Physics 122 – Class #28 (4/28/15) –

- Announcements

- Torque on an electric motor
- Motional EMF
- Faraday's Law
- Flux

Recitation

This week recitation introduces Flux and Faraday's Law.

Reading Assignments

Chapter 32, EXCEPT section 32.10

Chapter 33. Omit 33.6, 33.9, 33.10

You need to really understand Faraday's law and Lenz's law as well as generators and transformers. We will also understand the equation for potential across an inductor, but you will not be responsible for RL or LC circuits.

Extra Credit Opportunity

Show up in recitation this week and take the same electricity quiz you took at beginning of term.

Eval Forms

Tuesday recitation	66714
Thursday afternoon	66808
Thursday evening	66956

Delivery person??

Final Homework

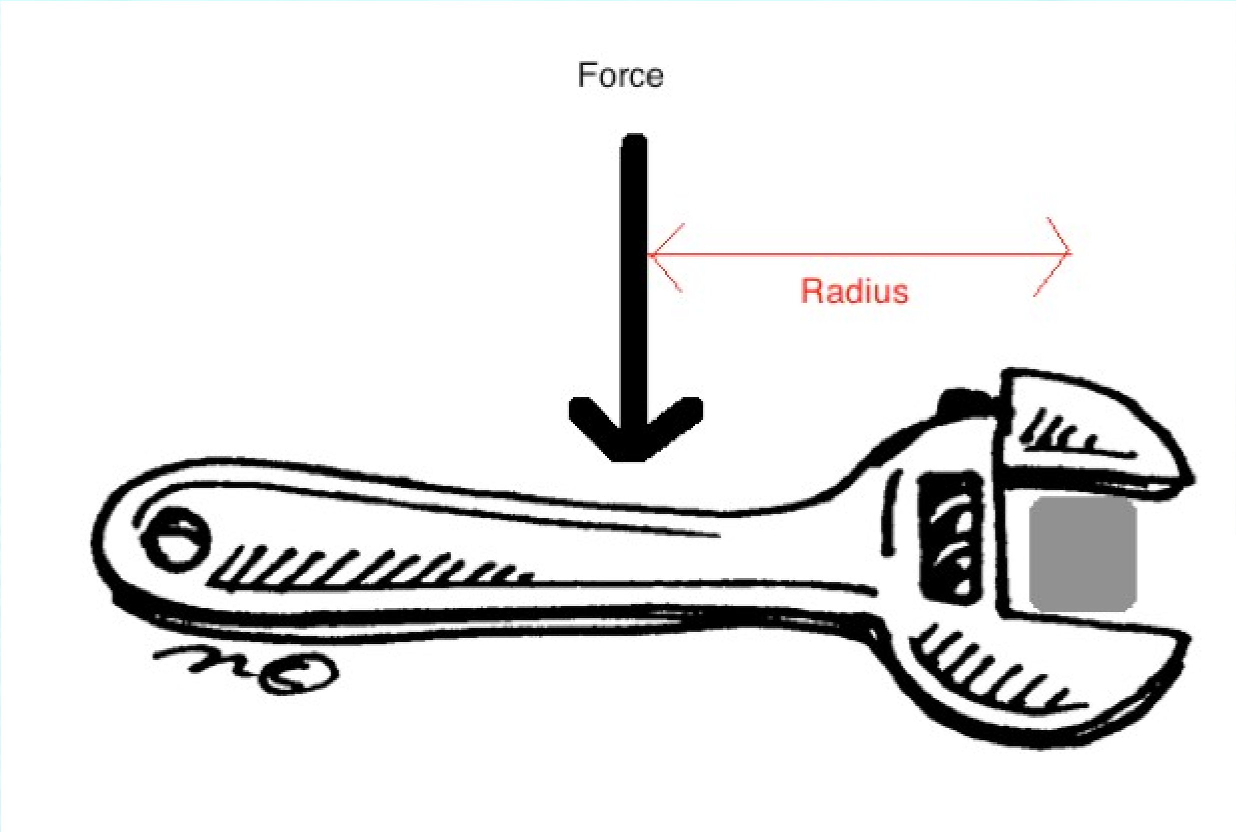
Written homework #10.

33.49, 33.54. Slide from class #29 (explain why the magnet in the copper tube falls slowly)

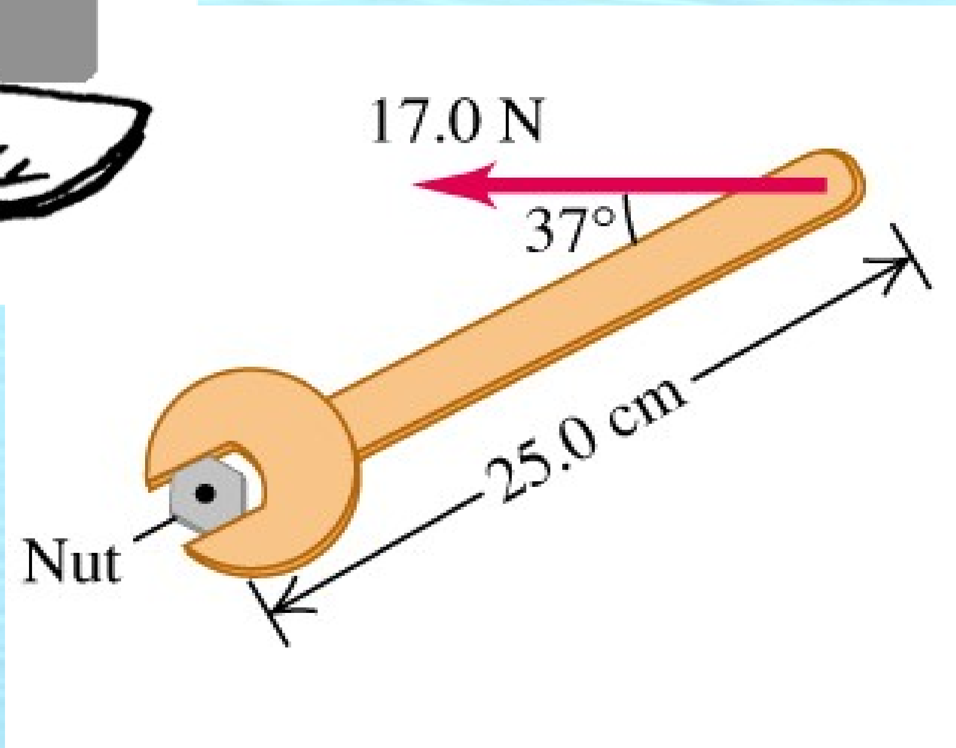
MP Assignment #13

33.1, 33.3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 18, 19, 28, 29, 30, 31, 39, 41, 42, 50, 60

Torque



$$\vec{\tau} = \vec{r} \times \vec{F}$$

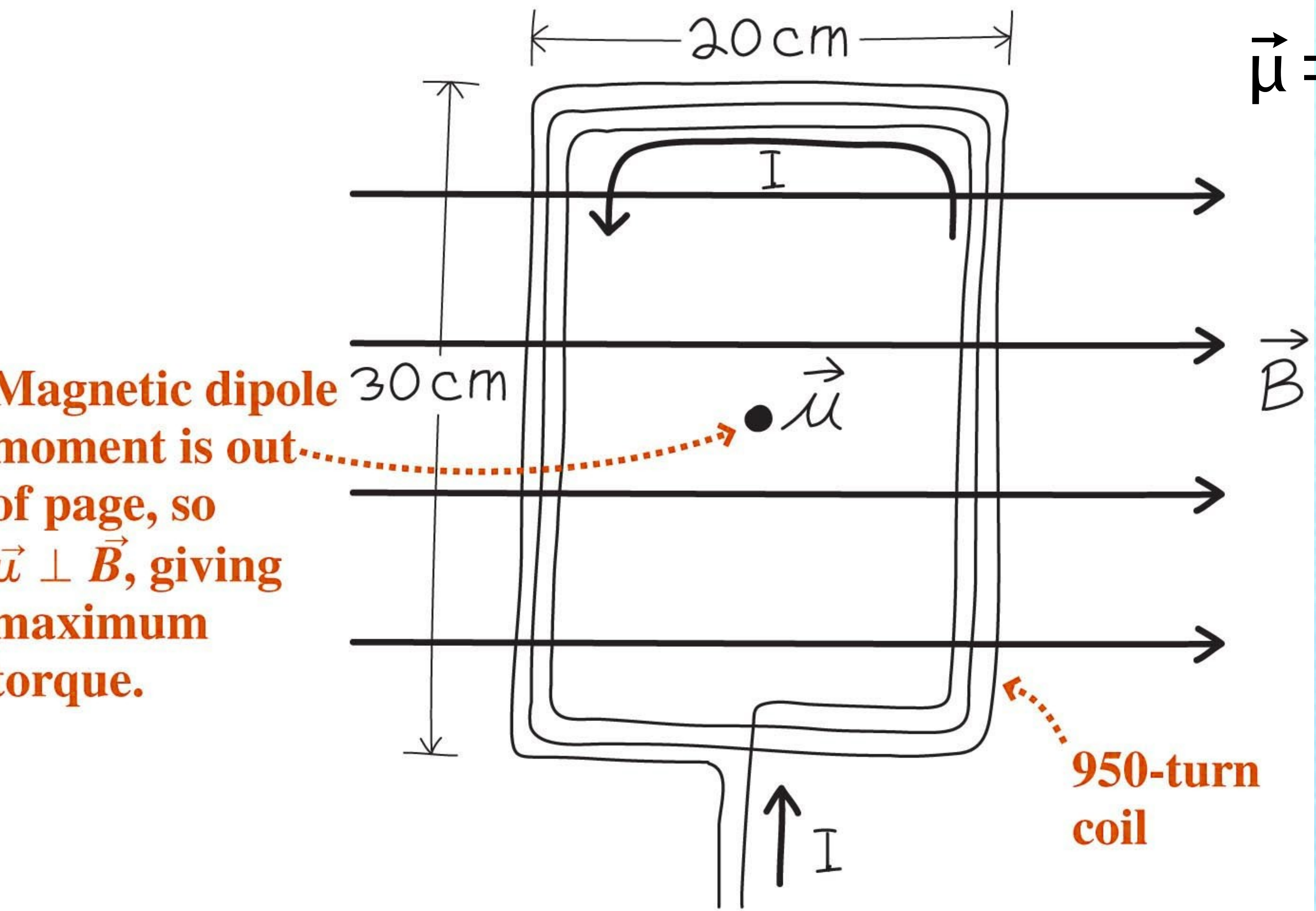


Only the part of the
Force at right angles
To the “moment arm”
Twists the bolt

Torque on a current loop is proportional to magnetic moment.

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

$$\vec{\mu} = I \ \vec{A}$$



Torque on a current loop is proportional to magnetic moment.

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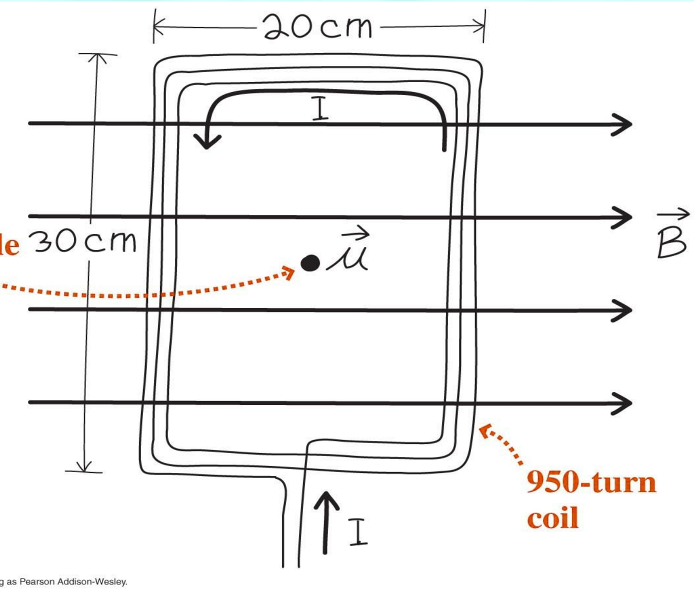
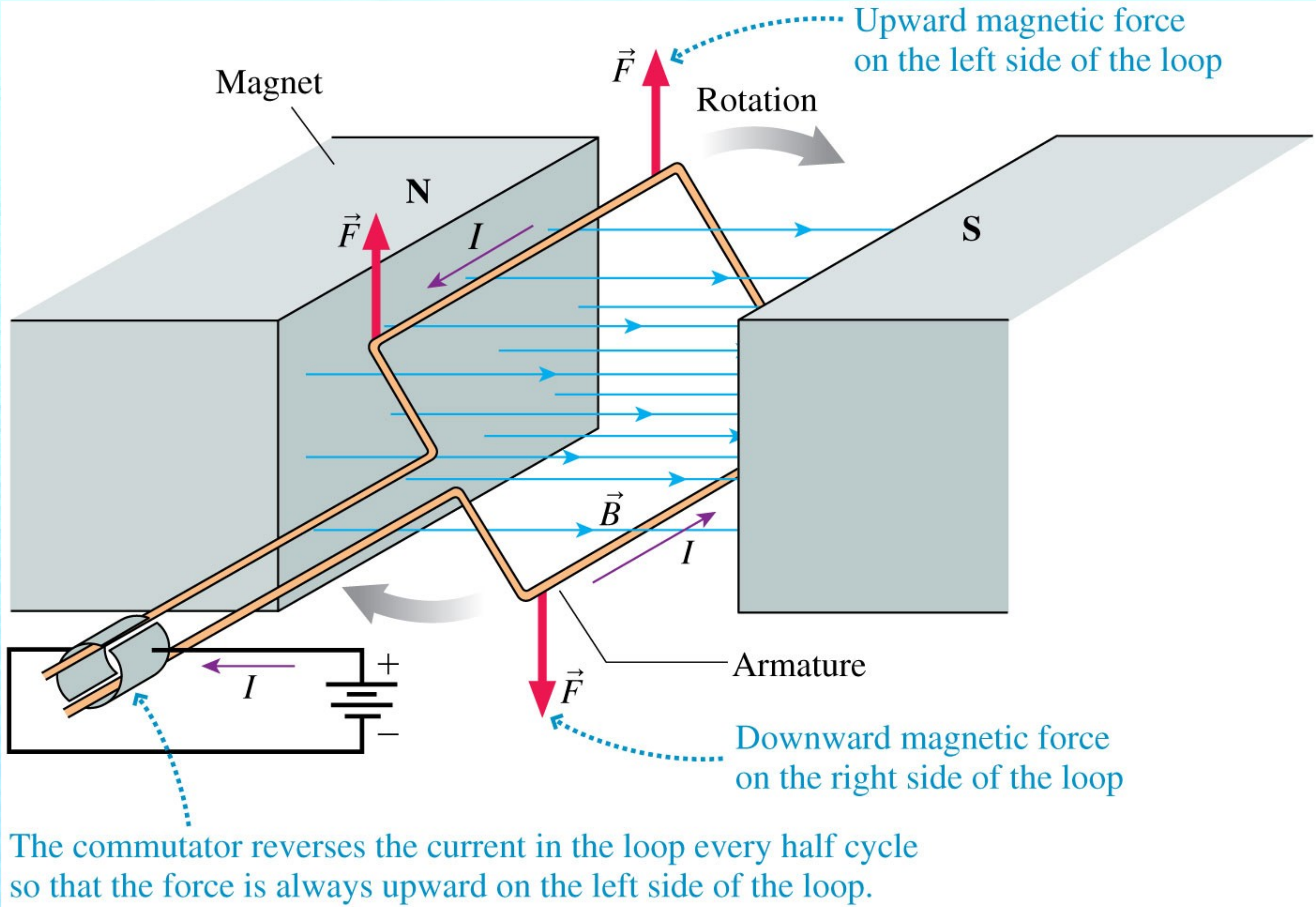


A Simple Electric Motor



Clicker

If released from rest, the current loop will

A. Move upward.
B. Move downward.
C. Rotate clockwise.
D. Rotate counterclockwise.
E. Do something not listed here.

Electric Motor demonstrations

DC Electric Motor

http://www.youtube.com/watch?v=Xi7o8cMPI0E&feature=fvw

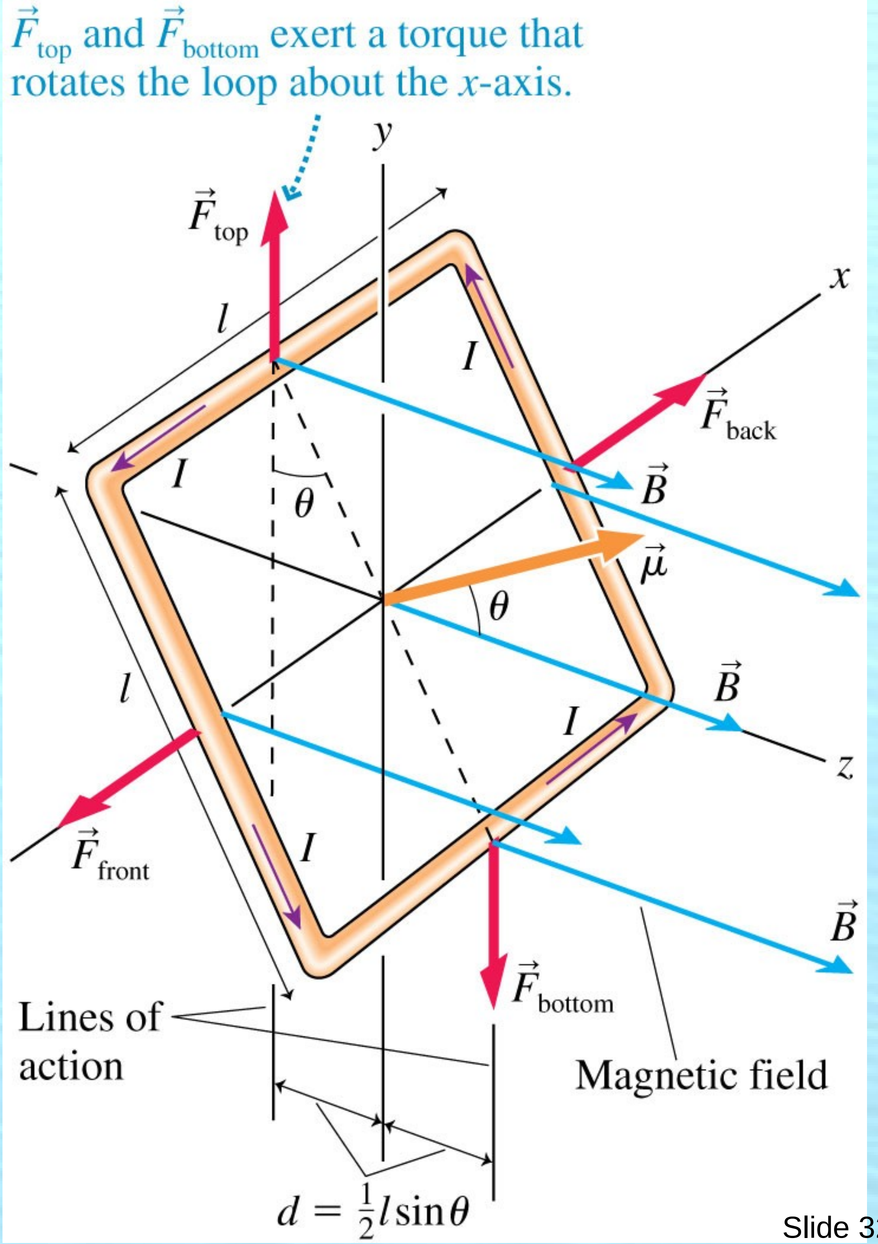
http://www.youtube.com/watch?v=FjNnRyLexNM

Homopolar motor **"The simplest motor of the world"**

http://www.youtube.com/watch?v=zOdboRYf1hM&NR=1

A Uniform Magnetic Field Exerts a Torque on a Square Current Loop

- $\vec{F}_{\text{front}}$ *and* $\vec{F}_{\text{back}}$ *are opposite eachother and cancel.*
- Both $\vec{F}_{\text{top}}$ and $\vec{F}_{\text{bottom}}$ exert a force of magnitude $F = IlB$ around a moment arm $d = ½l\sin\theta$.



A Uniform Magnetic Field Exerts a Torque on a Square Current Loop

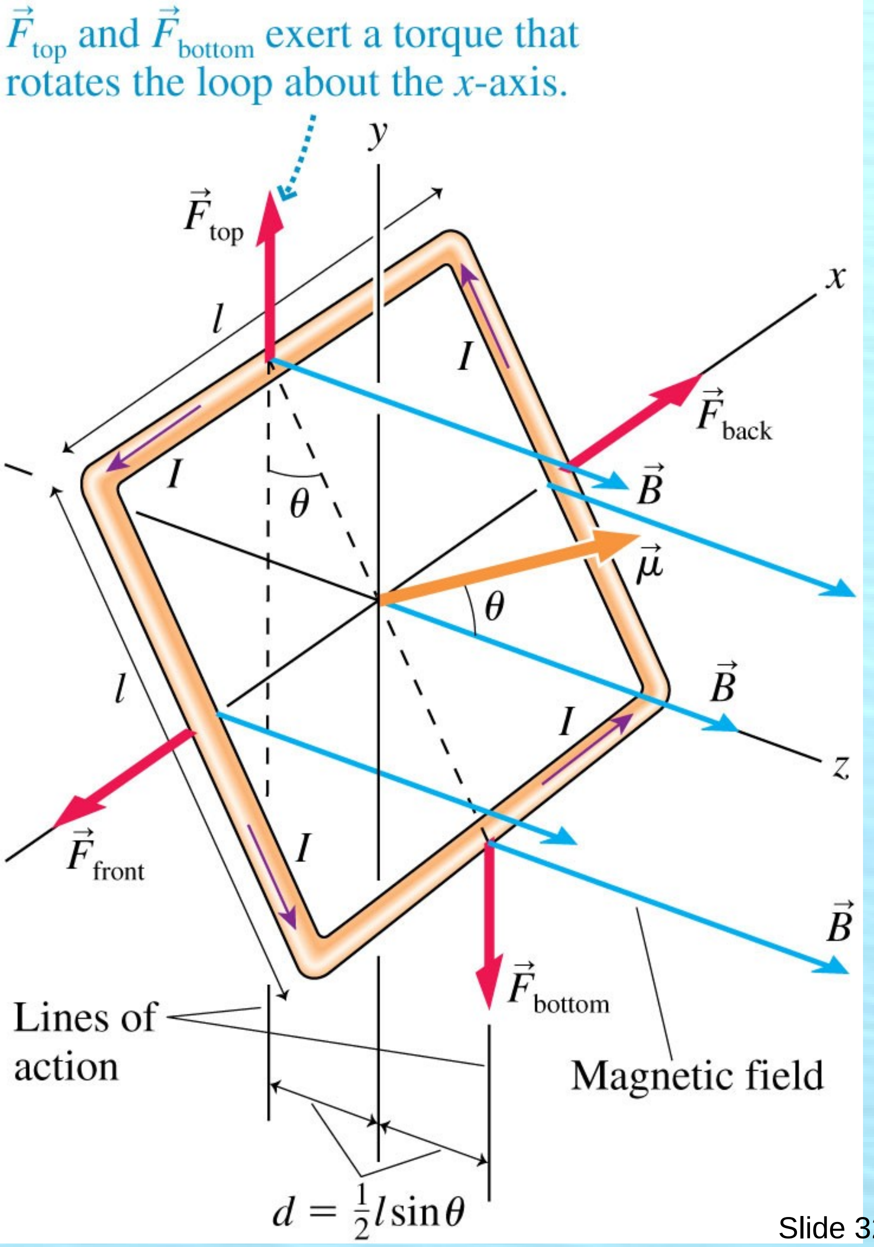
- The total torque is:

  $\tau = 2Fd = (Il^2)B\sin\theta = \mu B\sin\theta$

  where $\mu = Il^2 = IA$ is the loop's magnetic dipole moment.

- Although derived for a square loop, the result is valid for a loop of any shape:

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$



Why is magnetic dipole moment a useful concept?

It's good for understanding motors.

Protons and electrons have dipole moments.

This is particularly surprising since electrons have zero size.

Even at the quantum level, particles act like spinning balls of charge!

MRI works by flipping over every proton in the Water-molecules in your body!

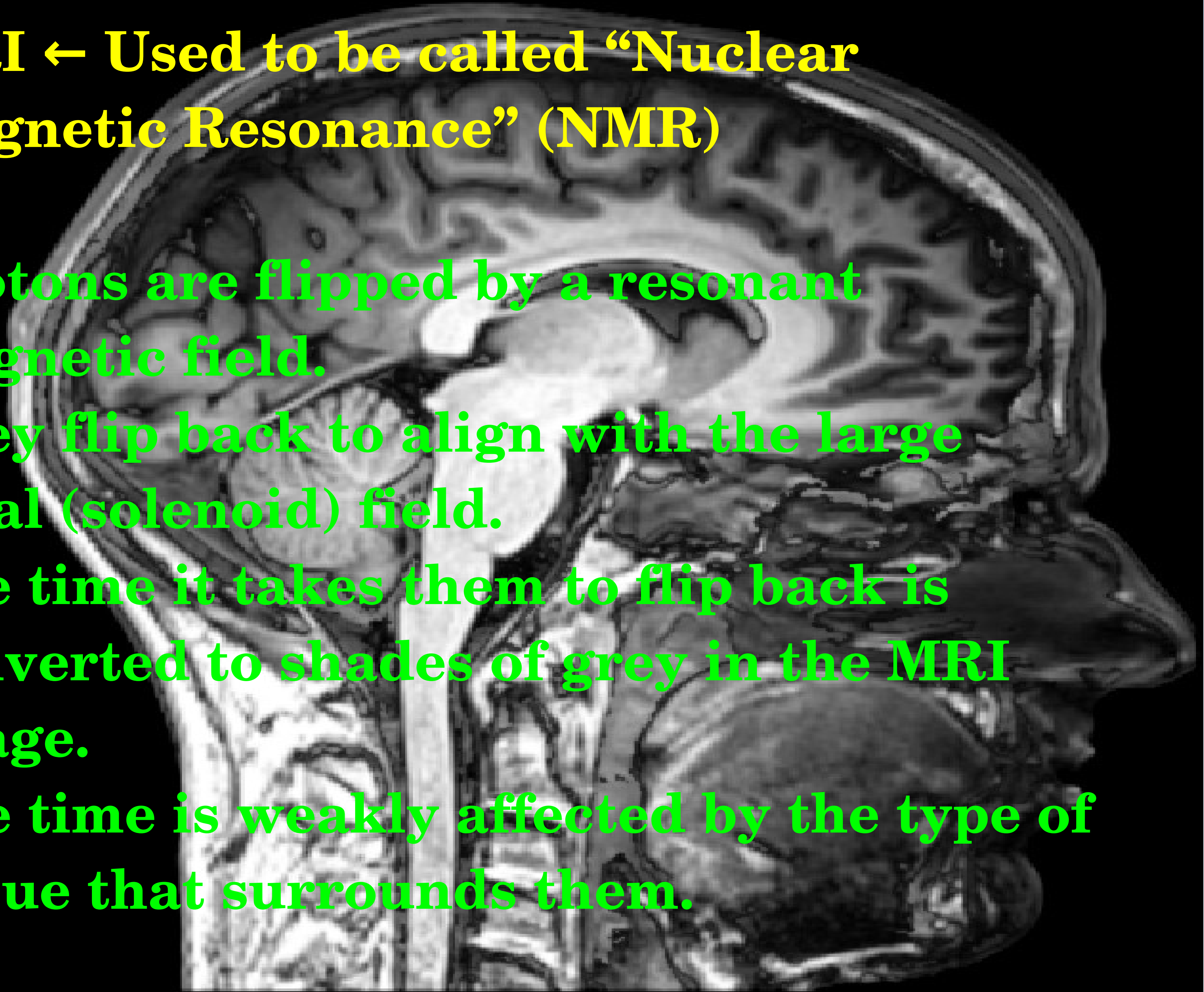
MRI ← Used to be called "Nuclear Magnetic Resonance" (NMR)

Protons are flipped by a resonant magnetic field.

They flip back to align with the large axial (solenoid) field.

The time it takes them to flip back is converted to shades of grey in the MRI image.

The time is weakly affected by the type of tissue that surrounds them.



An electric motor is made from 100 turns of Copper wire in a rectangle 10 cm on a side. It is placed in a 10 milliTesla magnetic field. What is the maximum torque with a 100 amp current?

(A) 0.001 N-m
(B) 0.01 N-m
(C) 0.1 N-m
(D) 1 N-m
(E) 10 N-m

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

$$\vec{\mu} = I \vec{A}$$

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There is a force on charges whenever V cross B is not zero.

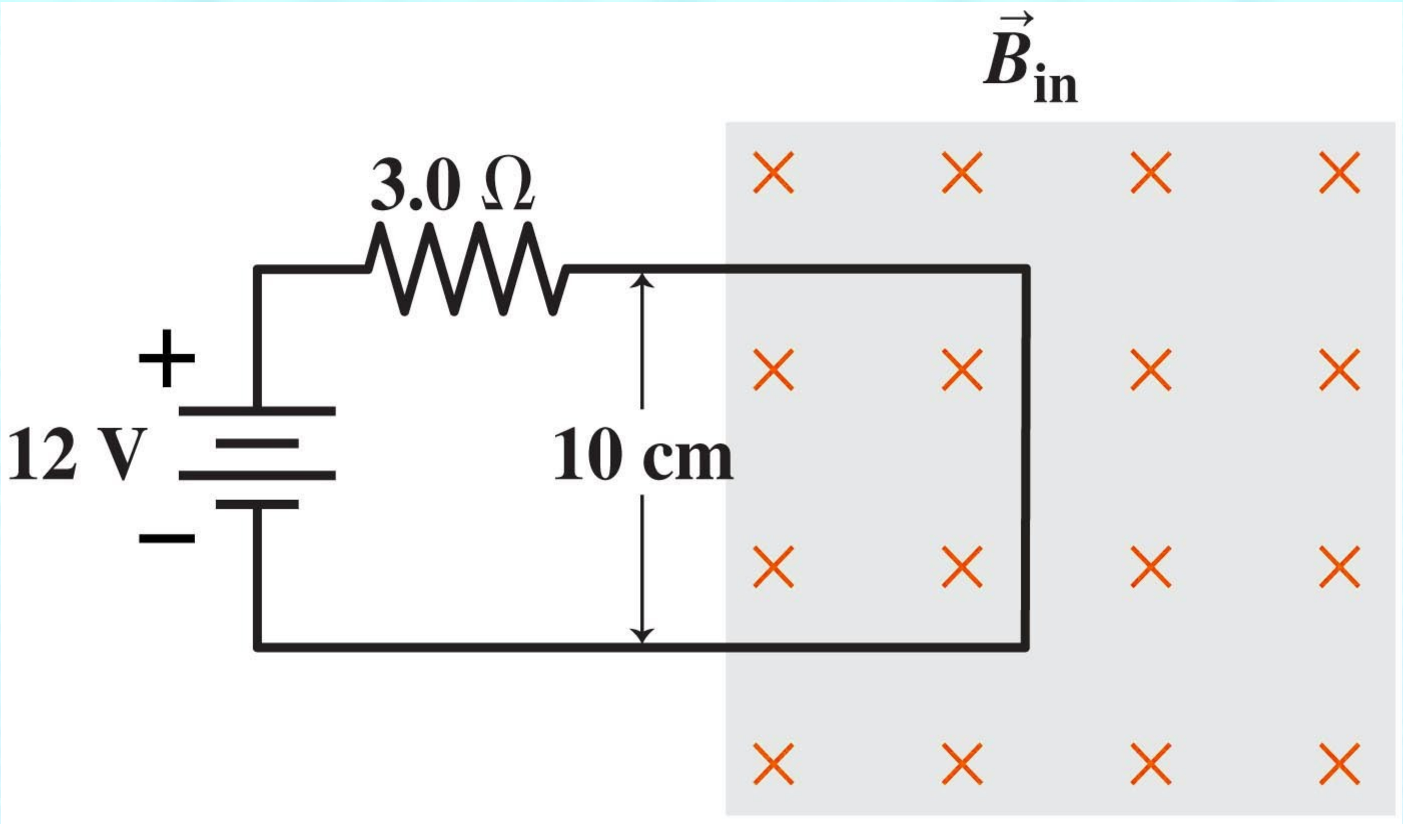
Magnetic force on a charge ---> $\vec{F} = q\,\vec{v} \times \vec{B}$

Magnetic force on all charges In a volume AL ---> $\vec{F} = nAq\,L\,\vec{v}_d \times \vec{B}$

$$\vec{F} = I\,\vec{L} \times \vec{B}$$

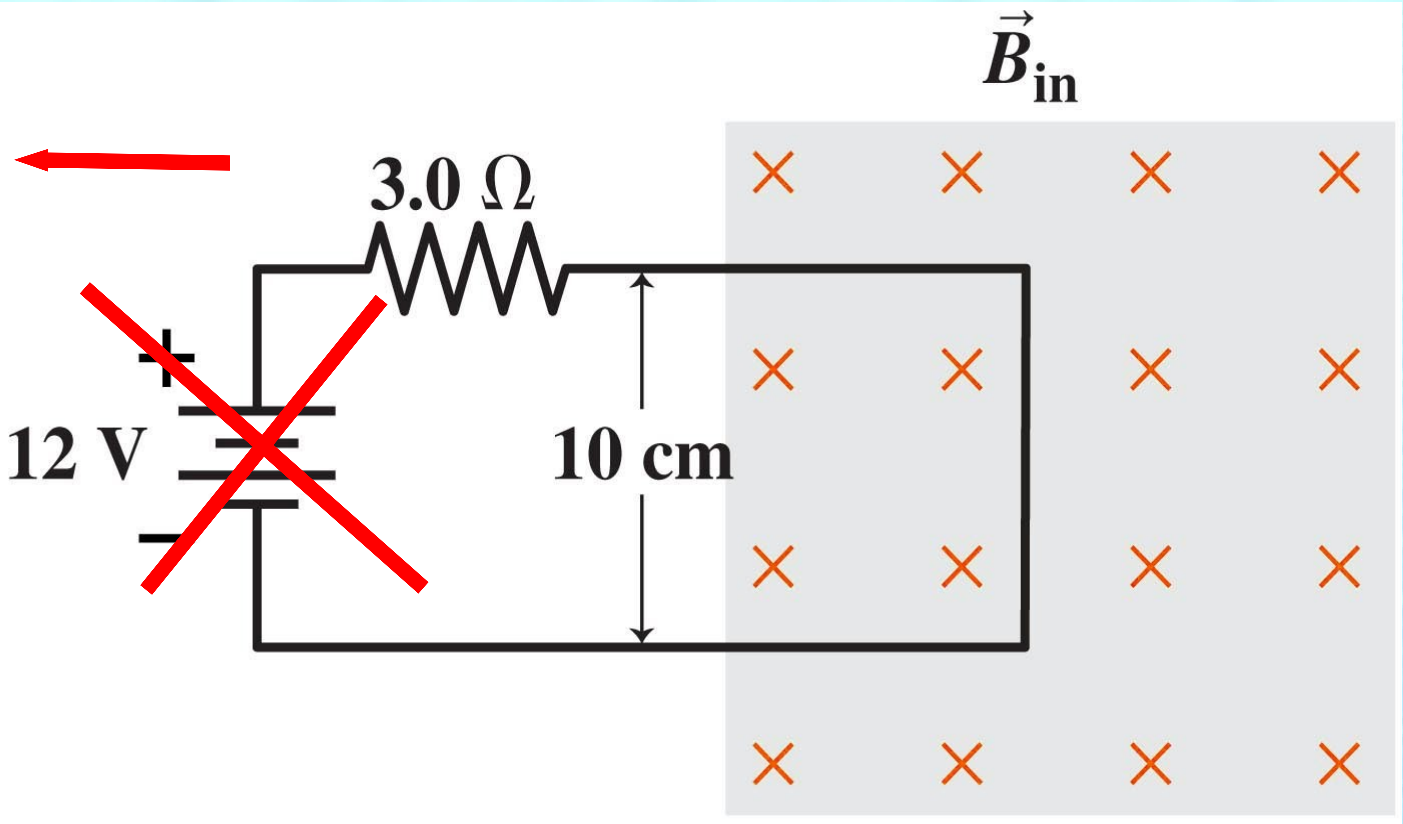
The battery creates a current, and
The B-field pushes back on the wire.

$$\vec{F} = I\,\vec{L} \times \vec{B}$$



What if there was no battery and you Pulled the wire out of the B-field?

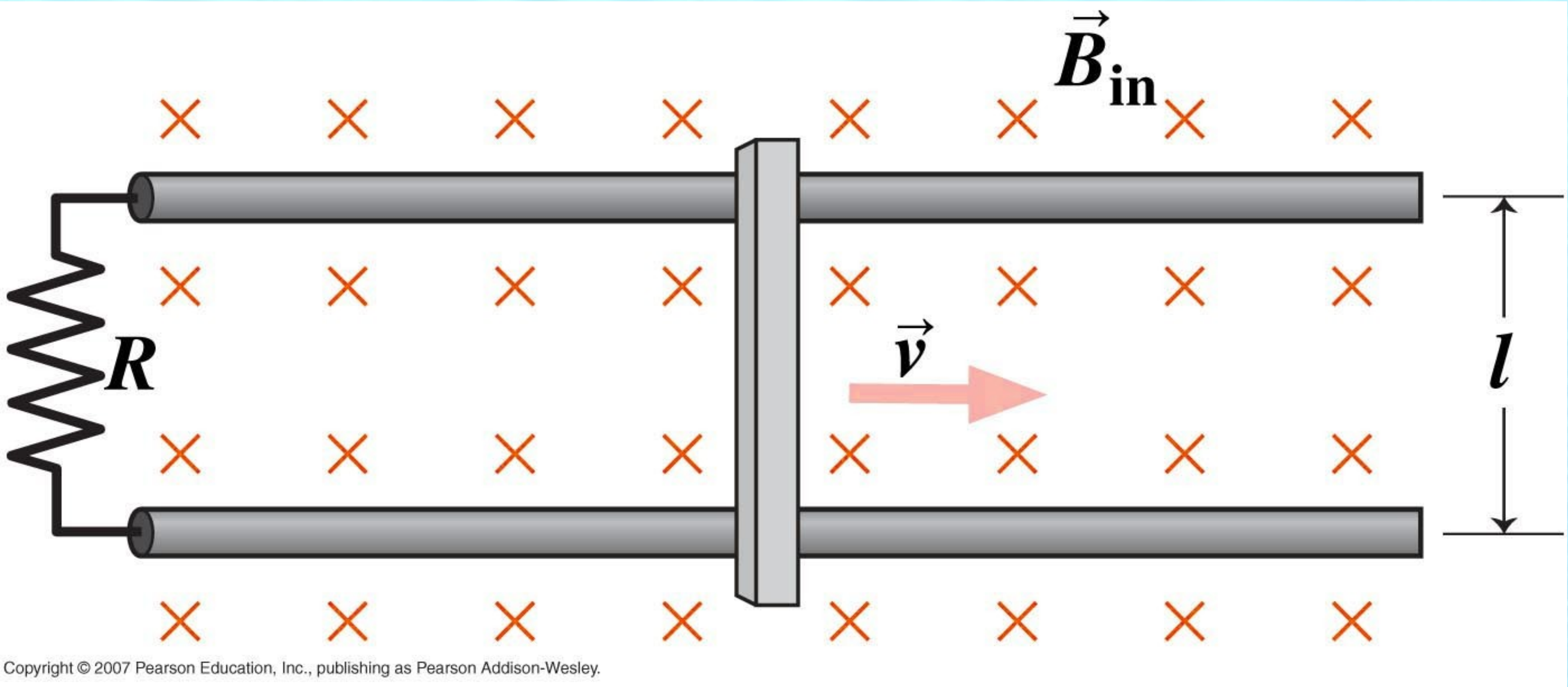
$$\vec{F} \text{ per electron} = q\, \vec{v}_{pull} \times \vec{B}$$



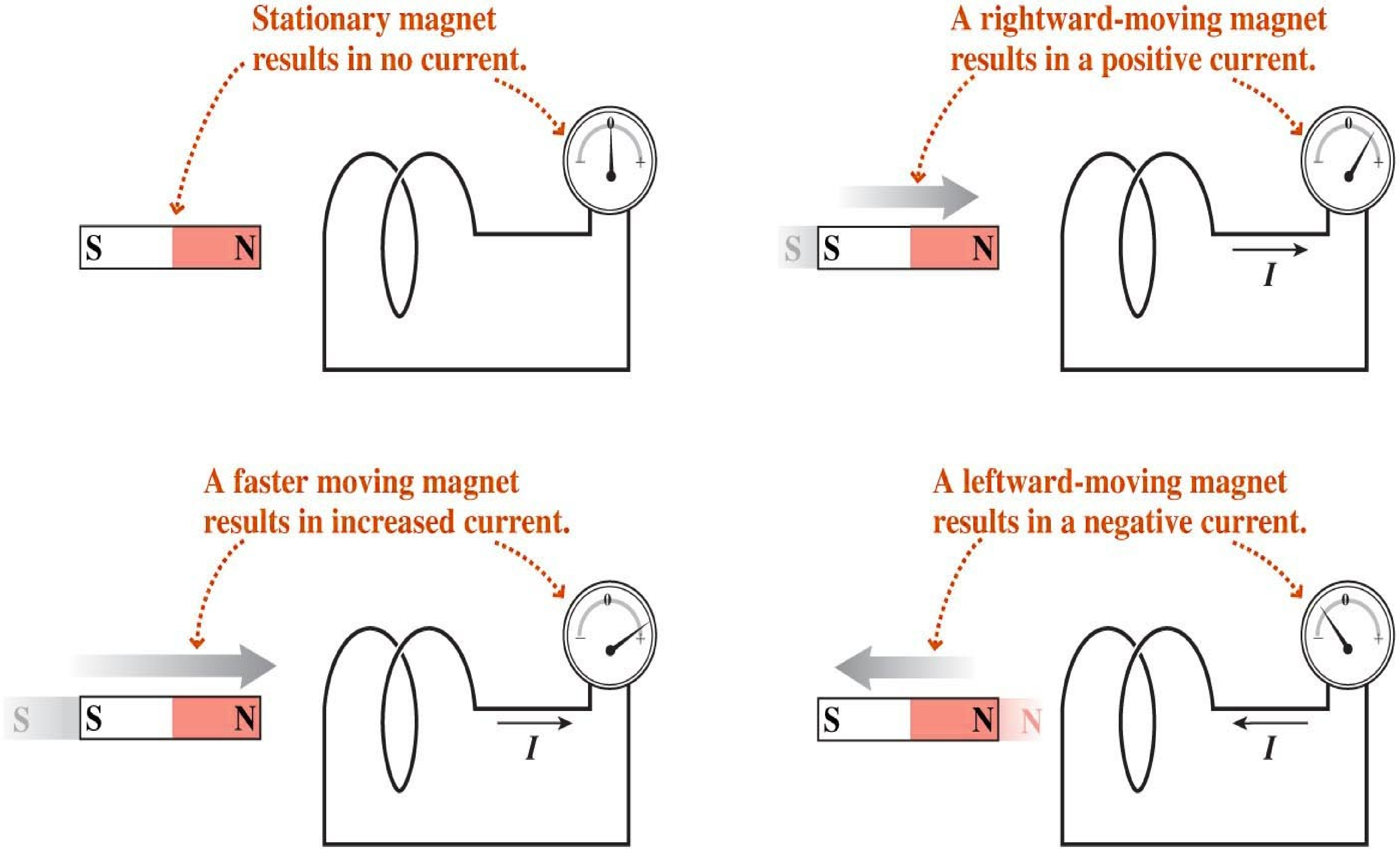
Here there is no battery … the B-field pushes on the electrons

When the crossbar moves … and makes a current.

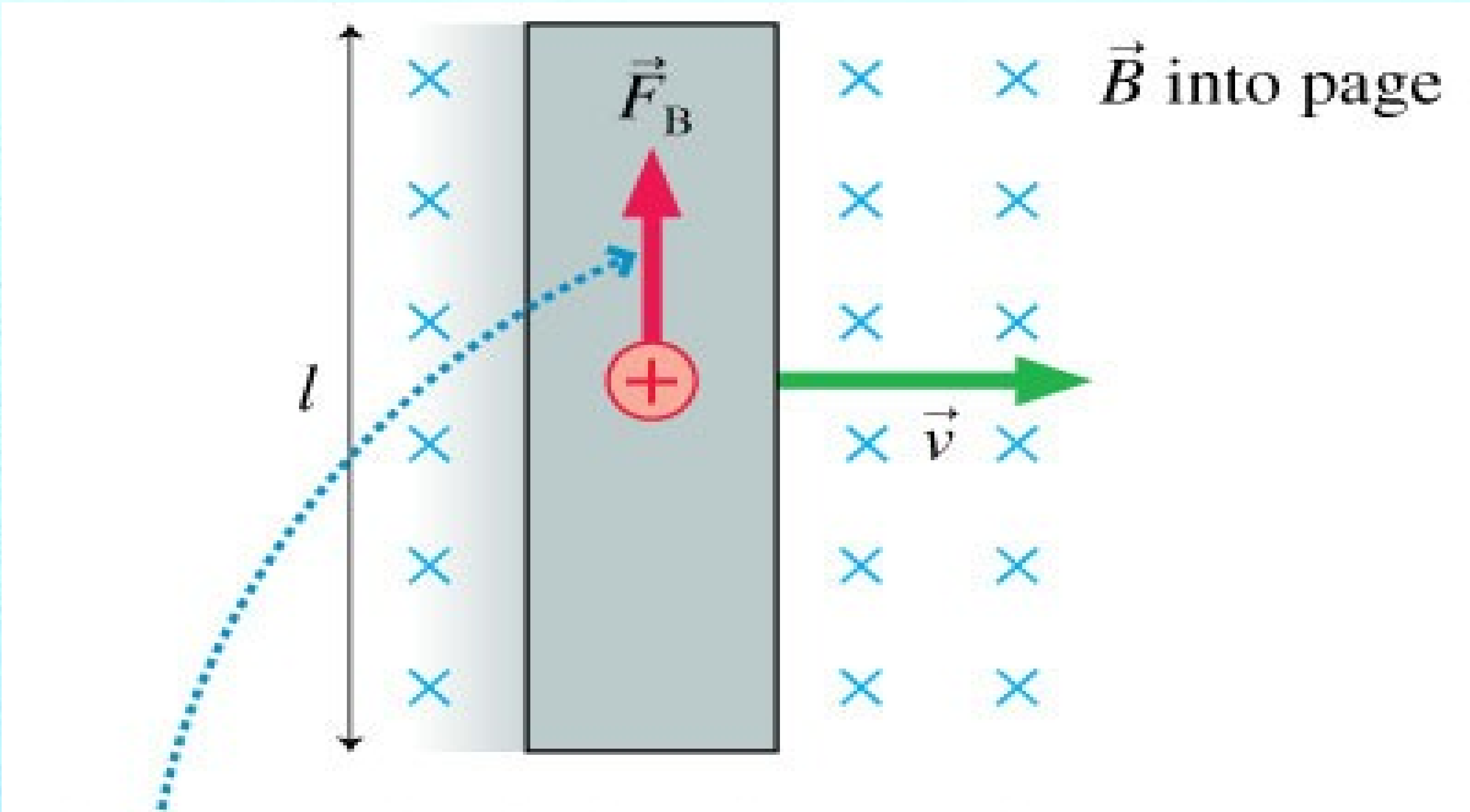
Slide-wire generator



Any time you change the magnetic field In a loop, you cause a current

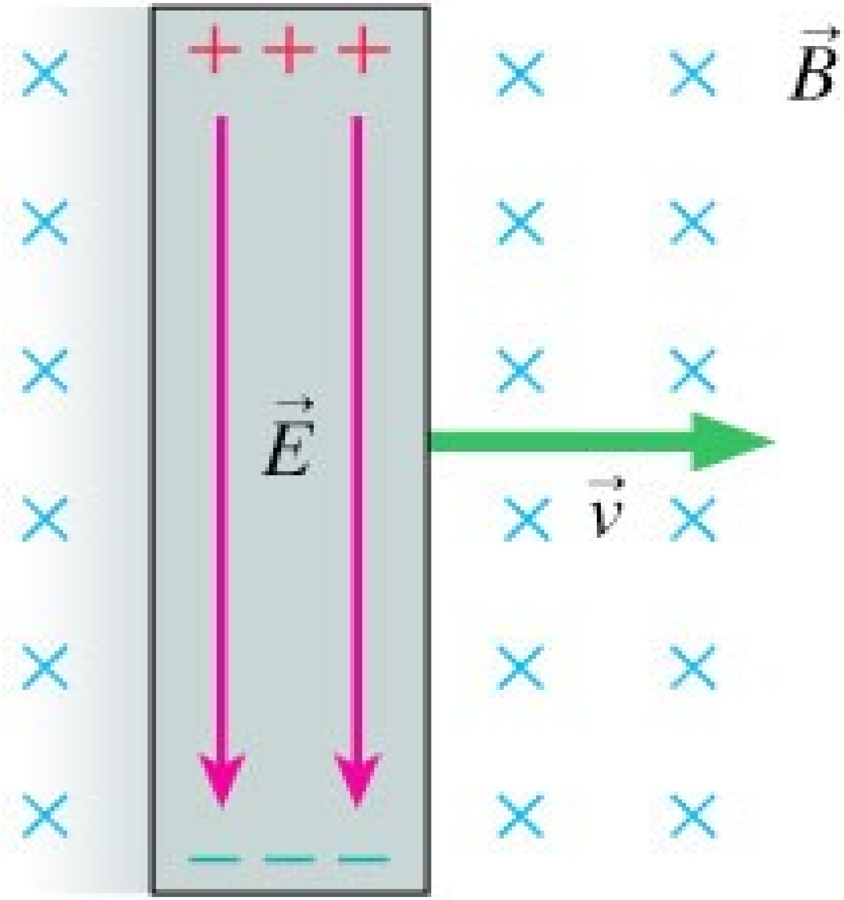


Motional emf



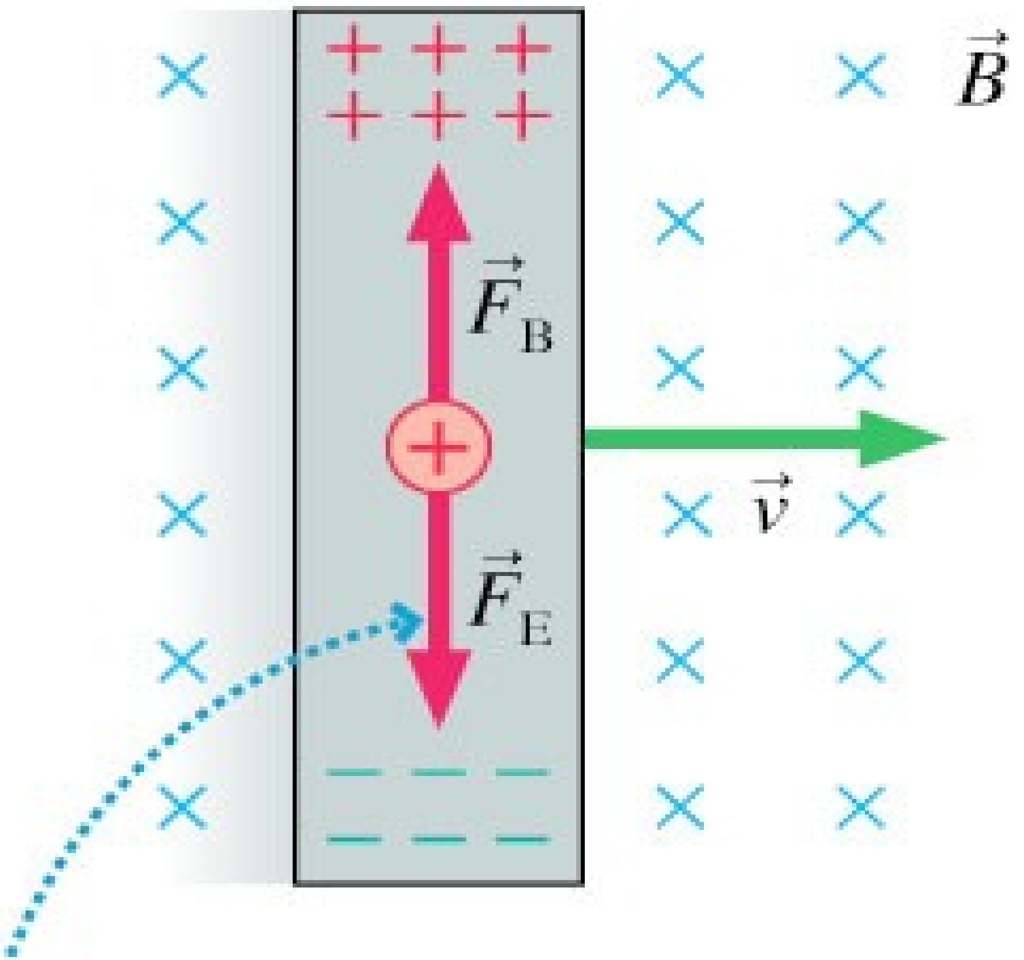
Charge carriers in the wire experience an upward force of magnitude $F_B = qvB$. Being free to move, positive charges flow upward (or, if you prefer, negative charges downward).

Motional emf



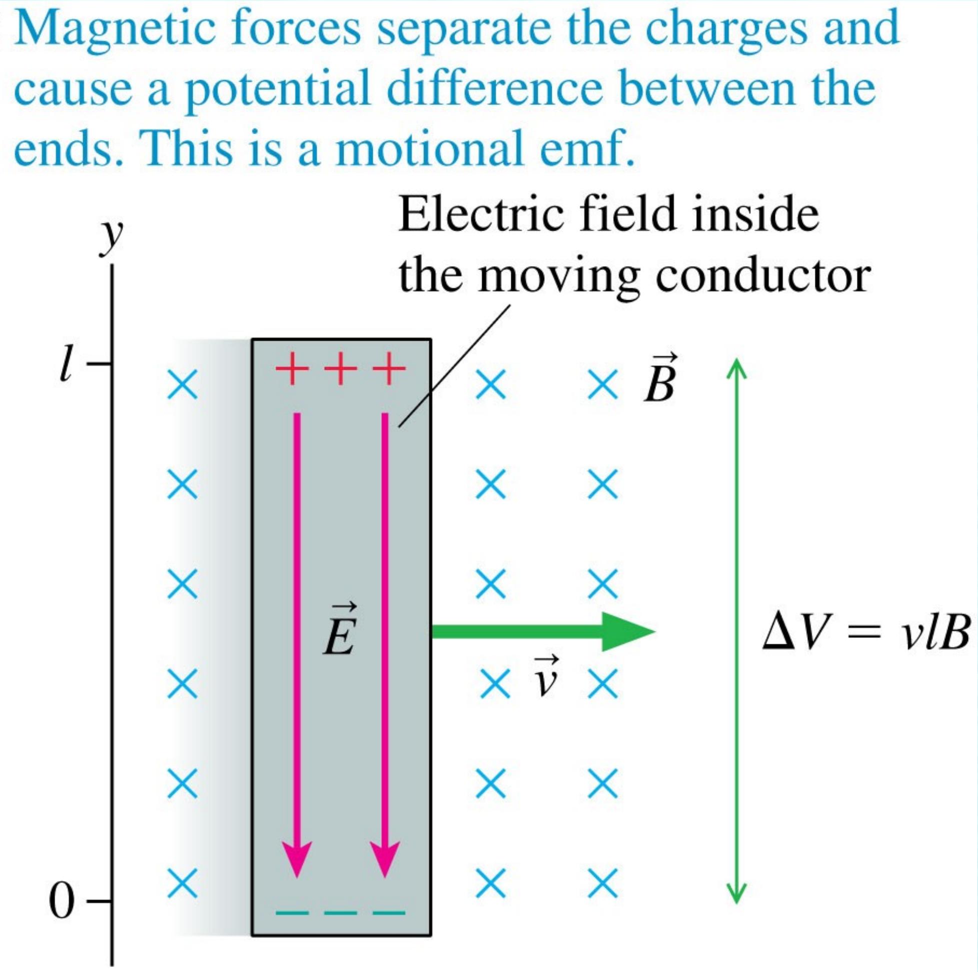
The charge separation creates an electric field in the conductor. $\vec{E}$ increases as more charge flows.

Motional emf



The charge flow continues until the downward electric force $\vec{F}_E$ is large enough to balance the upward magnetic force $\vec{F}_B$. Then the net force on a charge is zero and the current ceases.

Motional emf

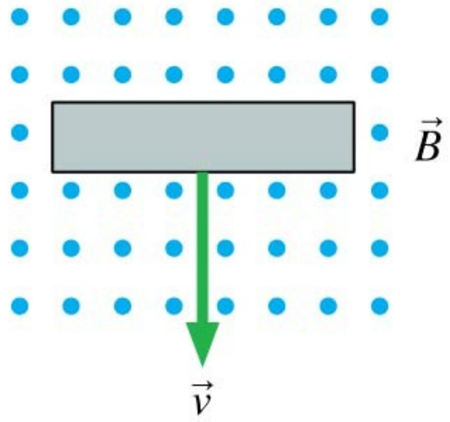


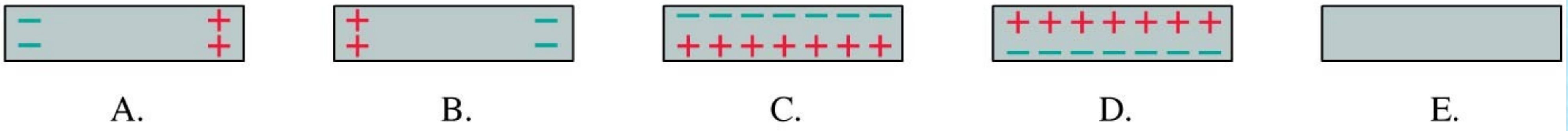
- The magnetic force on the charge carriers in a moving conductor creates an electric field of strength $E = vB$ inside the conductor.
- But Voltage is E L so ...
- For a conductor of length l, the motional emf perpendicular to the magnetic field is:

$$\mathcal{E} = vlB$$

Clicker

A metal bar moves through a magnetic field. The induced charges on the bar are





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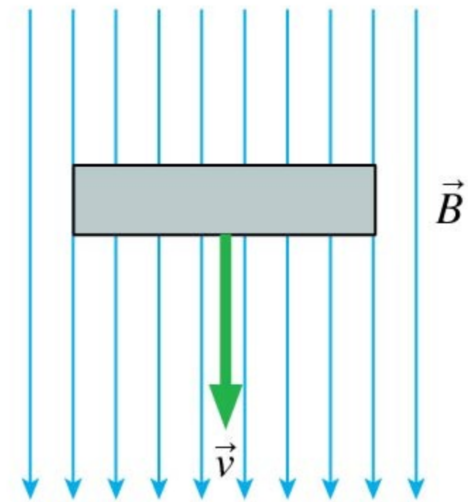
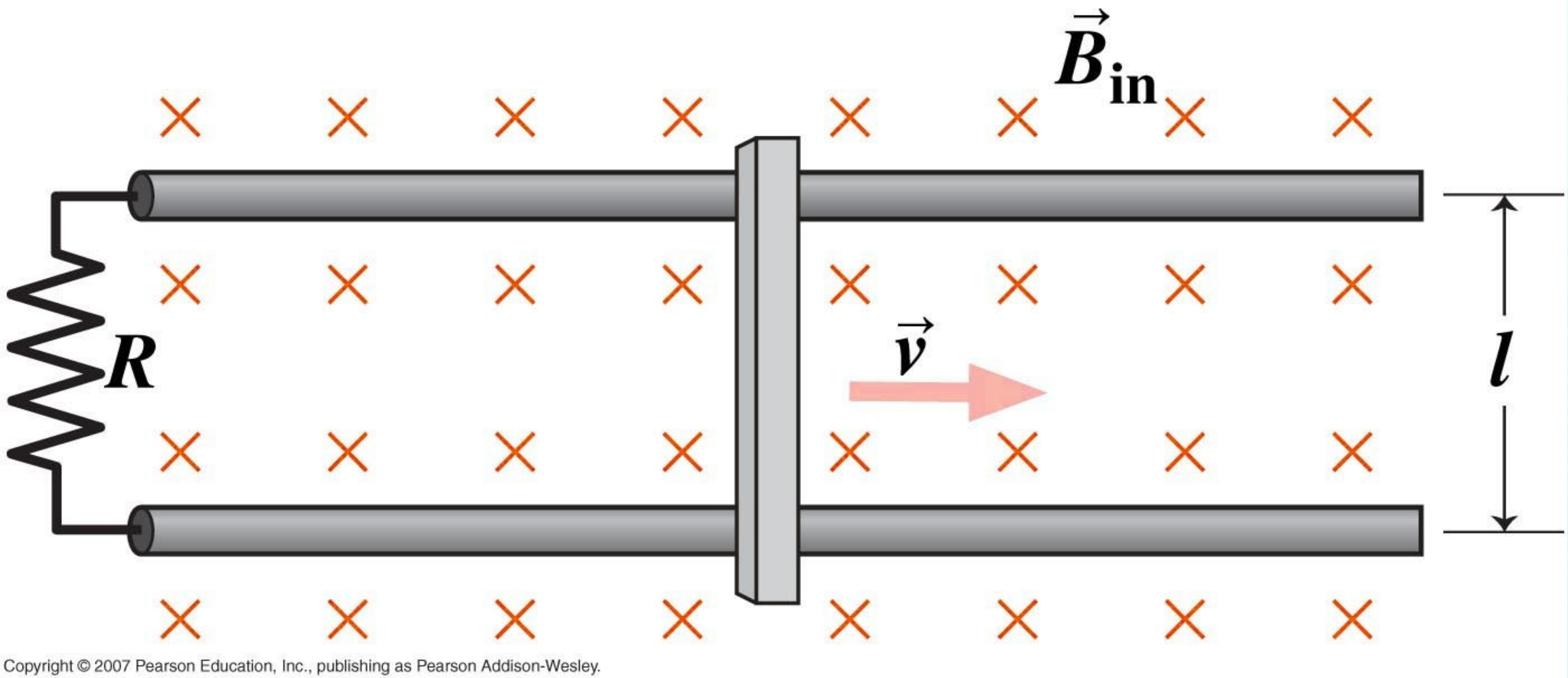


A. B. C. D. E.

$F = qvB$

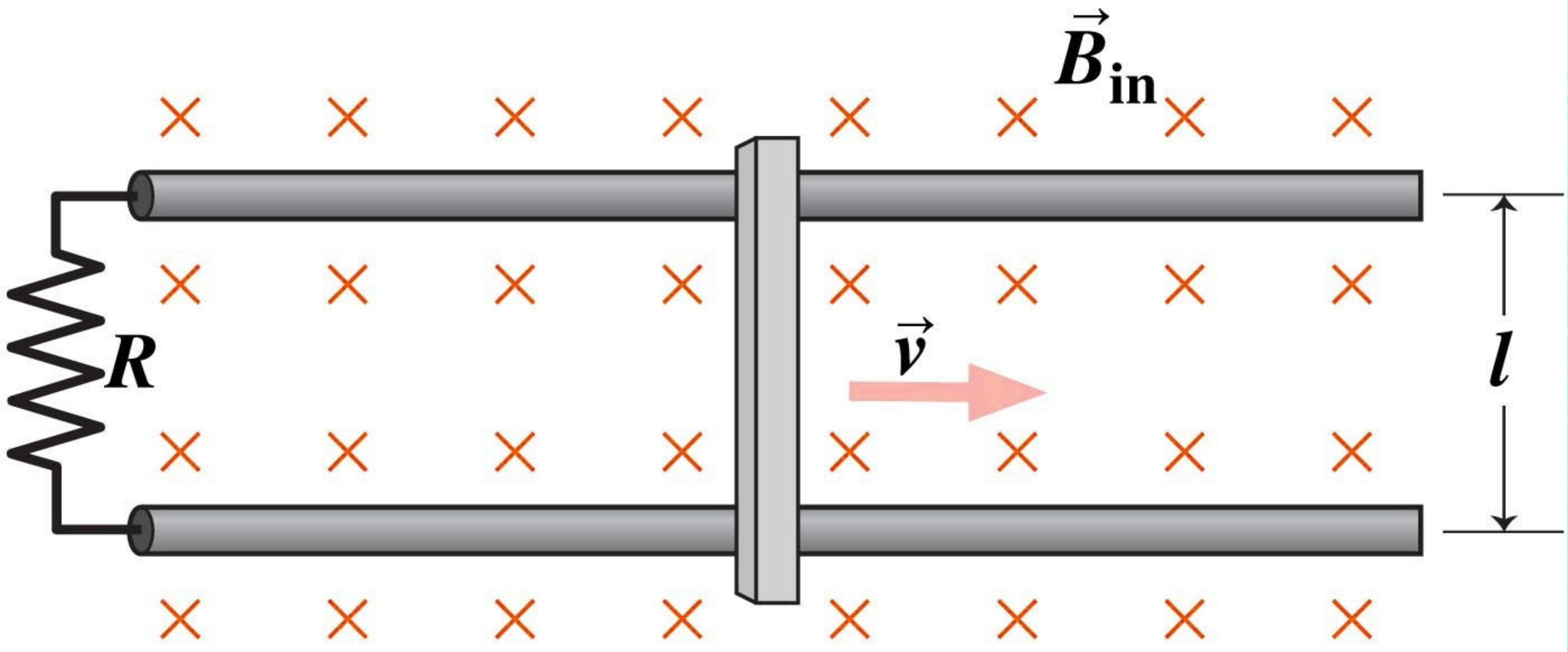
$E = F/q = vB$

$\varepsilon = EL = vBL$



$$\varepsilon = vlB = \frac{dA}{dt}B = \frac{d\Phi_B}{dt}$$

$$\Phi_B = \vec{A} \cdot \vec{B}$$



Faraday's Law

Changing magnetic fluxes produce electric fields and hence voltages (also called emfs).

$$\Phi_B = \vec{B} \cdot \vec{A} \leftarrow \text{Flux for B const. ovr space}$$

$$\varepsilon = \frac{-d\Phi_B}{dt} \leftarrow \text{Faraday 's Law (of induction)}$$

Faraday's Law – Why?

Changing magnetic fluxes produce electric fields and hence voltages.

$$\varepsilon = \frac{-d\Phi_B}{dt}$$ ¿

$$\varepsilon = -\int \vec{E} \cdot d\vec{r}$$

If only electric fields

$$\varepsilon = -\int \left(\vec{E} + \vec{v} \times \vec{B} \right) \cdot d\vec{r}$$

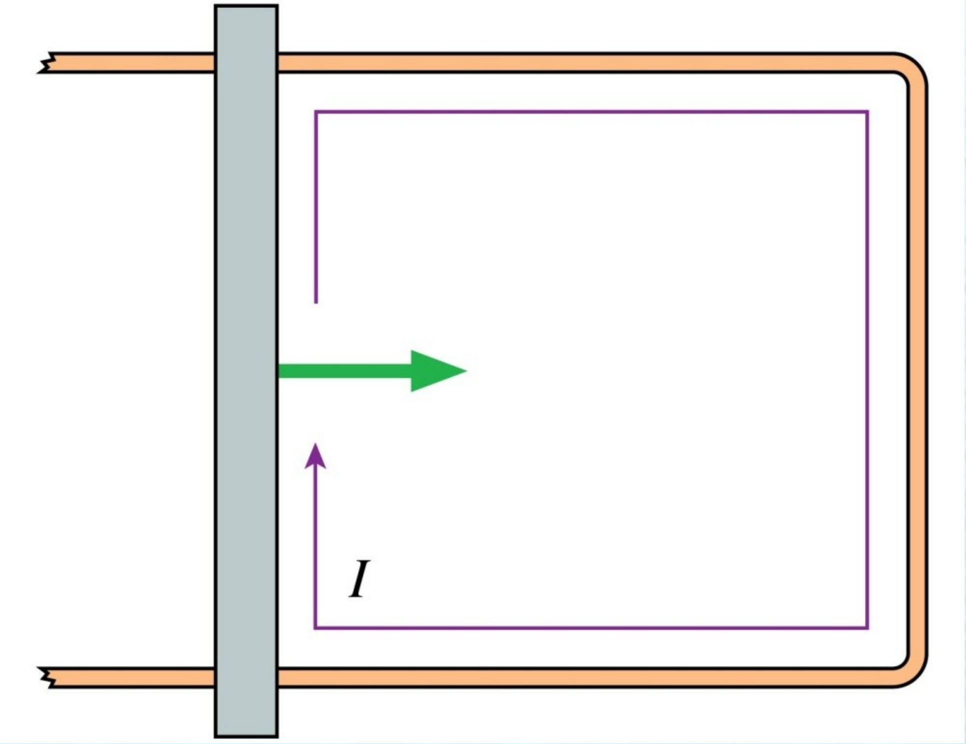
If elec. And magnetic fields

Units check out ...

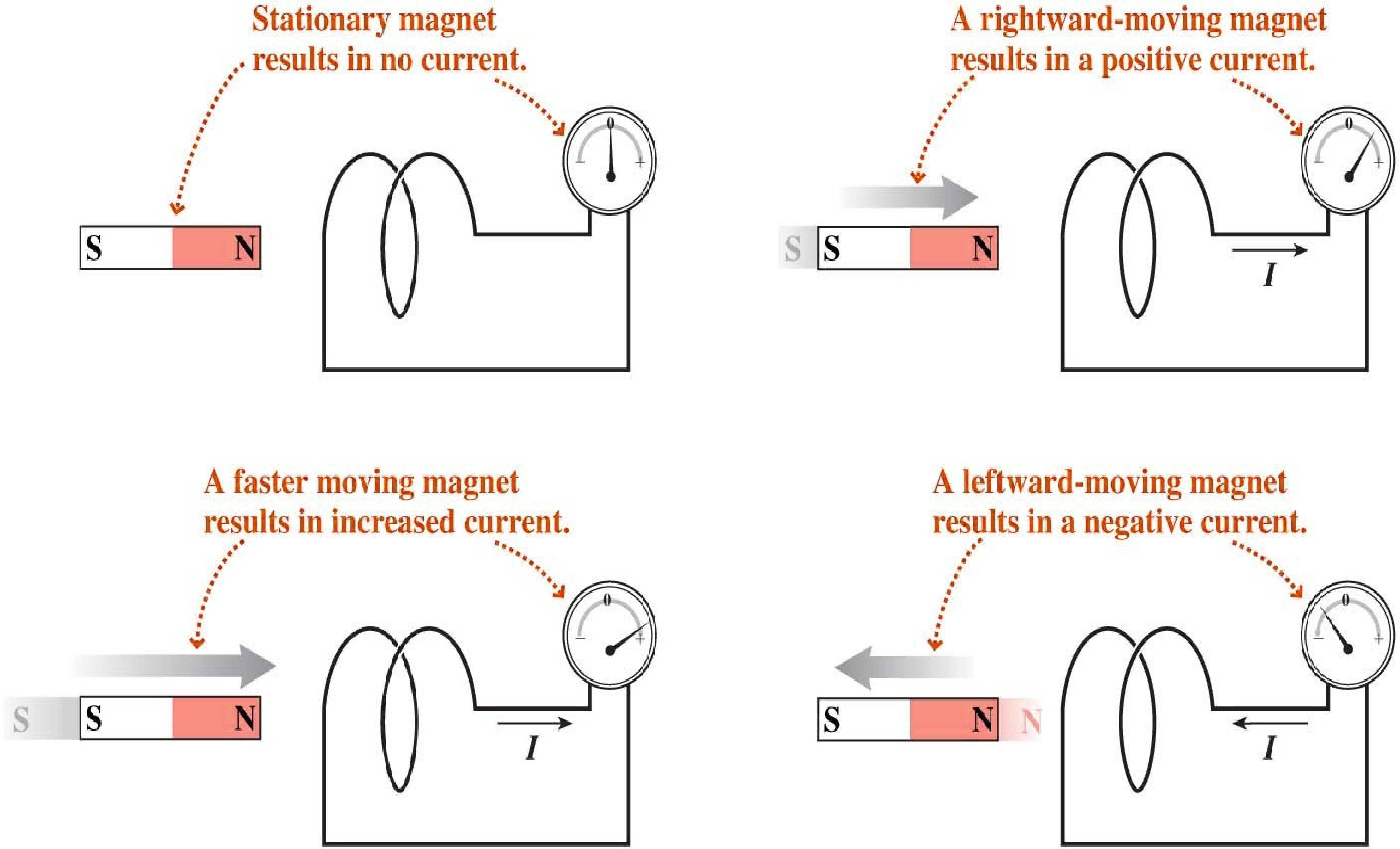
Clicker

$$\vec{F} = q\,\vec{v}_{push} \times \vec{B}$$

An induced current flows clockwise as the metal bar is pushed to the right. The magnetic field points

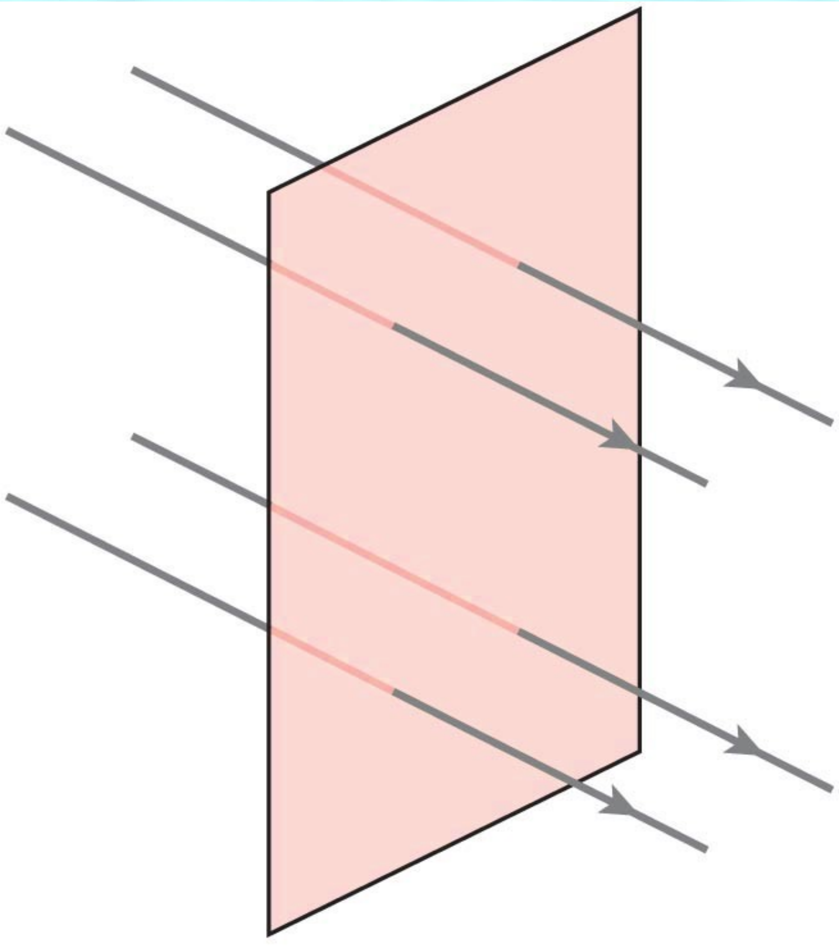


A. Up.
B. Down.
C. Into the screen.
D. Out of the screen.
E. To the right.


Stationary magnet
results in no current.
S
N
0
−
+
A rightward-moving magnet
results in a positive current.
S
S
N
I
A faster moving magnet
results in increased current.
S
S
N
I
A leftward-moving magnet
results in a negative current.
S
N
N
I

What is magnetic flux?

Flux – flow – like water through a river, or magnetic field lines through a surface.



$$\Phi_E = \int \vec{E} \cdot d\vec{A}$$

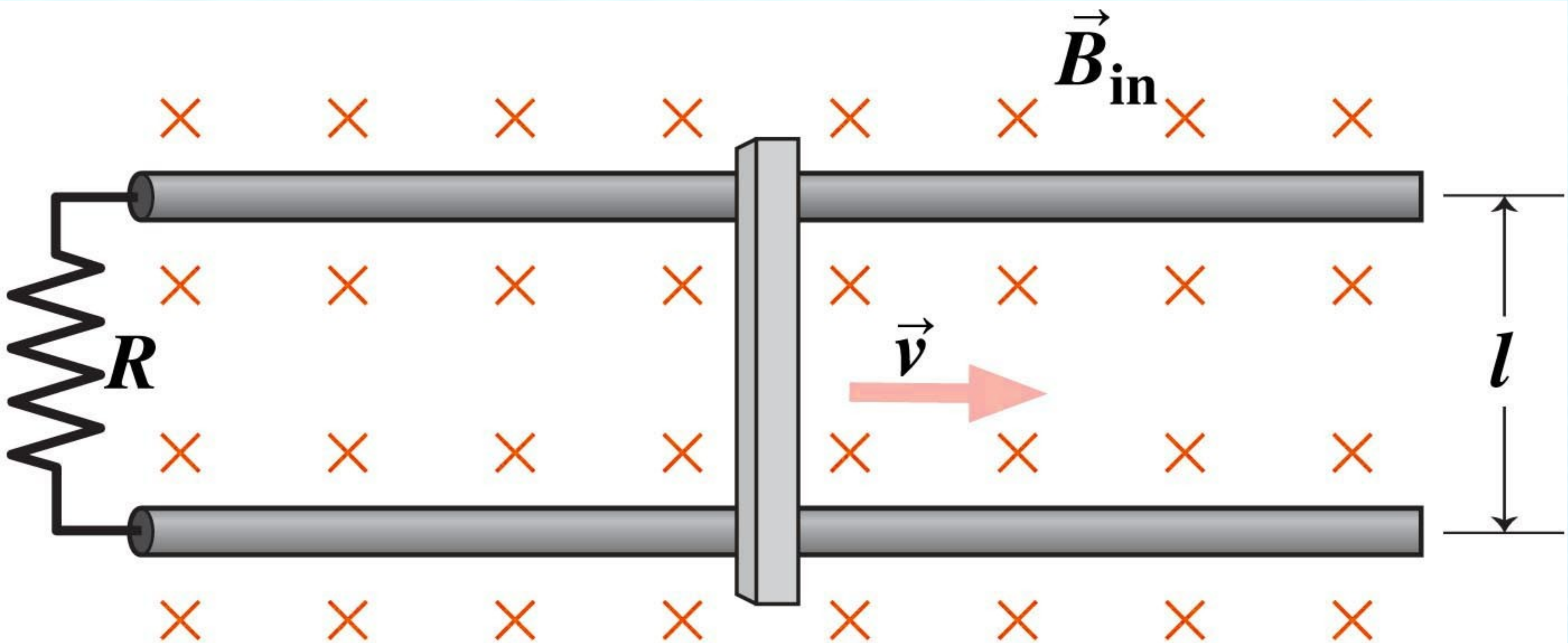
$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

For B uniform over area A:

$$\Phi_B = \vec{B} \cdot \vec{A}$$

Work done by magnetic force on electrons in a moving wire

Slide-wire generator



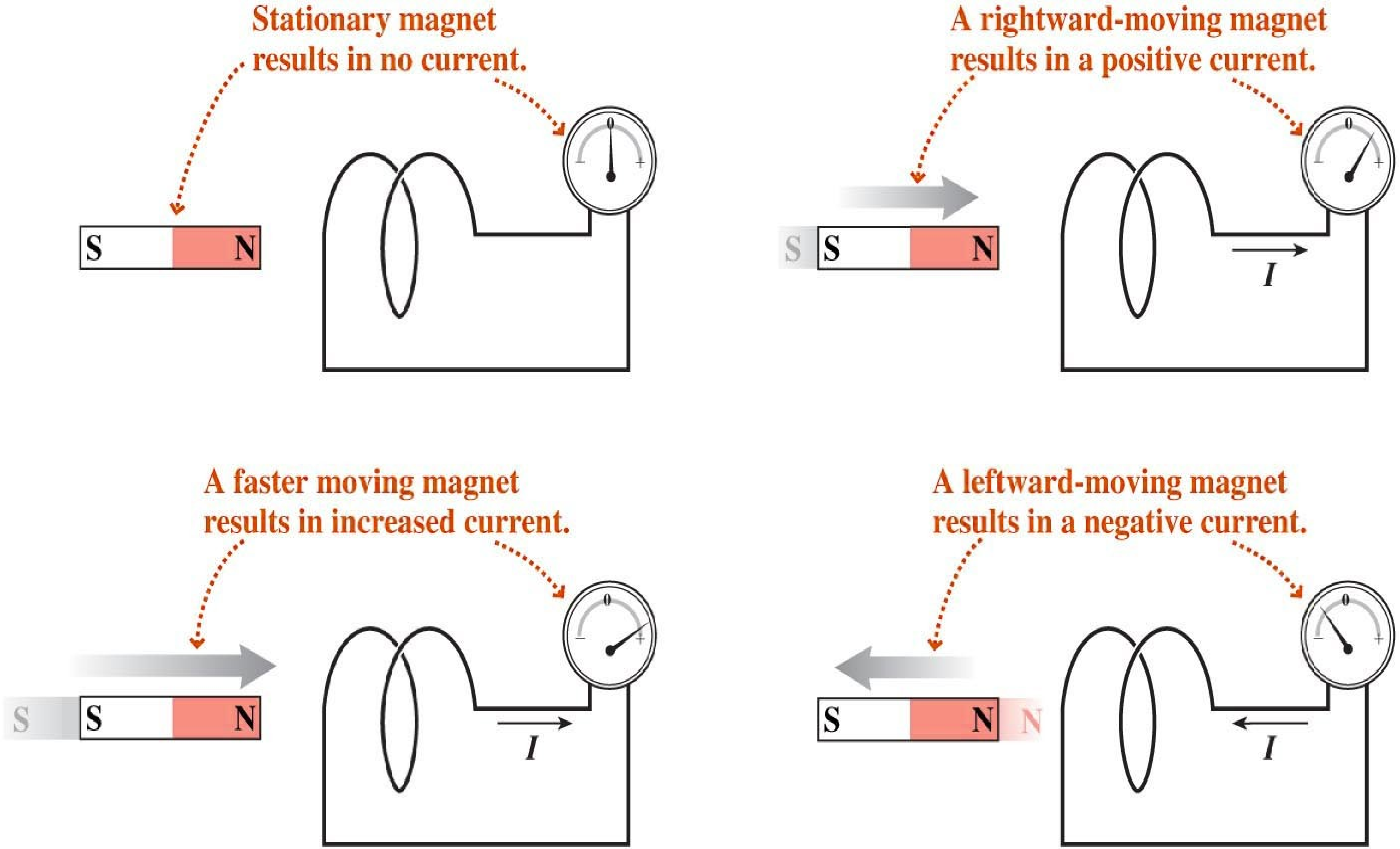
Ways to change flux

Let $\vec{B}$ be uniform over the loop. Then

$$\Phi_B = \int \vec{B} \cdot d\vec{A} \rightarrow \vec{B} \cdot \vec{A}$$

$$\frac{d\Phi_B}{dt} = \frac{d\vec{B}}{dt} \cdot \vec{A} + \frac{d\vec{A}}{dt} \cdot \vec{B}$$

- Can move loop into stronger or weaker B.
- Can increase/decrease B.
- Can rotate B.
- Can increase/decrease size of loop.
- Can rotate loop.


Stationary magnet
results in no current.
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