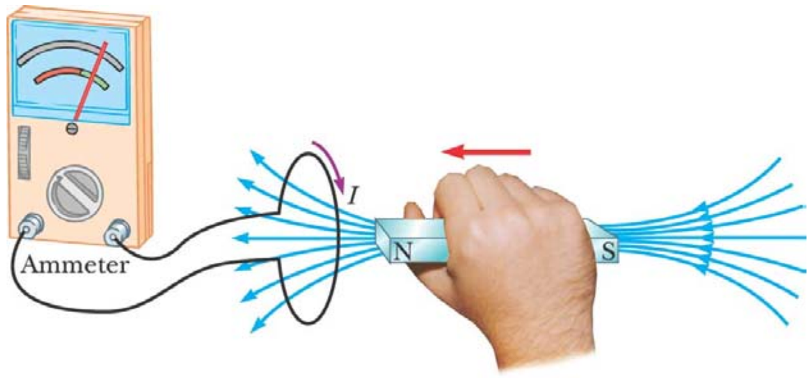
# Chapter 25

# Electromagnetic Induction

# Induction

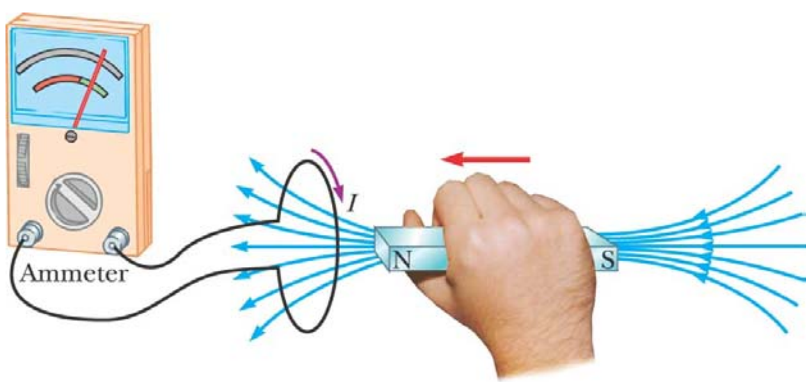
- A loop of wire is connected to a sensitive ammeter
- When a magnet is moved toward the loop, the ammeter deflects



(a)

# Induction

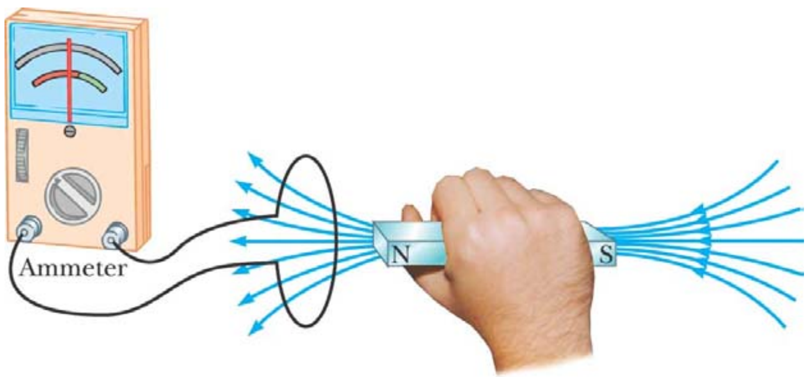
- An ***induced current*** is produced by a changing magnetic field
- There is an ***induced emf*** associated with the induced current
- A current can be produced without a battery present in the circuit
- Faraday's law of induction describes the induced emf




(a)

# Induction

- When the magnet is held stationary, there is no deflection of the ammeter
- Therefore, there is no induced current
  - Even though the magnet is in the loop

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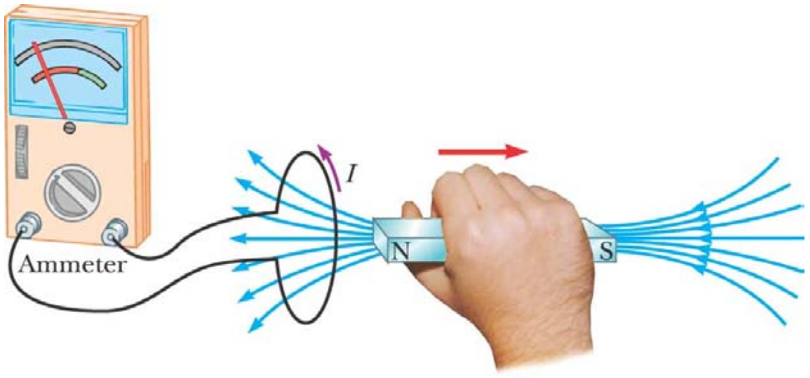
# Induction

- The magnet is moved away from the loop
- The ammeter deflects in the opposite direction



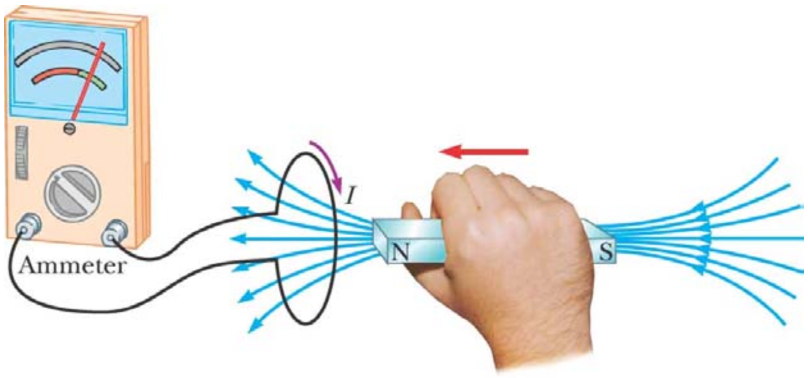
# Induction

- The ammeter deflects when the **magnet is moving toward or away from the loop**
- The ammeter also deflects when **the loop is moved toward or away from the magnet**
- Therefore, the loop detects that the magnet is moving relative to it
  - We relate this detection to a change in the magnetic field
  - This is the induced current that is produced by an **induced emf**

# Faraday's law

- Faraday's law of induction states that "the emf induced in a circuit is directly proportional to the time rate of change of the magnetic flux through the circuit"
- Mathematically,

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

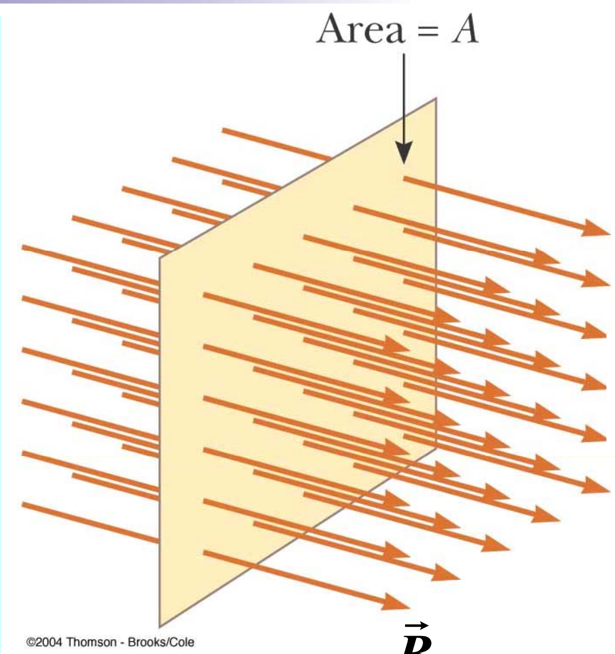


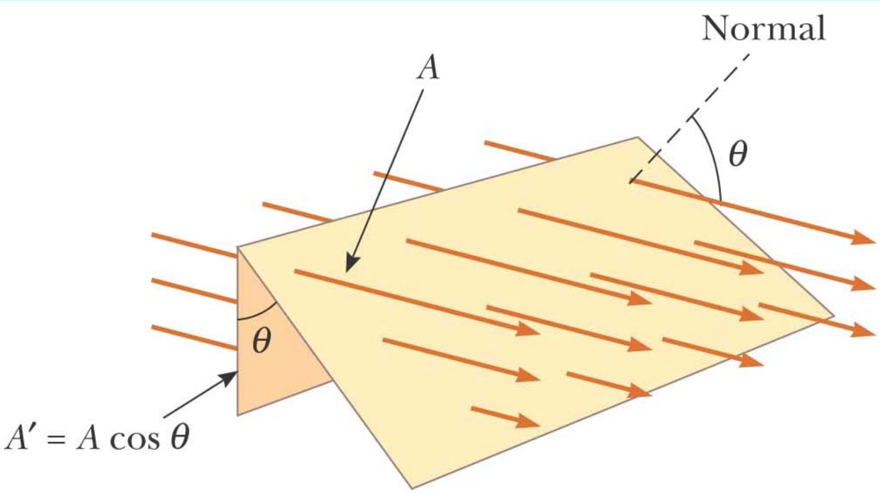
(a)

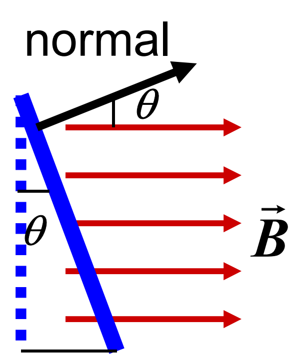
# Magnetic Flux

**Definition:**

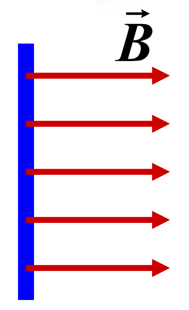
- ***Magnetic flux*** is the product of the magnitude of the magnetic field and the surface area, *A*, perpendicular to the field
- $\Phi_B = BA$
- The field lines may make some angle $\theta$ with the perpendicular to the surface
- Then $\Phi_B = BA \cos\theta$




$$\Phi_B = BA\cos\theta$$

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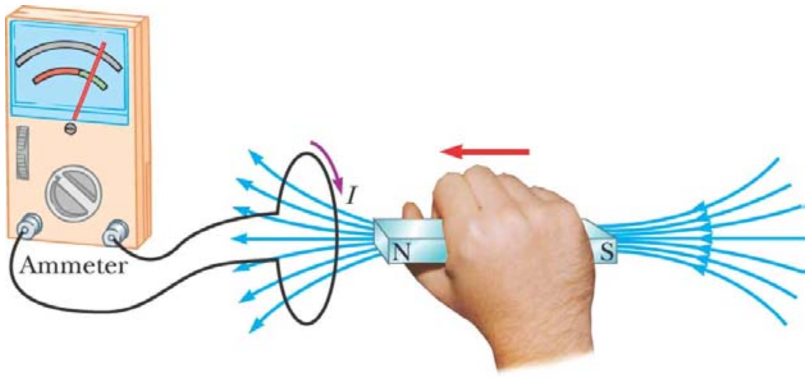
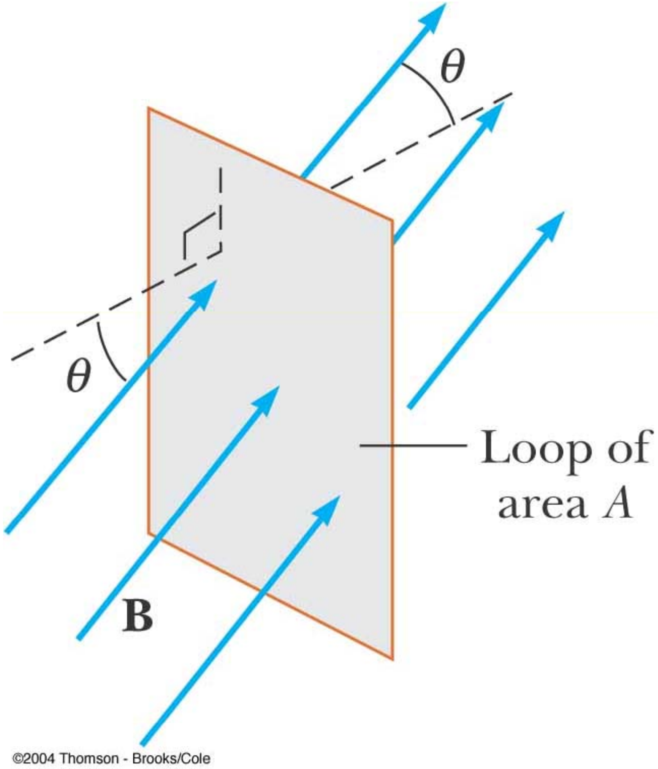


(a)

# Faraday's law

- Assume a loop enclosing an area $A$ lies in a uniform magnetic field **B**
- The magnetic flux through the loop is $\Phi_B = BA\cos\theta$
- The induced emf is

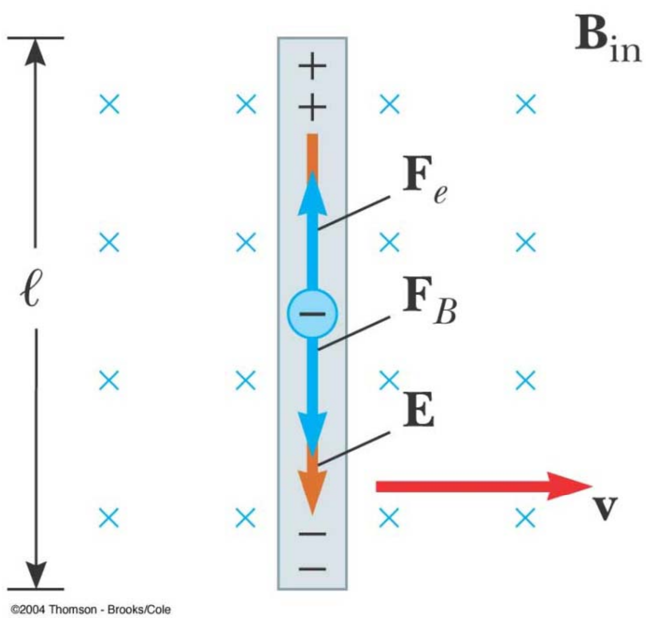
$$\varepsilon = -\frac{d(BA\cos\theta)}{dt}$$




- **Ways of inducing emf:**
- The magnitude of **B** can change with time
- The area ***A*** enclosed by the loop can change with time
- The angle $\theta$ can change with time
- Any combination of the above can occur

# Motional emf

- A **motional emf** is the emf induced in a conductor moving through a constant magnetic field
- The electrons in the conductor experience a force, $F_B = q\text{v}B$ that is directed along $\ell$

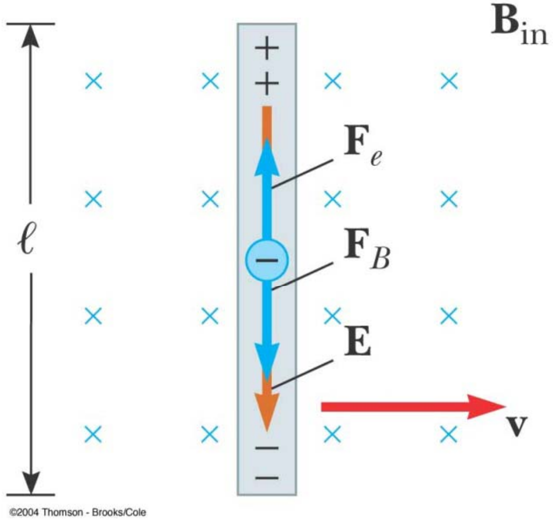


# Motional emf

$$F_B = qvB$$

- Under the influence of the force, the electrons move to the lower end of the conductor and accumulate there
- As a result, an electric field **E** is produced inside the conductor
- The charges accumulate at both ends of the conductor until they are in equilibrium with regard to the electric and magnetic forces

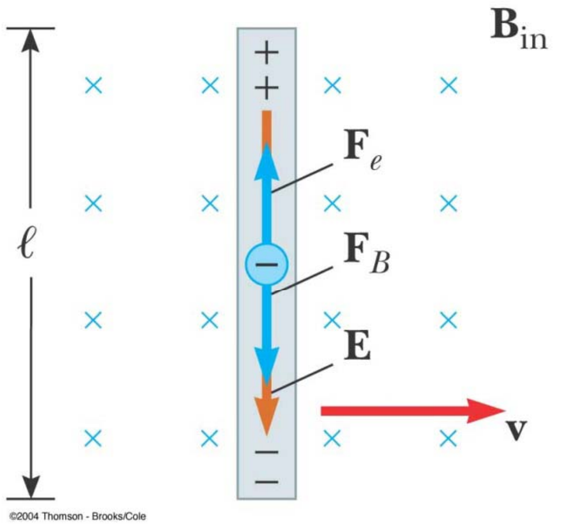
$$qE = qvB \quad \text{or} \quad E = vB$$



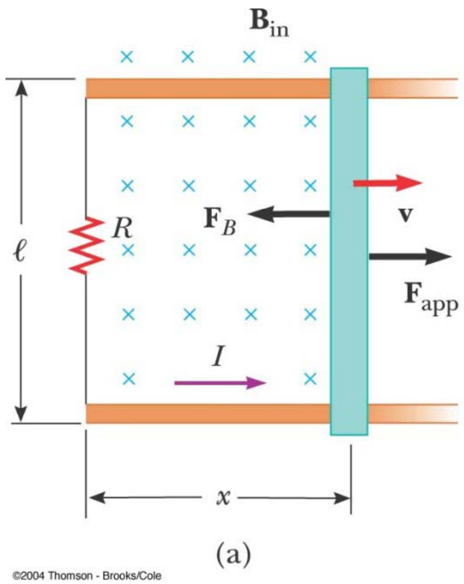
# Motional emf

**$E = vB$**

- A potential difference is maintained between the ends of the conductor as long as the conductor continues to move through the uniform magnetic field
- If the direction of the motion is reversed, the polarity of the potential difference is also reversed

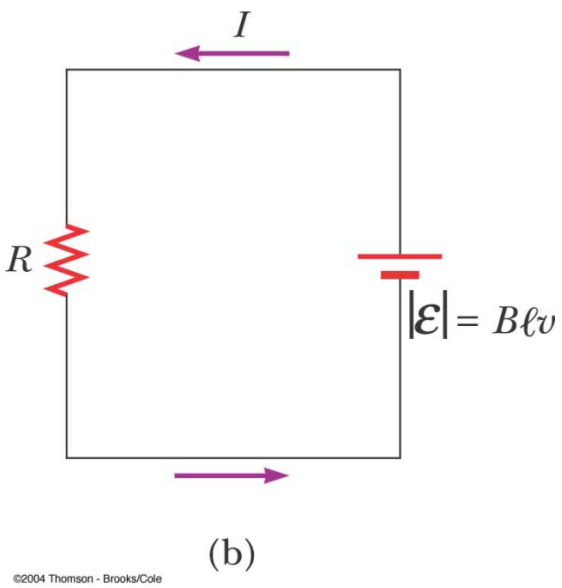


# Example: Sliding Conducting Bar




$$E = vB$$

$$\varepsilon = El = Blv$$



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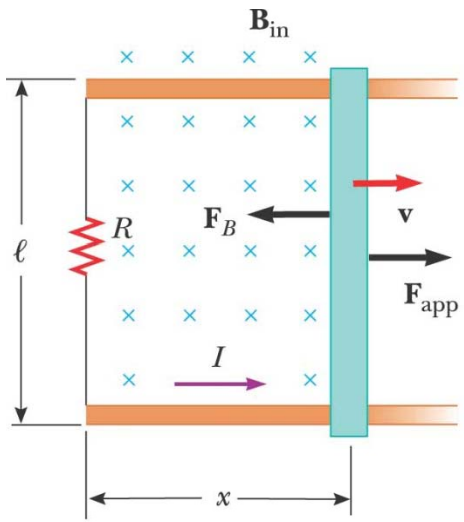


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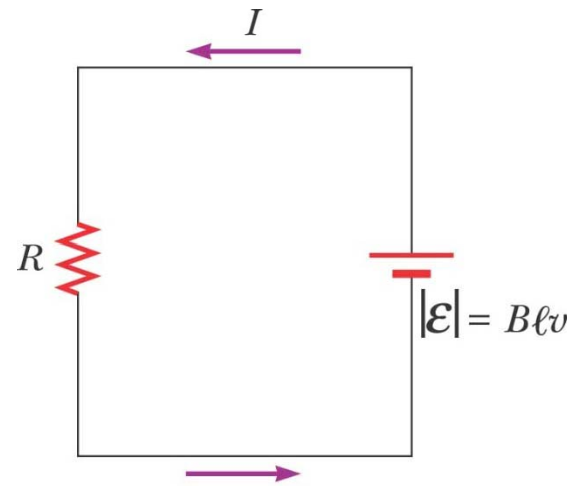


(b)



- The induced emf is

$$\varepsilon = -\frac{d\Phi_B}{dt} = -B\ell\frac{dx}{dt} = -B\ell v$$

$$I = \frac{|\varepsilon|}{R} = \frac{B\ell v}{R}$$

# Lenz's law

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

- Faraday's law indicates that the induced emf and the change in flux have opposite algebraic signs
- This has a physical interpretation that is known as **Lenz's law**
- **Lenz's law**: *the induced current in a loop is in the direction that creates a magnetic field that opposes the change in magnetic flux through the area enclosed by the loop*
- The induced current tends to keep the original magnetic flux through the circuit from changing

# Lenz's law

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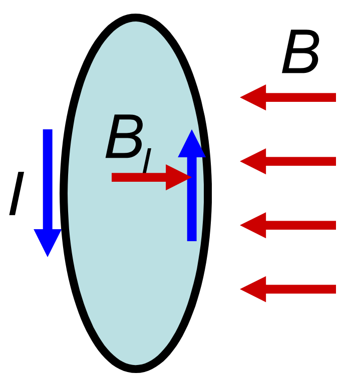
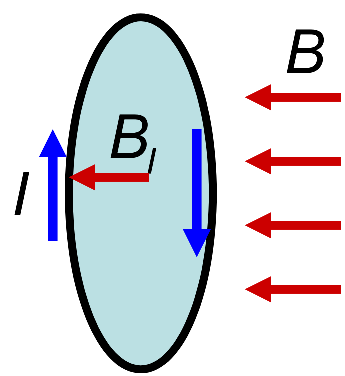
- The induced current tends to keep the original magnetic flux through the circuit from changing

***B*** increases with time




***B*** decreases with time

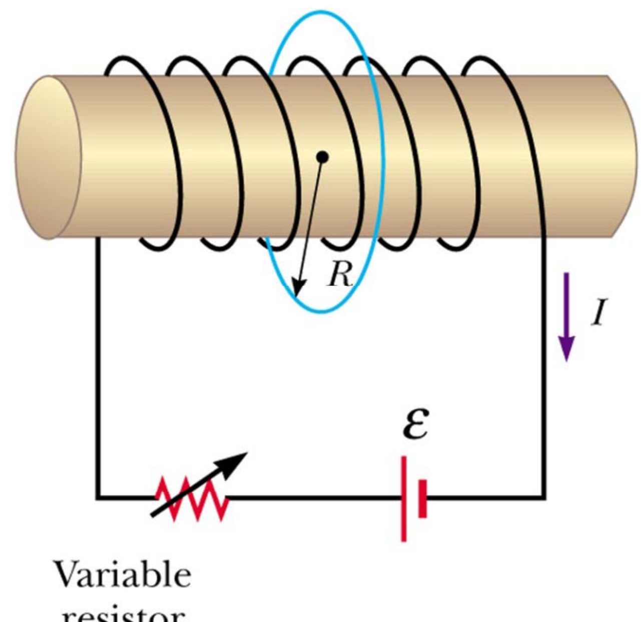


# Example

A single-turn, circular loop of radius ***R*** is coaxial with a long solenoid of radius ***r*** and length ***ℓ*** and having ***N*** turns. The variable resistor is changed so that the solenoid current decreases linearly from $I_1$ to $I_2$ in an interval **Δ***t*. Find the induced emf in the loop.

$$B(t) = \mu_o \frac{N}{l} I(t)$$

$$\Phi(t) = \pi r^2 B(t) = \mu_o \pi r^2 \frac{N}{l} I(t)$$





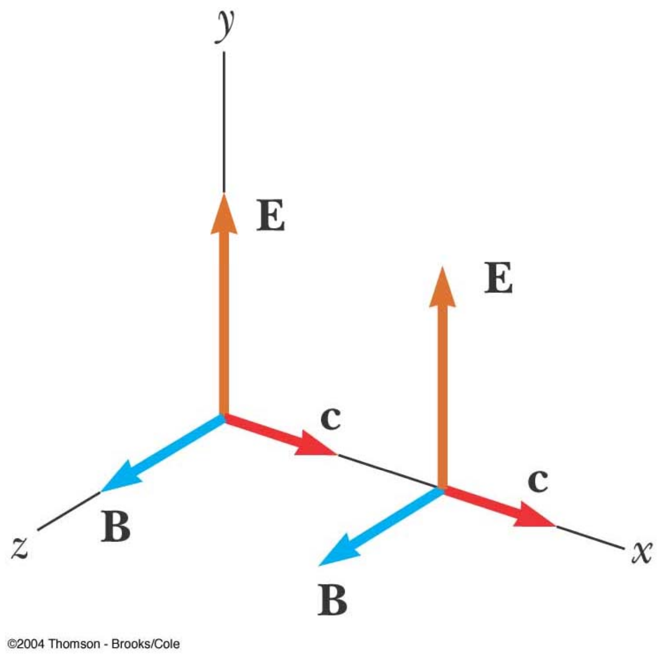

$$\varepsilon = -\frac{d\Phi(t)}{dt} = -\mu_o \pi r^2 \frac{N}{l}\frac{dI(t)}{dt} = -\mu_o \pi r^2 \frac{N}{l}\frac{I_2 - I_1}{\Delta t}$$

# Chapter 25

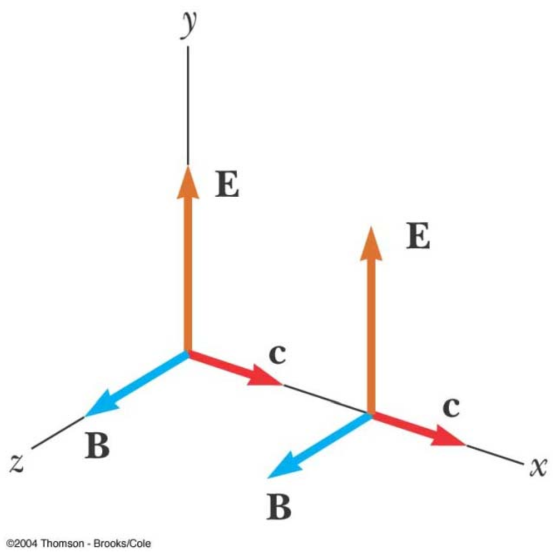
## Electromagnetic Waves

# Plane Electromagnetic Waves

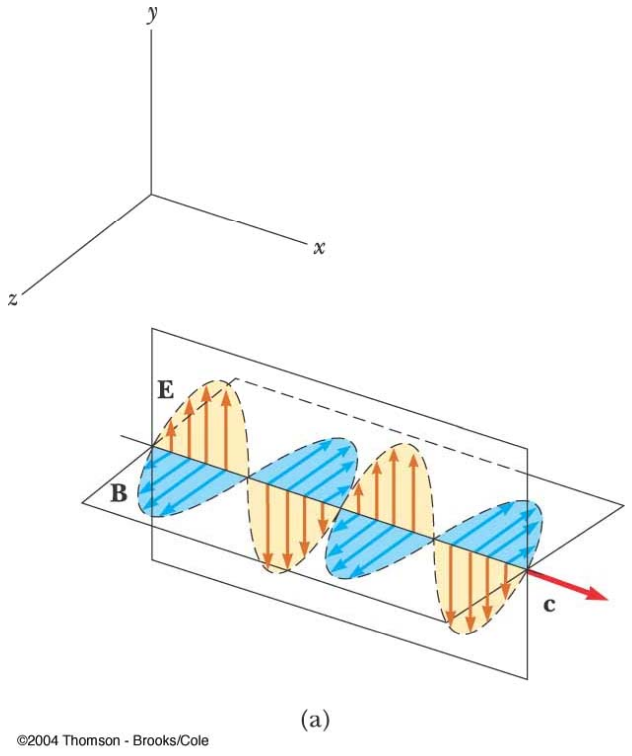
- Assume EM wave that travel in x-direction
- Then Electric and Magnetic Fields are orthogonal to x



# Plane Electromagnetic Waves

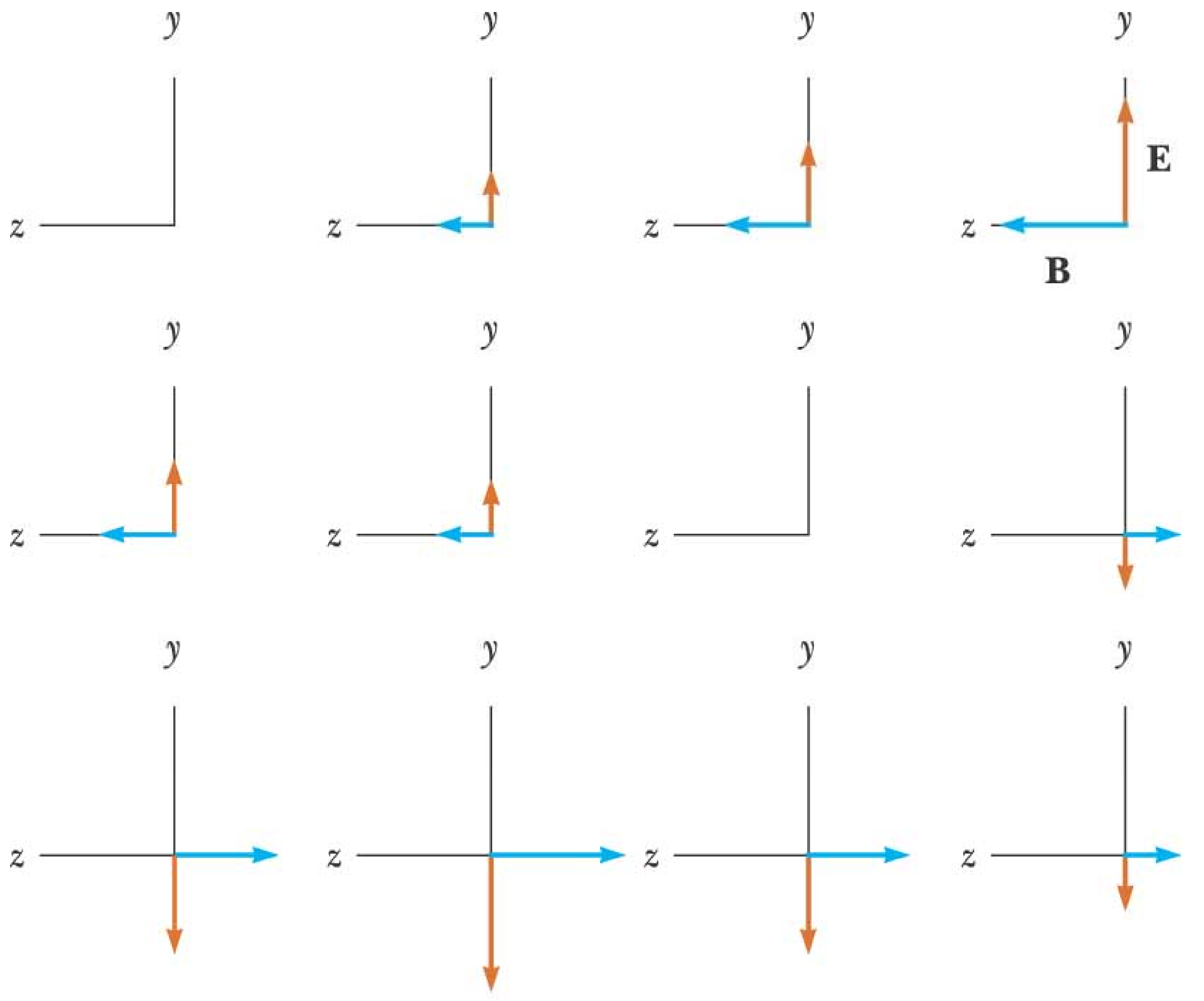



*E* and *B* vary sinusoidally with *x*




(a)

# Time Sequence of Electromagnetic Wave




(b)

# The EM spectrum

- Note the overlap between different types of waves
- Visible light is a small portion of the spectrum
- Types are distinguished by frequency or wavelength