# Chapter 29 – Electromagnetic Induction

Induction is critical to modern industrial life. It is the basis of generators and many motors. Without it light would not exist and thus life would not exist.

# Goals for Chapter 28

- Study the magnetic field generated by a moving charge
- Consider magnetic field of a current-carrying conductor
- Examine the magnetic field of a long, straight, current-carrying conductor
- Study the magnetic force between current-carrying conductors
- Consider the magnetic field of a current loop
- Examine and use Ampere’s Law

# Goals for Chapter 29

- Faraday’s Law
- Lenz’s Law
- Motional emf
- Induced electric fields
- Maxwell’s equations and see their application to displacement current

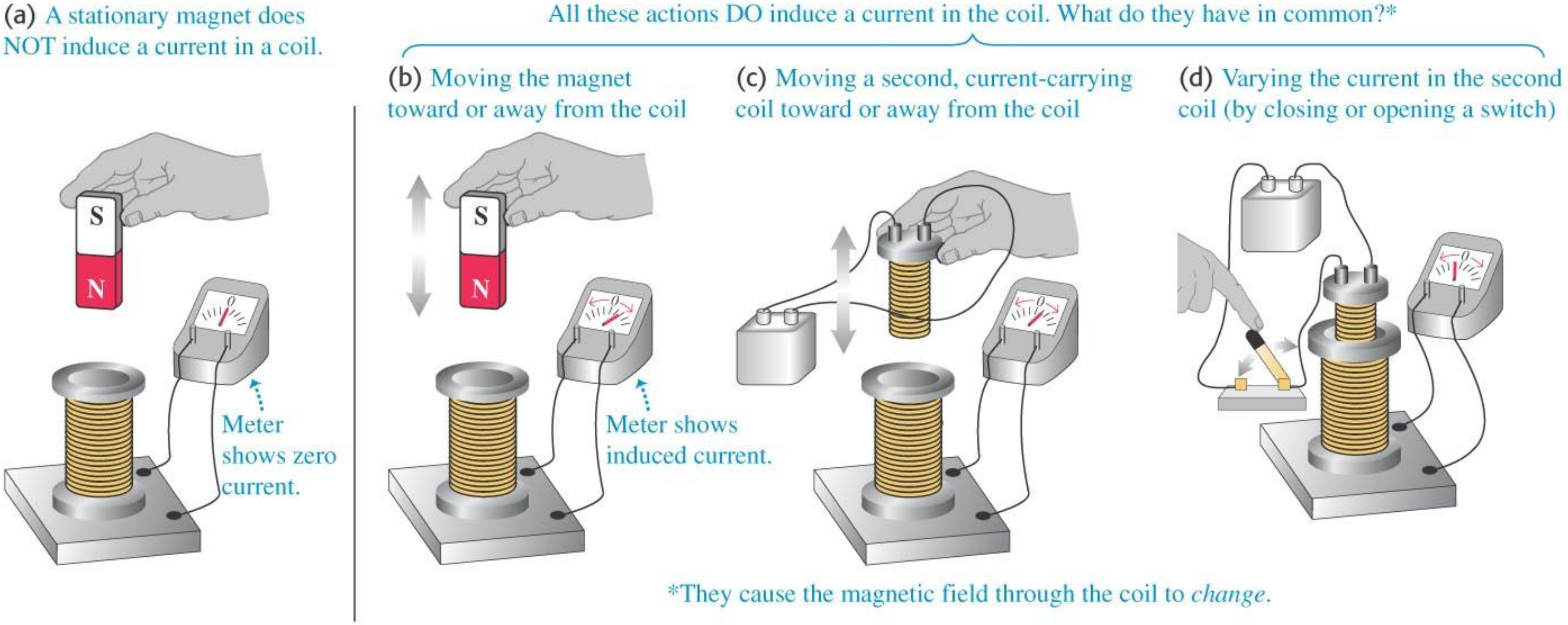
# Introduction

– The motion of a magnet can induce current in practical ways. If a credit card has a magnet strip on its back, “swiping” the card can generate tiny currents that send information to cash registers.


– A coil of wire and magnets set into motion around each other will generate currents in the wire. A source of mechanical energy can drive the rotation and make a waterfall into an electrical power station.

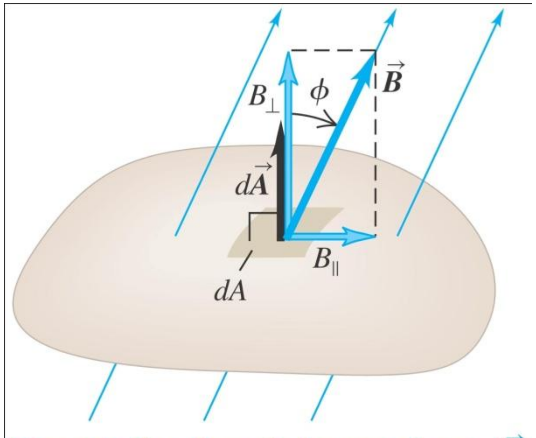
# Induced current

– Joseph Henry worked in the United States and Michael Faraday worked in England to discern the details of current generated in wire and permanent magnets in motion relative to each other.



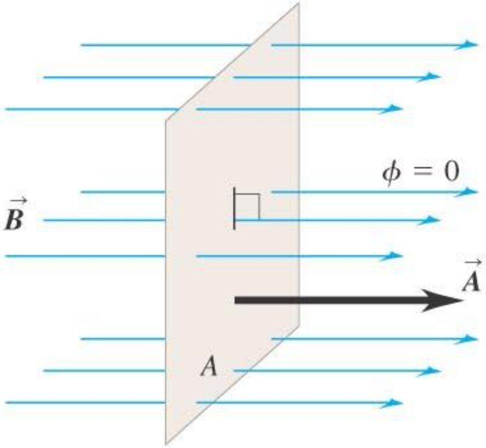
# Knowing the magnetic flux

– Regardless of what moves, knowing the magnetic flux around a conducting entity will allow determination of current induced.

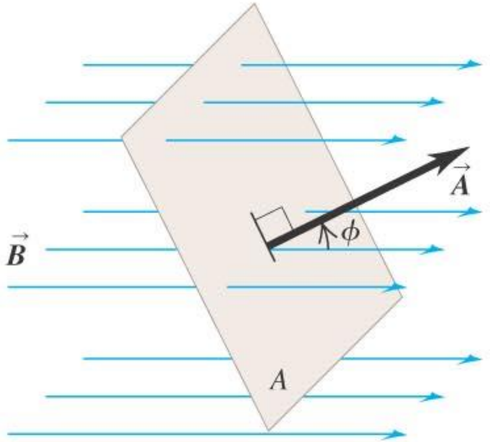



Magnetic flux through element of area $d\vec{A}$:
$d\Phi_B = \vec{B} \cdot d\vec{A} = B_\perp dA = B\, dA \cos\phi$

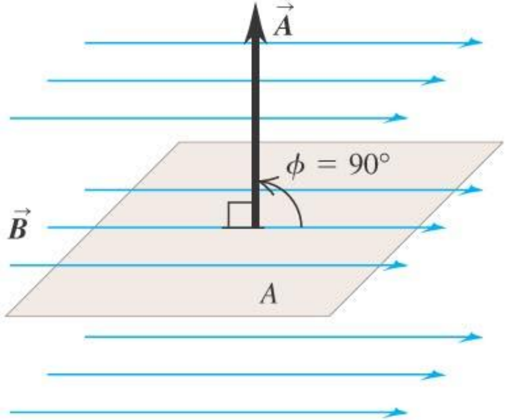
Surface is face-on to magnetic field:
- $\vec{B}$ and $\vec{A}$ are parallel (the angle between $\vec{B}$ and $\vec{A}$ is $\phi = 0$).
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA$.




Surface is tilted from a face-on orientation by an angle $\phi$:
- The angle between $\vec{B}$ and $\vec{A}$ is $\phi$.
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos\phi$.

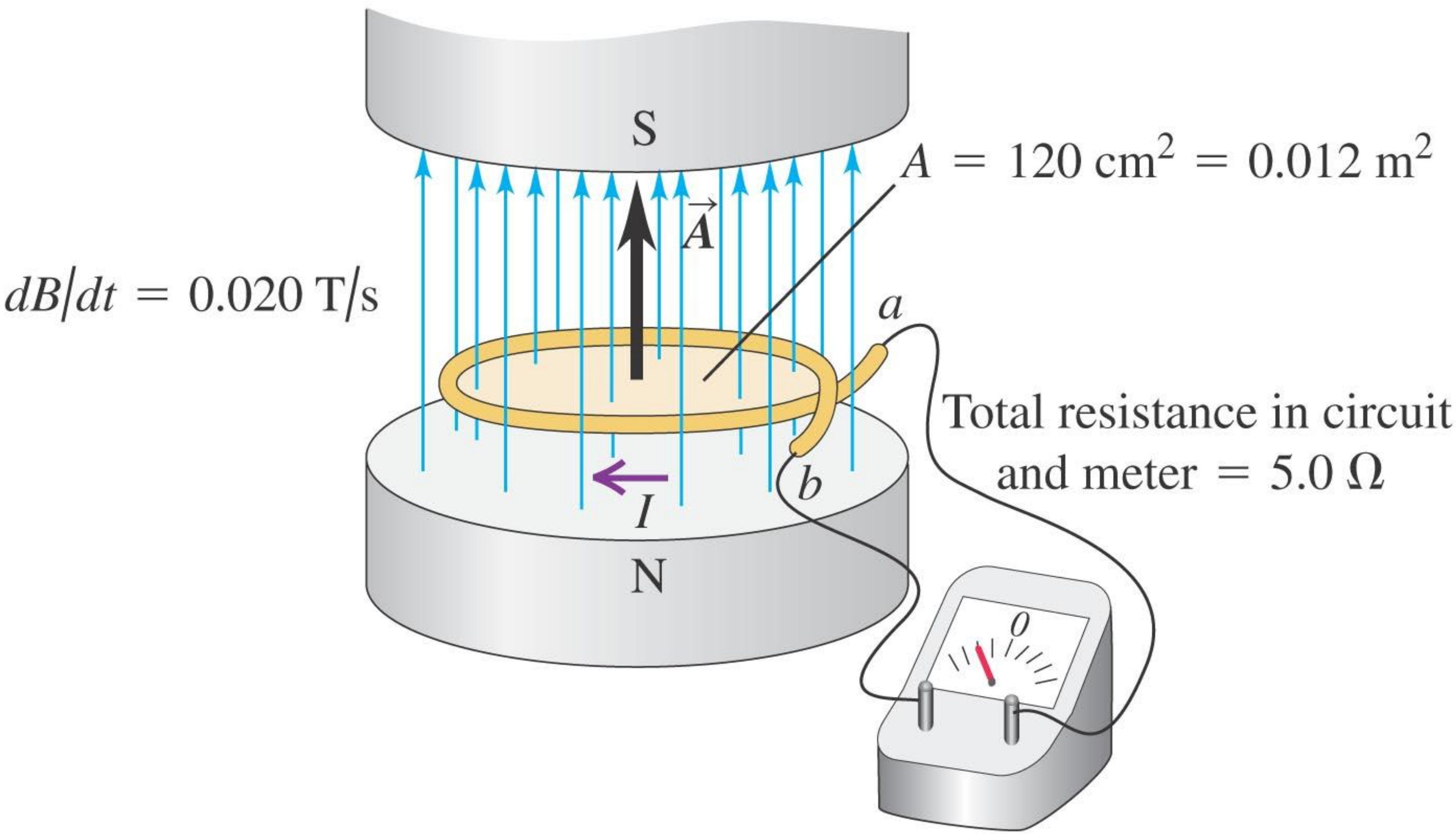



Surface is edge-on to magnetic field:
- $\vec{B}$ and $\vec{A}$ are perpendicular (the angle between $\vec{B}$ and $\vec{A}$ is $\phi = 90°$).
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos 90° = 0$.



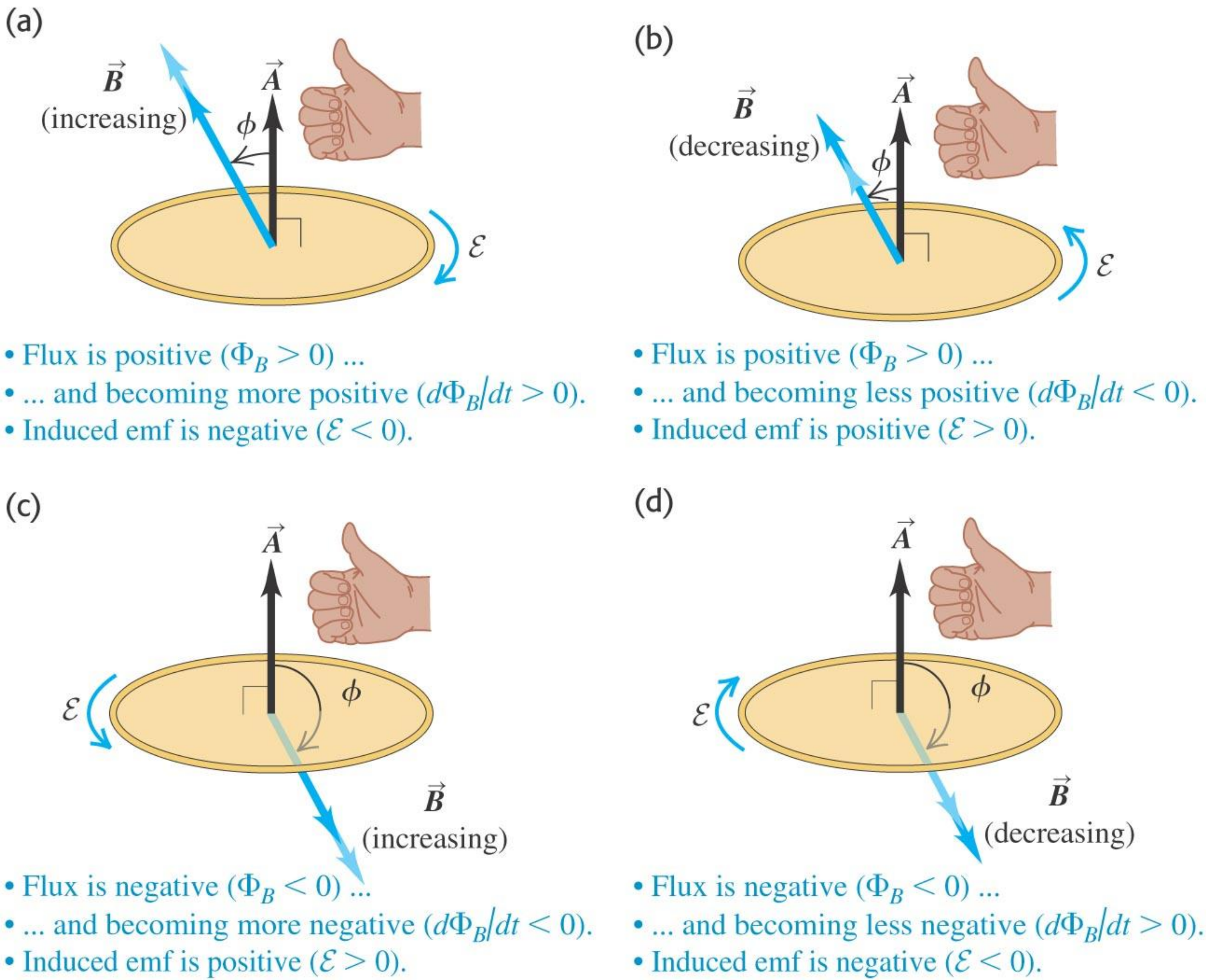
# EMF and the current induced in a loop

- A changing magnetic field induces an electric field – here the electric field is changing as well

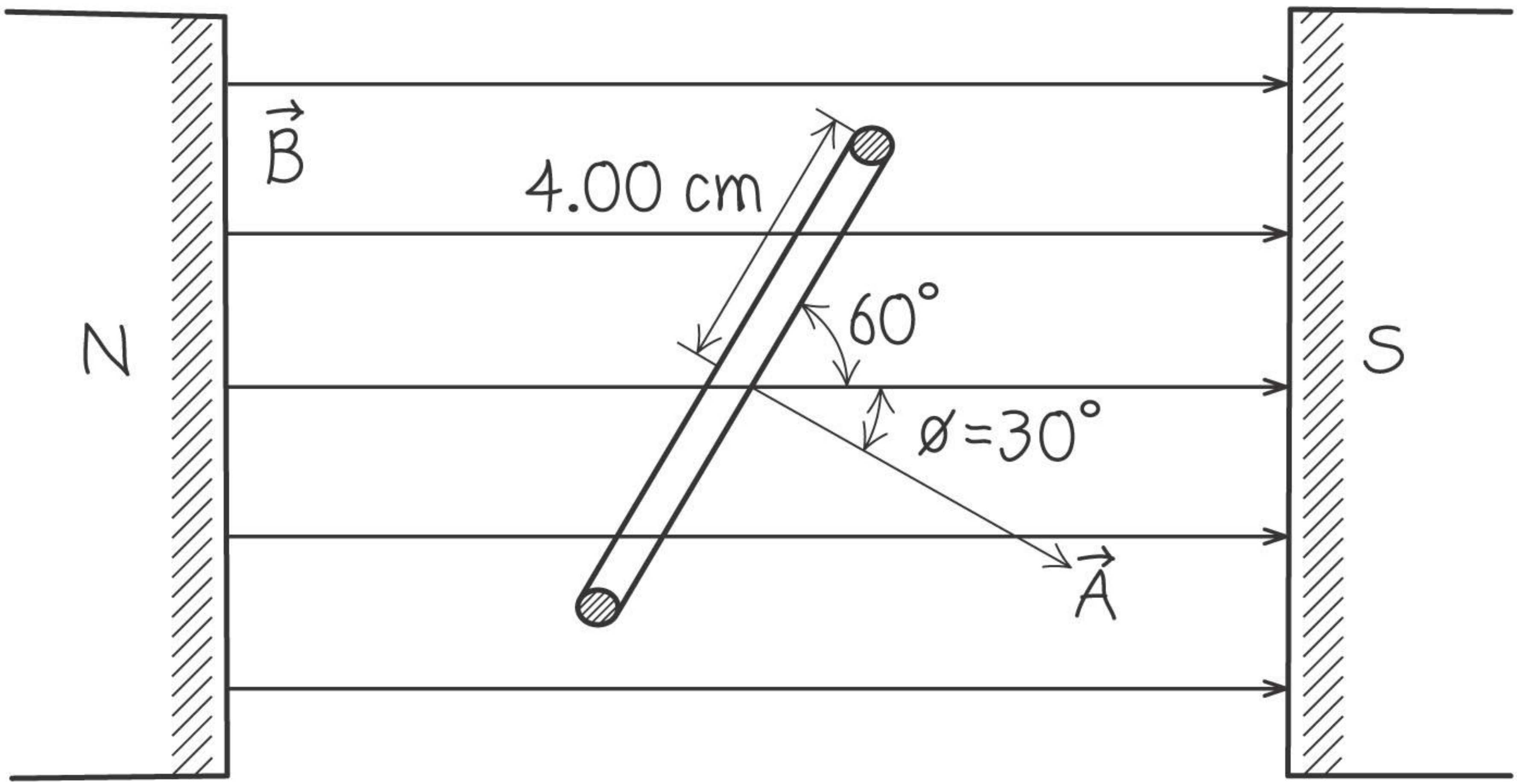


# Finding the direction of an induced emf

Induced EMF will produce current to create a magnetic field to OPPOSE the CHANGE in the original magnetic field

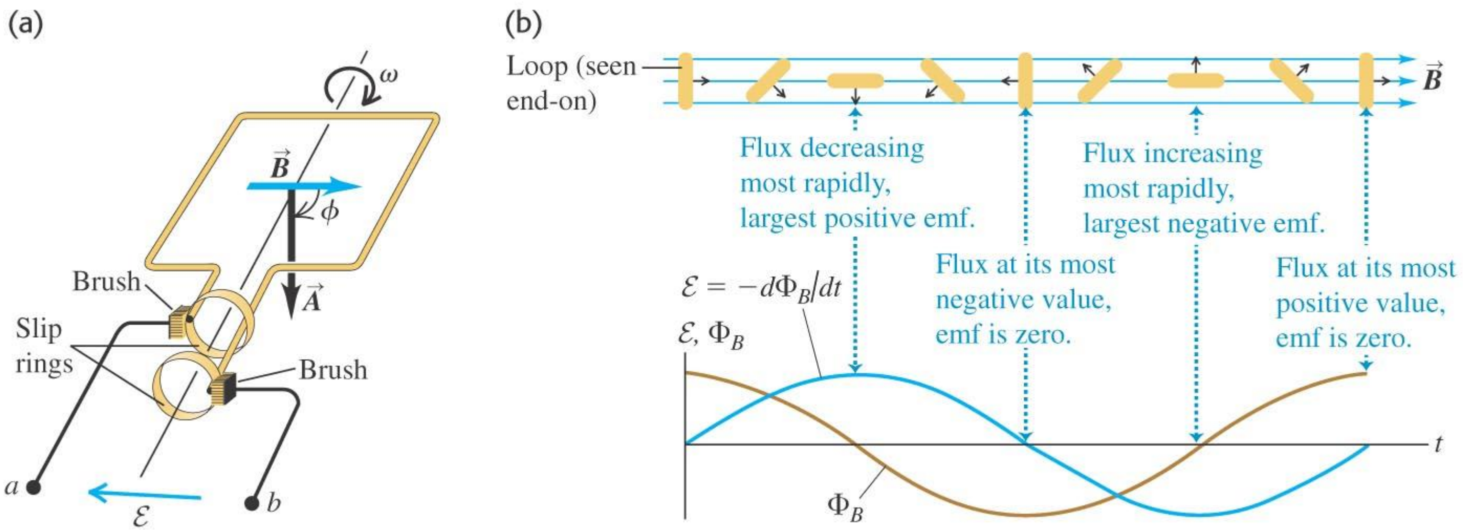


# Faraday’s Law



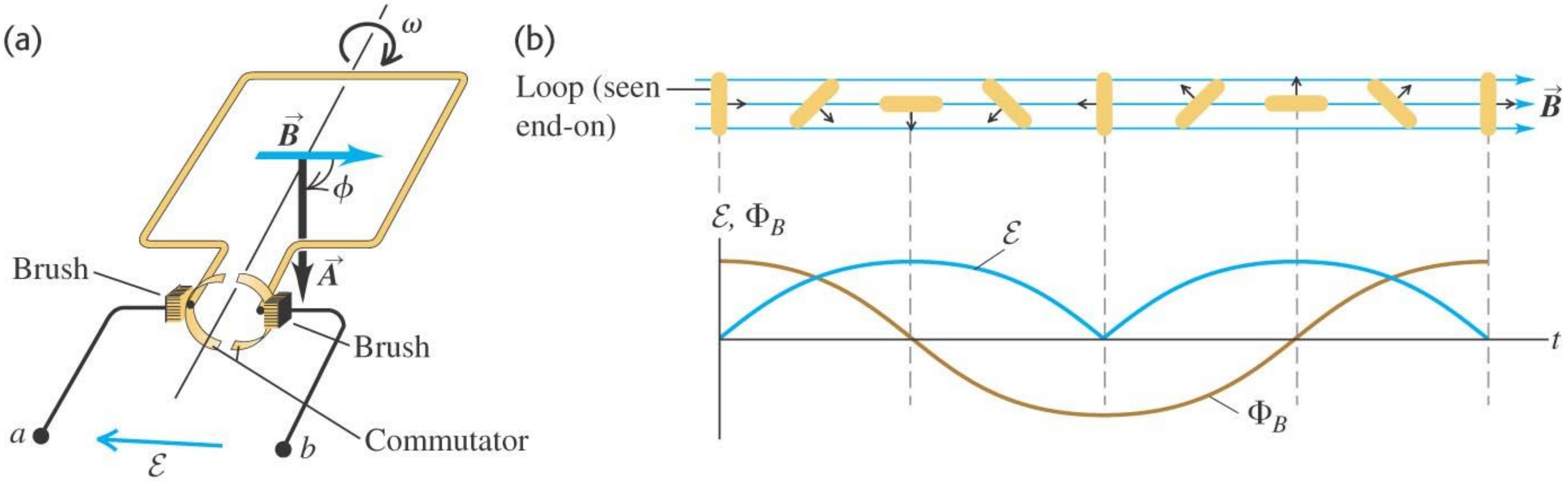
# Generator example

- A changing magnetic flux is actually what induces a changing electric field.
- Magnetic flux change is the field changes or if the direction changes



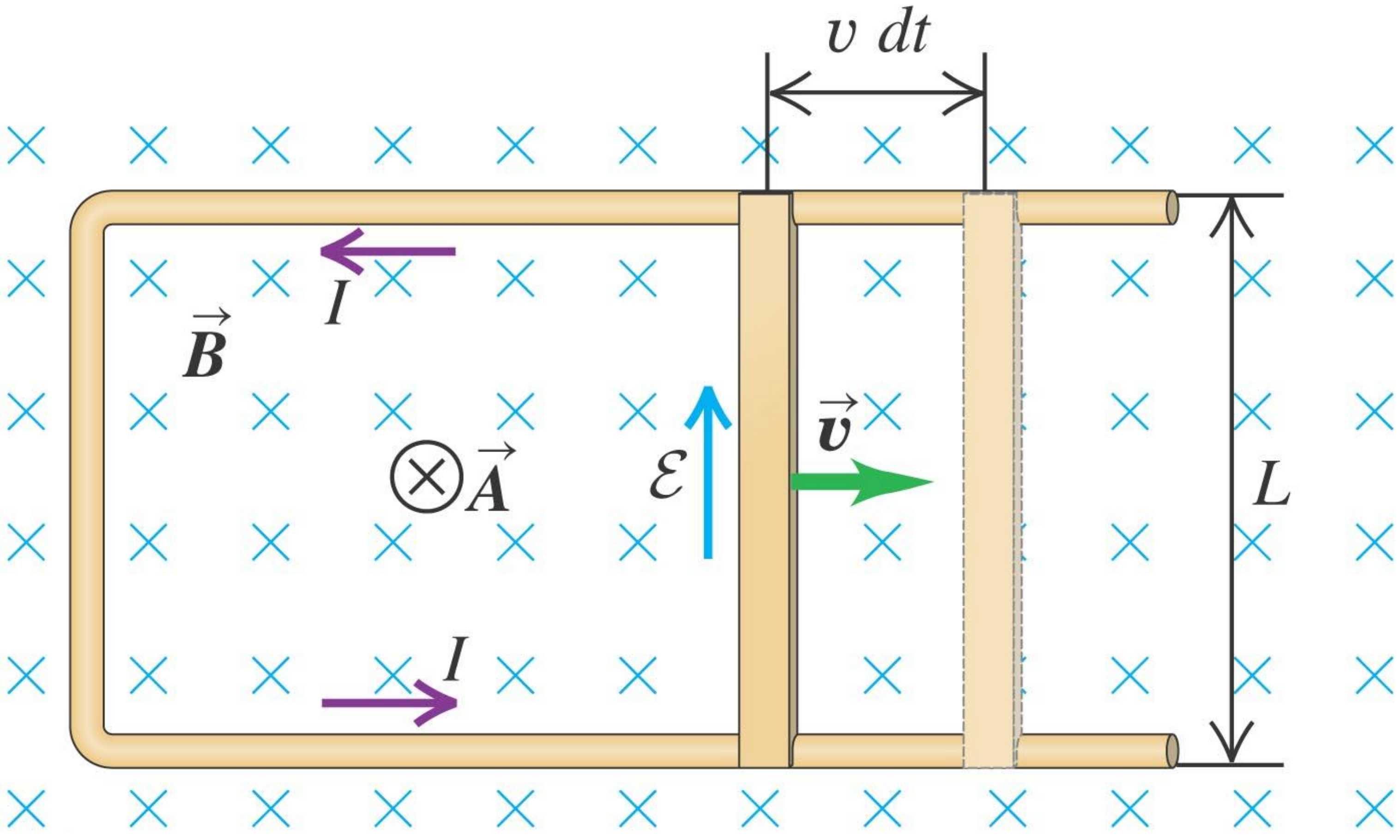

# Generator example II

- In a sense a DC generator is a motor run in reverse
- Back EMF in a motor.
- Motor back EMF ultimately limits the motor speed
- Back EMF reduces voltage available to drive the motor
- Hence the motor current is less with speed – torque drops



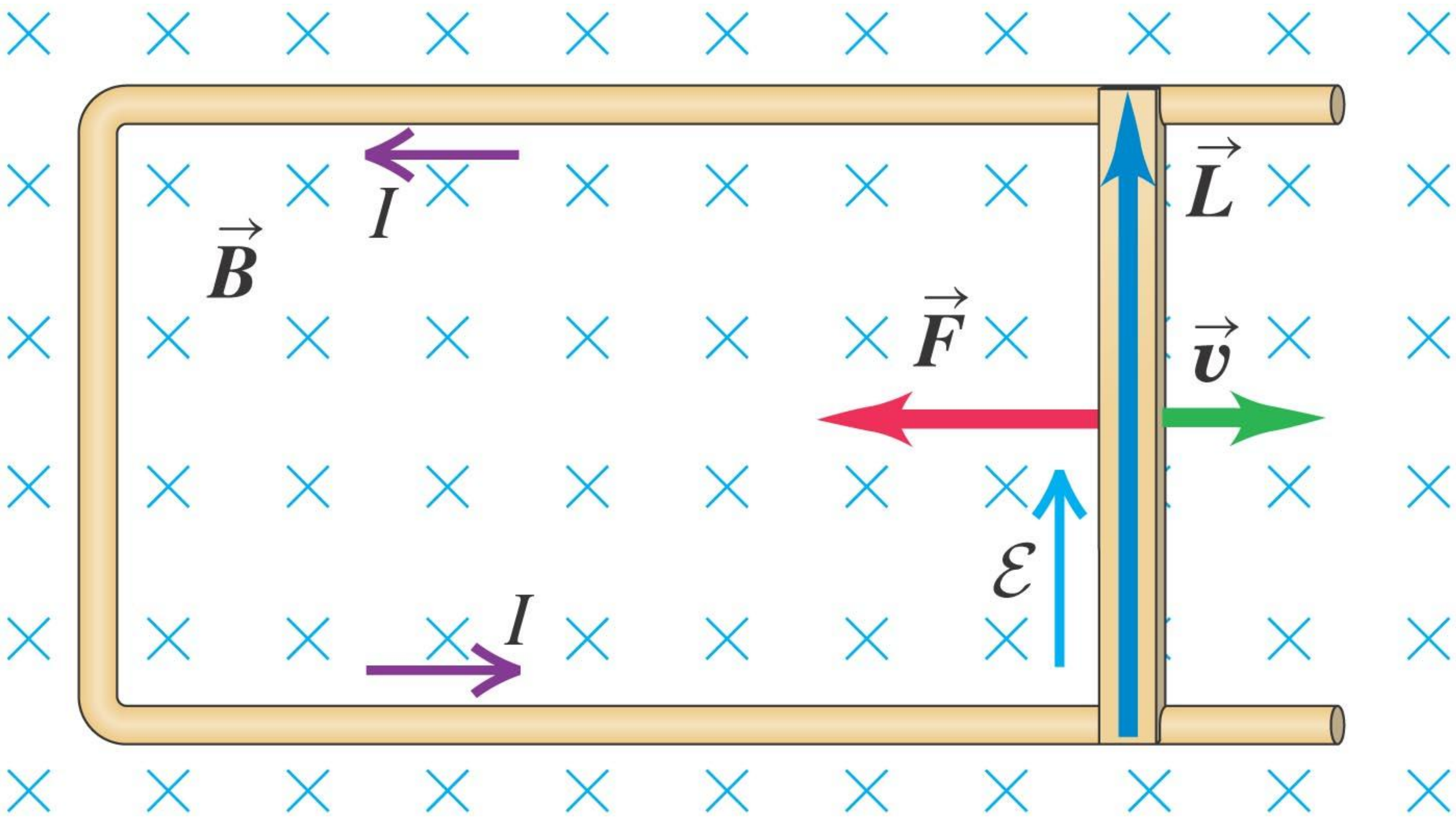
# Generator example III

- A linear motor is similar to a rotary motor but is linear
- A “rail gun” is an example



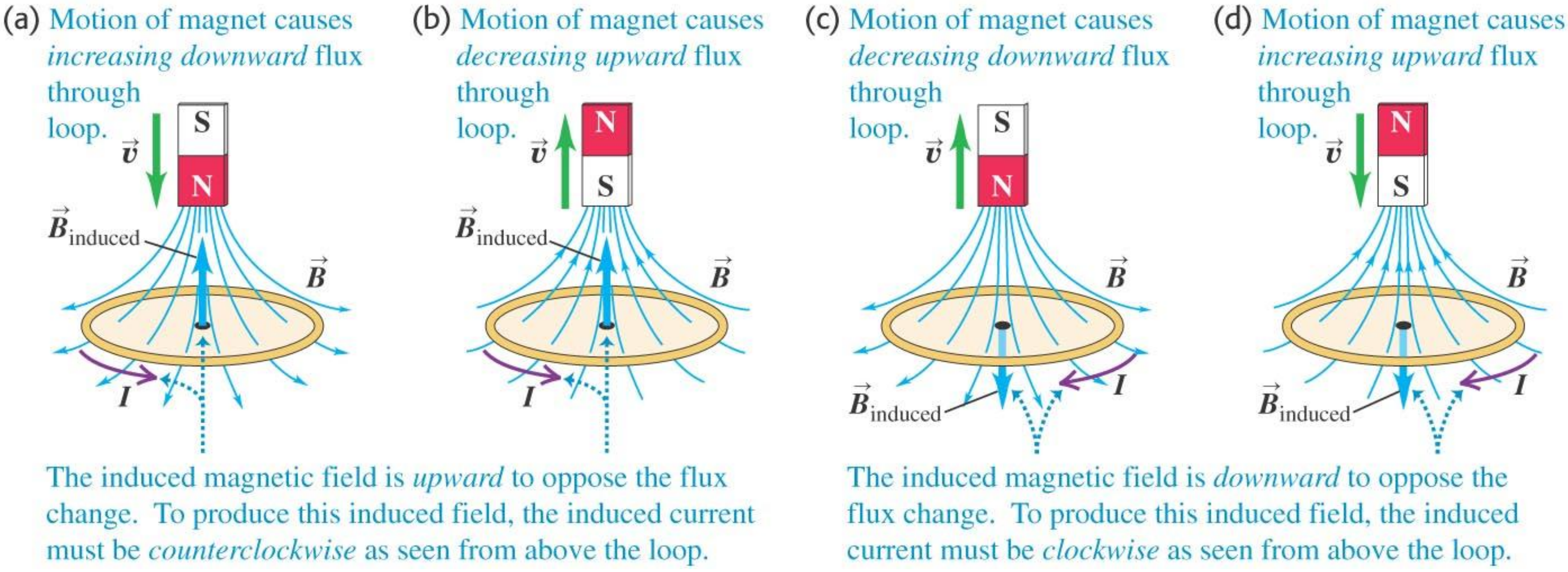
# Work and power in a slidewire generator

- A linear motor run backwards is a generator



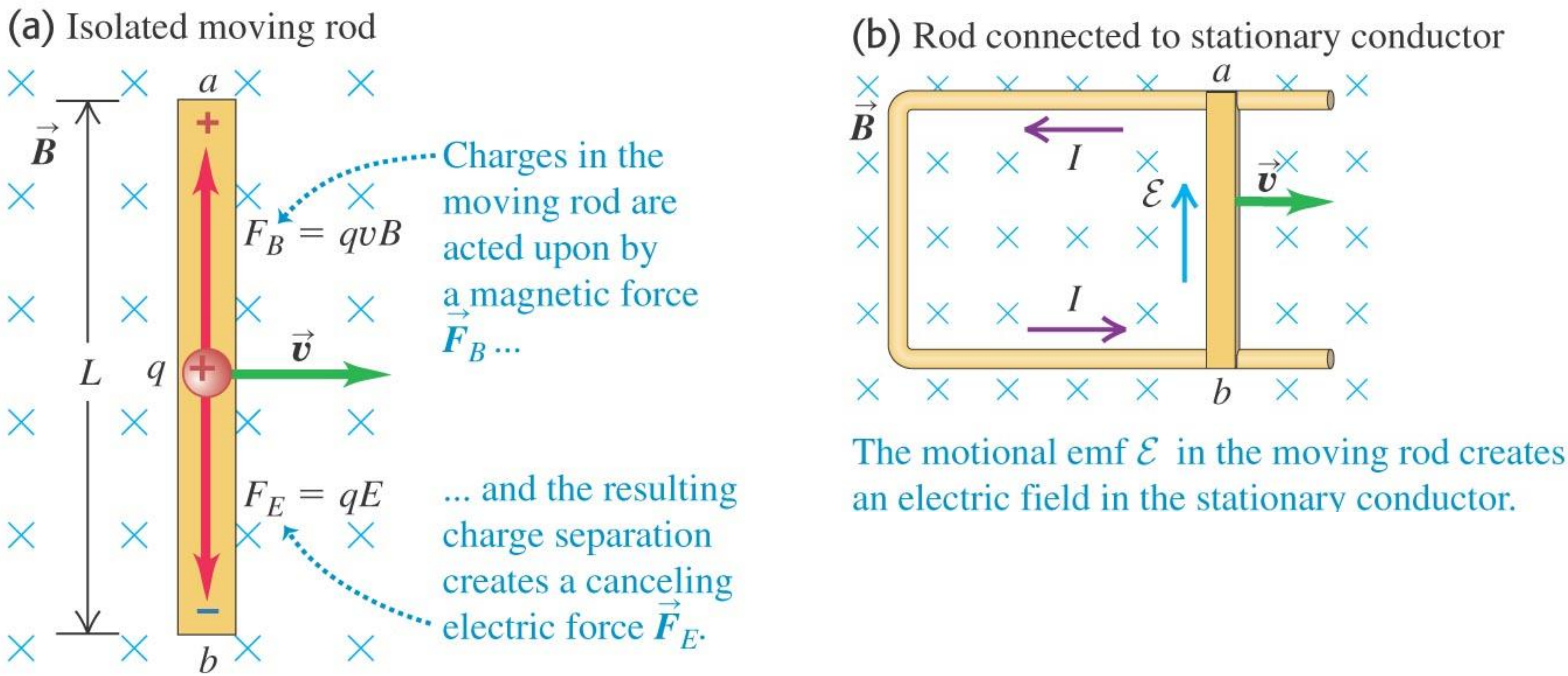
# Lenz's Law

- The direction of any magnetic induction effect is such as to oppose the cause of the effect.



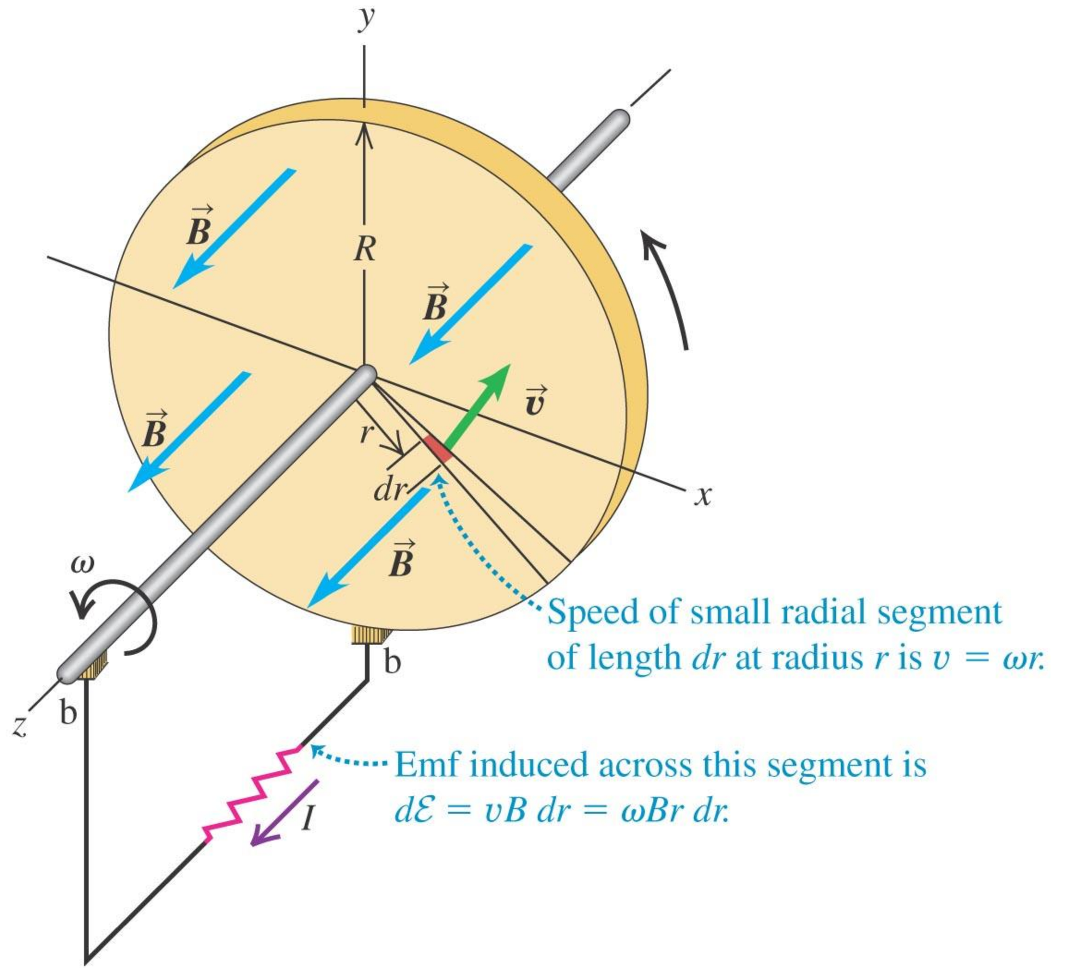
# A conducting rod moving in a uniform magnetic field

- The rod, velocity, and current are mutually perpendicular



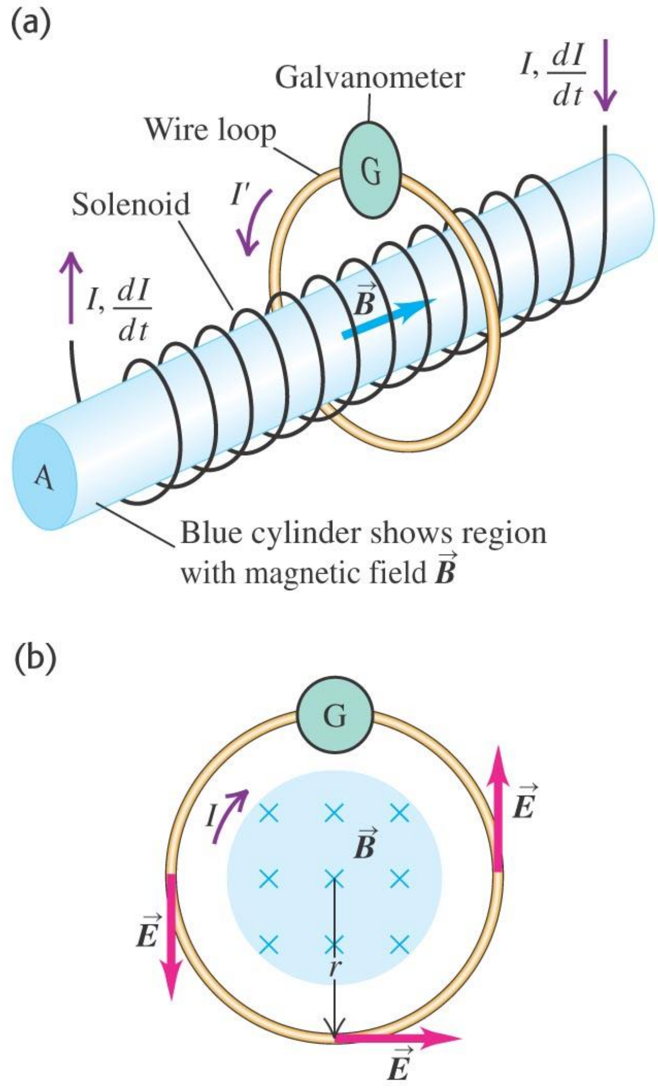
# The Faraday Disk dynamo

- Solid metal disk in a static B field
- What breaks the symmetry in this problem = rotation
- Eddy Current = electronic brakes



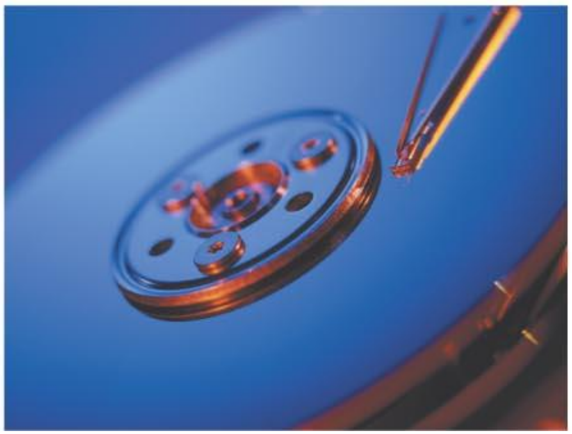
# Induced electric fields I

- The windings of a long solenoid carrying a current I



# Induced electric fields II

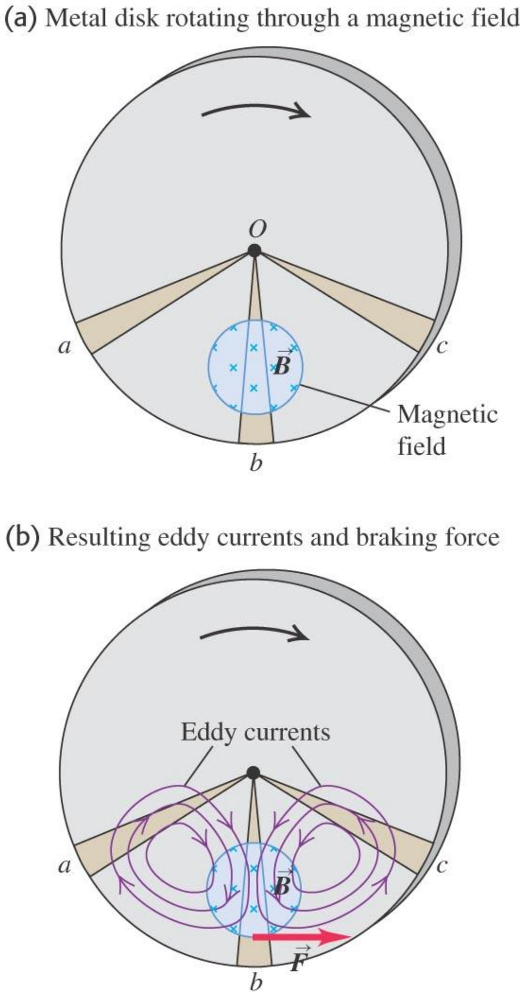
- Practical examples of induction
- It is in your everyday life

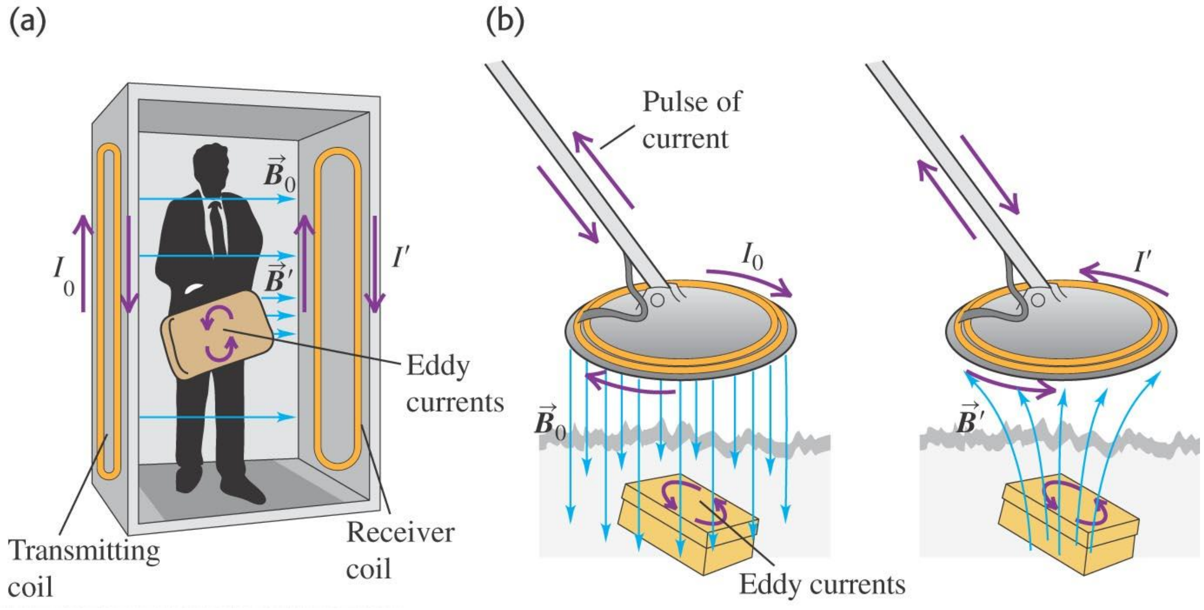


- Hard disks – read and write
- Motors in electric cars and hybrids – regenerative breaking
- Ignition in gas engines

# Eddy currents

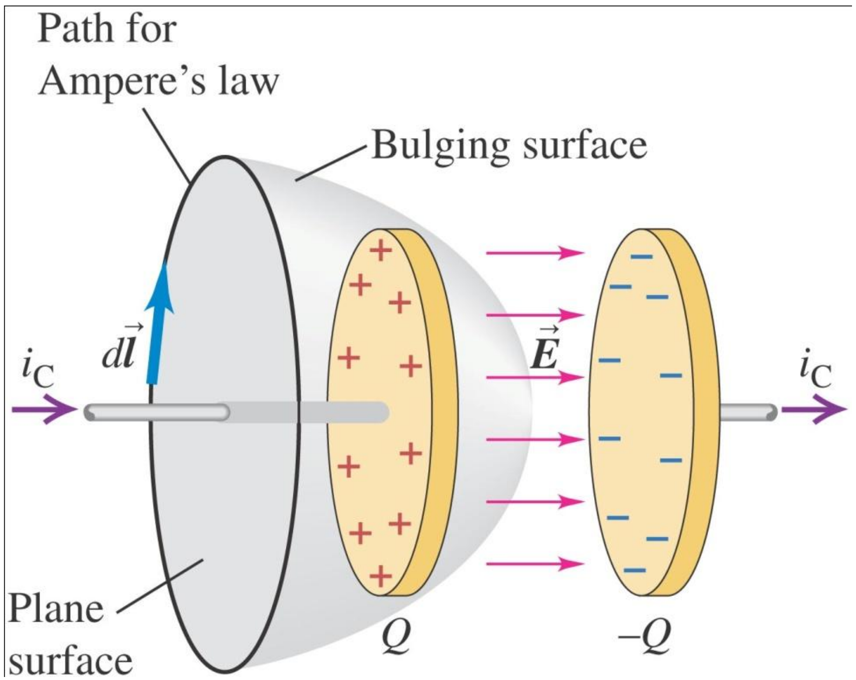
- Metal detection
- Airport and music store
- Eddy current braking

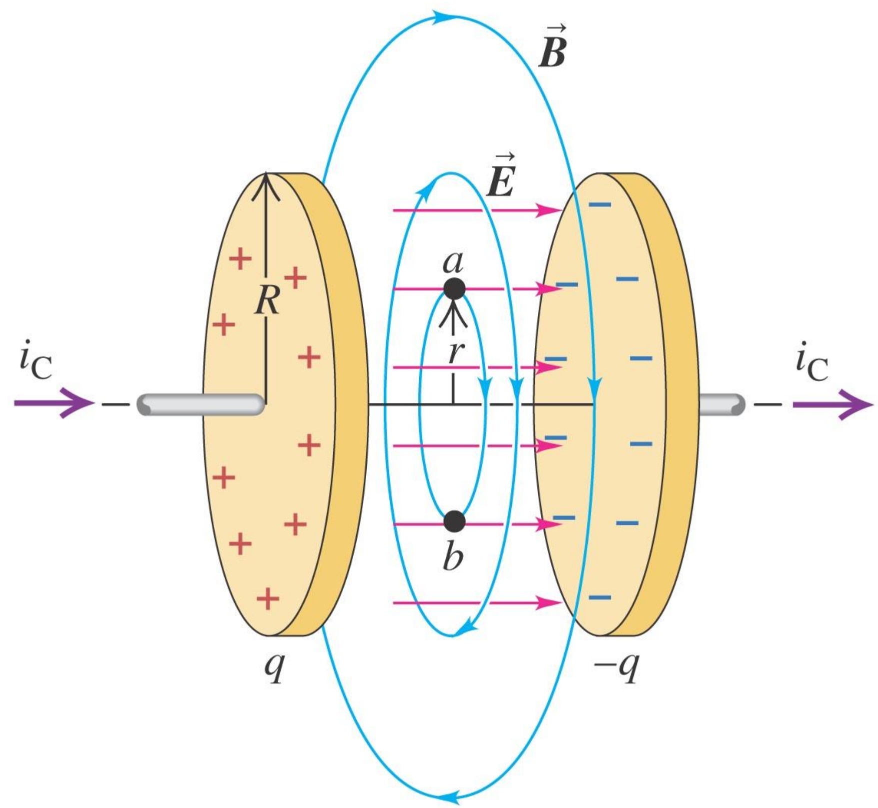


# Displacement current and Maxwell’s equations

- A varying electric field will give rise to a magnetic field.
- A varying magnetic field gives rise to an electric field
- Thus -> electromagnetic waves.



# Superconductivity and the Meissner effect

- When cooled below the critical temperature, superconductive materials lose all resistance to electrical current.
- Mercury was the first superconductor found
- We now have superconductors up to 140 K
- Perhaps room temperature superconductors will be found