CHAPTER 22

FARADAY'S LAW

MAXWELL'S EQUATIONS

Equation	Name	Explanation
$\oint \vec{E} \cdot \hat{n} dA = \frac{1}{\epsilon_0} \sum q_{\text{inside}}$	Gauss's Law for Electricity	• How charges produce electric fields • Used to derive Coulomb's Law
$\oint \vec{B} \cdot \hat{n} dA = 0$	Gauss's Law for Magnetism	• No magnetic monopoles • Constrains shape of magnetic field ("curly")
$\oint \vec{E} \cdot d\vec{l} = 0$	Faraday's Law	• Constrains shape of electric field (radially outward, cannot be "curly")
$\oint \vec{B} \cdot d\vec{l} = \mu_0 \sum I_{\text{inside}}$	Ampere's Law	• How currents produce magnetic fields • Used to derive Biot-Savart Law

MAXWELL'S EQUATIONS

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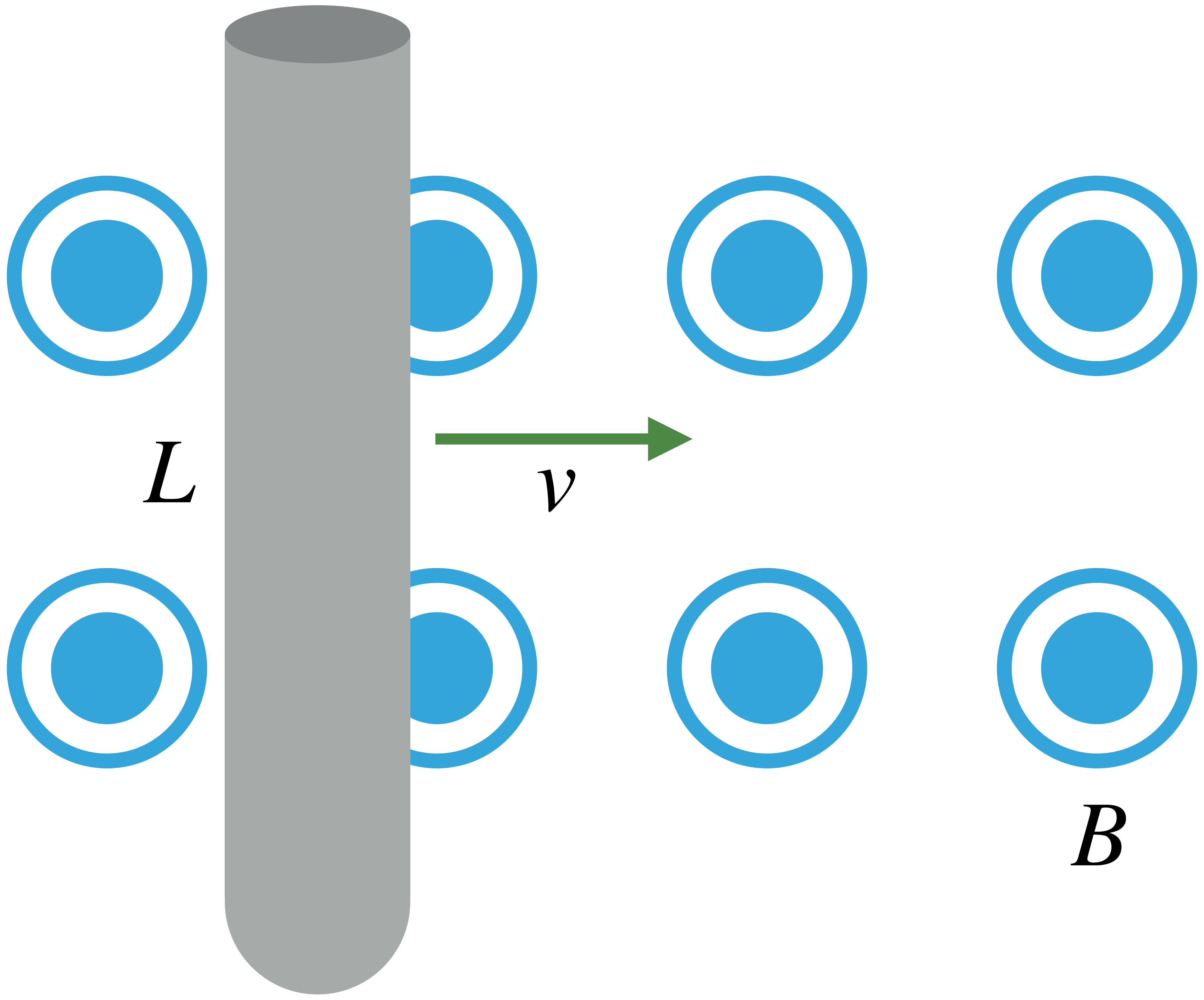
FARADAY'S LAW

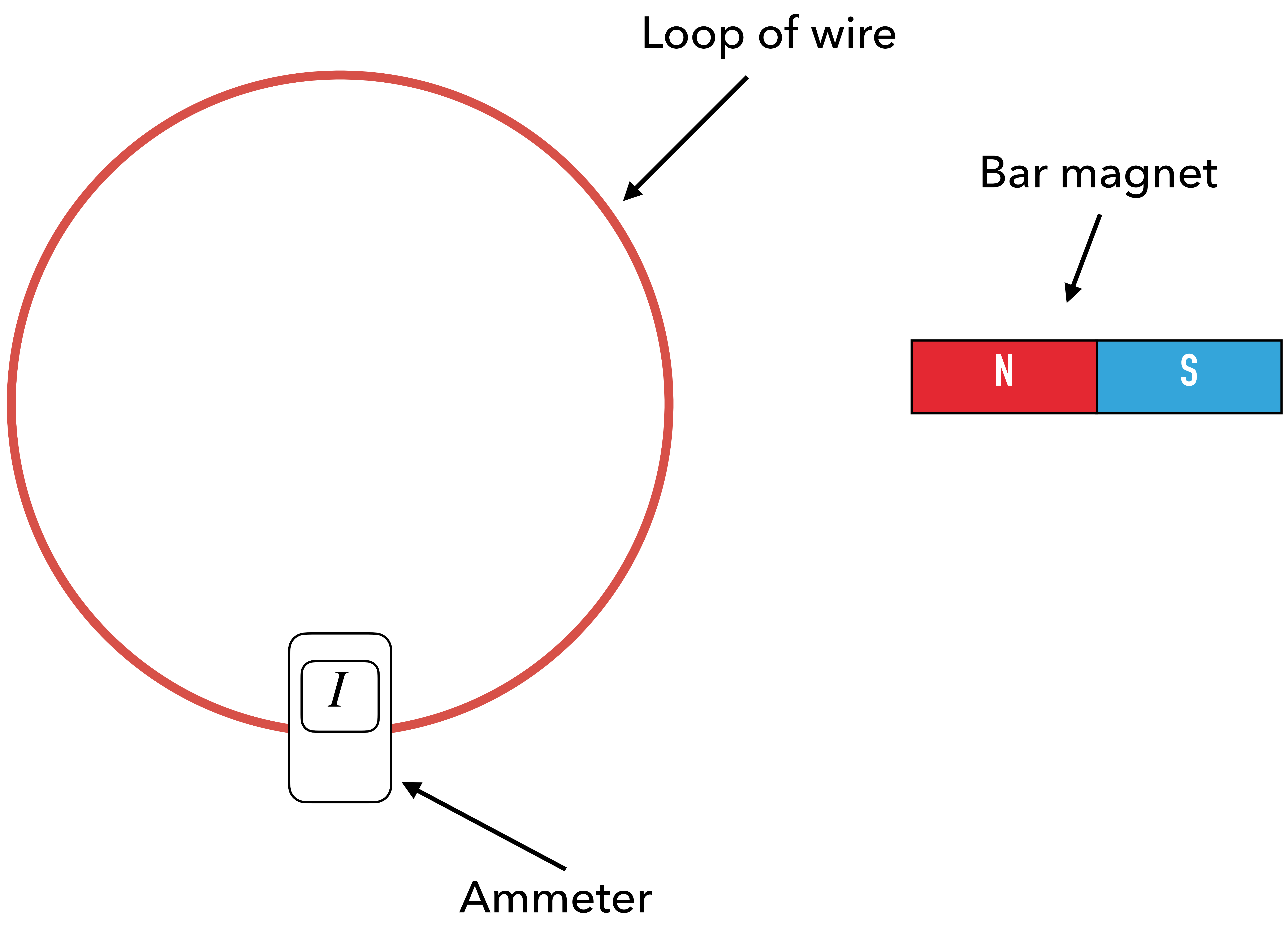
- Recall from chapter 20: motion relative to a magnetic field produces an emf
    - Motional emf
    - $\varepsilon = BLv$



QUESTION

- How do electric charges respond to a *changing* magnetic field?

AN EXPERIMENT



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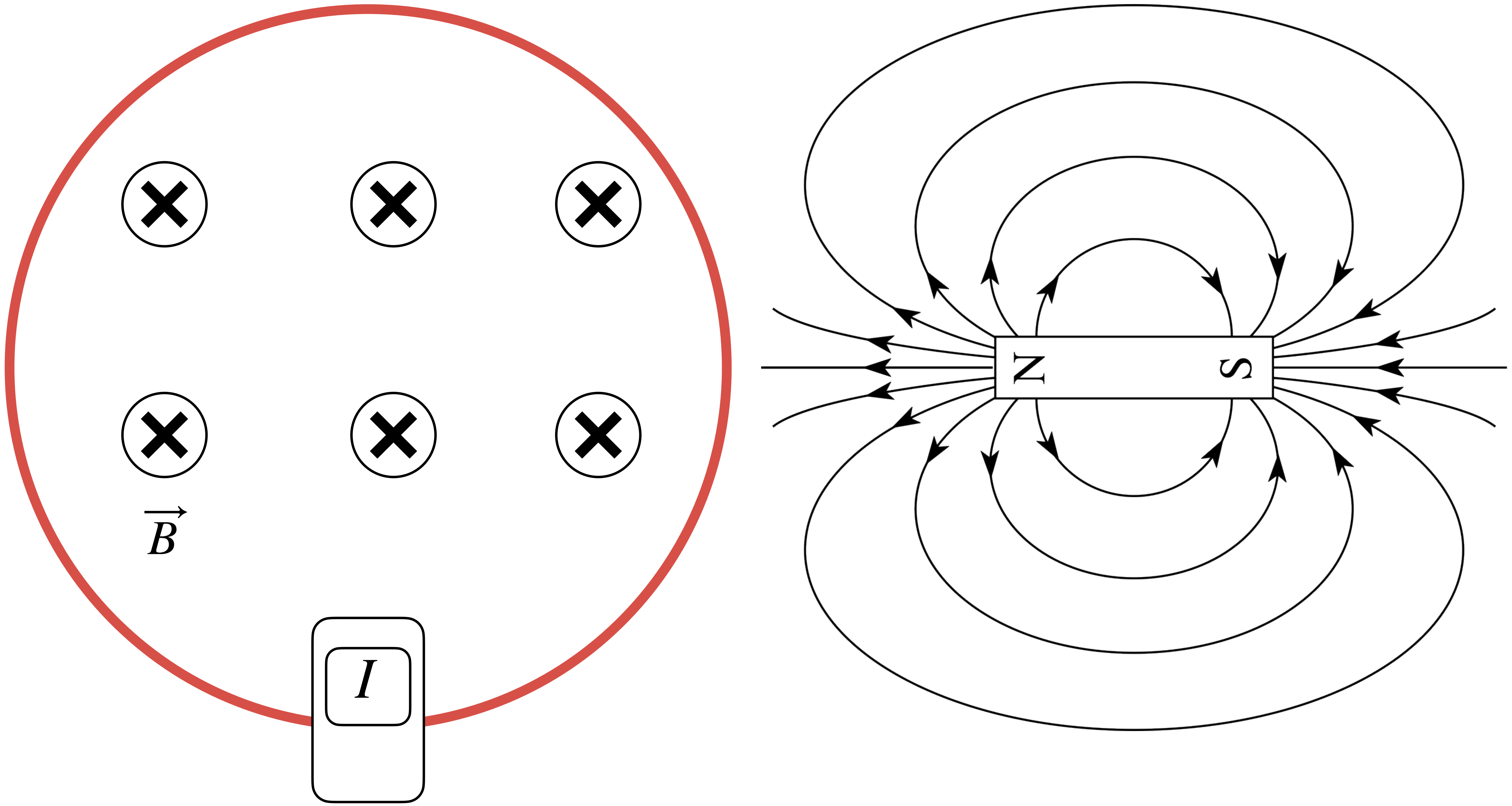

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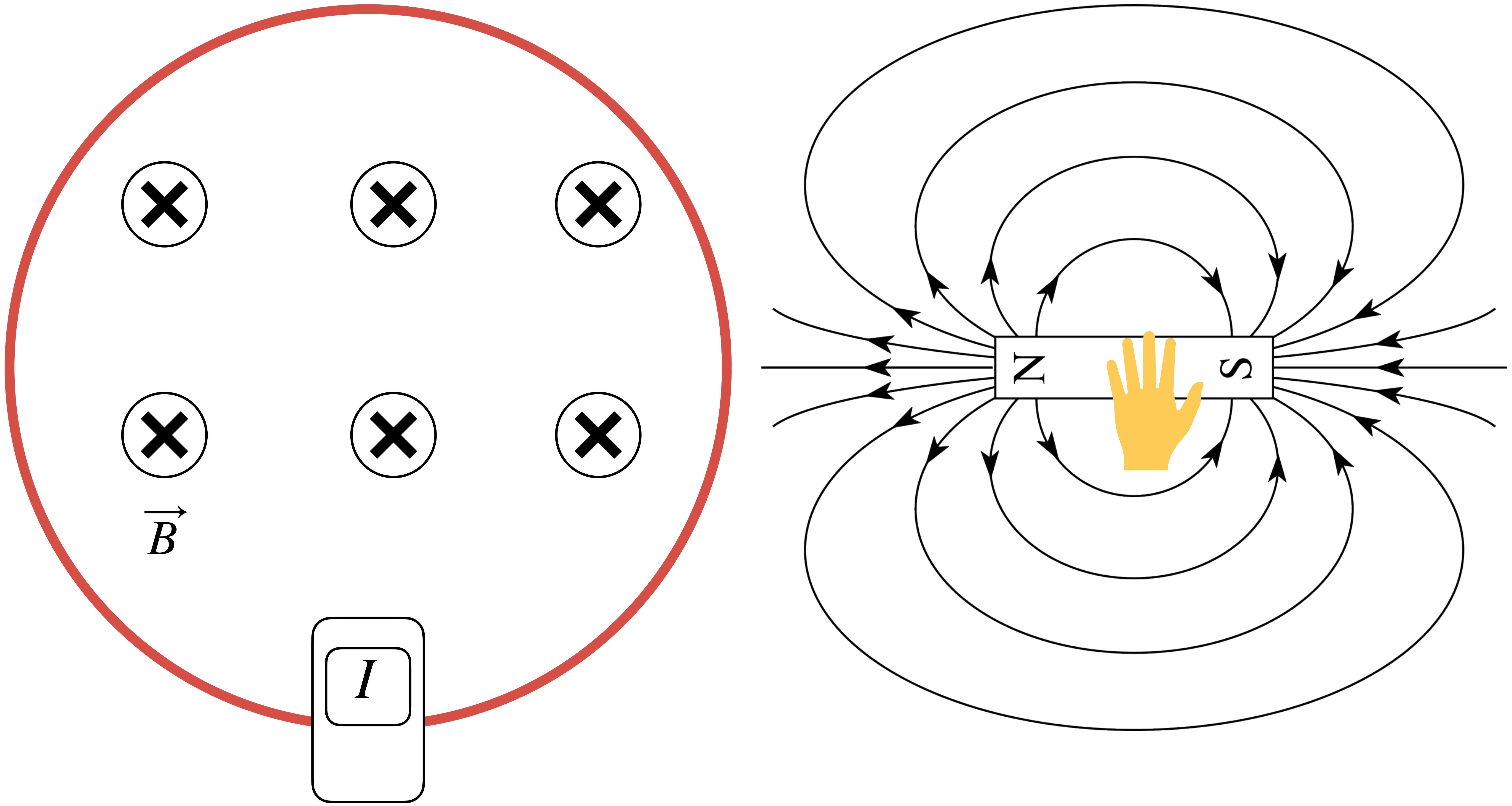

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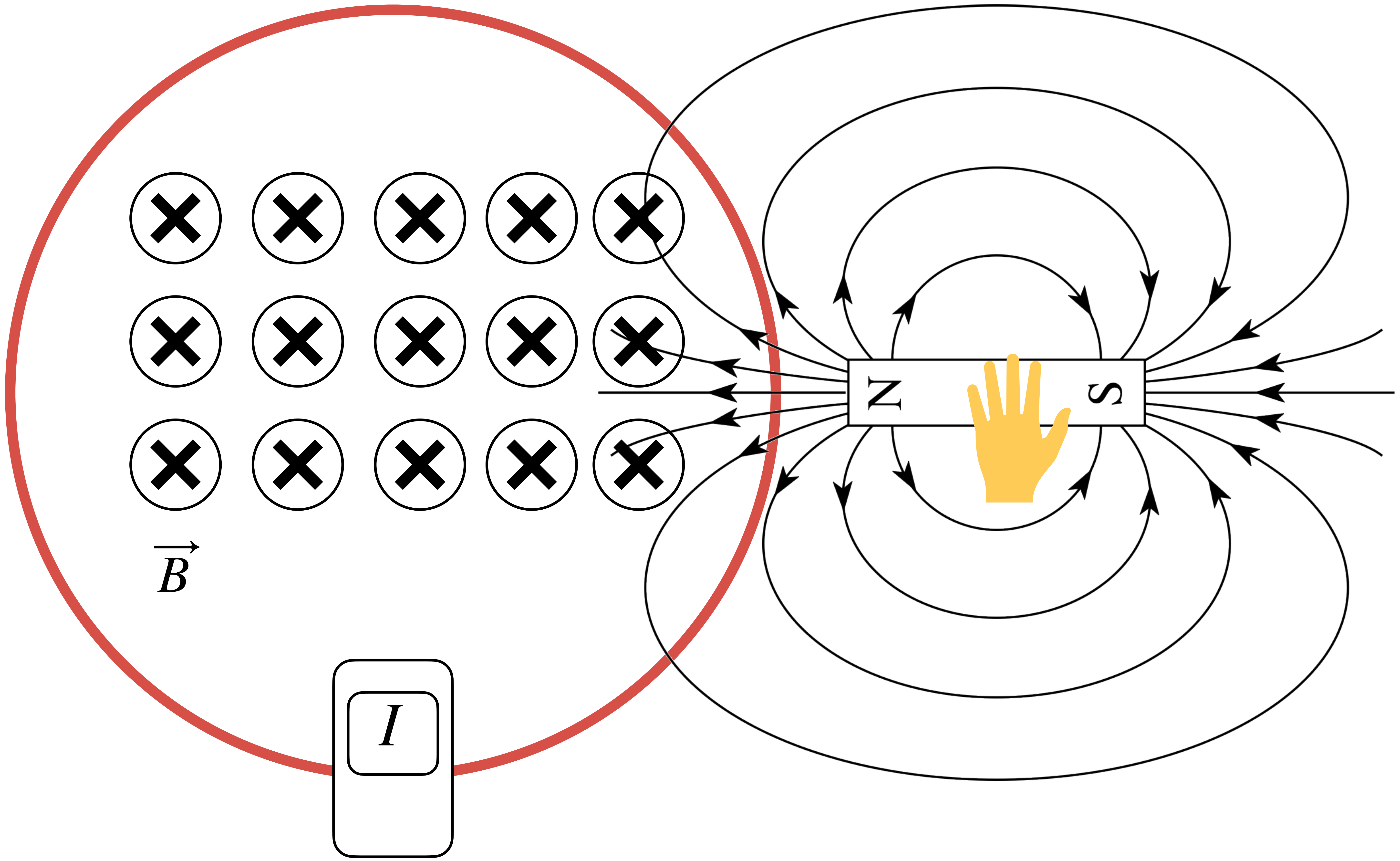

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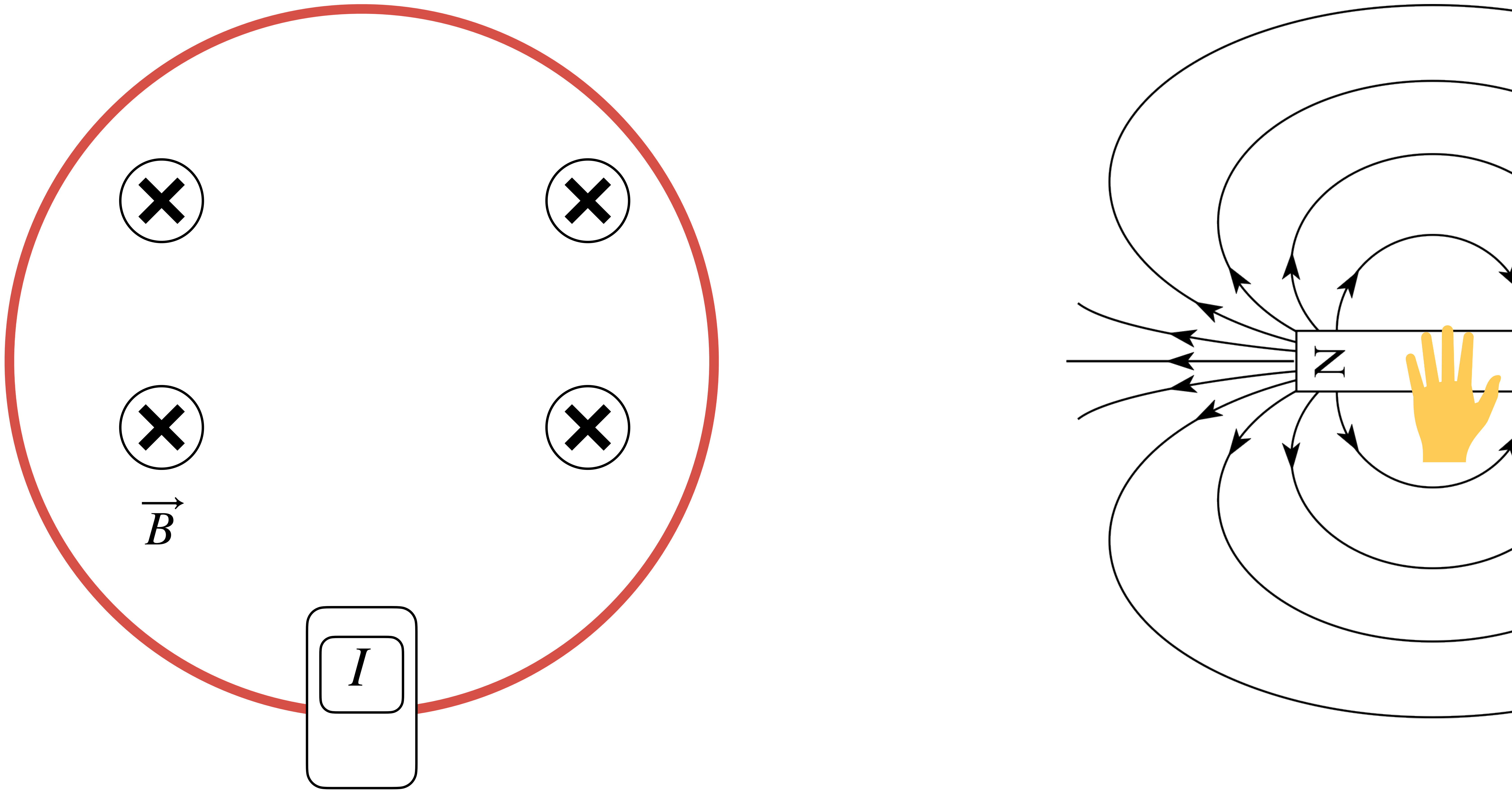

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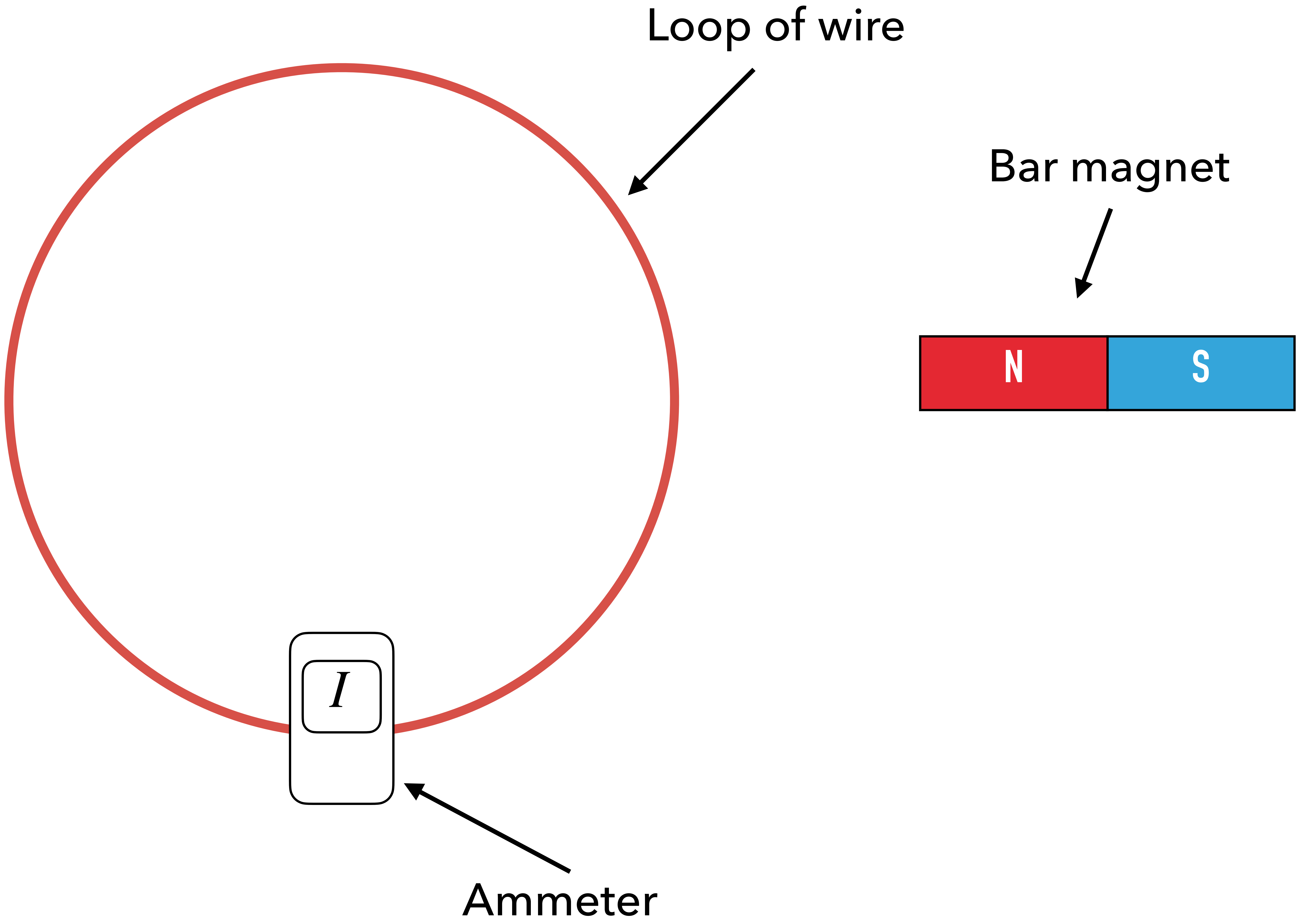
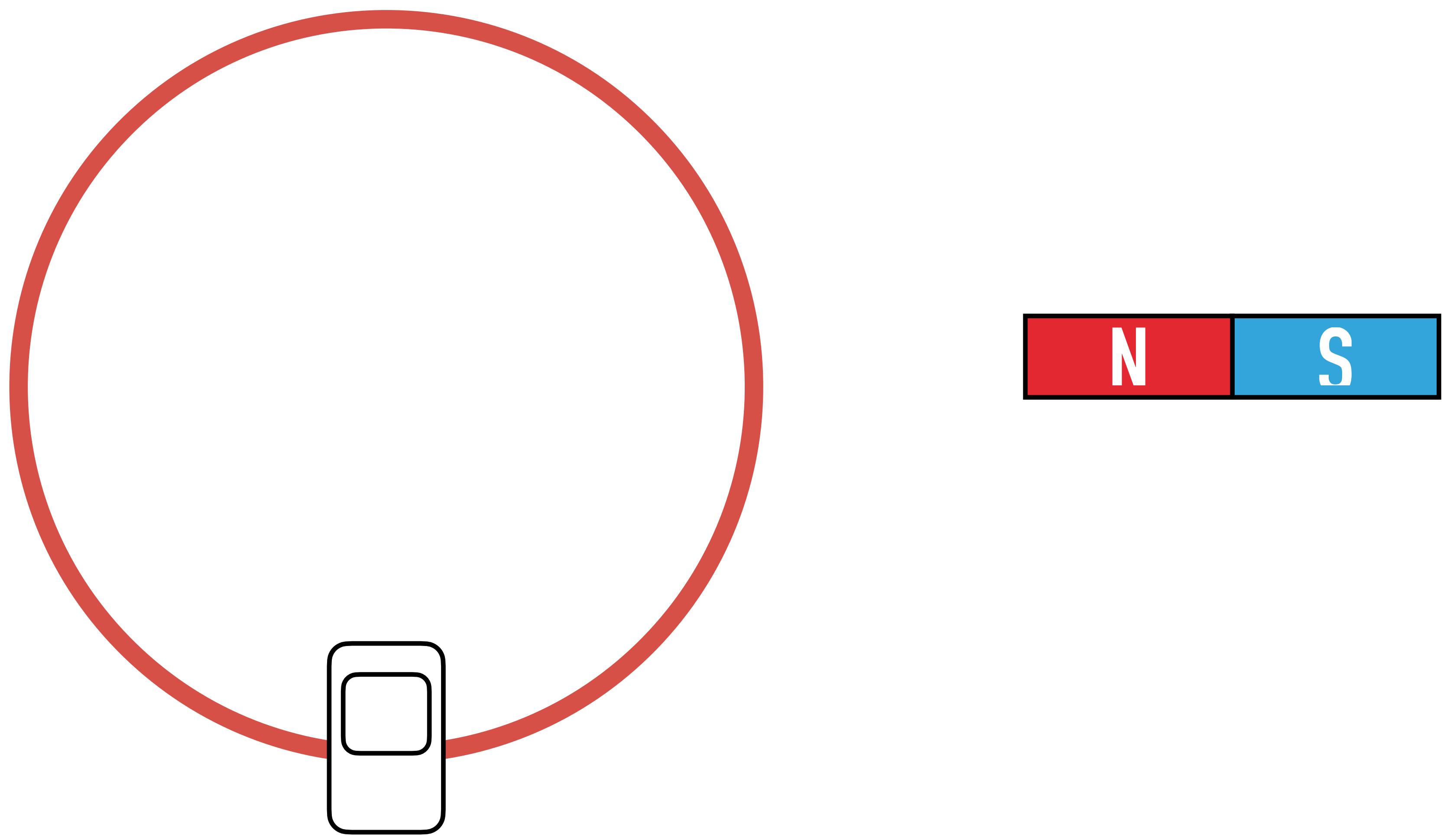


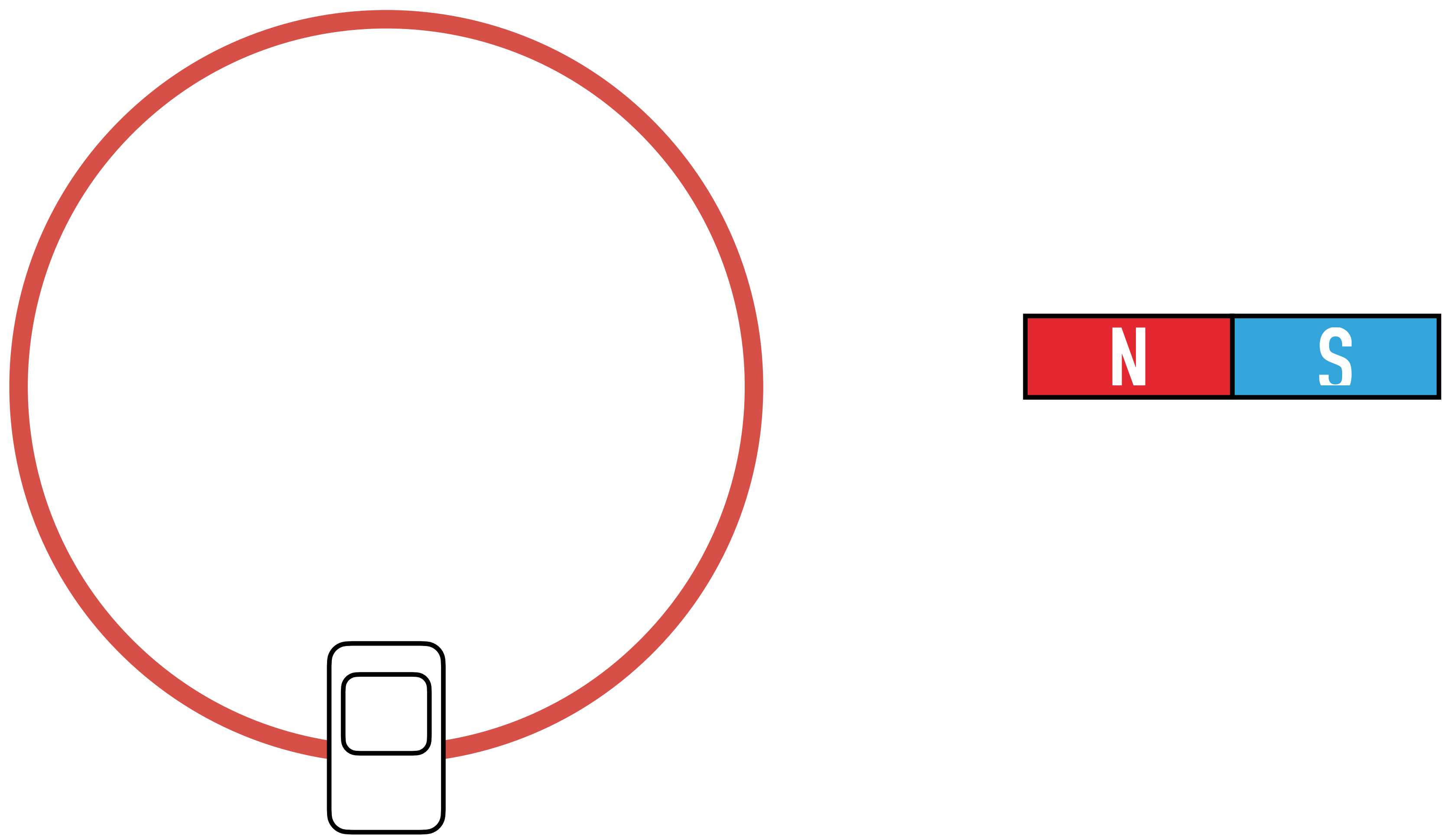
OBSERVATIONS

1. **A changing magnetic field causes a current!**



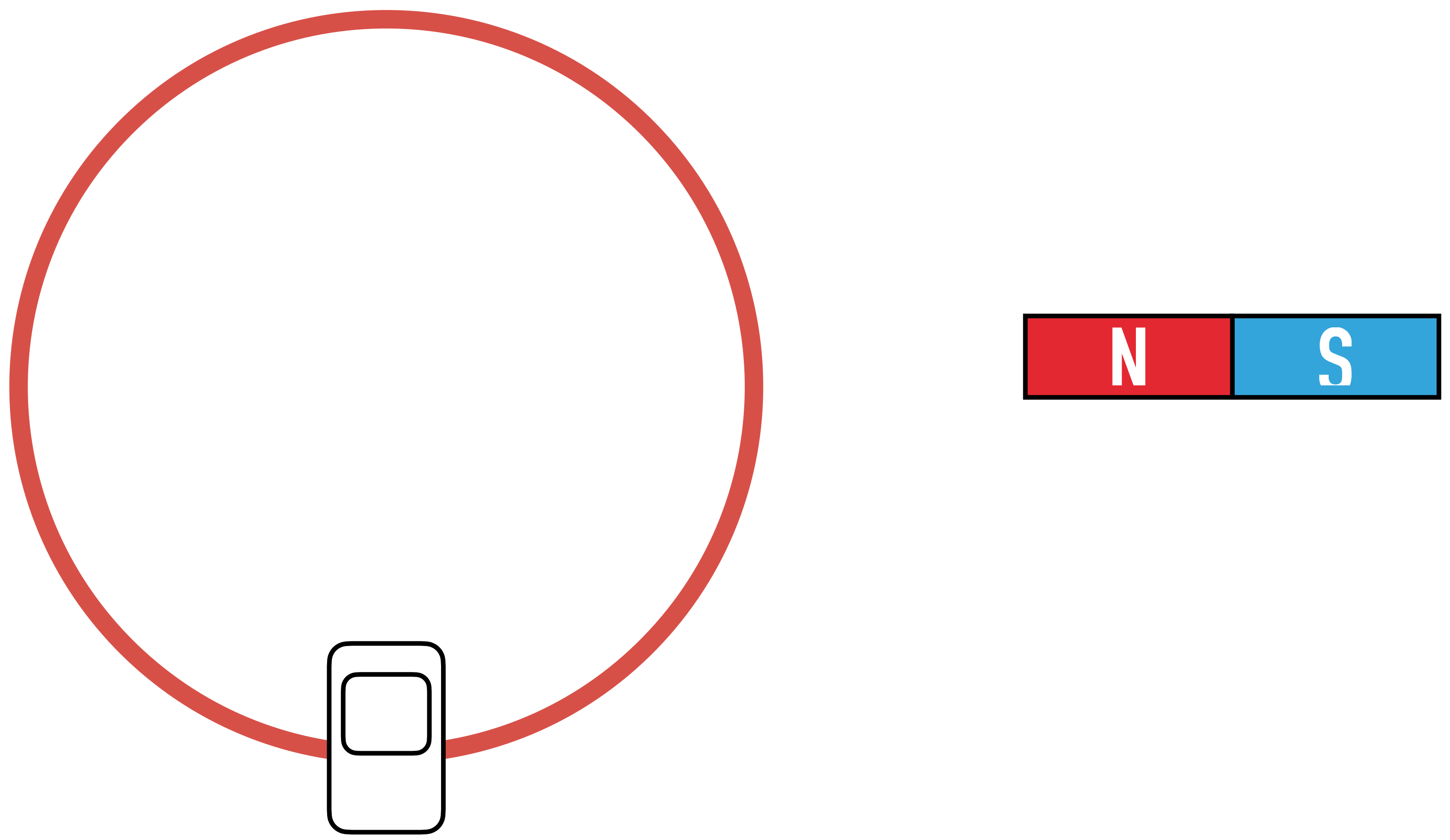
OBSERVATIONS

1. **A changing magnetic field causes a current!**
2. Unchanging magnetic field –> no current



OBSERVATIONS

1. **A changing magnetic field causes a current!**
2. Unchanging magnetic field –> no current
3. Faster motion causes a larger current



OBSERVATIONS

1. **A changing magnetic field causes a current!**

2. Unchanging magnetic field –> no current

3. Faster motion causes a larger current

4. Direction of current depends on direction of motion of magnet (and orientation!)

INDUCED EMF

- Current is caused by an emf in the wire
- Emf is caused by changing magnetic field

WHAT CAUSES THE EMF?

- Magnetic field *cannot do work*
- What is causing the charges in the wire to accelerate?

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- Magnetic field *cannot do work*
- What is causing the charges in the wire to accelerate?
  - It must be an *electric field*

CONCLUSION

A changing magnetic field creates an electric field!

QUANTIFYING THE RELATIONSHIP

- Changing magnetic field produces a curly electric field
- Curly electric field drives an emf ε in a loop of wire
- How is ε related to $\dfrac{dB}{dt}$?

OBSERVATIONS

Magnitude of induced emf in loop depends on:

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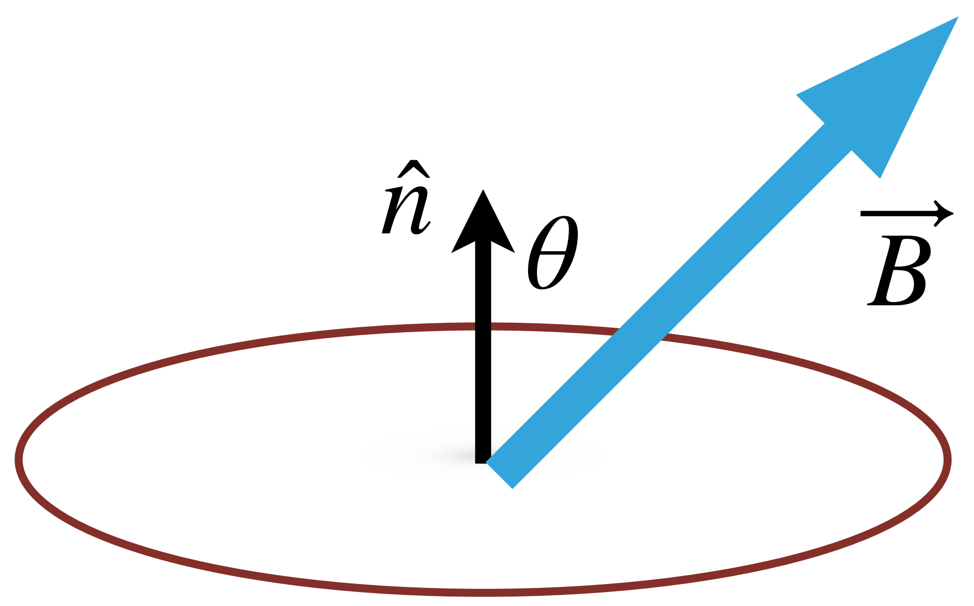
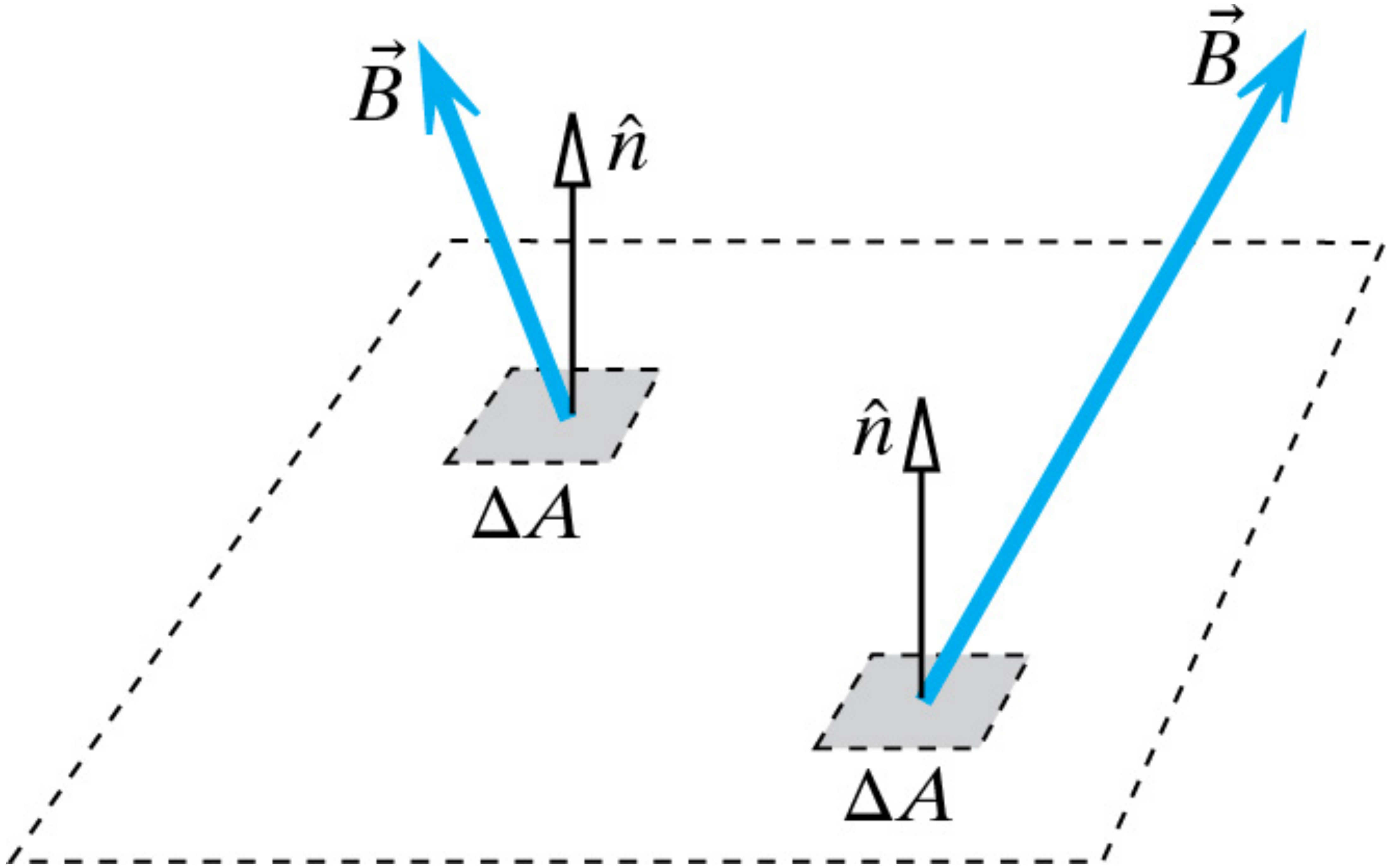
Magnitude of induced emf in loop depends on:

1. Rate of change of magnetic field (higher $\frac{dB}{dt} \rightarrow$ higher ε)
2. Area of loop (larger area $\rightarrow$ larger ε)
3. Angle of magnetic field through loop ($\varepsilon \propto \cos\theta$)



MAGNETIC FLUX

$$\phi_B = \sum \overrightarrow{B} \cdot \hat{n} \Delta A \rightarrow \int \overrightarrow{B} \cdot \hat{n} dA$$

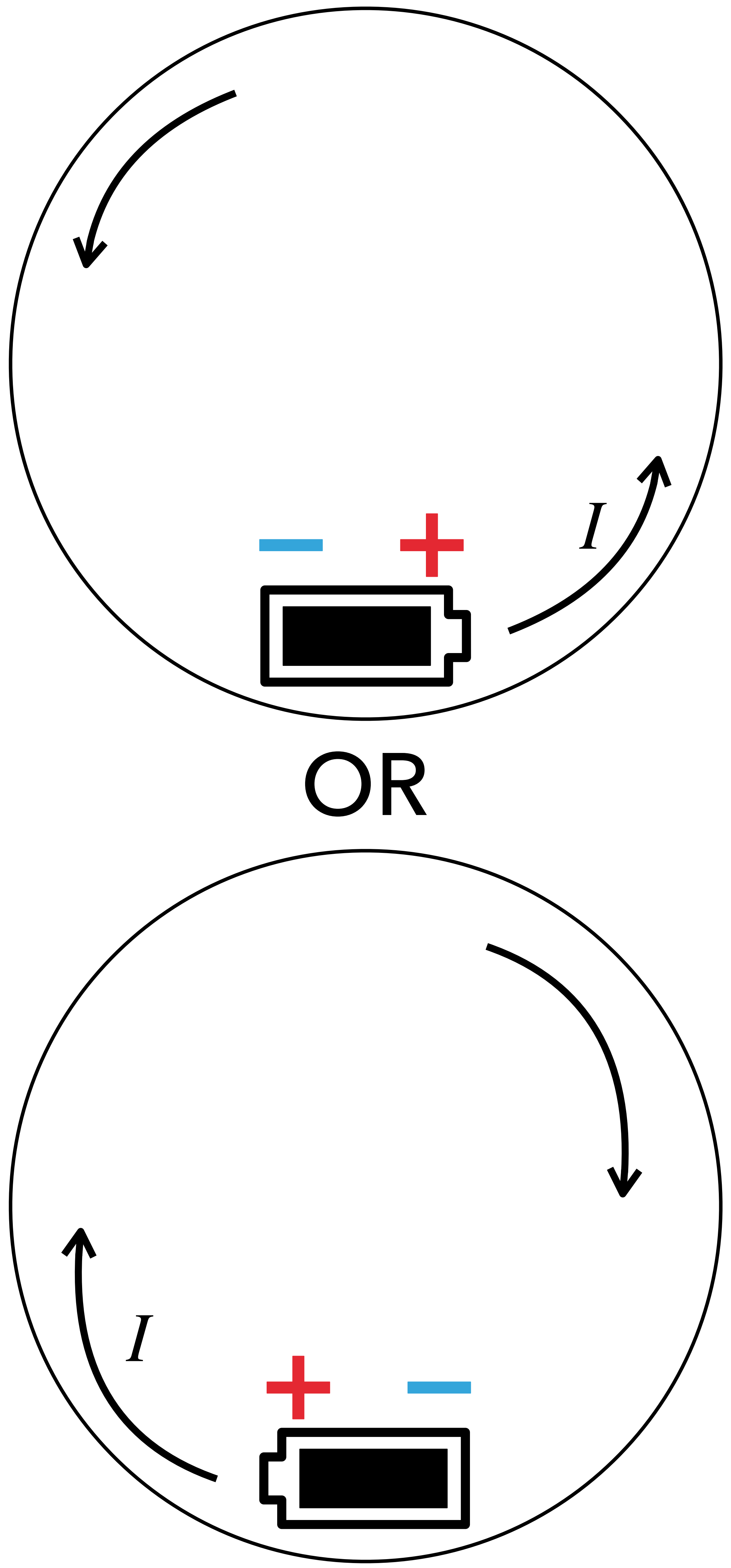


FARADAY'S LAW

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

THE SIGN (POLARITY) OF THE EMF

- How to determine the polarity of the induced emf?



FARADAY'S LAW (FORMAL VERSION)

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt}\int \vec{B} \cdot \hat{n} dA$$

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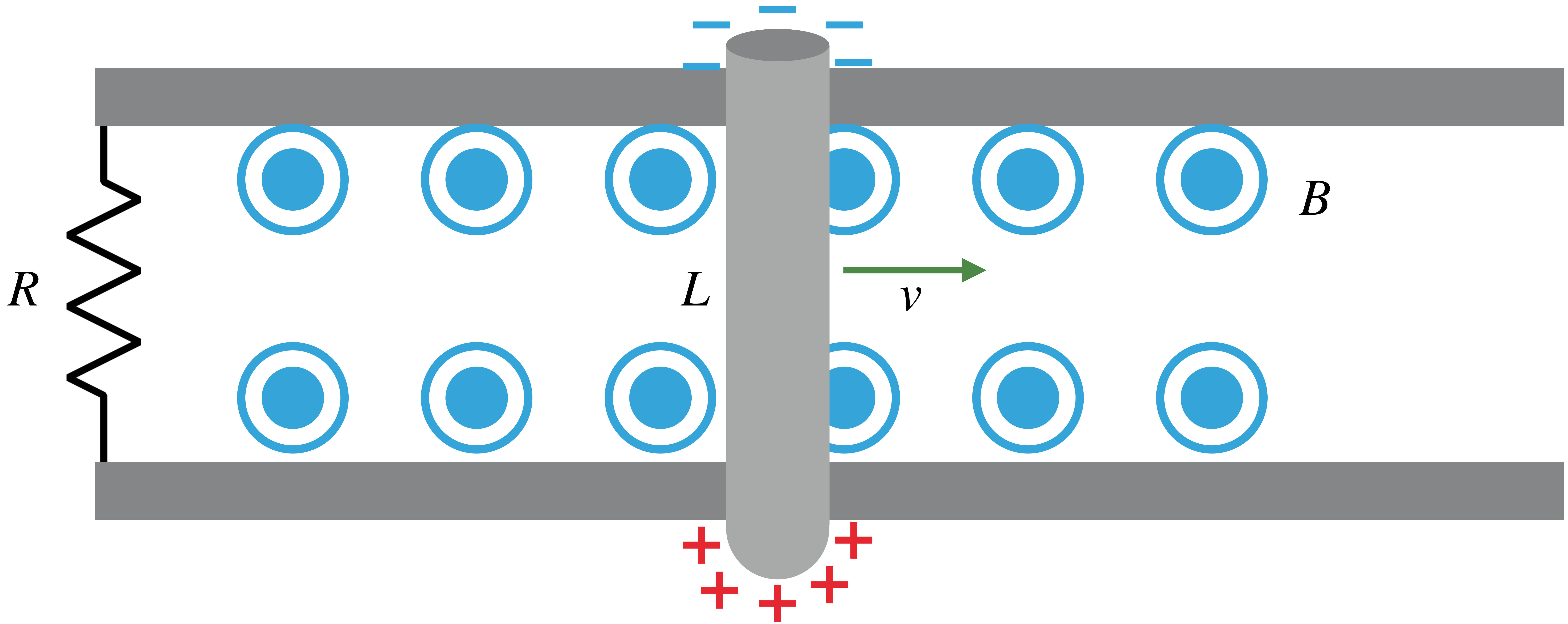
$\oint \vec{E} \cdot d\vec{l} = -\int \vec{B} \cdot \hat{n} dA$	Faraday's Law ✓	‣ **Curly electric field produced by time-varying magnetic field**
$\oint \vec{B} \cdot d\vec{l} = \mu_0 \sum I_{\text{inside}}$	Ampere's Law *	‣ How currents produce magnetic fields ‣ Used to derive Biot-Savart Law

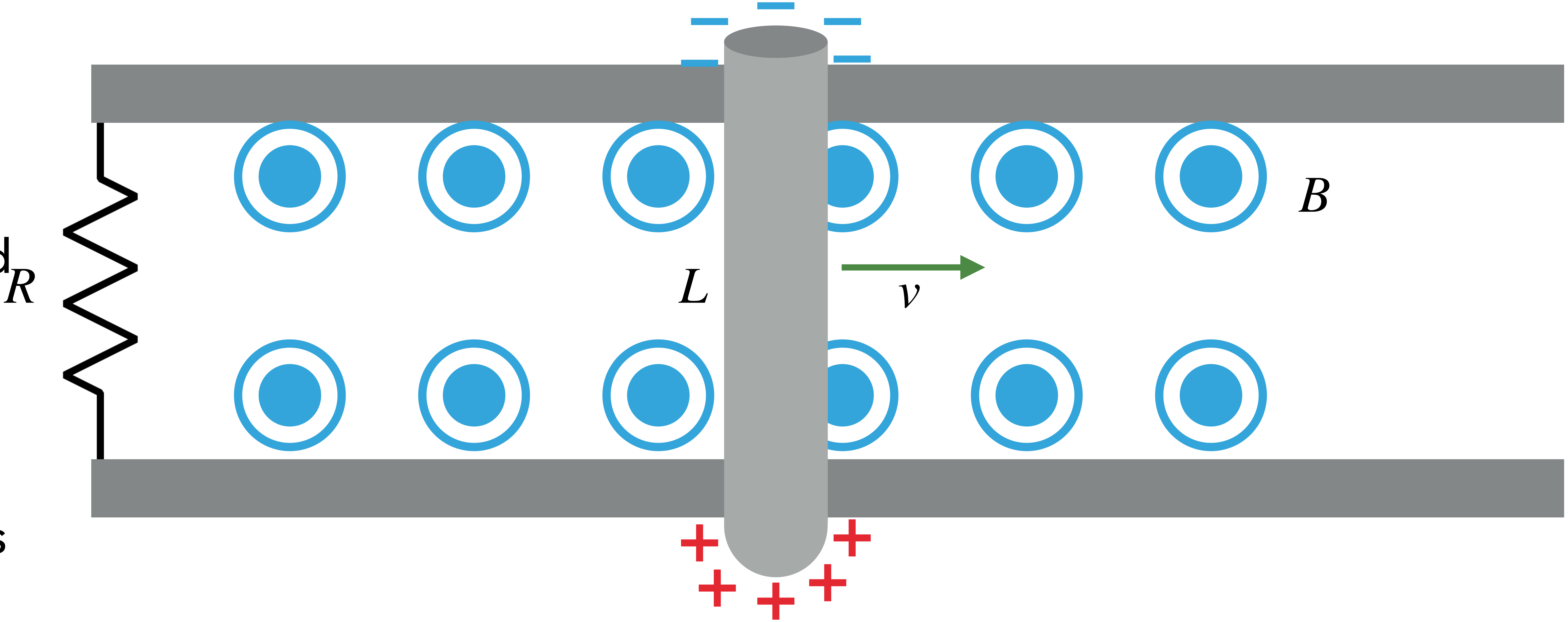
FARADAY'S LAW AND MOTIONAL EMF

- Recall: conducting bar sliding in presence of magnetic field
- $\varepsilon = BLv$



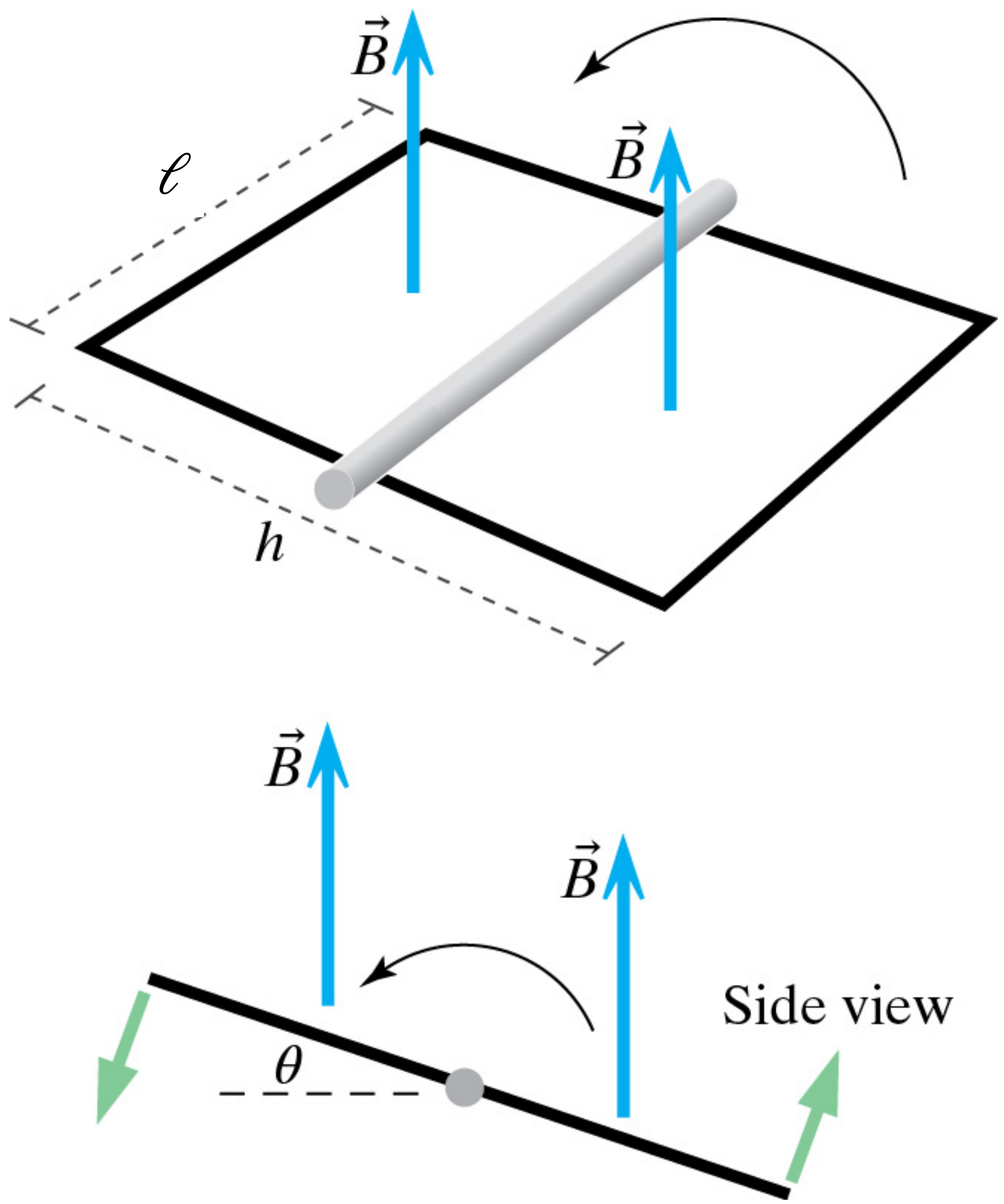
FARADAY'S LAW AND MOTIONAL EMF

- Recall: conducting bar sliding in presence of magnetic field
- $\varepsilon = BLv$
- Can derive with Faraday's Law

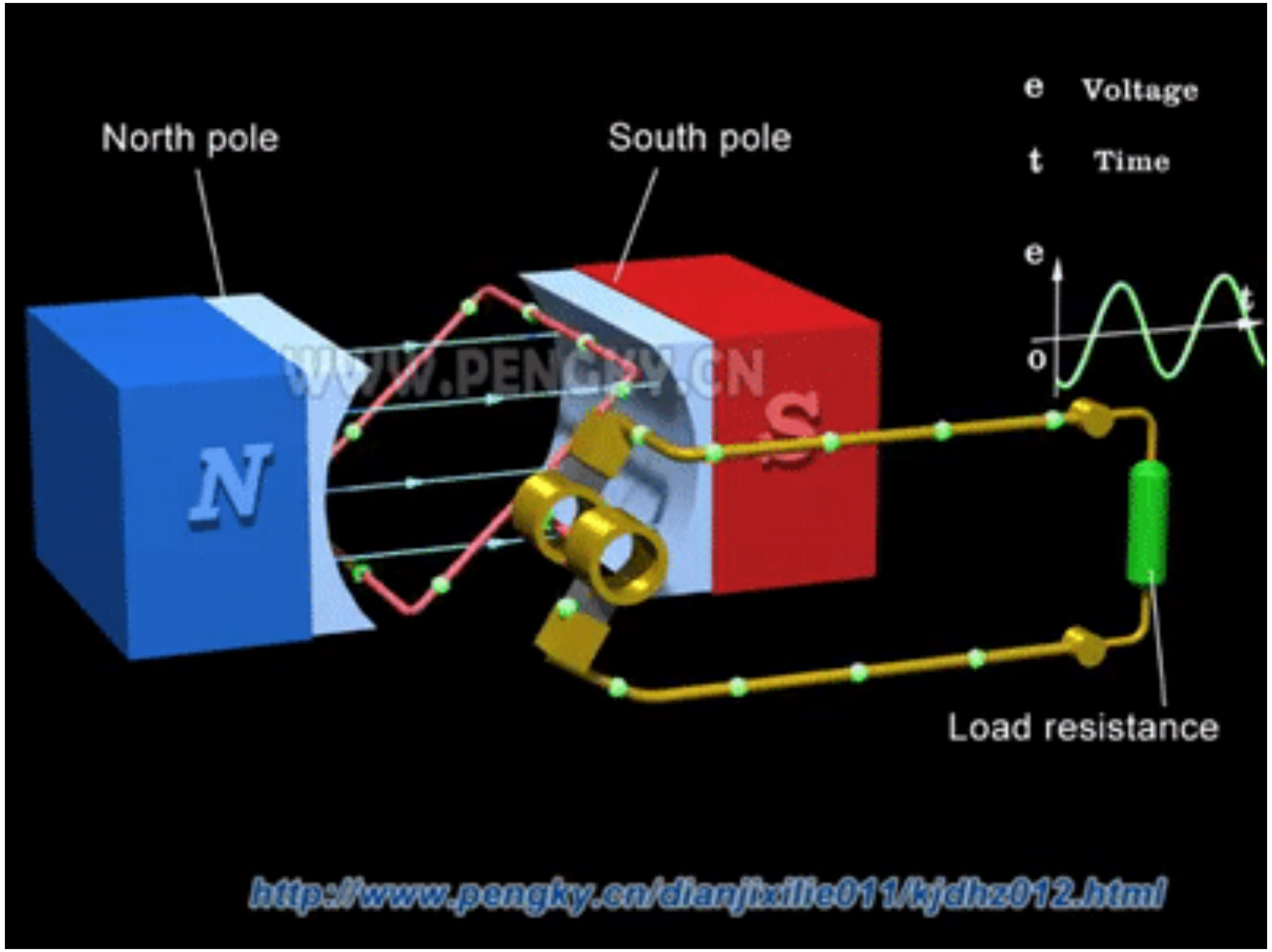


EXAMPLE

- Rotating loop of wire in presence of steady magnetic field
- Rotating at constant angular speed $\omega = \dfrac{d\theta}{dt}$



GENERATORS


North pole
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GENERATORS