# Magnetic Induction (chapter 31)

- an emf is induced in a circuit placed in a magnetic field which is *changing with time*
- An emf is induced in a circuit which *moves* in a magnetic field

Serway and Jewett sections 31.1, 31.2

*Practice: Chapter 31,*
*Objective Questions 1, 2, 5, 6*
*Conceptual Questions 1, 5, 7*
*Problems 11, 13, 27*

# Magnetic Flux

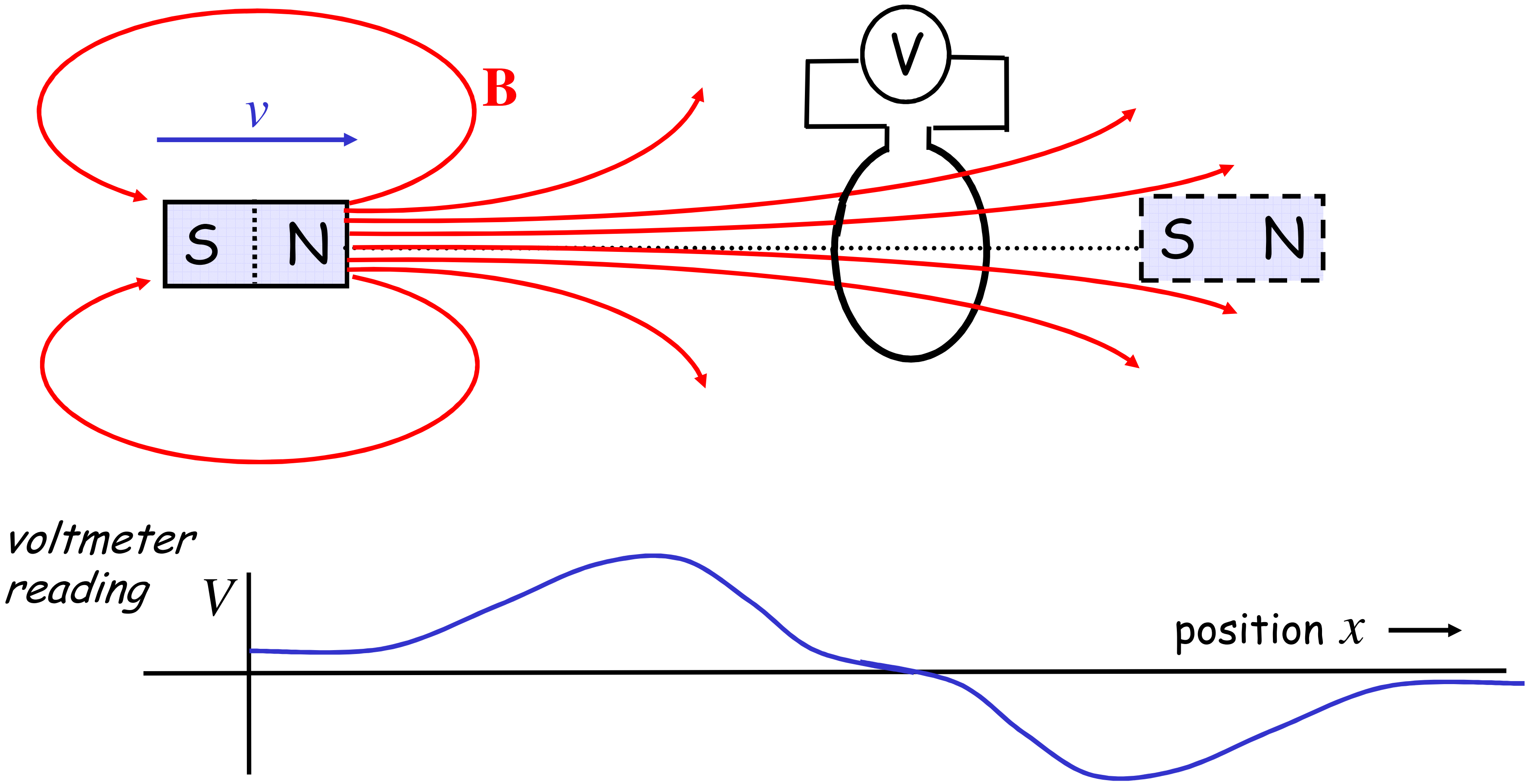
Flux through a surface *S*: $$\Phi_B = \int_S \vec{\mathbf{B}} \cdot \mathbf{d}\vec{\mathbf{A}}$$

*(* **dA** *is the "area vector", perpendicular to the surface.)*

- a *scalar* ; units, 1 $T \cdot m^2$ = 1 weber (Wb)
- represents "number of field lines through *S*"

# Induction

*Move a magnet at constant speed through a coil attached to a voltmeter:*



## Rule (Faraday's Law):

When the *magnetic flux* through a circuit *changes*, the emf induced in the circuit is:

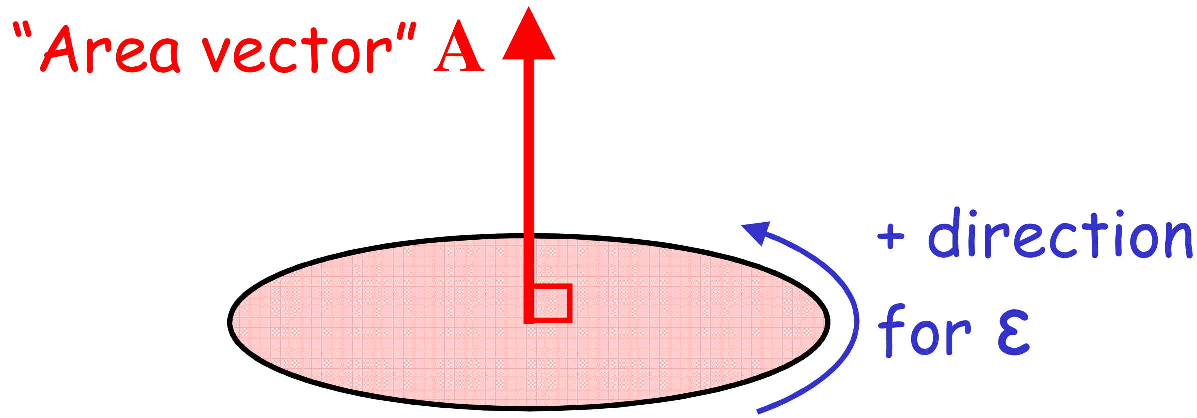
$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

(for a coil with N turns: $\mathcal{E} = -N\frac{d\Phi_B}{dt}$ )

Note $\Phi_B$ changes if:

1) ***B*** changes
2) the area of the circuit changes
3) the orientation of the circuit changes

## The "-" sign:

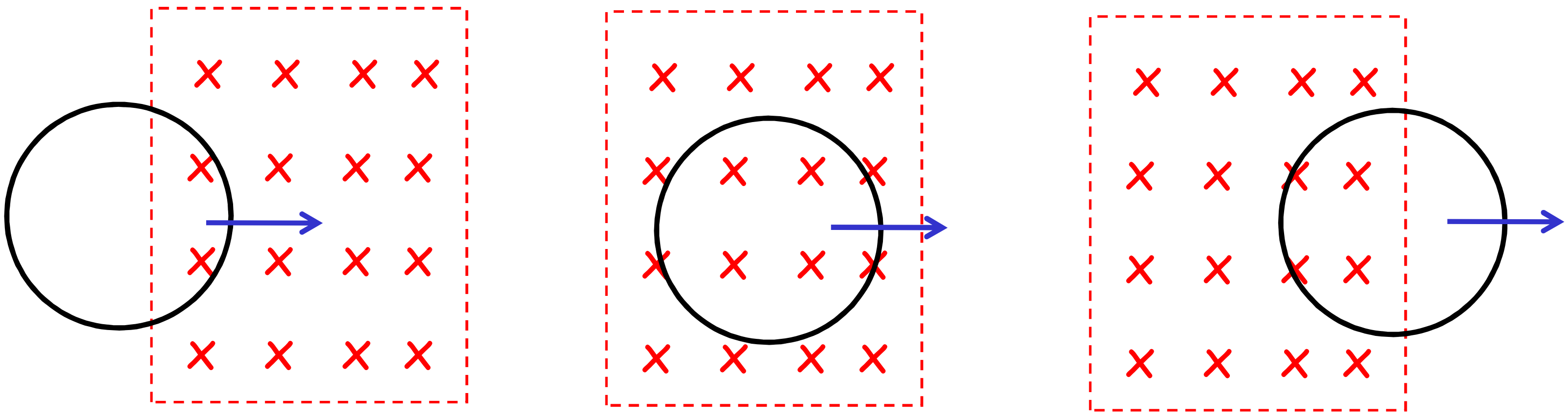



<u>Choose</u> a direction for **A**; then the R.H. rule defines a corresponding "positive" direction for ε.

So,

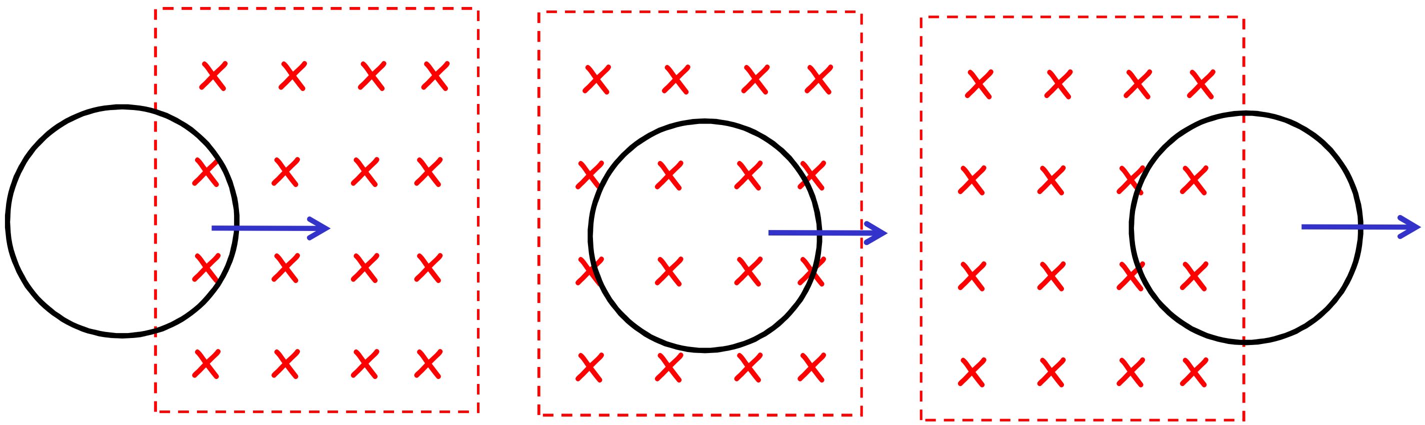
- **B** ↑, and increasing: ε is –ve ↻
- **B** ↑, and decreasing: ε is +ve ↺
- **B** ↓, and increasing: ε is +ve ↺
- **B** ↓, and decreasing: ε is –ve ↻

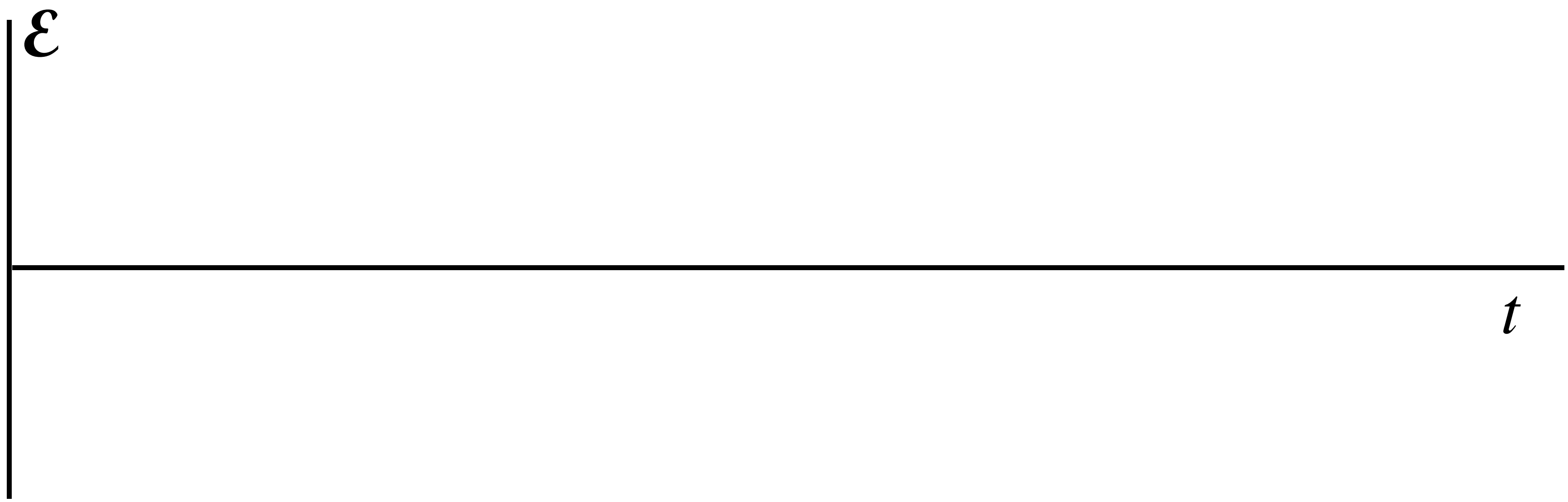
# Quiz



*The circular wire moves at constant speed through the region of magnetic field. The induced emf in the wire during this time*

A) is clockwise
B) is counterclockwise
C) changes from clockwise to counterclockwise
D) changes from counterclockwise to clockwise
E) is zero

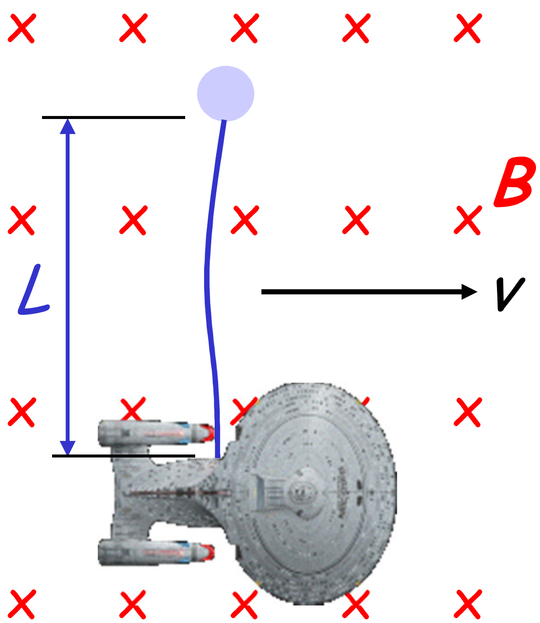




$\mathcal{E}$
$t$

# Motional emf

*eg.,* space shuttle tether experiment (Feb. 1996).




$v$ = 7.5 km/s

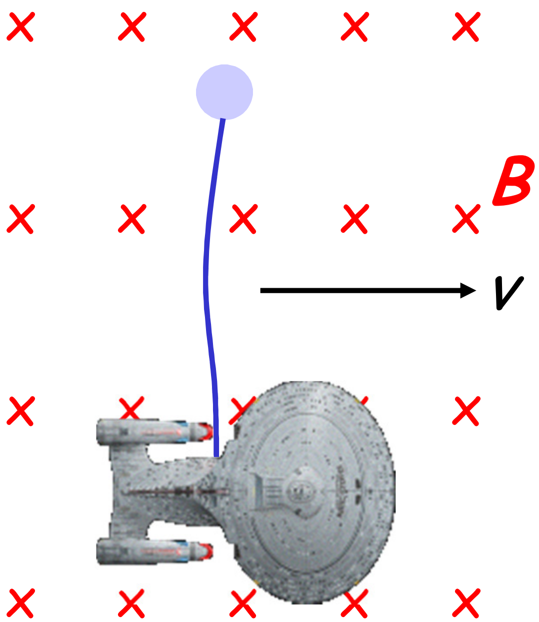
$B$ = 0.5x10$^{-4}$T

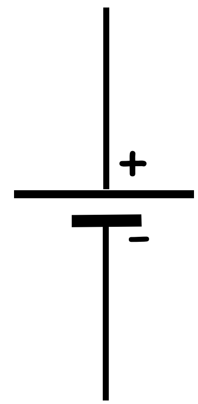
$L$ = 20 km

<u>Find</u>: emf in cable (= V between ends).
Which end is positive?

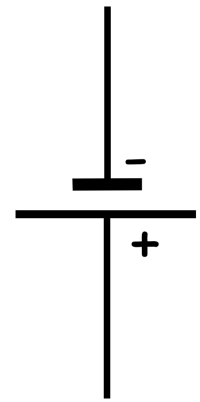
# Quiz

*The shuttle, wire, and sphere act like a battery (the circuit is completed by currents flowing directly through the ionosphere between the shuttle and the sphere) . Which way is the "battery" oriented?*



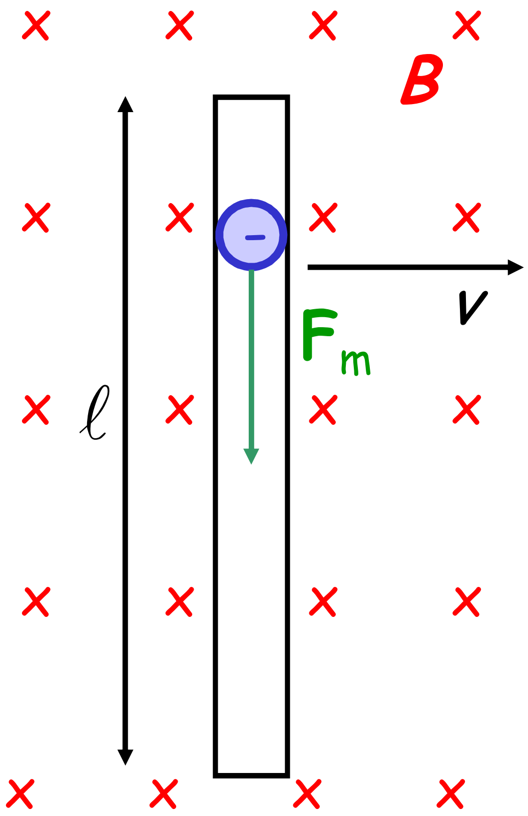

A)




B)

## Conductor moving in uniform ***B*** :

*Force on charge carrier:* $F_m = qvB$



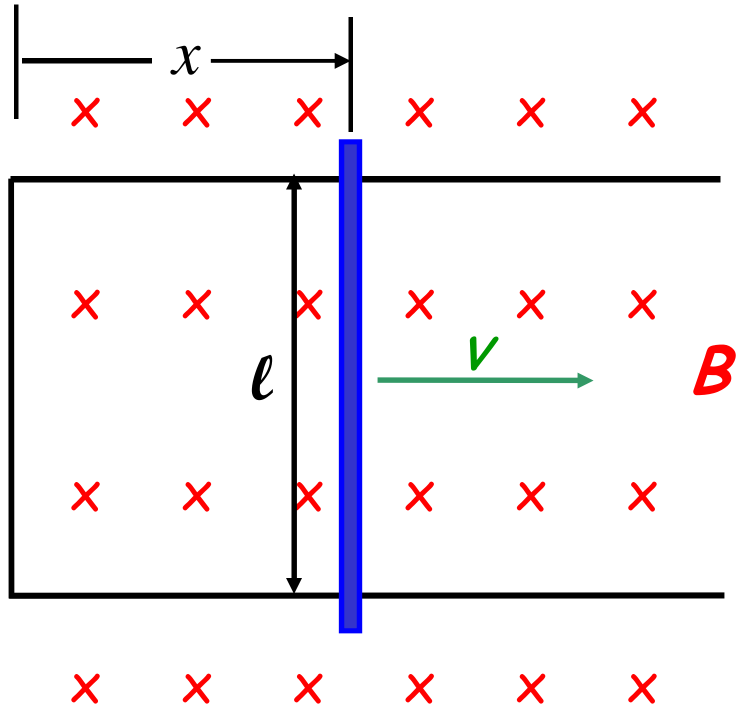

*As the electrons move slowly **along** the conductor, **parallel** to* **F**$_m$*, the work done on each charge is*

$$W = F_m \ell = qvB\ell$$

*The emf (work per unit charge) is*

$$\mathcal{E} = W/q = v\,\ell\,B$$

*(uniform field;* **B**, ***v***, *and length all mutually perpendicular)*

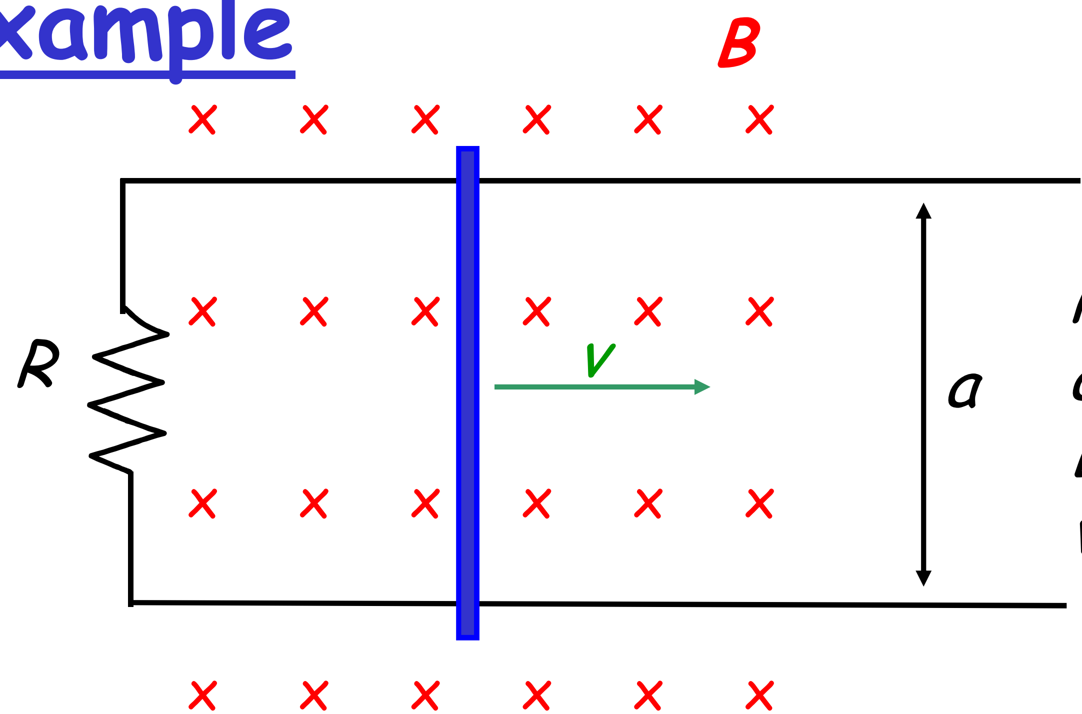



*We can derive the same expression, $\mathcal{E} = B \ell v$, from Faraday's Law, if we keep track of a complete circuit. Consider a conducting bar sliding along a a U-shaped conductor as shown.*

Flux enclosed by circuit = $B \ell x$

$$\varepsilon = -\frac{d\Phi}{dt}$$

# Example

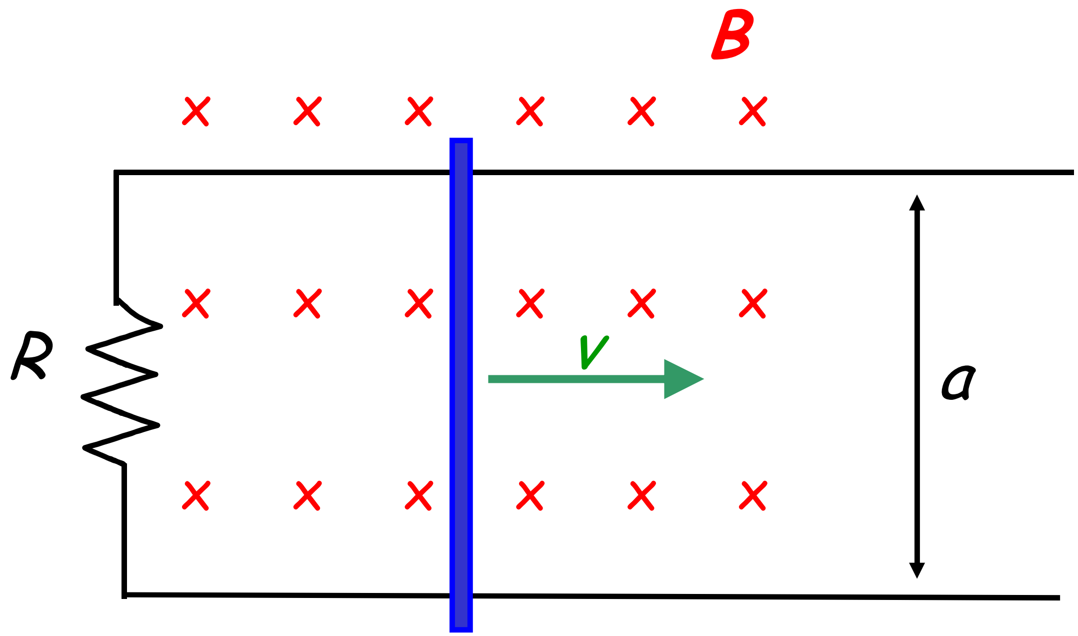



$R = 5\Omega$
$a = 25\text{cm}$
$B = 2\text{T}$
$v = 3\text{m/s}$

Find:

i) emf
ii) current
iii) force to keep bar moving
iv) power to keep bar moving

# Quiz




The *magnetic* force on the bar will be:

A) up the page
B) down the page
C) left
D) right
E) zero.

# Quiz

*A circuit of area A is made from a single loop of wire connected to a resistor of resistance R. It is placed in a uniform external field B (at right angles to the plane of the circuit). B is reduced uniformly to zero in time $\Delta t$. The **total charge** which flows through the resistor is:*

A) independent of $\Delta t$
B) proportional to $\Delta t$
C) inversely proportional to $\Delta t$
D) zero

# Summary

## Faraday's Law:

A changing magnetic flux induces an emf in a circuit:

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

## Moving Conductor:

The induced emf in a straight conductor moving through a uniform field is equal to $BLv$, if $\mathbf{B}$, $\mathbf{L}$, and $\mathbf{v}$ are all mutually perpendicular.