Week 1: Everything Is Electric
Week 2: Is It Magic, or Is It Magnets?
Week 3: On Your Wavelength: Electromagnetic Waves
Week 4: Physics of Sound & Music
Week 5: Energy, Thermodynamics & The Arrow of Time
Week 6: Push and Pull: Force & Motion
Week 7: Go With the Flow: Physics of Fluids
Week 8: A Warm Planet in a Cold Universe: How the Earth Stays Warm, and Why It's Getting Warmer

Physics Principles

Remember: Changing Magnetic Fields Induce Electric Fields

Changing Electric Fields Induce Magnetic Fields

Electromagnetic Waves

Polarization

Different Wavelengths Are Different

Photon Energy

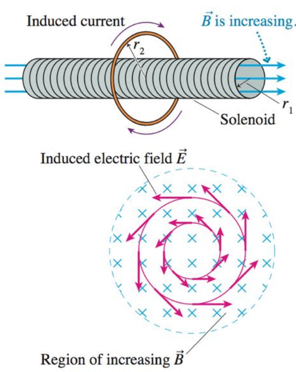
Changing Magnetic Fields Create Electric Fields

Magnetic information storage

A changing magnetic field induces an electric field.

A changing electric field induces a magnetic field too.

One of the coolest things ever discovered



Unifying Electricity and Magnetism

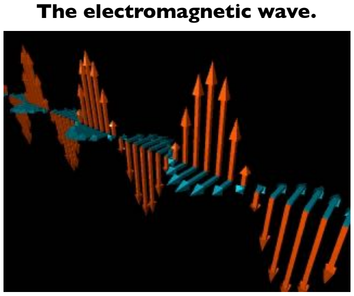
$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$$

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

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

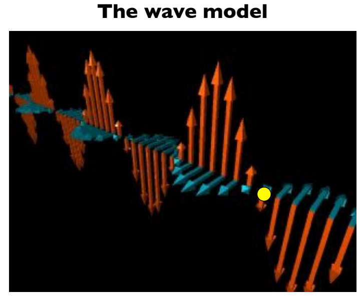
$$\nabla \times \vec{B} = \mu_0 \vec{j} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

The electromagnetic wave.



An oscillating charge will emit an electromagnetic wave.
It's a wave of electric and magnetic fields.

The wave model



One way to think about them.

Energy Scale

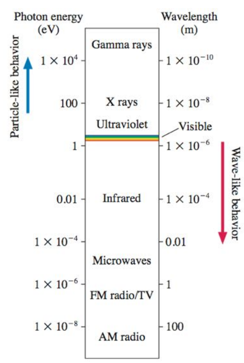
Process	Energy
Breaking a hydrogen bond between two water molecules	0.24 eV
Energy released in metabolizing one molecule of ATP	0.32 eV
Breaking the bond between atoms in a water molecule	4.7 eV
Ionizing a hydrogen atom	13.6 eV

1 eV is about the minimum amount of energy to make something happen at an atomic scale.

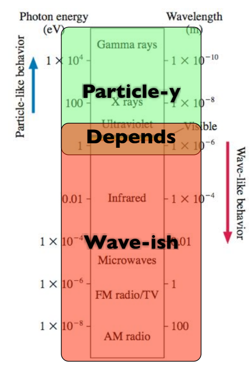
The Electromagnetic Spectrum

Wave	Wavelength	Photon energy
FM Radio	10 feet	½ millionth eV
Microwave	6 inches	8 millionths eV
Thermal Radiation	1/10 of a hair	1/10 eV
Red	10x red blood cell	2 eV
Blue	6x red blood cell	3 eV
Ultraviolet	4x red blood cell	4 eV

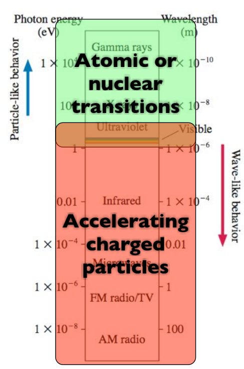
The Electromagnetic Spectrum



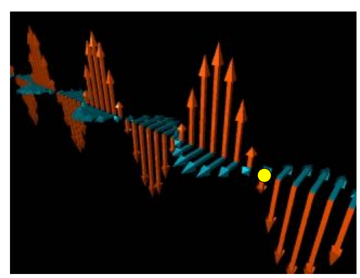
The Electromagnetic Spectrum



Making Waves



Radio waves

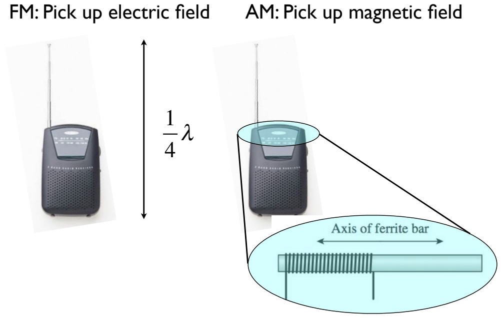


Electric field vertical, magnetic field horizontal.

FM & AM Radio

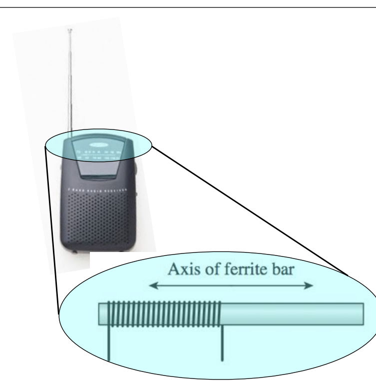
FM: Pick up electric field

AM: Pick up magnetic field



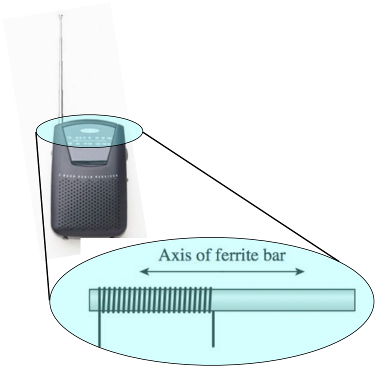
AM Radio

Where is the station?



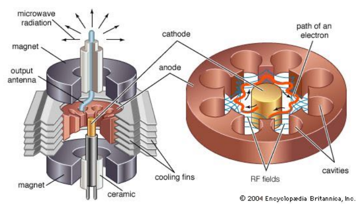
AM Radio

What else can it pick up?



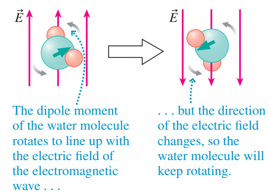
Why must an antenna be on the outside of the car?

Microwave Oven



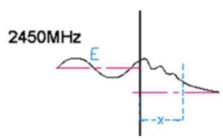
High intensity electromagnetic waves, with large electric fields

Microwave Oven



High intensity electromagnetic waves, with large electric fields

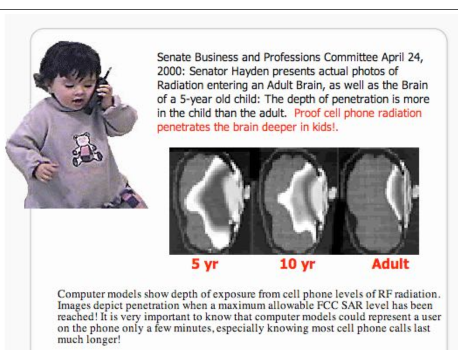
Microwave Oven



Penetration depth is 1-3", depending on material

High intensity electromagnetic waves, with large electric fields

The wavelength of the radiation from your phone is about the same as that of your microwave oven.



Talking On the Phone... How Dangerous?

The microwaves from a cell phone have the following properties:

P = 0.60 W
f = 1.9 GHz

$$I = \frac{0.60\ \text{W}}{4\pi(0.050\ \text{m})^2} = 19\ \text{W/m}^2$$

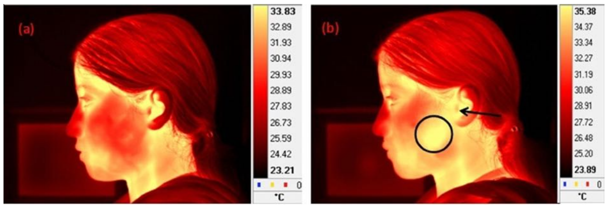
$$E_0 = 120\ \text{V/m}$$

$$E_{\text{photon}} = 7.9\ \mu\text{eV}$$

Sunlight: 1000 W/m²

Inside cells: 10,000,000 V/m

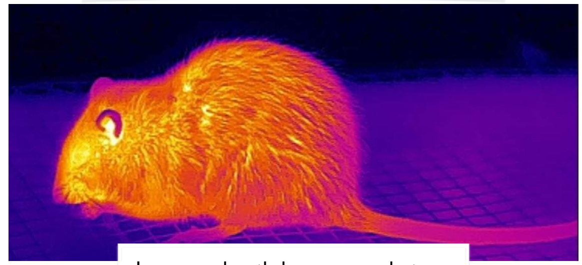
Breaking DNA: 4 eV



1 minute on the phone

15 minutes on the phone

Thermal Radiation



Long wavelength, low energy photons.

Warming the Walls

A human has about 1.8 m² of skin. If a person is unclothed in dry air of 24°C (75 °F), the skin will be about 33°C.

Suppose this unclothed person is taking part in a study of thermal comfort. The air will be kept at 24°C, but the temperature of the room's walls will be varied.

a. How much energy does the person's body radiate away?
b. Suppose the walls of the room are 24°C, the same as the air. How much energy does the person absorb by radiation?
c. What is the net loss of energy by radiation?
d. Now suppose the walls are much colder than the air temperature: 10°C (50 °F). (This would be quite cold to the touch.) What will be the net loss by radiation now?

a) P = 870 W
b) P = 770 W
c) P = 100 W
d) P = 235 W

Sit in a room with warm air and cold walls

or

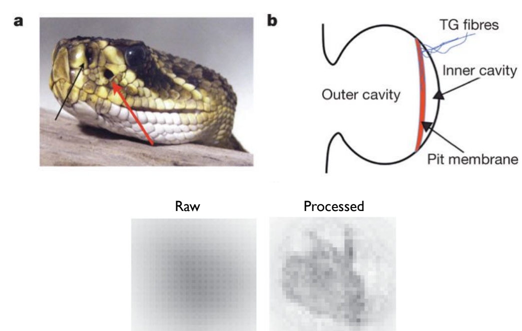
Pull down your trousers and sit on a cold steel bench?

Warming the Bench

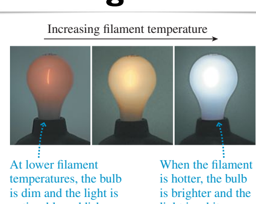
Suppose you are sitting, naked, on a steel bench with a temperature of 0°C (The only thing insulating the core of your body (temperature 37°C) is a layer of skin and fat; we'll assume that the insulation is comparable to a layer of fat 1.2 cm thick. The area in contact with the bench is 0.16 m².

What is the rate of heat loss by conduction?

100 W ← Equal to basal metabolic rate.



As things get warmer, the wavelength of emitted radiation gets shorter.



100 Watts = 4 Watts?

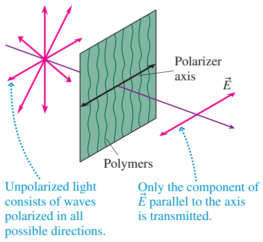
A typical incandescent lamp has a filament at a temperature of approximately 2500 °C.

What is the peak wavelength of the emission?

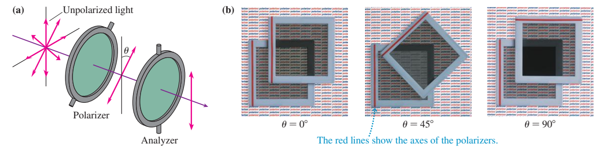
$$\lambda_{\text{peak}} = \frac{2.9\times10^{6}\ \text{nm}\cdot\text{K}}{2773\ \text{K}} = 1050\ \text{nm}$$

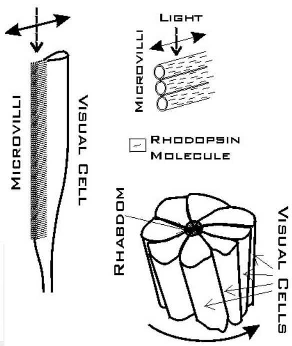
Polarization

FIGURE 25.28 A polarizing filter.



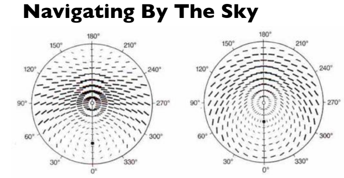
Polarization



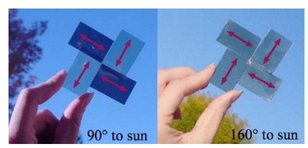


Detection depends on polarization

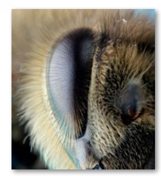
Navigating By The Sky



Polarization of skylight



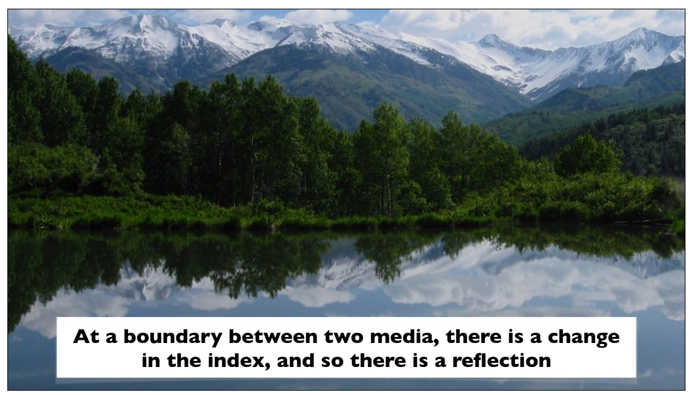
Bee eyes detect polarization



The Index of Refraction

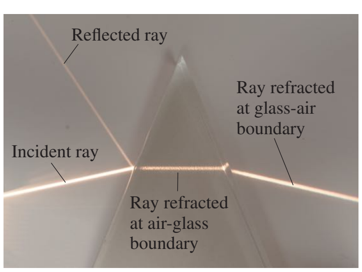
$$n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the material}} = \frac{c}{v}$$

The index of refraction determined by the speed of light in a material

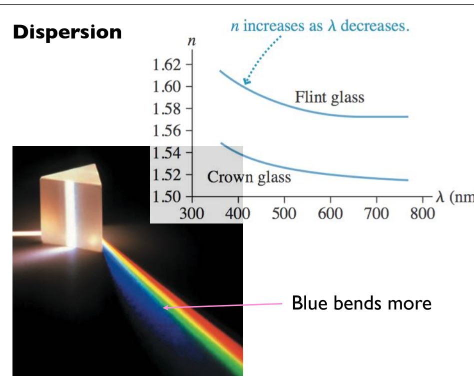


At a boundary between two media, there is a change in the index, and so there is a reflection

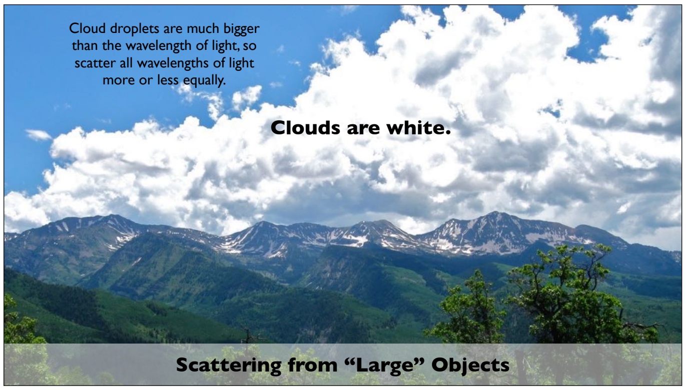
A difference in index causes bending (refraction) too.



Dispersion



Blue bends more

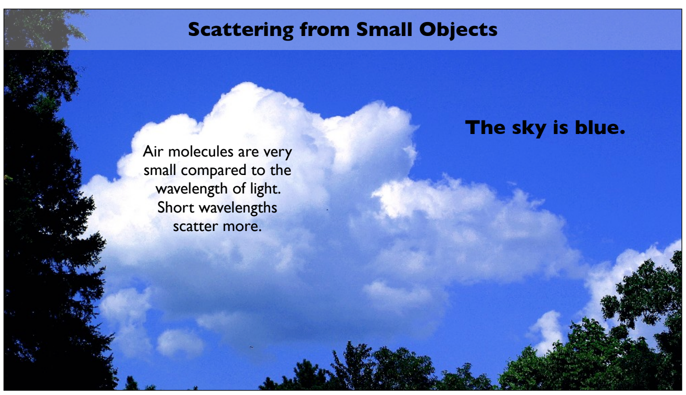


Skin is made of transparent components, with differing indices of refraction. The size of the elements is a bit larger than the wavelength of light, so all colors scatter equally.

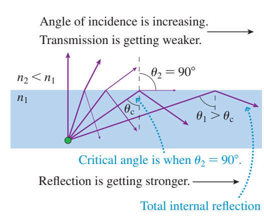
Net result: No pigment means white skin.

Not white.
Transparent.

Match index of refraction: Transparent.



Total Internal Reflection



$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Critical angle of incidence for total internal reflection

Making a Rainbow