Phys 102 – Lecture 13

Motional EMF & Lenz' law

Physics 102 recently

Basic principles of magnetism

- Lecture 10 – magnetic fields & forces
- Lecture 11 – magnetic dipoles & current loops
- Lecture 12 – currents & magnetic fields

Connection between electricity & magnetism

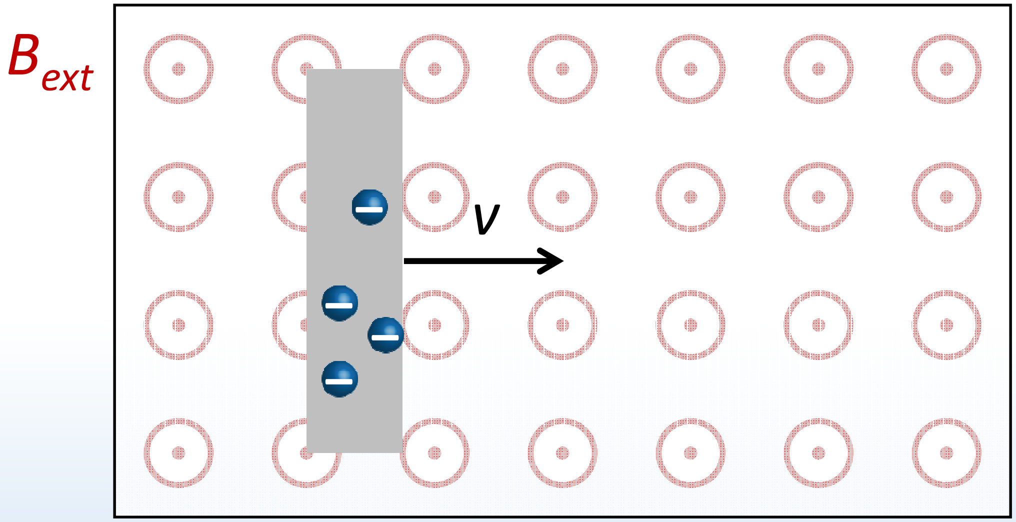
- Lecture 13 – motional EMF & Lenz' law
- Lecture 14 – Faraday's law of induction
- Lecture 15 – electromagnetic waves

Today we will...

- Learn how electric fields are created from...
  - Motion in magnetic fields ("motional EMF")
  - Changing magnetic fields
- Learn *Lenz' law*: principle unifying electricity and magnetism
- Apply these concepts:
  - Magnetoreception
  - Electrical generators & hybrid cars

CheckPoint 1: Moving bar

A conducting bar moves in a uniform external *B* field at speed *v*



Magnetic force pushes – electrons to top, leaves + charge at bottom of bar

Separated + and – charge induces *E* field & ΔV $\quad \varepsilon = E_{ind} L = vB_{ext} L$

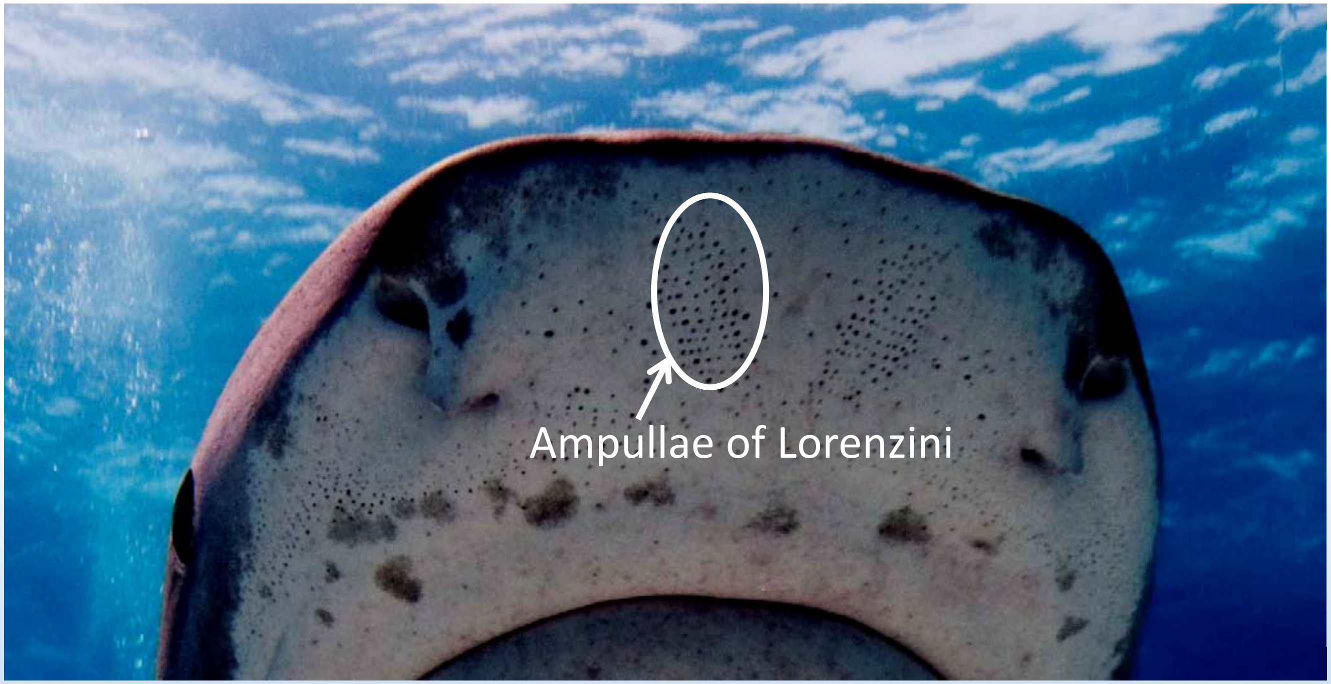
At equilibrium, forces must sum to zero

$$F_B = qvB_{ext} = F_E = qE_{ind}$$

Moving bar acts like a battery!
Motional EMF

Magnetoreception in sharks

Sharks can sense changes in magnetic fields

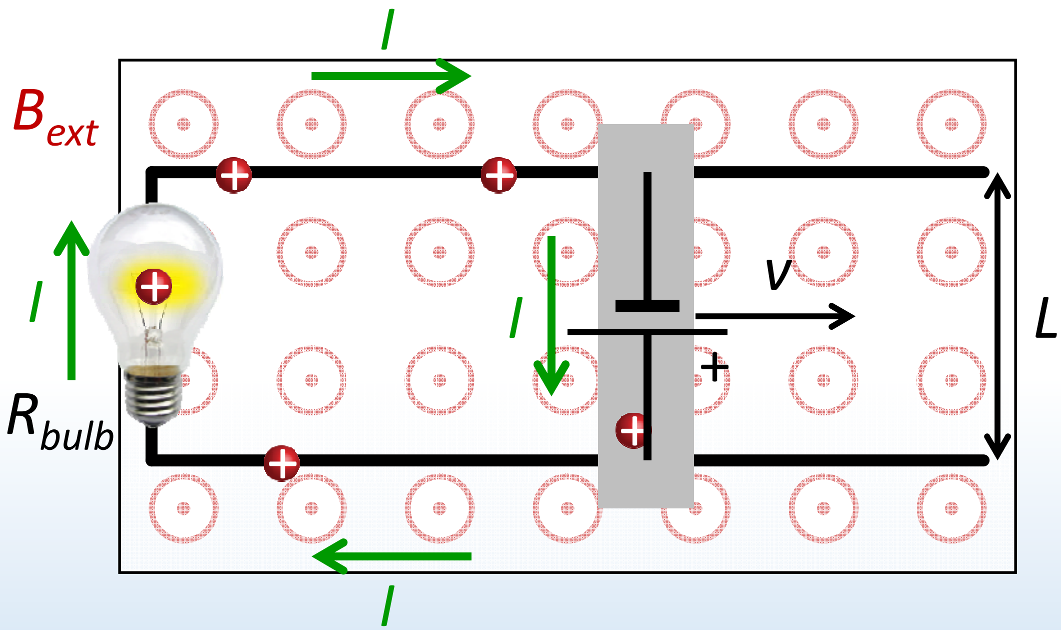


Shark do not have magnetic organelles like magnetotactic bacteria, but they do have “ampullae of Lorenzini”, which sense *E* field

Model of magnetoreception in sharks: motional EMF from moving in *B* field generates *E* field detected by ampullae

Motional EMF

Bar slides with speed *v* on a conducting track in a uniform *B* field



Can moving bar drive current around the circuit?

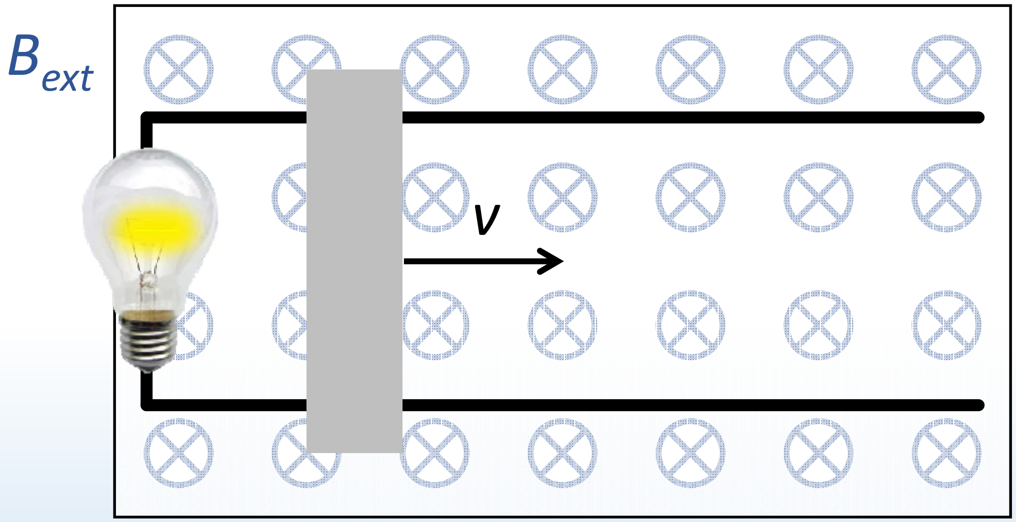
+ charges in moving bar experience force down
Electrical current induced clockwise!

$$\varepsilon = vB_{ext}L \qquad I = \frac{vB_{ext}L}{R_{bulb}}$$

(Recall that e– actually move, opposite current)

ACT: CheckPoint 2.1

The conducting bar moves to the right in the opposite *B* field



Which way does the current flow?

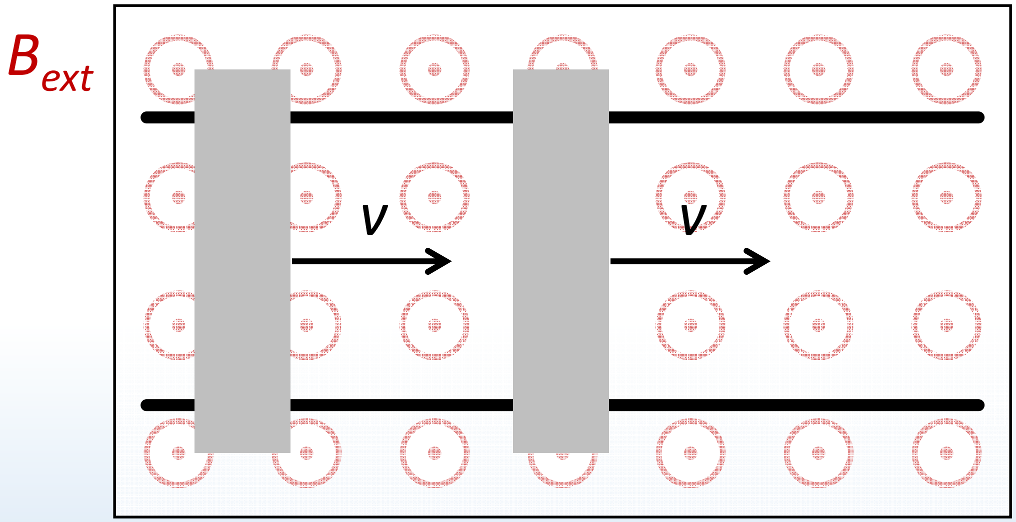
A. Clockwise

B. Counterclockwise

C. The current is zero

ACT: Two metal bars

Circuit now has two metal bars moving right at the same speed v

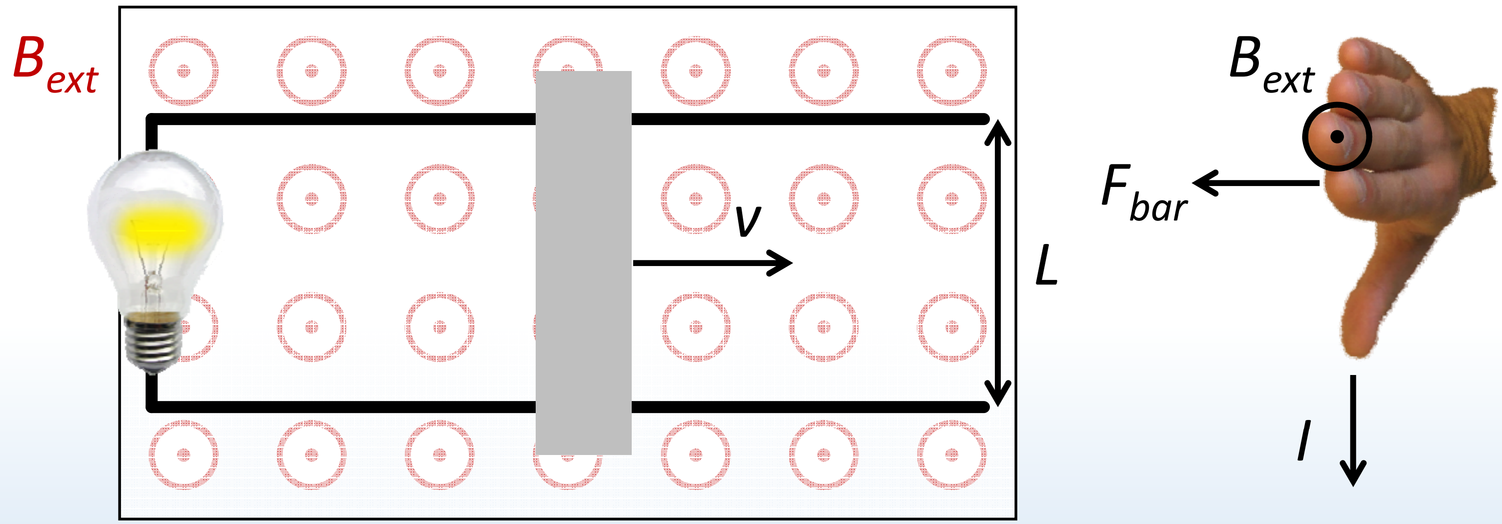


Which way does the current flow?

A. Clockwise
B. Counterclockwise
C. The current is zero

Motional EMF and force

Where does the energy come from to generate electricity?



Moving bar carries current, so B field exerts a force F_{bar}

$$F_{bar} = ILB_{ext}\sin\theta$$

Note: F_{bar} is NOT F_B which drives current around loop

F_{bar} opposes v, so bar decelerates

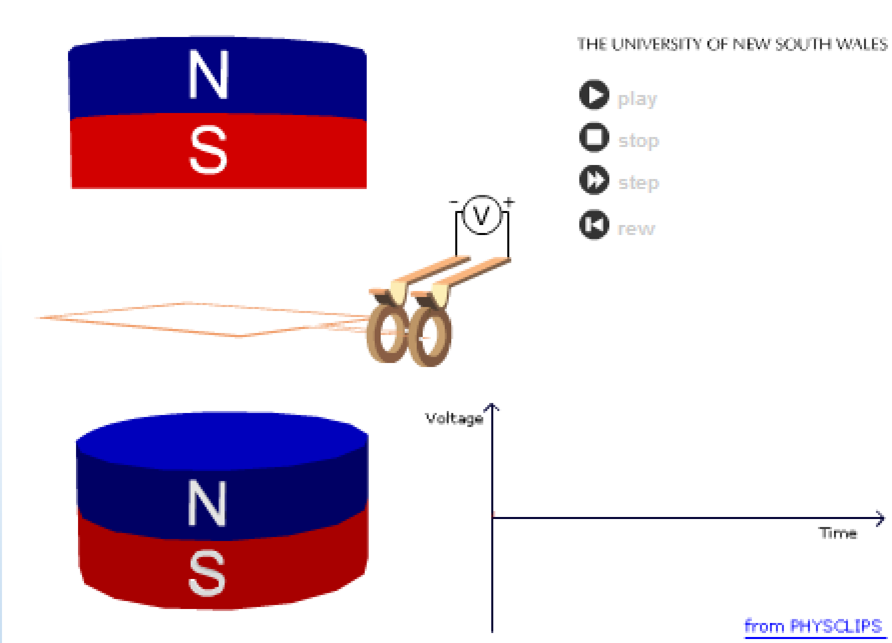
To maintain constant v, you must provide external force F_{ext} opposing F_{bar}

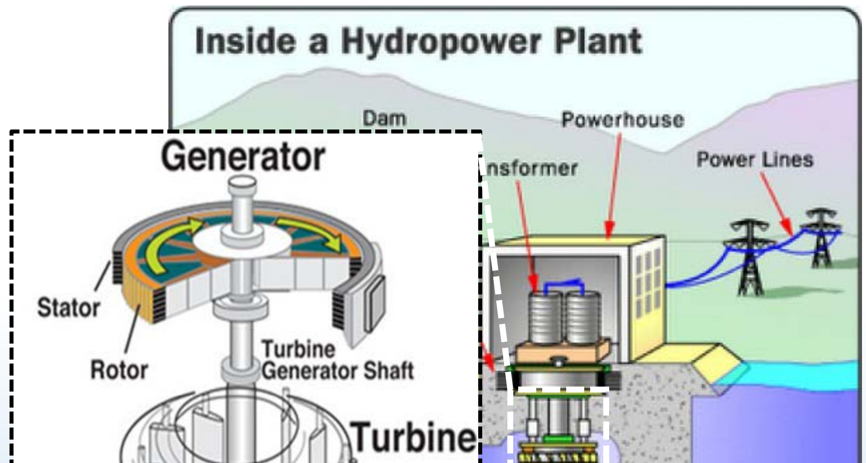
F_{ext} does the work to generate electrical energy

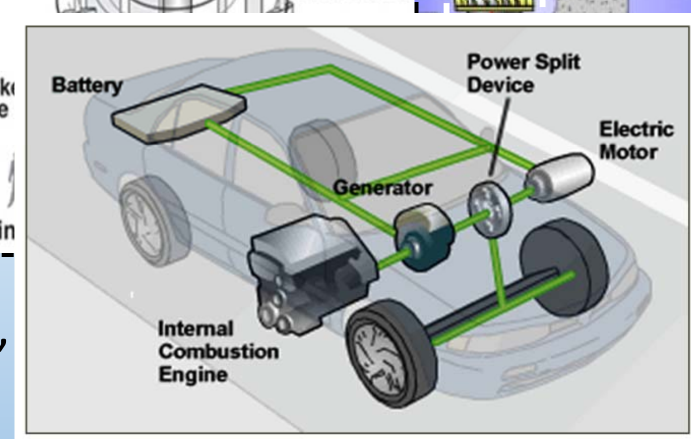
Electrical generators

Motional EMF is the basis for modern electrical generation

Instead of sliding bar, use spinning loop in *B* field







External torque (from turbine, gas engine,

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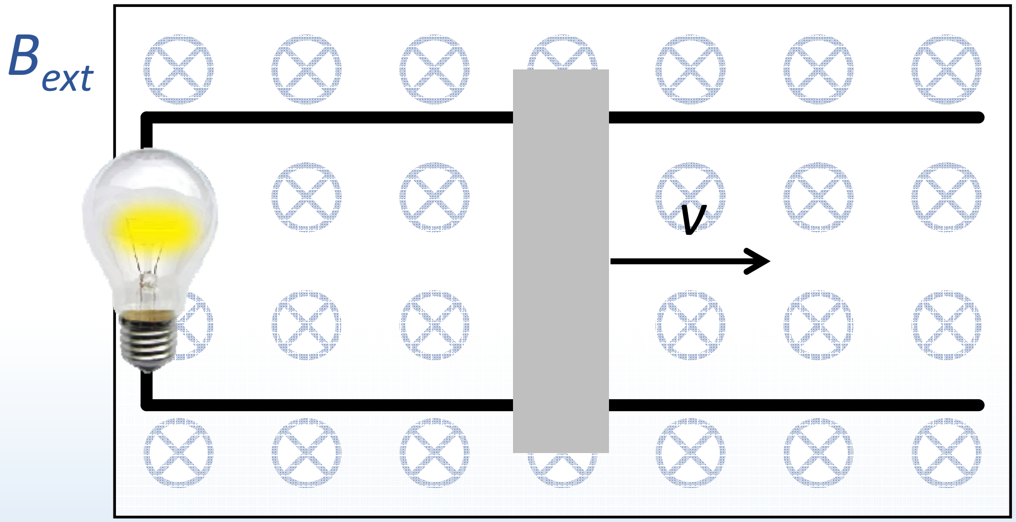
ACT: CheckPoint 2.2

The *B* field is now reversed and points into the page.



To keep the bar moving at the same speed, the hand must supply:

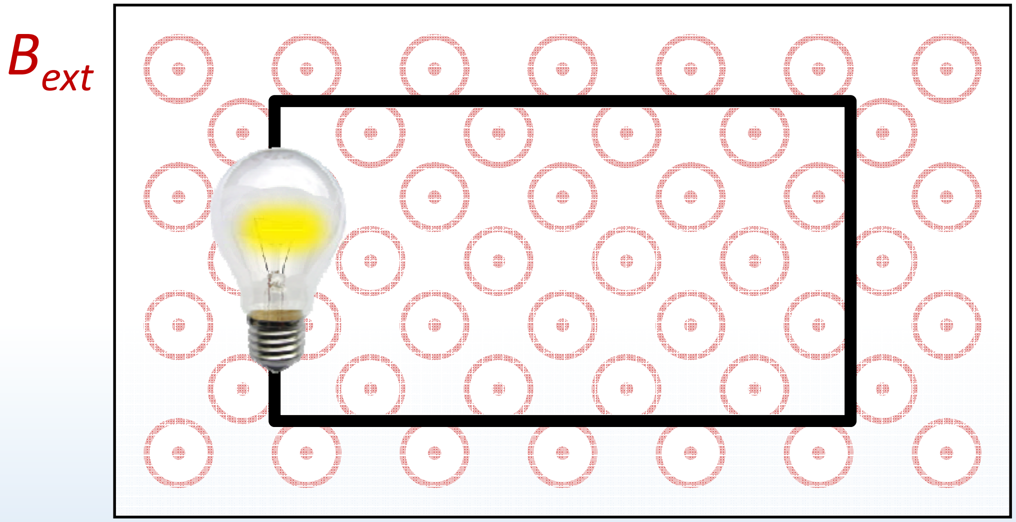
A. A force to the right

B. A force to the left

C. No force, the bar slides by inertia

Changing B field

Now loop is fixed, but *B* field changes



If B_{ext} increases, current *I* flows clockwise

If B_{ext} decreases, current *I* flows counterclockwise

If B_{ext} is constant, no current flows

What is changing here and in previous cases? Magnetic flux Φ!

Magnetic flux

Flux "counts" number of *B* field lines passing through a loop

$$\Phi \equiv BA\cos\varphi$$

B field in loop

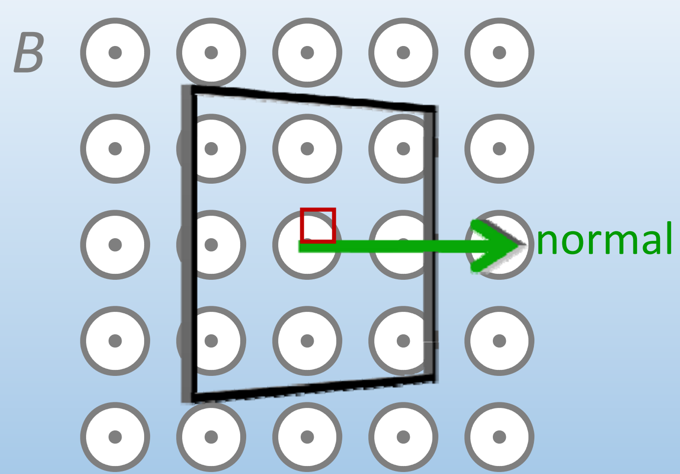
Area inside loop filled with *B* field

Angle between normal vector and *B* field

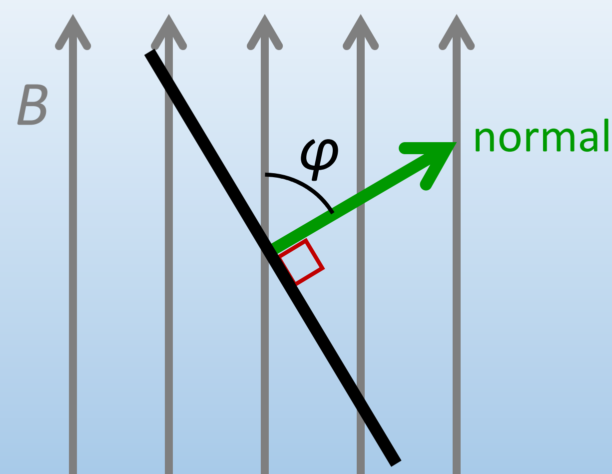
Unit: Wb ("Weber")

1 Wb = 1 T·m^2

Angle φ affects how many *B* field lines pass through loop



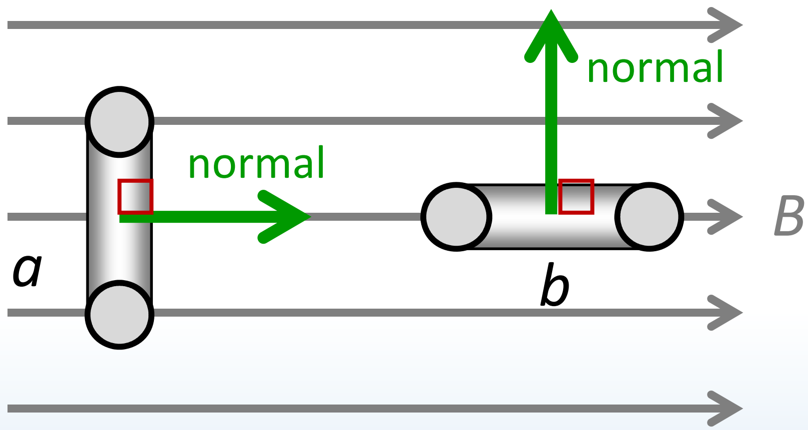
Top view



Side view

CheckPoint 3.1

Compare the flux through loops *a* and *b*



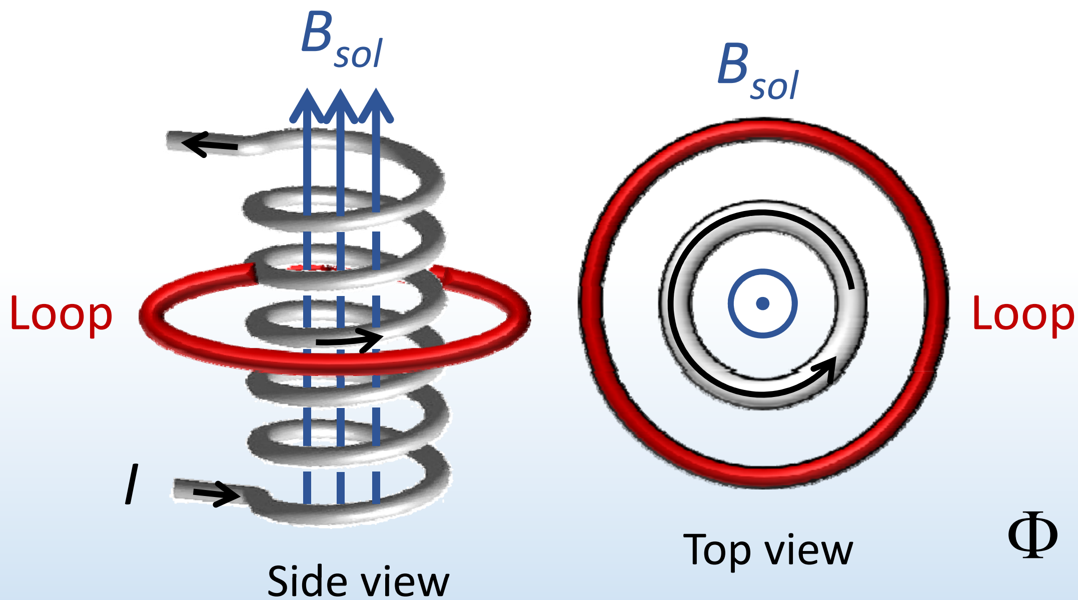
A. $\Phi_a > \Phi_b$

B. $\Phi_a < \Phi_b$

C. $\Phi_a = \Phi_b$

Magnetic flux practice

A solenoid generating a *B* field is placed inside a conducting loop. What happens to the flux Φ through the loop when...



$$\Phi \equiv BA\cos\varphi$$

The area of the solenoid increases?

The current in the solenoid increases?

The area of the loop increases?

Lenz's law

Induced EMF ε *opposes change* in flux Φ

If Φ increases:

ε generates new B field

opposite external B field

If Φ decreases:

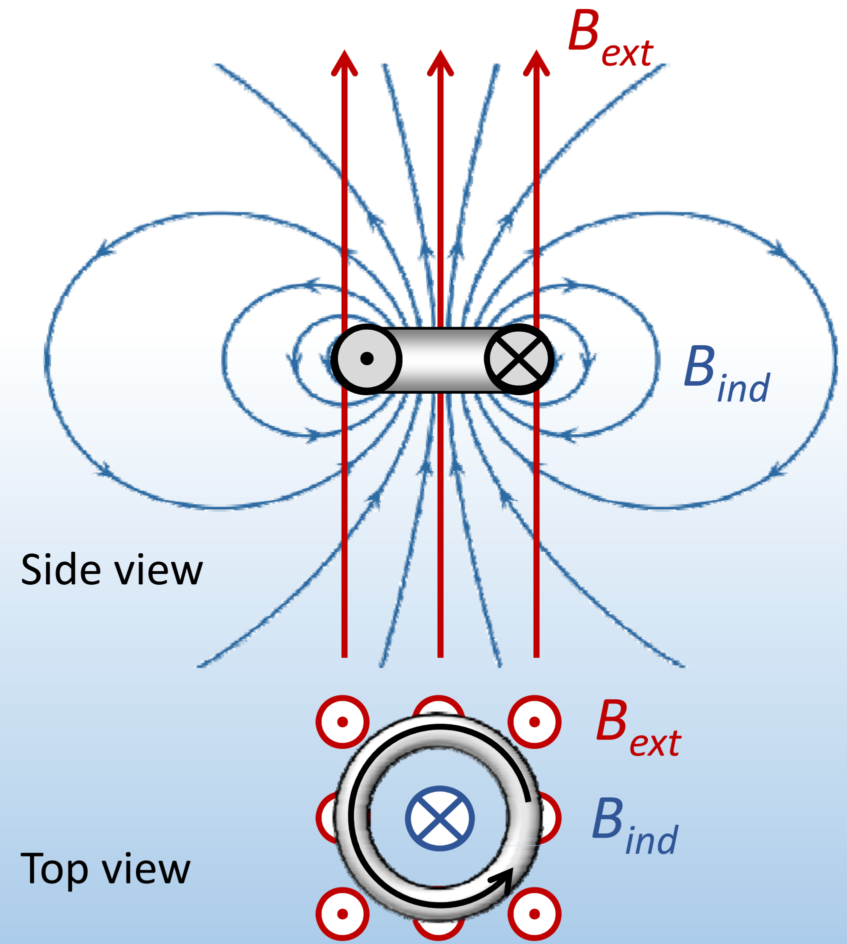
ε generates new B field

along external B field

If Φ is constant:

ε is zero

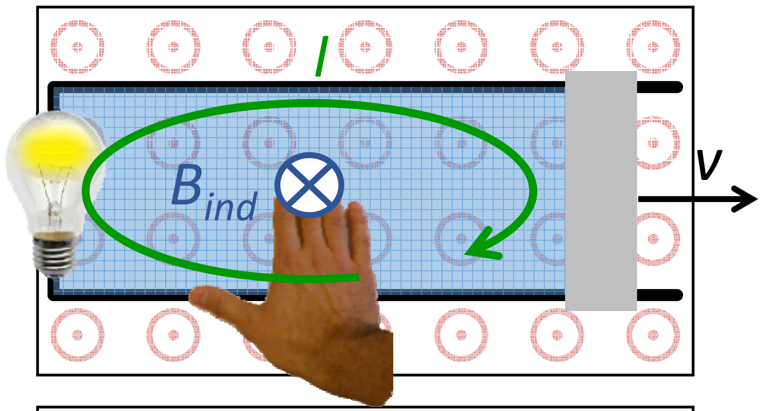
One principle explains all the previous examples!



Lenz's law: changing loop area

ε <u>*opposes change*</u> in flux Φ

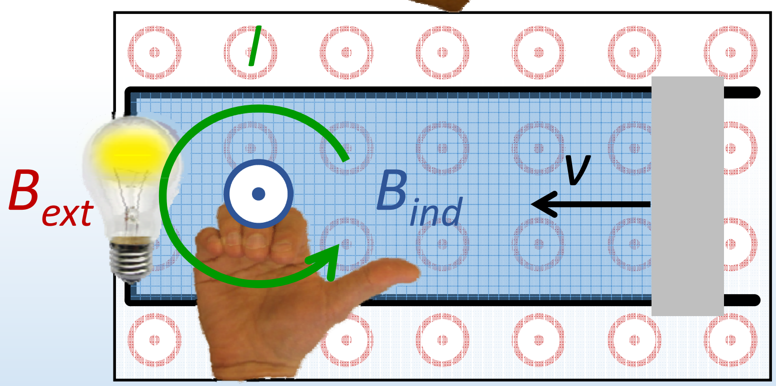
EX 1



A & Φ increases

ε generates B_{ind} <u>opposite</u> B_{ext}

EX 2

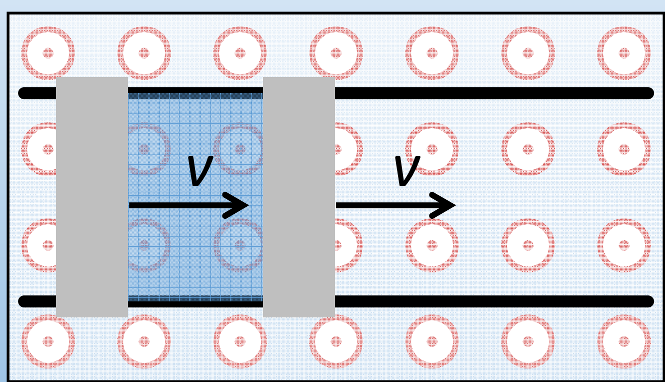


A & Φ decreases

ε generates B_{ind} <u>along</u> B_{ext}

Same answers as before!

EX 3

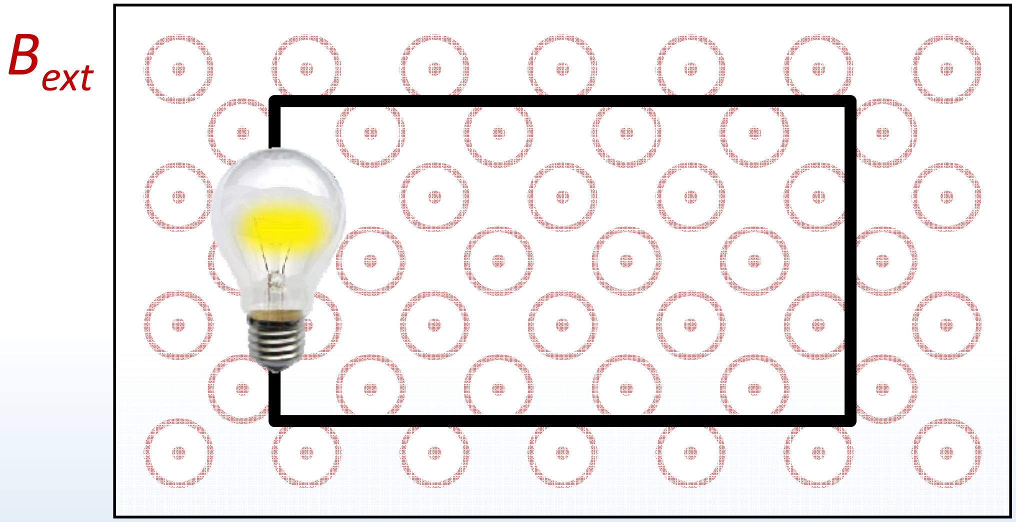


A & Φ remains constant

ε is <u>zero</u>

ACT: Lenz' law: changing B field

A loop is placed in a uniform, increasing *B* field



In which direction does the induced *B* field from the loop point?

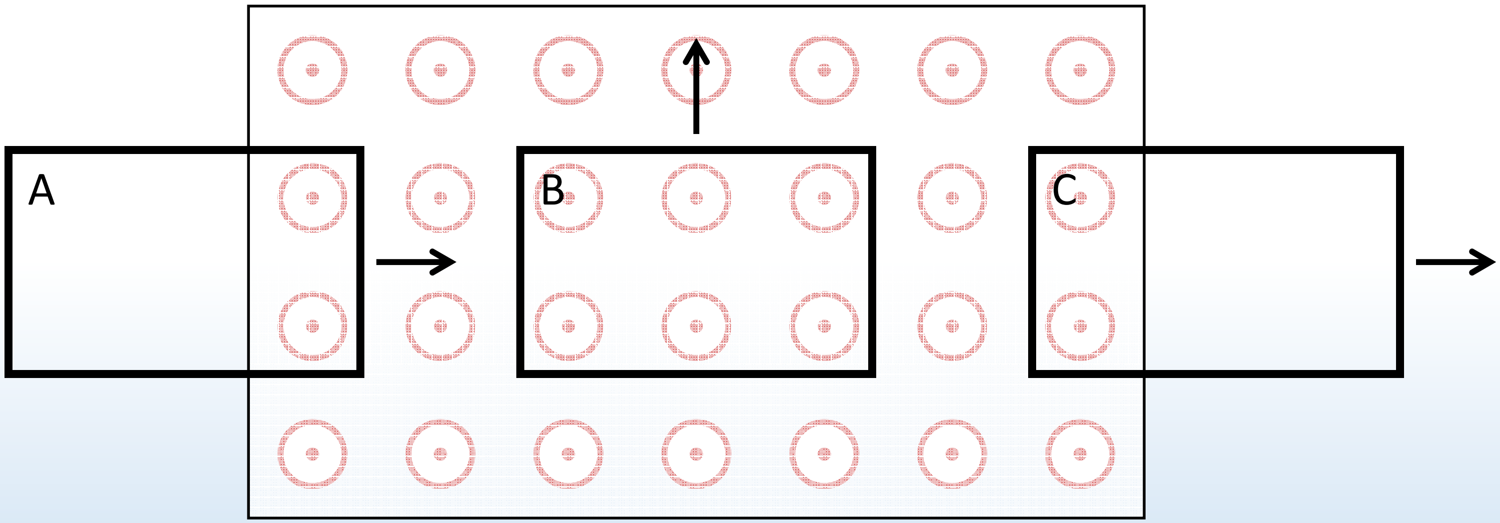
A. Into the page

B. Out of the page

C. There is no induced *B* field

ACT: moving loops

Three loops are moving in a region containing a uniform *B* field. The field is zero everywhere outside.



In which loop does current flow ***counterclockwise*** at the instant shown?

A. Loop A

B. Loop B

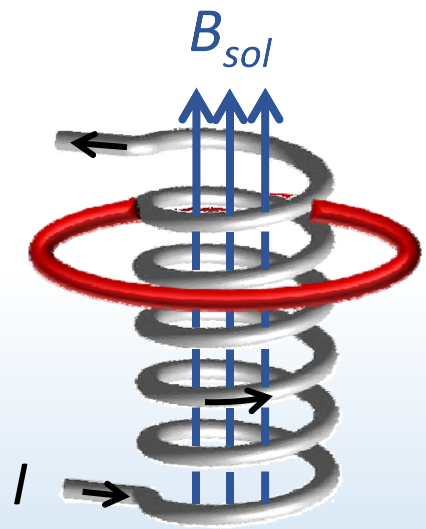
C. Loop C

ε *opposes change* in flux Φ

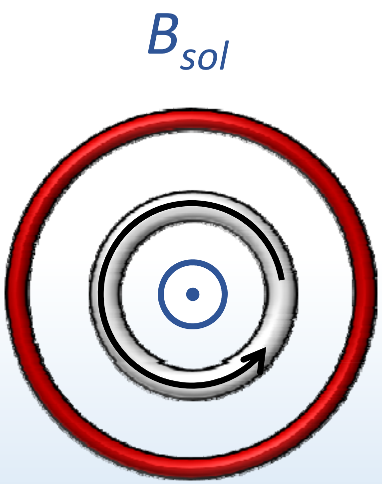
ACT: Solenoid & loop

A solenoid is driven by an ***increasing*** current. A loop of wire is placed around it. In which direction does current in the loop flow?

A. Clockwise
B. Counterclockwise
C. The current is zero



Side view



Top view

Induction cannon

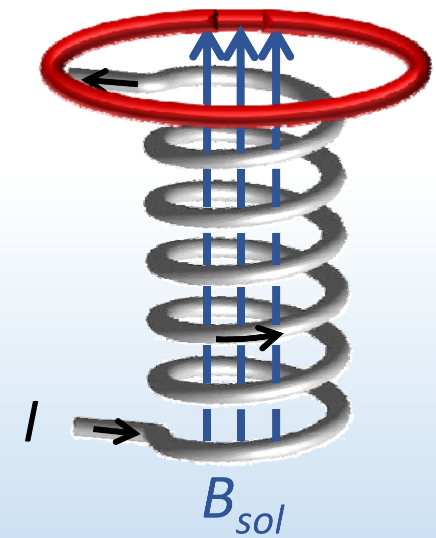
A solenoid is driven by an increasing current. A loop of wire is placed around it.

Current loop and solenoid behave like magnetic dipoles

Opposite currents = opposite polarities

Recall Lect. 11

Like poles repel, so loop shoots up!



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Summary of today's lecture

- Electric fields are created from

  Motion in magnetic fields ("motional EMF")

  Changing magnetic fields

- Lenz' Law: EMF ε *opposes change* in flux Φ

ε does NOT oppose Φ

ε opposes change in Φ

Lenz' law gives direction of EMF

Faraday's law gives us magnitude of EMF (next lecture!)