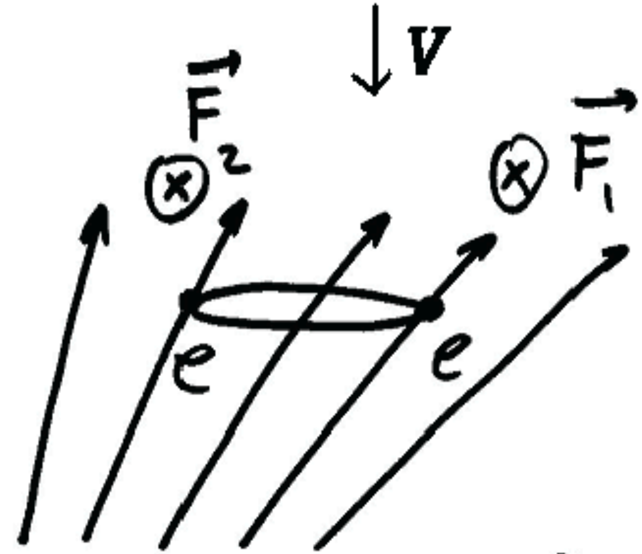


Two copper loops are moving in (A) uniform (B) nonuniform magnetic field. There is an induced current in

1. none of the loops
2. (A) only
3. (B) only
4. both loops

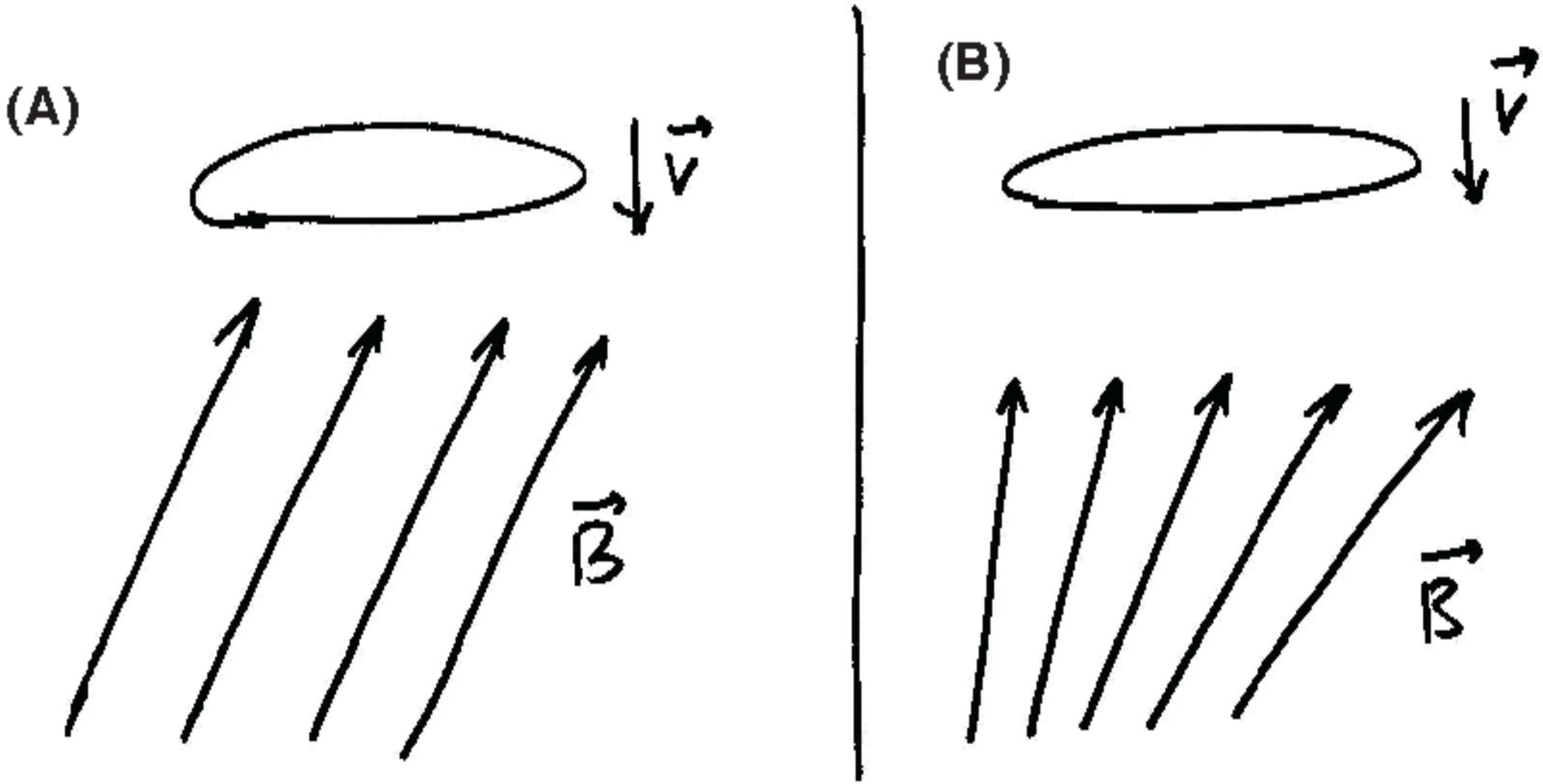
$$|F| = |q| B v_{\perp}$$





$$|\vec{F_1}| = |\vec{F_2}|$$

$$|\vec{F_1}| \;?\; |\vec{F_2}|$$



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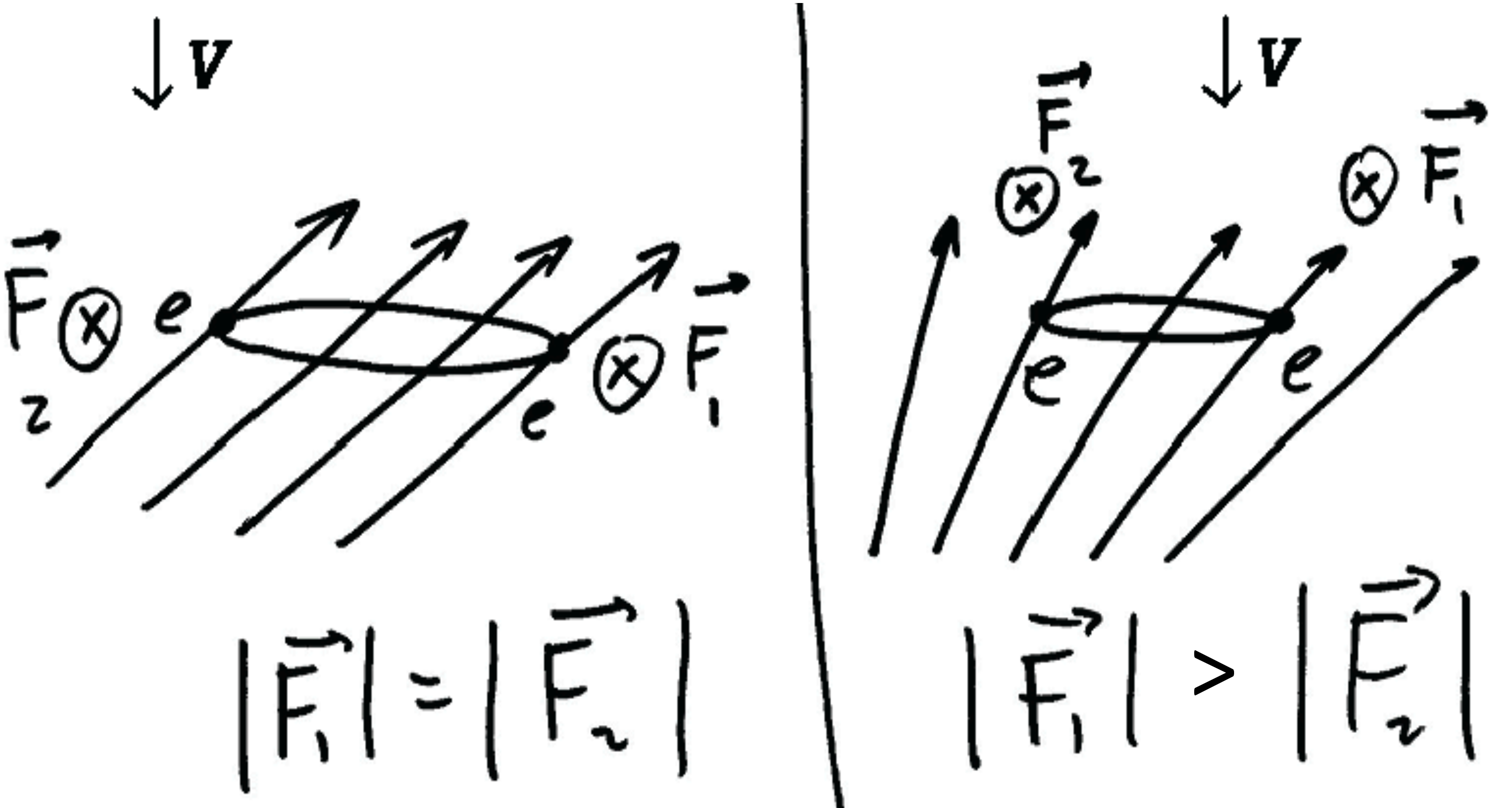


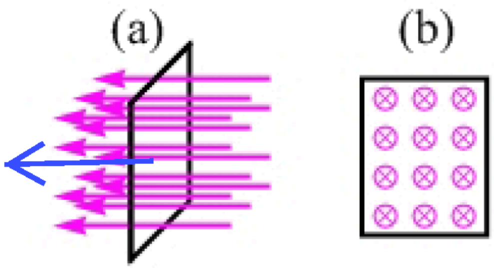
The number of magnetic field lines in the loop ...

1. does not change 2. changes

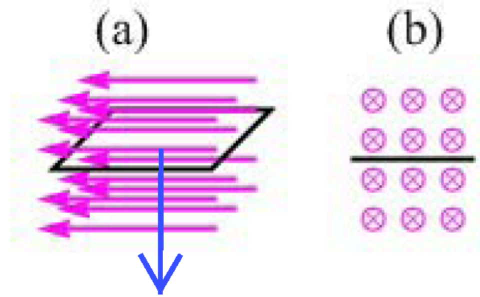
Magnetic flux

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

The more field lines pass through an area, the larger the flux.

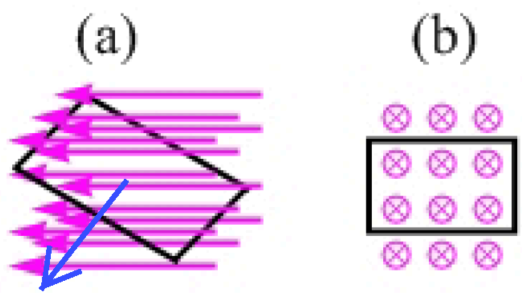


Lots of flux.



No flux.

θ is the angle between the field and the “normal” to the area (⊥)



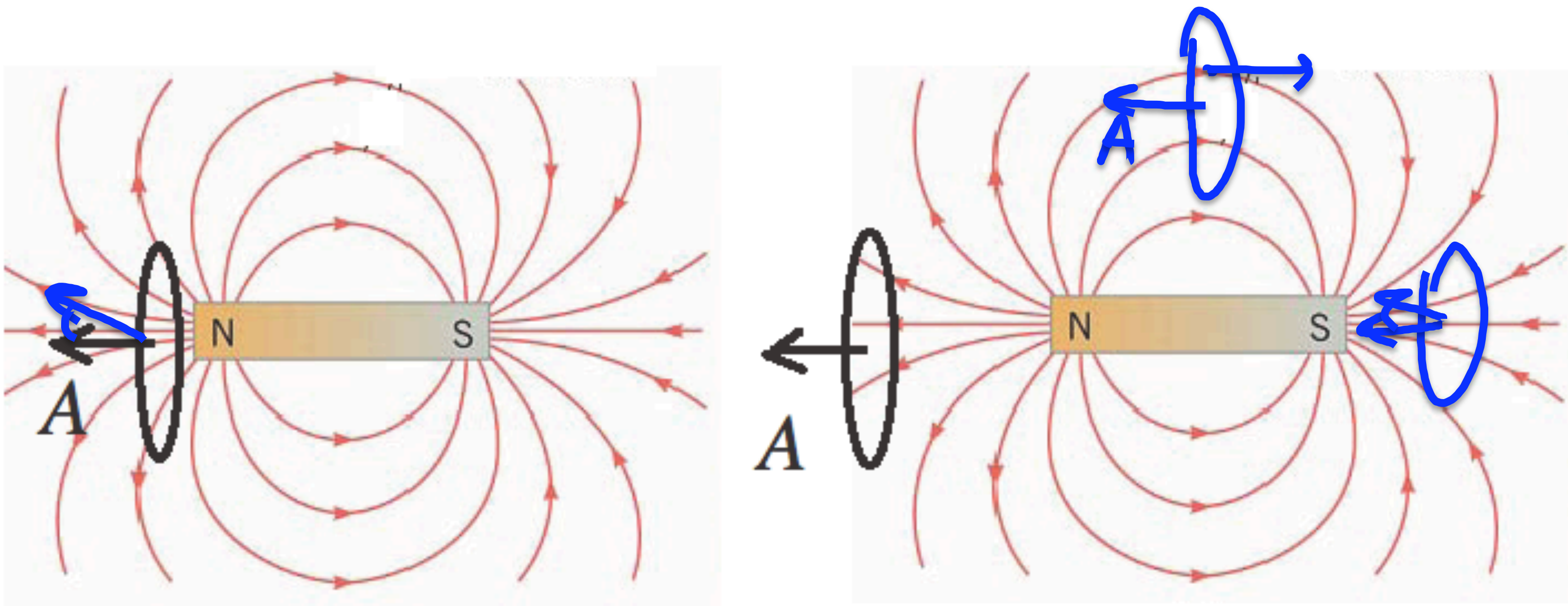
Some flux.

Comparing flux

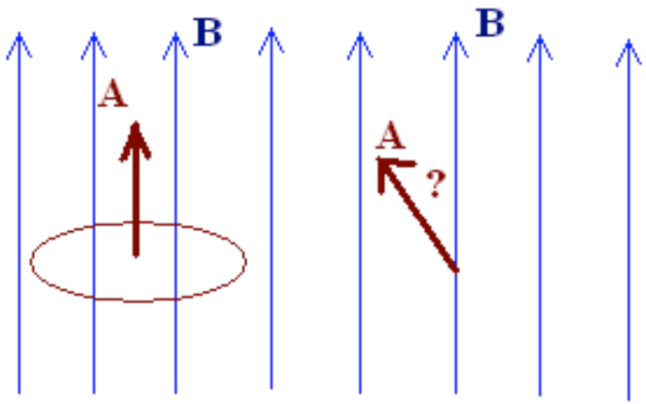
1. the flux in the loop is positive
2. the flux in the loop is negative

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

1. there is more flux in the loop on the left
2. there is less flux in the loop on the left



(How can we achieve (a) negative flux? (b) maximum flux?)



A loop is in magnetic field; initially with the area vector parallel to the field.

At which angle should we turn the loop so the magnetic flux through it would be 50 % of the original value?

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

1. less than 30^0
2. 30^0
3. more than 30^0

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

Lenz's Law

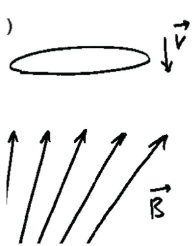
Lenz's Law: A changing magnetic flux induces a response that ***tends to oppose the change***.

E

external | 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.



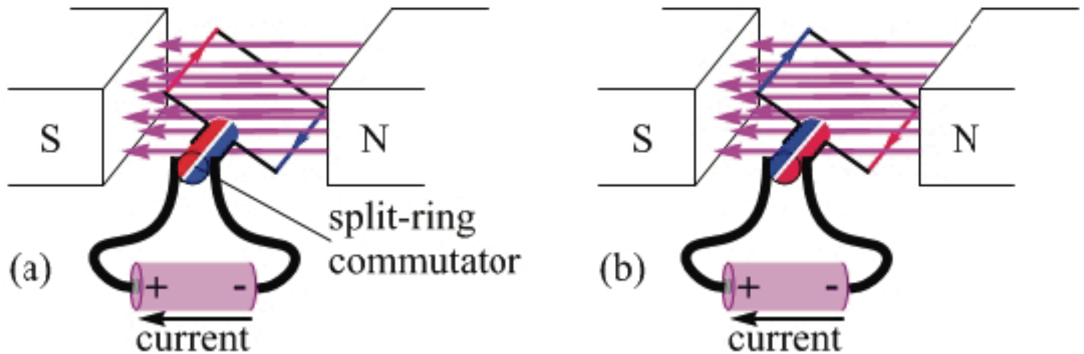
$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

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

Electric generators

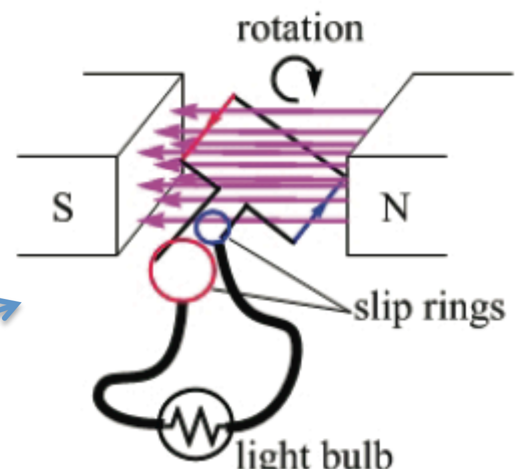
$$\Phi_B = BA\cos\theta$$

If a current is passed through the coil, the interaction of the magnetic field with the current causes the coil to spin – that's a motor.



$$|EMF_{max}| = N*BA\omega$$

If we spin the coil, the changing flux through the coil induces a current – now it's a generator.



Transformers

Both coils are exposed to the same changing flux, so:

$$-\frac{\Delta\Phi}{\Delta t} = \frac{\Delta V_1}{N_1} = \frac{\Delta V_2}{N_2} \quad \Leftarrow \quad |\varepsilon| = \left| N\frac{\Delta\Phi}{\Delta t} \right|$$

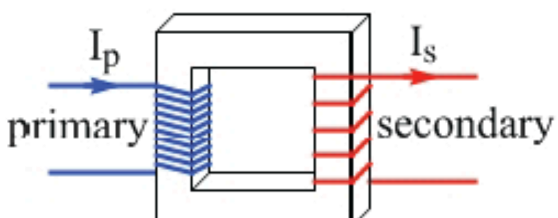
Energy (or, equivalently, power) has to be conserved, so:

$$P = \Delta V_1 I_1 = \Delta V_2 I_2$$ so

$$\frac{N_1}{N_2} = \frac{\Delta V_1}{\Delta V_2} = \frac{I_2}{I_1}$$

V is proportional to N

I is inversely proportional to N.



10 : 5 turns ratio (Primary : secondary)

Voltage “stepped down” by factor of 2,

Current “stepped up” by factor of 2,

Power in = power out [ideal transformer]

A pictorial approach to Lenz's Law

Example: A wire loop in the plane of the page is in a uniform magnetic field directed into the page. Over some time interval the field is doubled. What direction is the induced current in the loop while the field is changing?

Step 1: Draw a "Before" picture, showing the field passing through the loop before the change takes place.

Step 2: Draw an "After" picture, showing the field passing through the loop after the change.

Step 3: Draw a "To Oppose" picture, showing the direction of the field the loop creates to oppose the change.

Step 4: Use the right-hand rule to determine which way the induced current goes in the loop to create that field.

A pictorial approach to Lenz's Law

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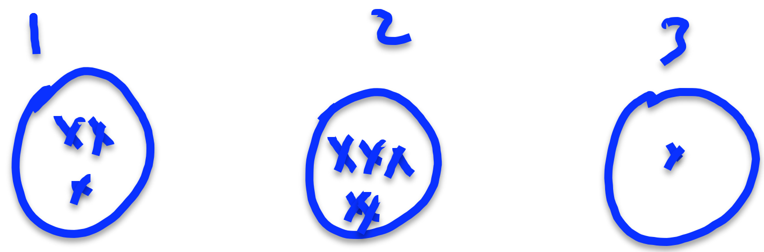
Before



After

A pictorial approach to Lenz's Law

Example: A wire loop in the plane of the page is in a uniform magnetic field directed into the page. Over some time interval the field is doubled. What direction is the induced current in the loop while the field is changing?

Step 2: Draw an "After" picture, showing the field passing through the loop after the change.

What kind of Change?

How to oppose (slow down) this change?

Change →

After

What should be the direction of the *induced* B?

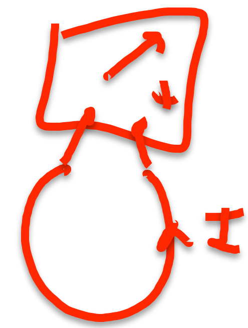
1. into   2. out

A pictorial approach to Lenz's Law

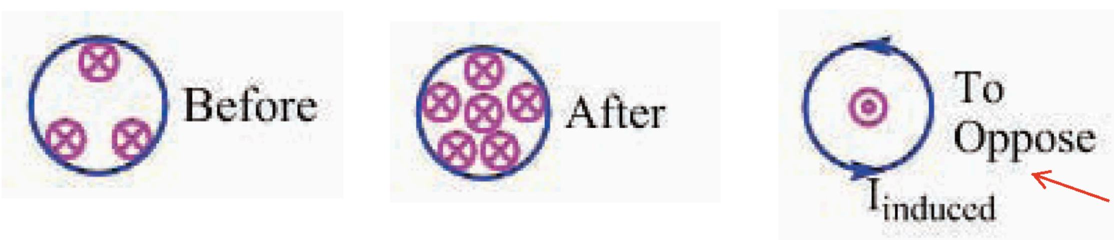
Example: A wire loop in the plane of the page is in a uniform magnetic field directed into the page. Over some time interval the field is doubled. What direction is the induced current in the loop while the field is changing?

Step 3: Draw a "To Oppose" picture, showing the direction of the field the loop creates to oppose the change.

Step 4: Use the right-hand rule to determine which way the induced current goes in the loop to create that field.



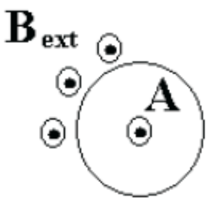
One field line is enough for the To Oppose picture - that's enough to determine the direction of the induced current.



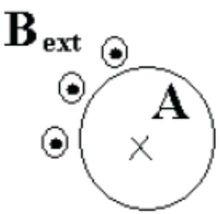
What?
or
To support - what?

Area vector vs. …

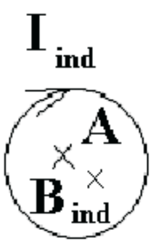
It is very important to match all the directions correctly.



"Positive flux" means "the direction of the external B field is *parallel* to (the same as) the direction of the area vector (and v.v.). Also, you can switch both vectors.



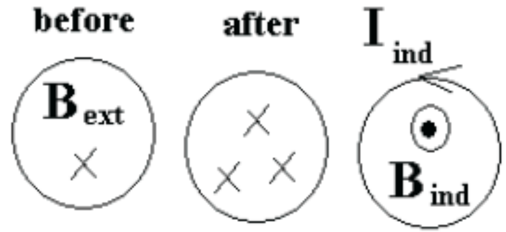
"Negative flux" means "the direction of the external B field is *anti-parallel* to (opposite to) the direction of the area vector (and v.v.). Also, you can switch both vectors.



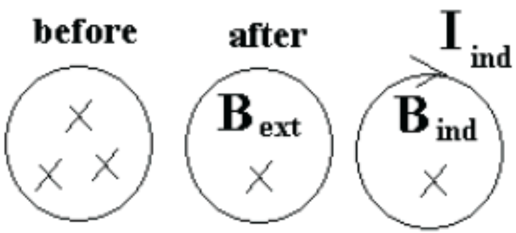
"Positive (induced) current" means "the direction of the induced B field is *parallel* to (the same as) the direction of the area vector (and v.v.). Also, you can switch both vectors.

"Negative (induced) current" means "the direction of the induced B field is *anti-parallel* to (opposite to) the direction of the area vector (and v.v.). Also, you can switch both vectors.

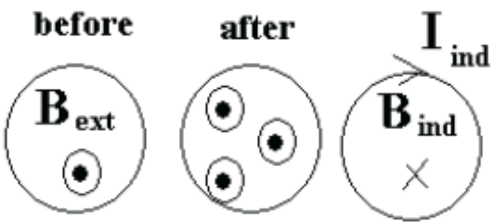
Four options



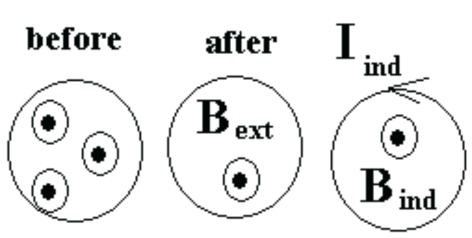
An external B field is ***in*** the page and ***increasing*** in its magnitude. The induce B field opposes changes and *opposes* the external field and has the direction *opposite* to the external B field.



An external B field is ***in*** the page and ***decreasing*** in its magnitude. The induce B field opposes changes and *supports* the external field and has *the same* direction as the external B field.



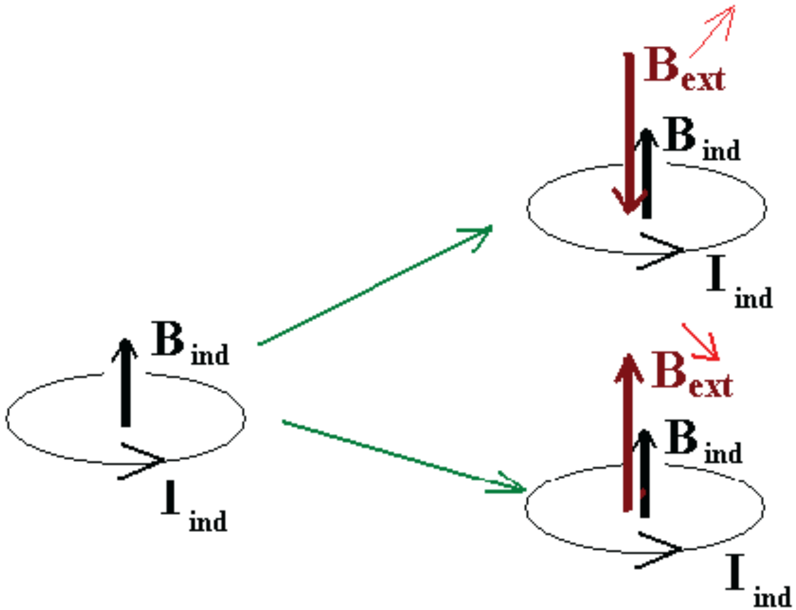
An external B field is ***out of*** the page and ***increasing*** in its magnitude. The induce B field opposes changes and *opposes* the external field and has the direction *opposite* to the external B field.



An external B field is ***out of*** the page and ***decreasing*** in its magnitude. The induce B field opposes changes and *supports* the external field and has *the same* direction as the external B field.

Some combinations

(working backwards)



Let's say we know the direction of the induced current I_{ind} => we know the direction of the induced magnetic field B_{ind} (as a current in the loop and the field in it).

There are two situations which can lead to the known direction of the induced field.

A). An external magnetic field is anti-parallel to the induced one and its magnitude increases.

B). An external magnetic field is parallel to the induced one and its magnitude decreases.