

Magnetic forces review

Please try chapter 24 problem 39 on page 827.

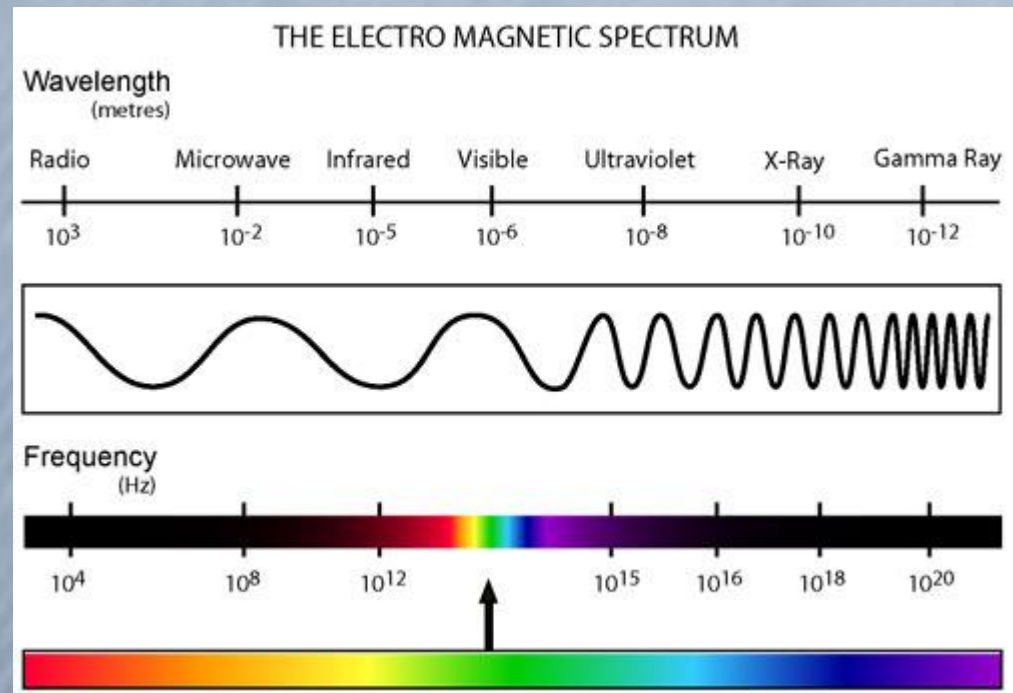
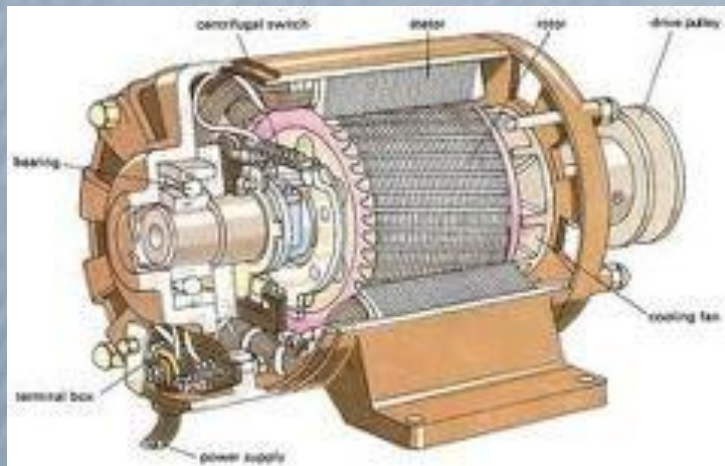
“A square current loop 5.0cm on each side carries...”

Electromagnetic Induction and Waves

- EM induction of electric currents
- Effects of moving conductors in B fields
- Effects of conductors in changing B fields
- Eddies
- Electromagnetic Waves
- Polarization, Photons
- Electromagnetic spectrum

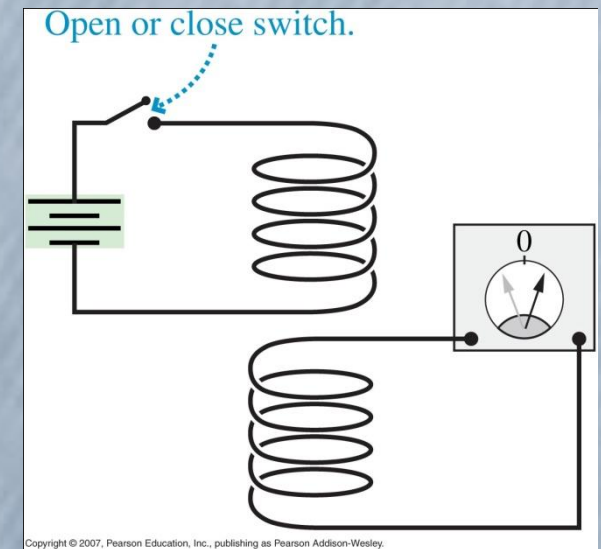
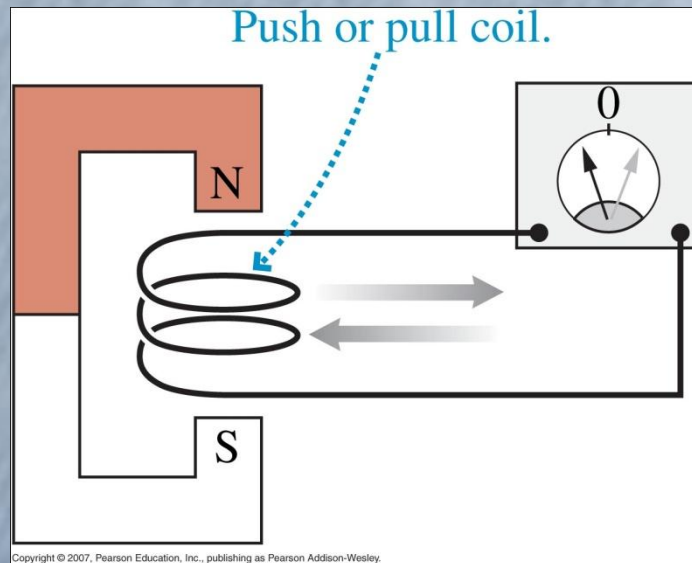
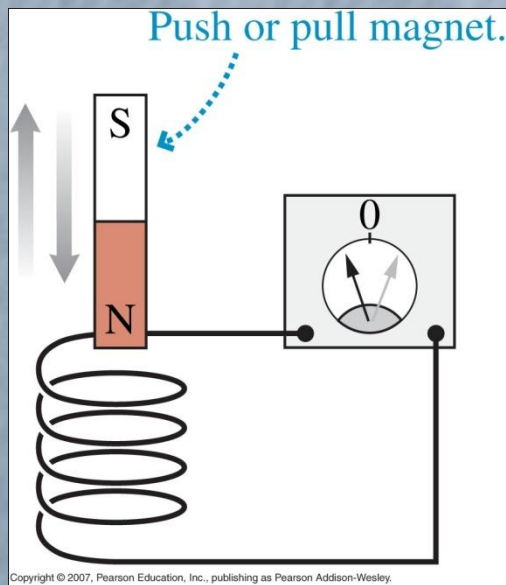
EM induction and waves

- EM Induction – making currents from changing magnet fields
- EM waves – radio, microwaves, light, X-rays



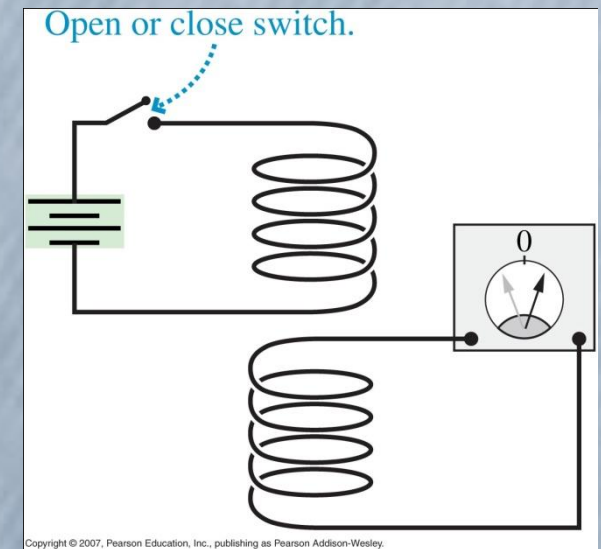
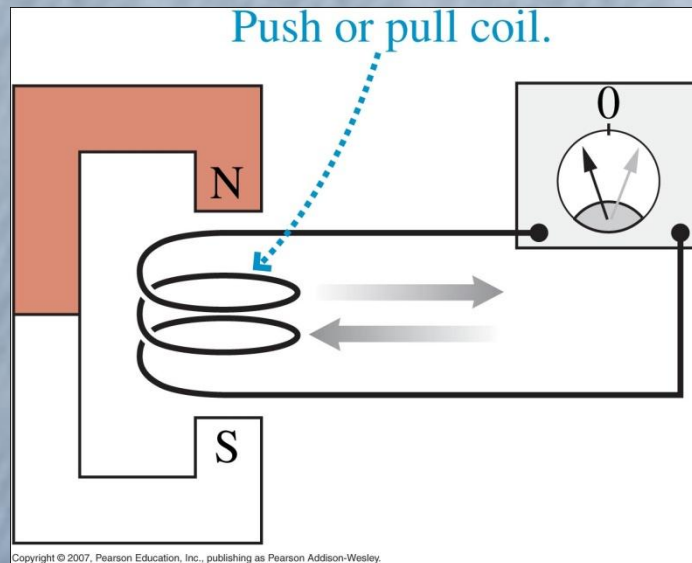
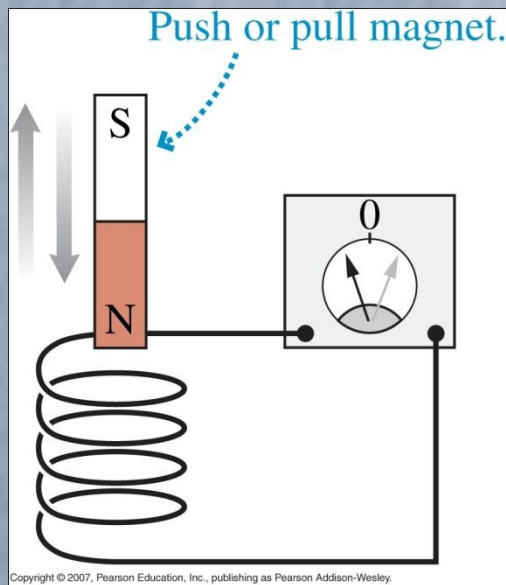
Induced Current

- We have seen that a magnetic field exerts a force on a moving charge or current
- Faraday found that a changing magnetic field will move a charge, inducing a current



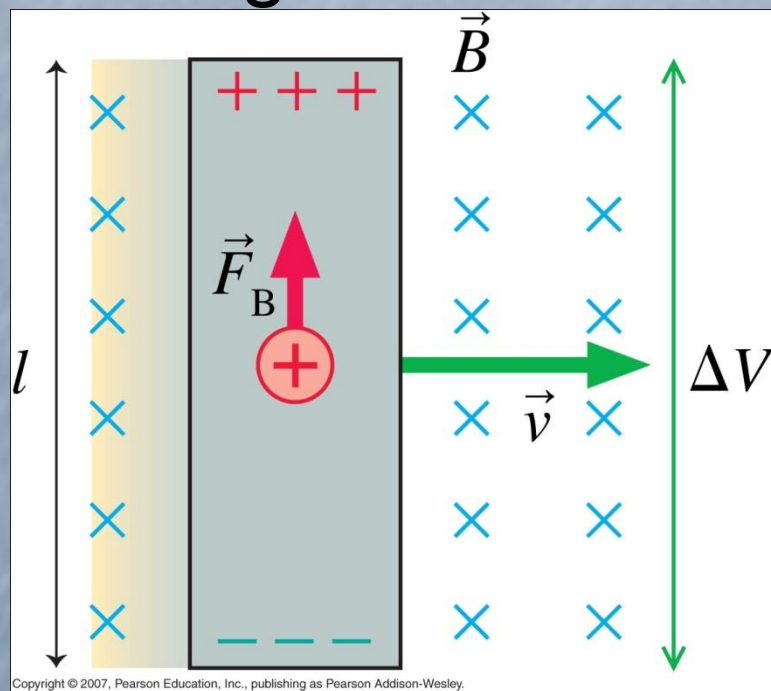
Induced Current

- A changing magnetic field creates an **induced current** in a circuit.
- The process is called **electromagnetic induction**

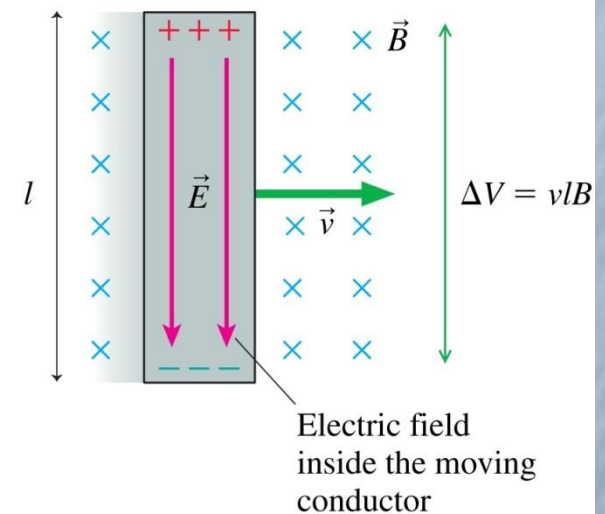


Motional emf

- A conductor moving in a magnetic field experiences a changing magnetic field
- The charge moves in the conductor, creating an electric field



(b) Magnetic forces separate the charges and cause a potential difference between the ends. This is a motional emf.



Motional emf

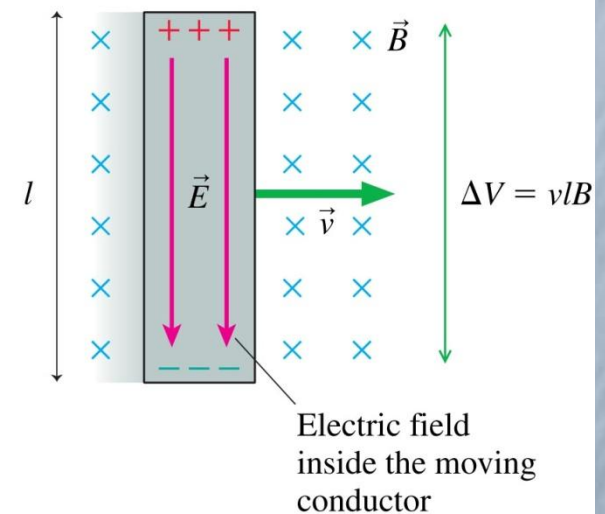
- If the wire is moving at velocity, v , the charges move, until the forces from the electric field (E), and magnetic field (B) balance.

$$F_B = qvB$$

$$F_E = qE$$

$$E = vB$$

(b) Magnetic forces separate the charges and cause a potential difference between the ends. This is a motional emf.



Motional emf

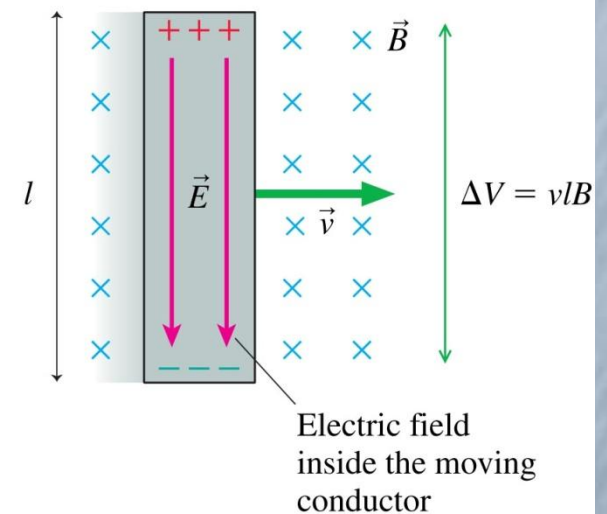
- The motional emf across the wire length l , moving in a magnetic field, B , at velocity v , is found from

$$E = \frac{V_{emf}}{l}$$

$$E = vB$$

$$V_{emf} = v l B$$

(b) Magnetic forces separate the charges and cause a potential difference between the ends. This is a motional emf.



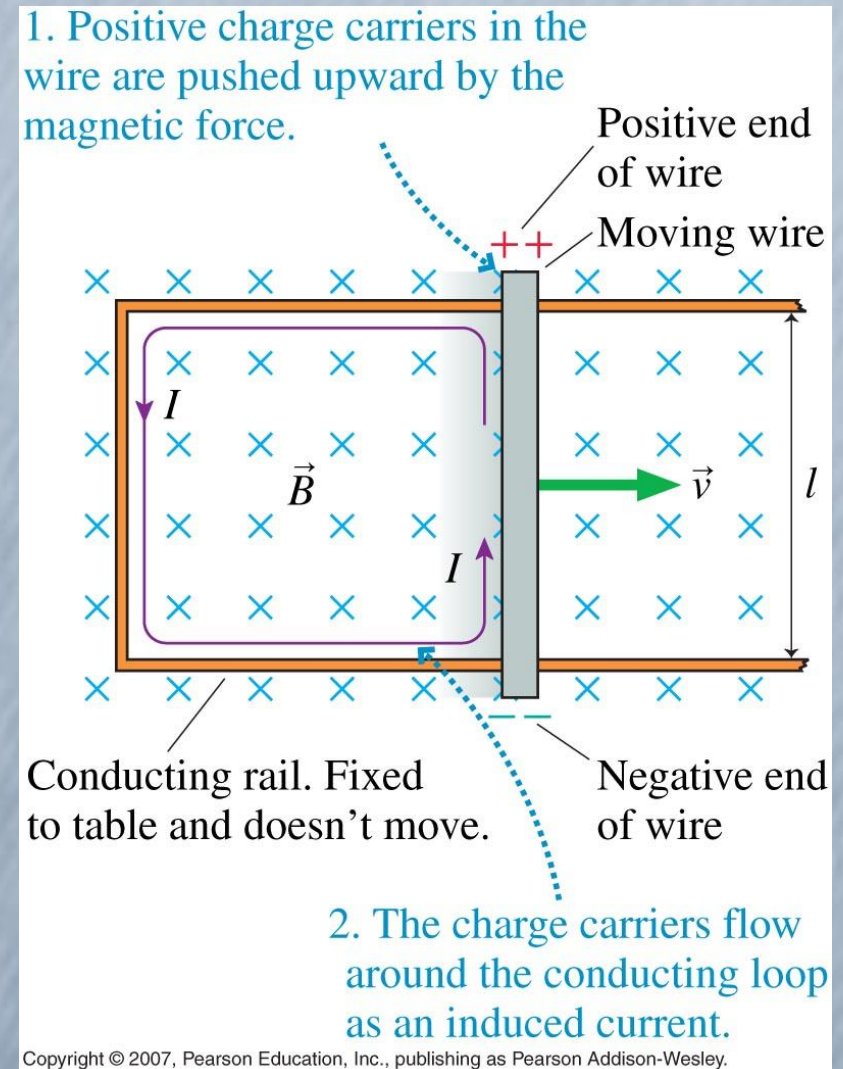
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Energy of induced currents

Consider a conductor moving along rails in a magnetic field

We now have a current loop, and given the resistance, R , can calculate the current

$$I = \frac{V_{emf}}{R} = \frac{v l B}{R}$$

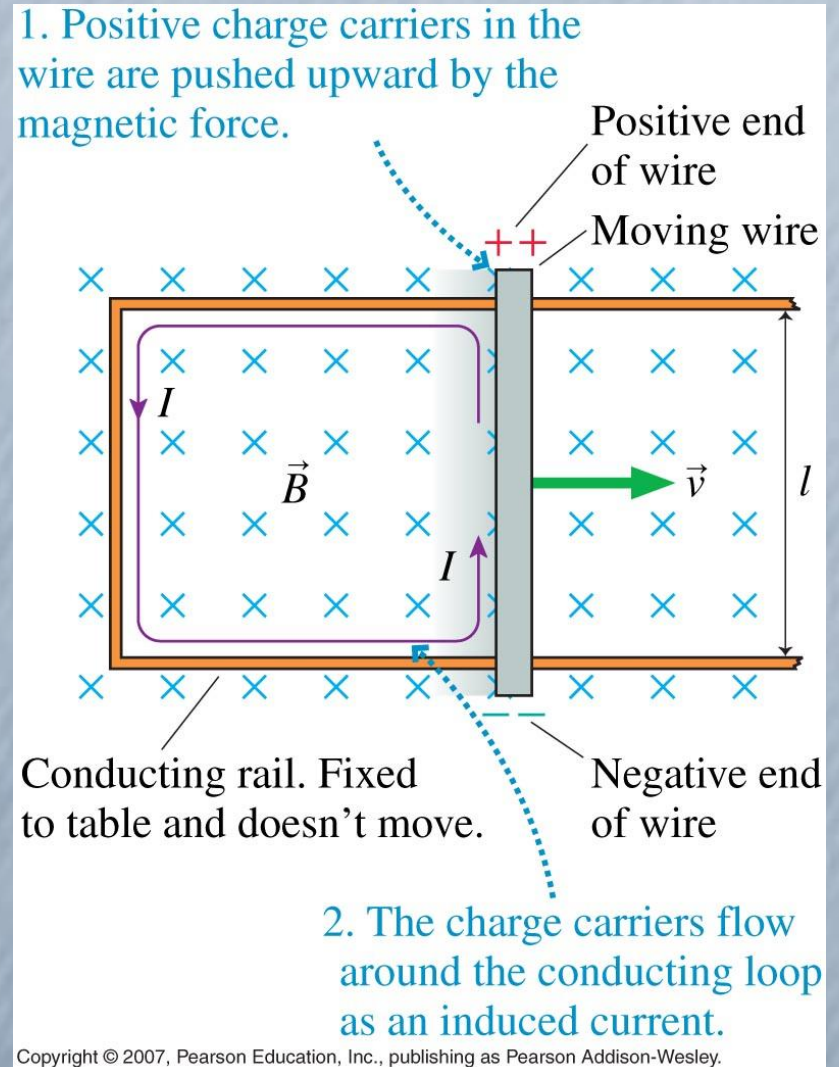


Energy of induced currents

The force on the wire can be found from

$$F_{wire} = BIl = B \left(\frac{v l B}{R} \right) l$$

$$F_{wire} = \frac{v l^2 B^2}{R}$$



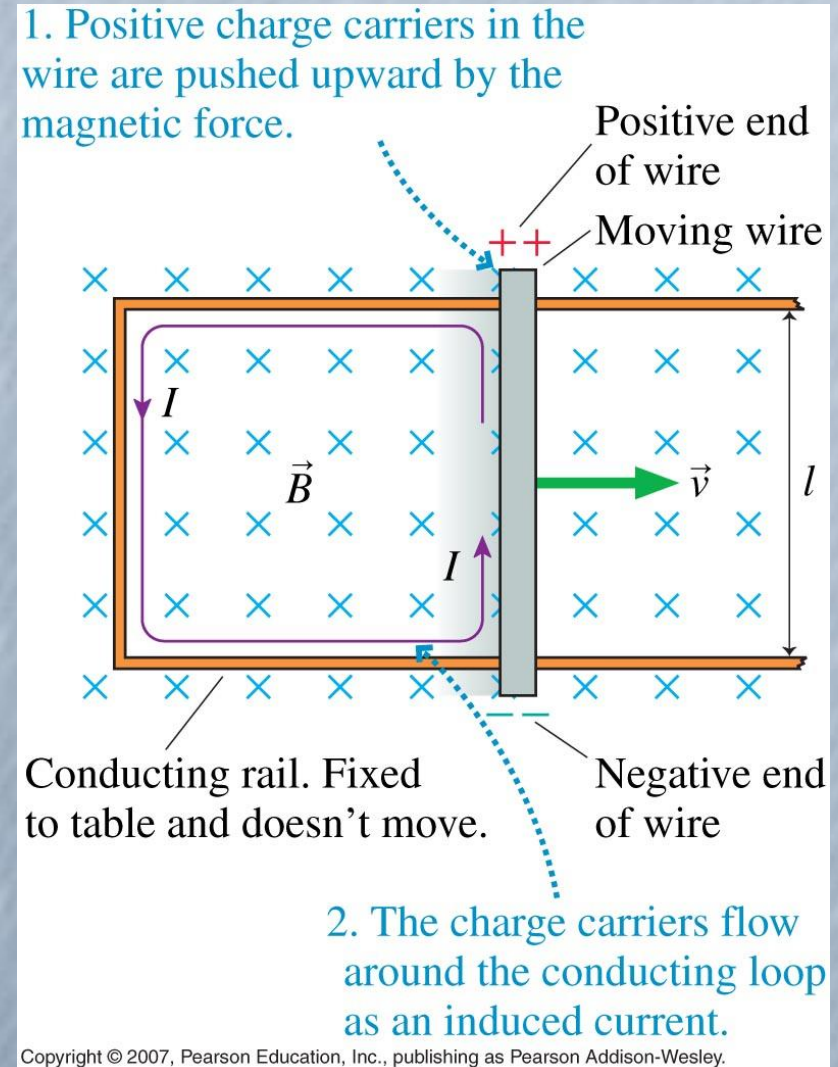
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Energy of induced currents

We can substitute for the power needed to drag the wire, and the power dissipated by electrical resistance

$$P_{input} = F_{wire} v = \frac{v^2 l^2 B^2}{R}$$

$$P_{output} = I^2 R = \frac{v^2 l^2 B^2}{R}$$

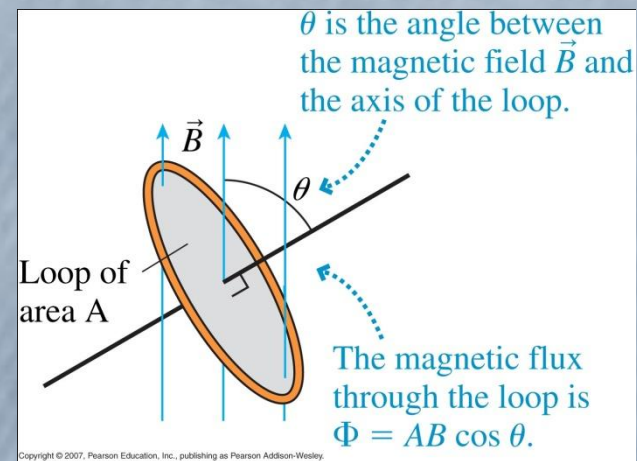


Magnetic flux

In order to calculate a changing magnetic field, or the changing field seen by a wire moving through a magnetic field, we need a new quantity, **magnetic flux**.

A loop of wire, area A , in a magnetic field, B , at angle θ , is said to have a magnetic flux, Φ :

$$\Phi = AB \cos \theta$$

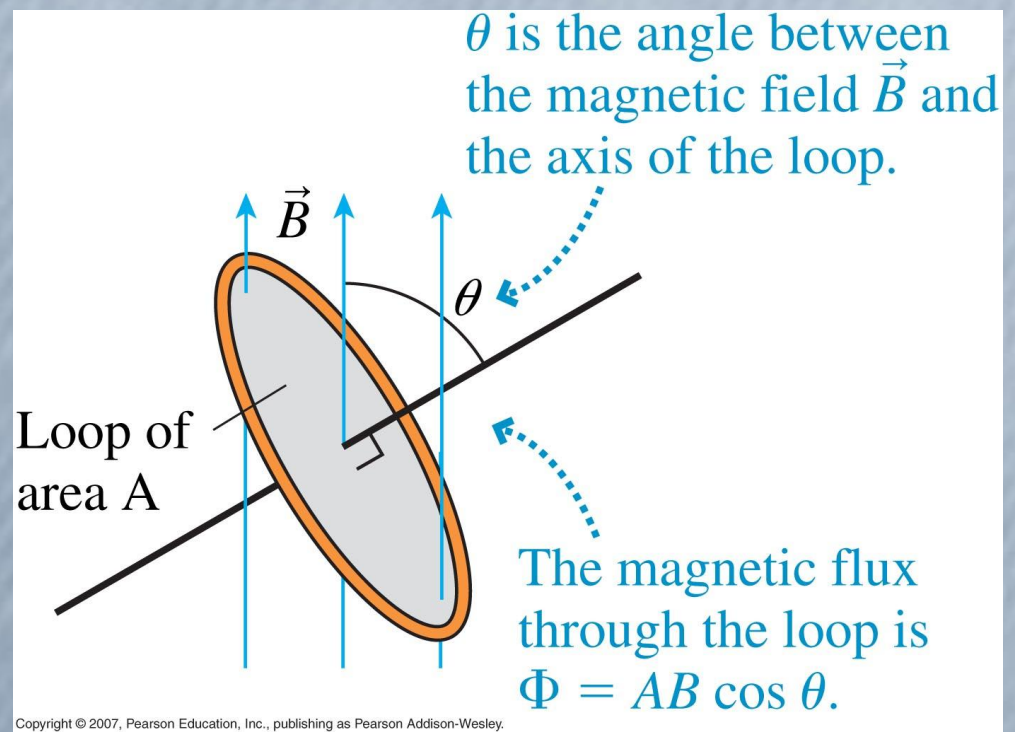


Magnetic flux

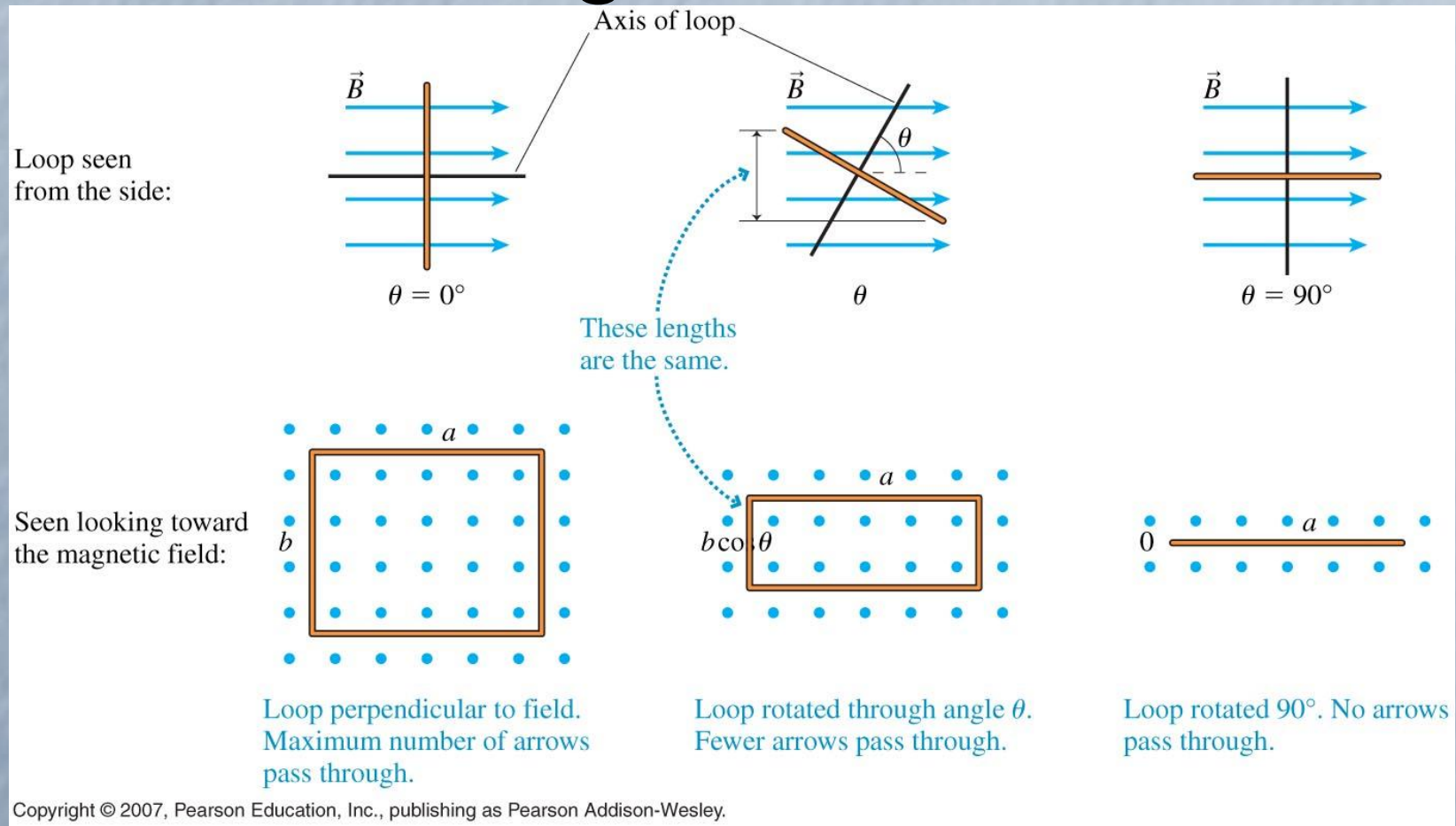
A loop of wire, area A , in a magnetic field, B , at angle θ , is said to have a magnetic flux, Φ :

$$\Phi = AB \cos \theta$$

Units: Tm^2 or weber



Magnetic flux



$$\Phi = AB \cos \theta$$

Lenz's Law

A changing magnetic flux through a loop will induce a current in that loop.

The direction of the induced current always create a magnetic field which opposes the change in flux

Lenz's Law

Note: Flux can change in 3 ways

- The magnetic field increases or decreases
- The loop changes area or angle
- The loop moves into or out of a magnetic field

A loop moving through a uniform B field won't induce a current.

Faraday's Law

Faraday's law tells us the magnitude of the V_{emf} , or \mathcal{E} in a coil is equal to the rate of change of magnetic flux:

$$\mathcal{E} = \frac{\Delta\Phi}{\Delta t}$$

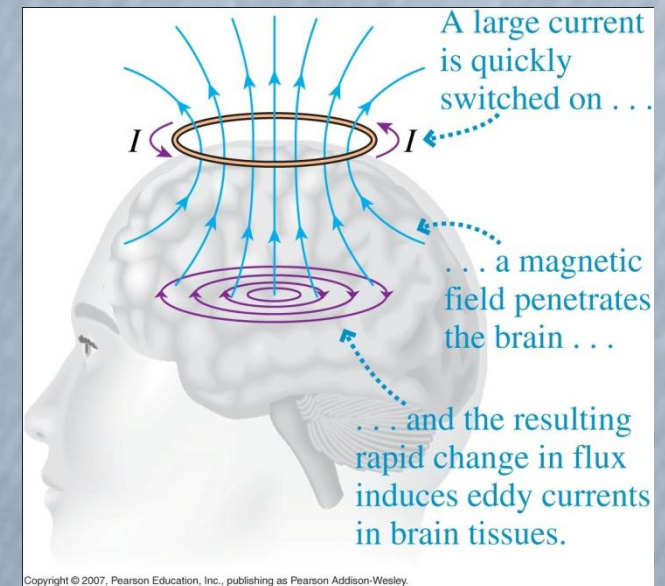
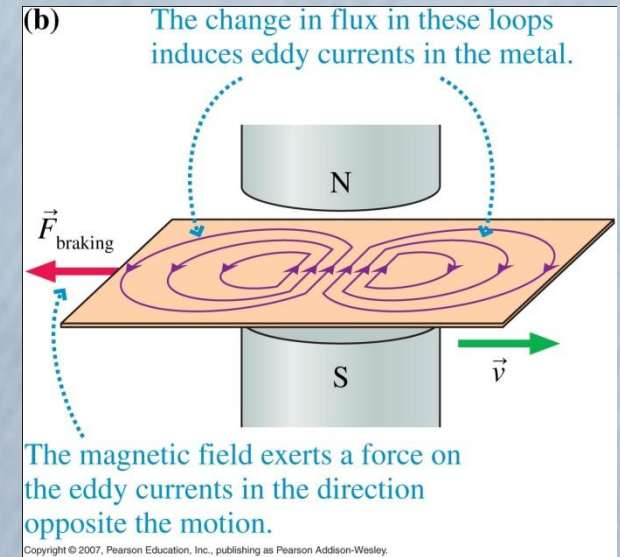
Faraday's Law

If there are N loops in a coil, the total V_{emf} , or \mathcal{E} in the coil is equal to the rate of change of magnetic flux times N :

$$\mathcal{E} = N \frac{\Delta\Phi_{\text{coil}}}{\Delta t}$$

Eddy Currents

- The induced currents which are opposing the motion of the conductor are called **eddy currents**
- Occur in magnetic braking, induction heating.
- And as a treatment for migraine and depression – Transcranial magnetic stimulation



Induction for fields

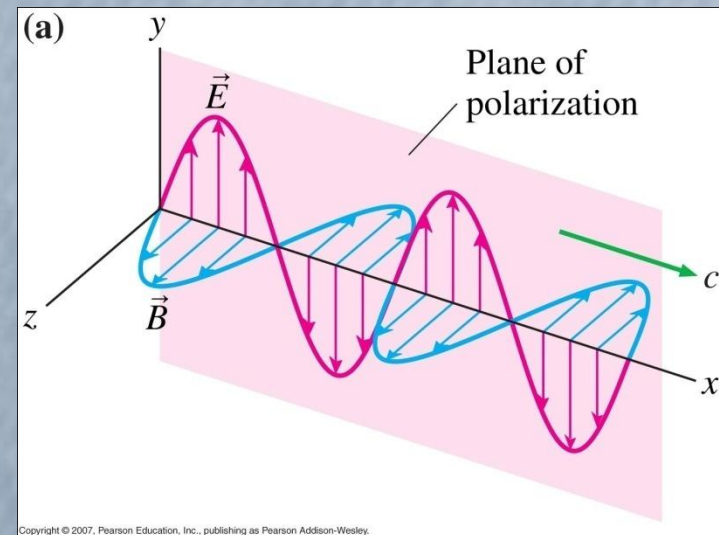
- Faraday's Law states a changing magnetic field produces an electric field.
- James Clerk Maxwell in 1865 proposed that a changing electric field produces a magnetic field.
- Its very difficult to see the magnetic field – it's smaller by a factor:

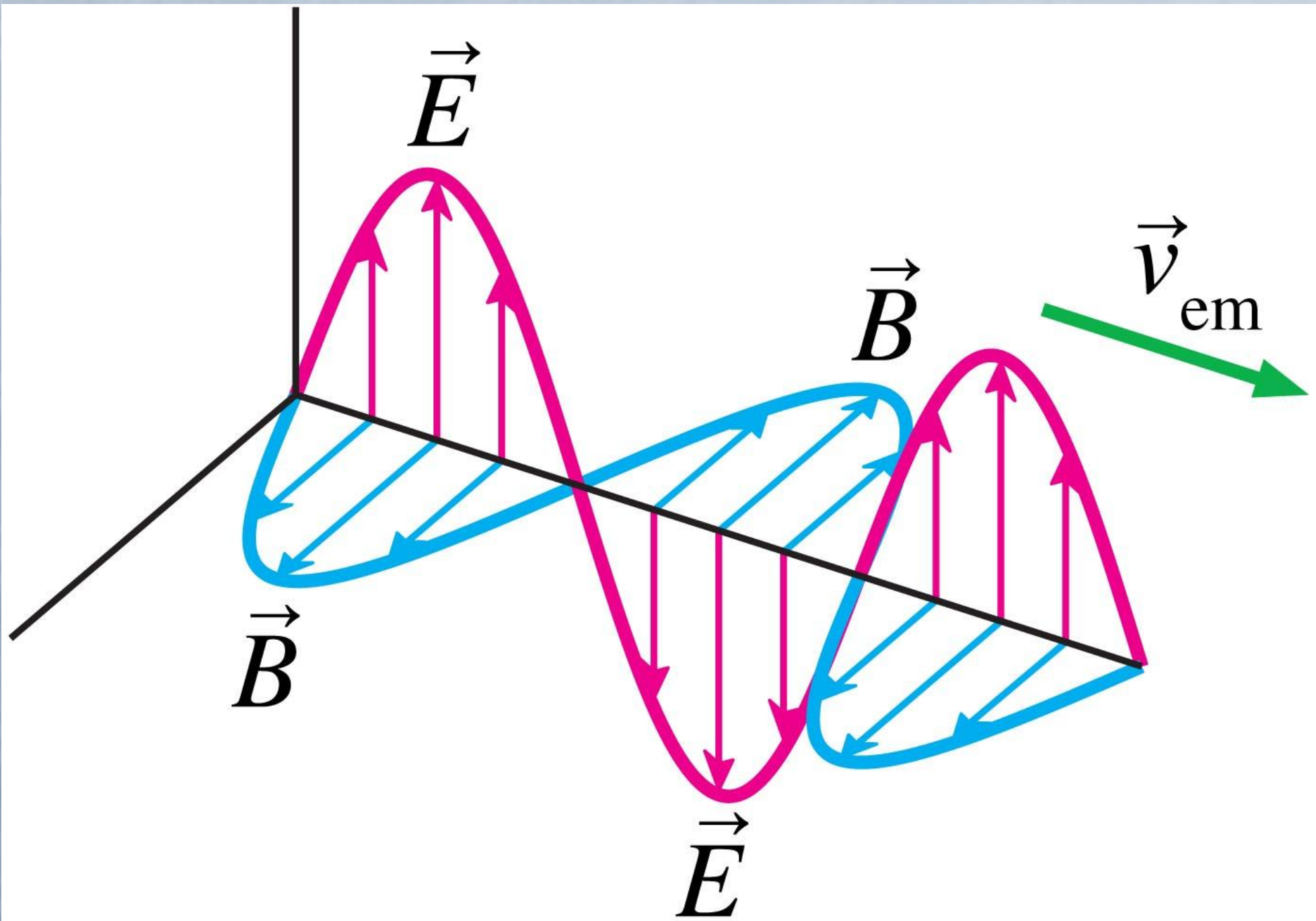
$$B = \frac{E}{\sqrt{\epsilon_0 \mu_0}}$$

Induction for fields

- Numerically, this factor turned out to be the speed of light, c , in a vacuum – 299,792,458m/s
- He proposed light was a wave made from changing of electromagnetic fields.

$$B = E\sqrt{\mu_0\epsilon_0} = \frac{E}{c}$$





Properties of Electromagnetic Waves

In Chapter 14-20 (Section IV) we will learn more about waves.

Property of waves is that the frequency f , of waves with a wavelength, λ , are related to the speed of the waves, c

$$c = \lambda f$$

Energy in Electromagnetic waves

The intensity, I , of a wave, is defined as the power per unit area:

$$I = \frac{P}{A}$$

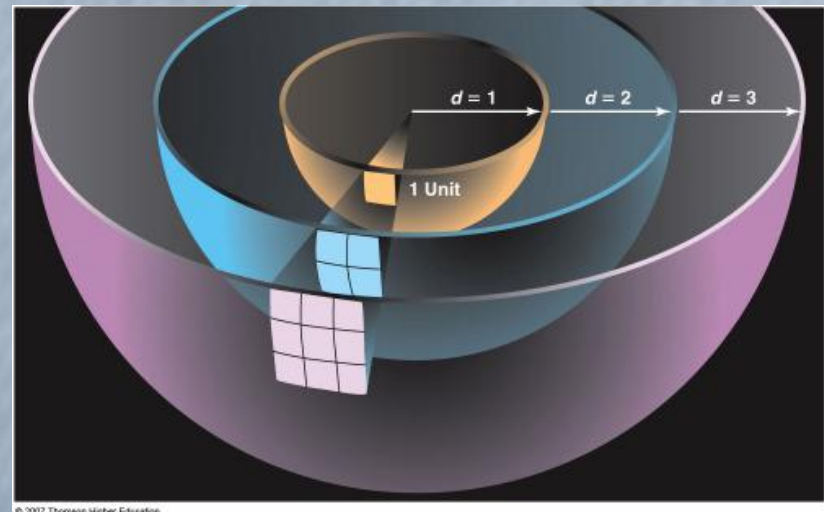
Units of $\text{J s}^{-1} \text{ m}^{-2}$.

Energy in Electromagnetic waves

For a point source – the area A , is the area of a sphere:

$$I = \frac{P_{\text{source}}}{4\pi r^2}$$

Units of $\text{J s}^{-1} \text{ m}^{-2}$.

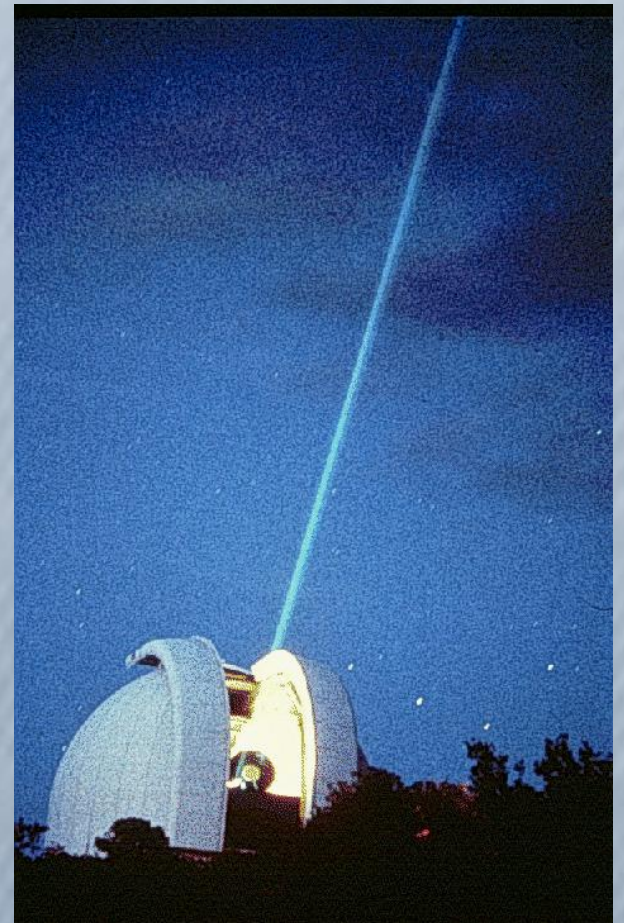


Energy in Electromagnetic waves

For a laser, the area is constant, no dependence on r .

$$I = \frac{P_{\text{laser}}}{A_{\text{beam}}}$$

Units of $\text{J s}^{-1} \text{m}^{-2}$.



Energy in Electromagnetic waves

We can show that

$$I = \frac{P}{A} = \textit{EnergyDensity} \times \textit{Velocity}$$

Remember the energy density of an electric field is

$$u = \frac{1}{2} \epsilon_0 E^2$$

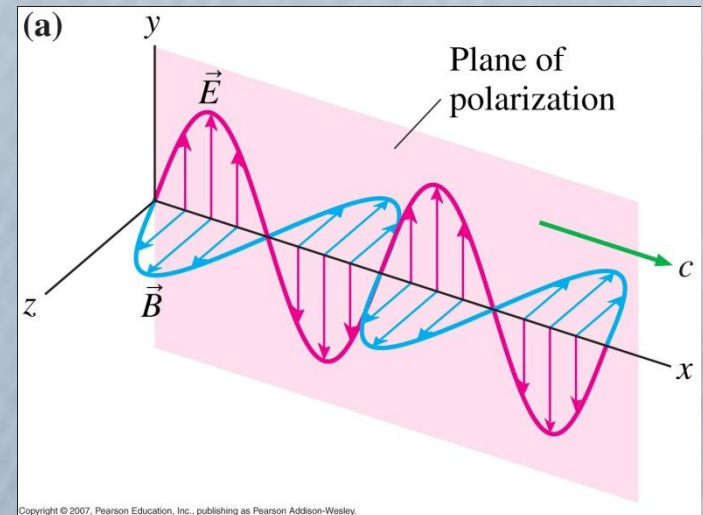
Energy in Electromagnetic waves

The Intensity of an Electromagnetic wave is

$$I = \frac{P}{A} = \frac{1}{2} c \epsilon_0 E^2 = \frac{1}{2} \frac{c}{\mu_0} B^2$$

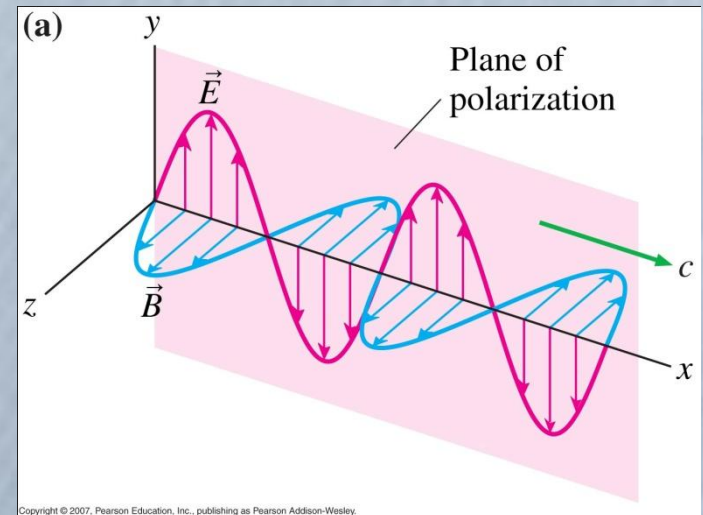
Polarization

- The electric field in this plane wave will excite free electrons as it passes through a material
- The electrons will absorb energy from the wave.
- If the electrons can only move in one direction, the absorption is directional



Polarization

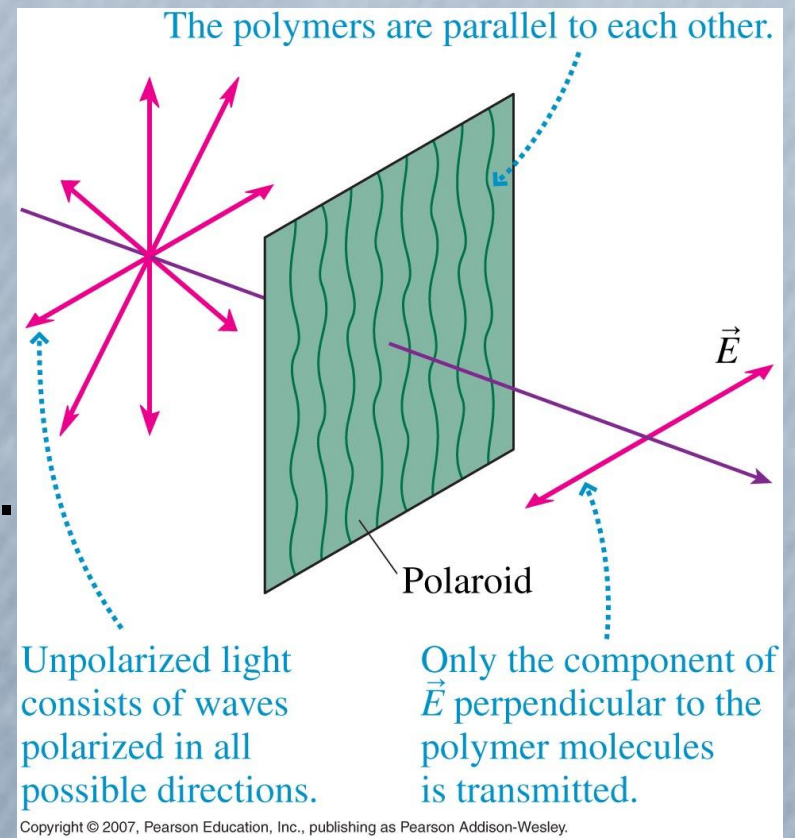
- The absorber needs to be of similar dimensions as the wave.
- Radio waves – cm distances
- Light waves – μm distances



Polarization

- Polaroid can be thought of chains of molecules, where electrons are free to travel along the chains
- If the E field lines up with the chains, then the energy in the EM wave is absorbed.

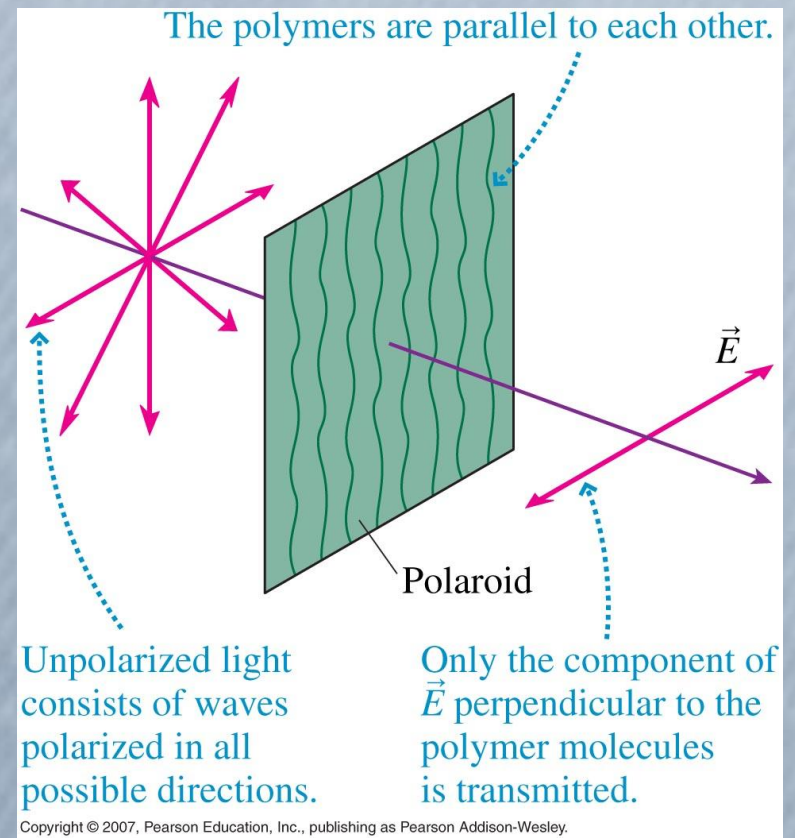
$$E_{transmitted} = E_{incident} \cos \theta$$



Polarization – Malus' law

- I is proportional to E^2 .
- Intensity goes as $\cos^2\theta$
- Malus' Law relates the transmitted to the incident intensities:

$$I_{transmitted} = I_{incident} \cos^2 \theta$$



Notes on Polarization

We've spoken about linear polarization, we can also have circular polarization, where the plane of the polarization rotates about the direction of travel.

Polarization also happens in reflection and scattering.

Photons or Waves ?

In some experiments, it is useful to think of EM radiation not as waves, but as particles – called **photons**.

The energy of the photon is related to the wavelength, or frequency, where h is Planck's constant, $h=6.63 \times 10^{-34}$ Js

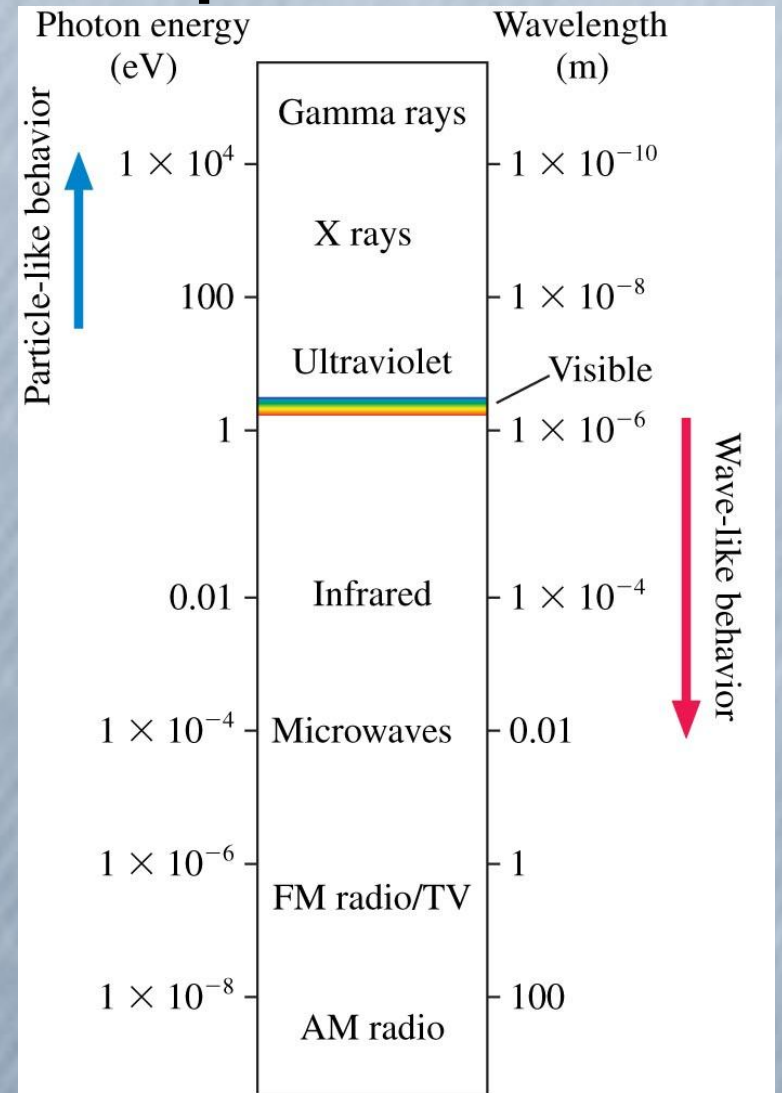
$$E_{\text{photon}} = hf = \frac{hc}{\lambda}$$

The Electromagnetic Spectrum

The electromagnetic spectrum is a categorization of all electromagnetic waves by frequency, wavelength or photon energy.

$$f = \frac{c}{\lambda}$$

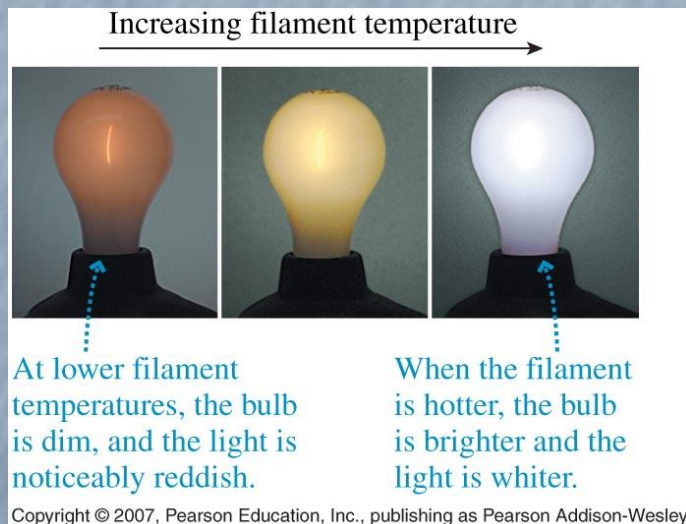
$$E_{\text{photon}} = hf$$



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Radiation from a heated material

- In chapter 12, the power radiated by a body at temperature T is described from Stefan's Law.
- Where e is the emissivity (property of the material), σ is the Stefan-Boltzmann constant and A is the area

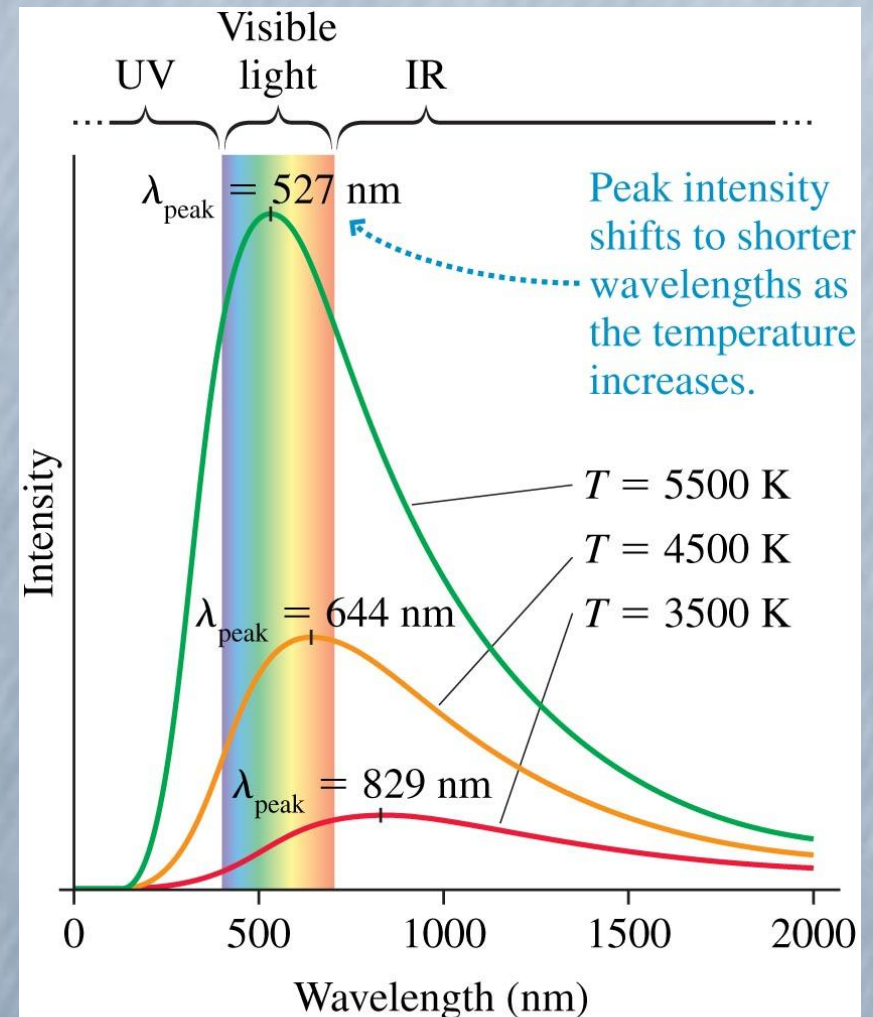


$$\frac{Q}{\Delta t} = e \sigma A T^4$$

The color of a material at temperature T

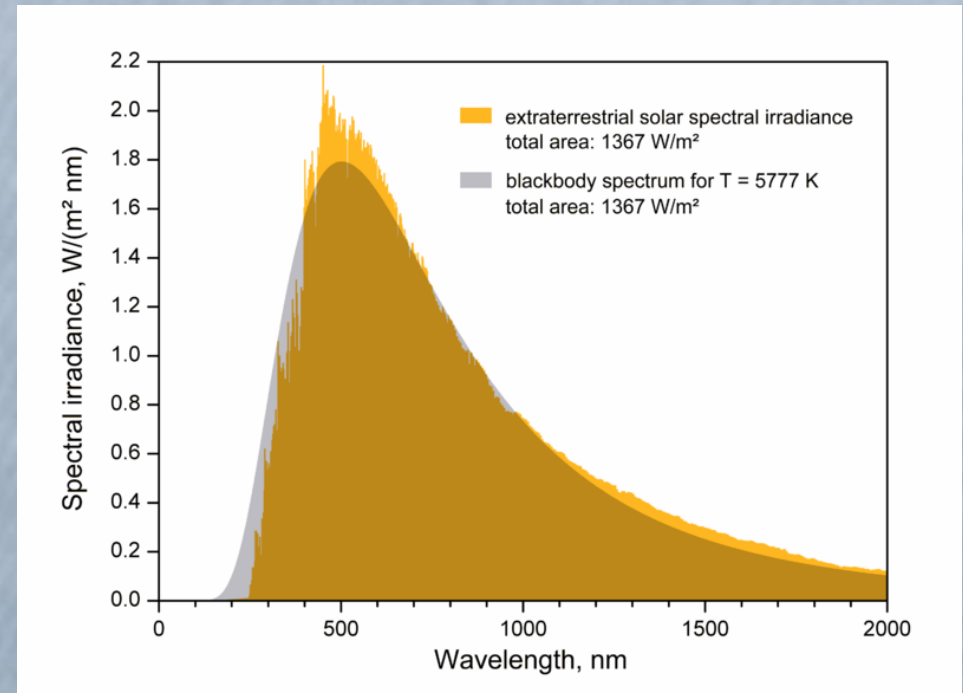
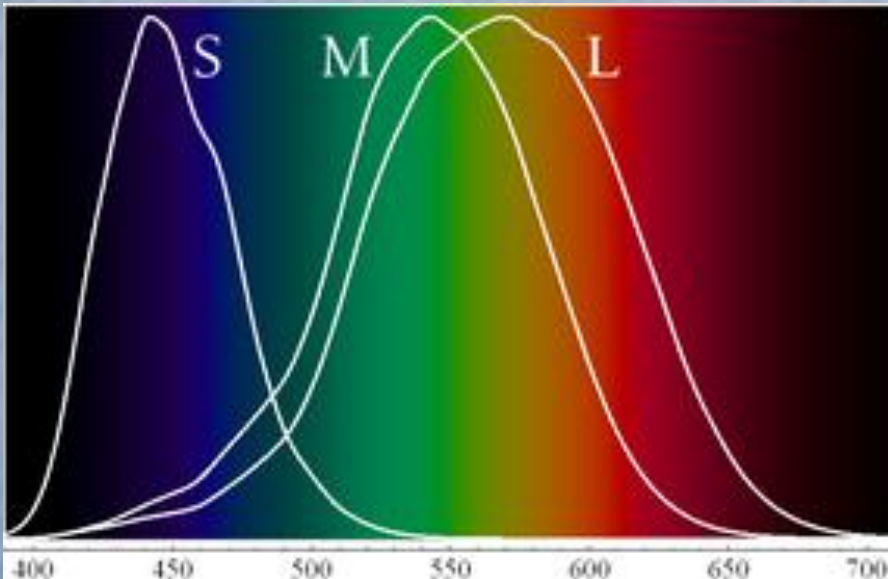
The peak wavelength of the EM radiation emitted by a material at temperature T is described by Wien's Law

$$\lambda_{peak}(nm) = \frac{2.9 \times 10^6 nm \cdot K}{T}$$



Visible radiation

Color is a neurological response in humans – we have 3 primary colors because we have 3 types of sensors. Their response is near the peak wavelength from the Sun



Maxwell's Equations

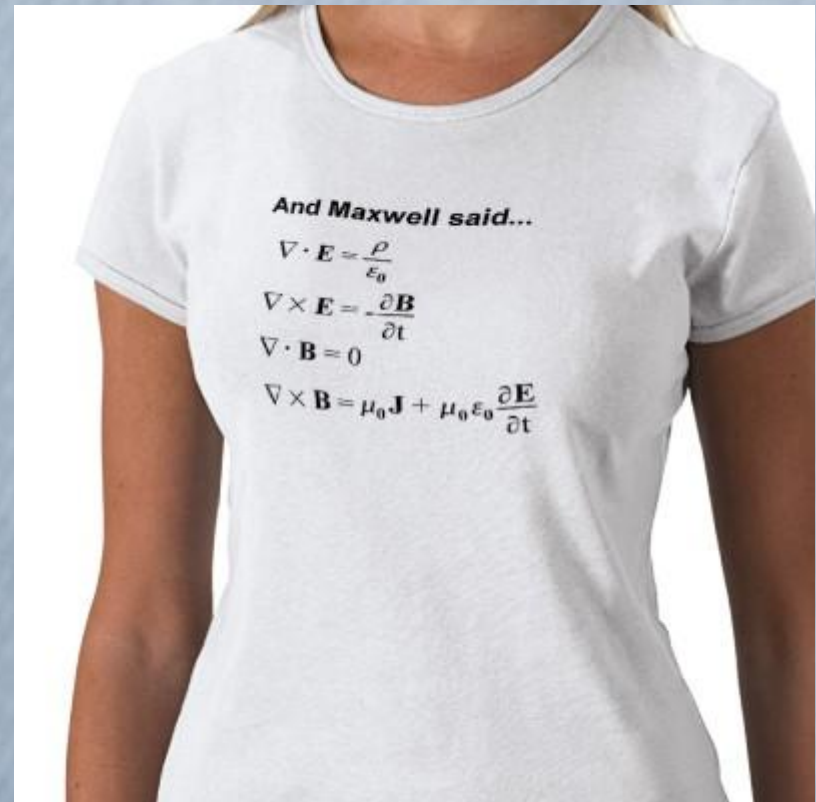
All of Electromagnetism in
four equations

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$



Summary

- EM induction of electric currents
- Effects of moving conductors in B fields
- Effects of conductors in changing B fields
- Eddies
- Electromagnetic Waves
- Polarization, Photons
- Electromagnetic spectrum

Homework problems

Chapter 25 Problems

46, 50, 52, 55, 56, 57, 61, 64