EXPLAIN:

1. Energy and Radiation

Defining Energy is Hard!

- "Energy is the capacity to perform work"
  - (but physicists have a special definition for "work," too!)
- Part of the trouble is that scientists have "appropriated" common English words and given them special meanings
- But part of the trouble is that the concept is absolutely central to understanding the physical world, so deeply buried in our language it's hard to get our heads around

Conservation of Energy

- Energy can be stored
- Energy can move from one piece of matter to another piece of matter
- Energy can be transformed from one type of energy to another type of energy
- **The First Law of Thermodynamics:**
  - **During all this moving and transforming the total amount of energy never changes.**

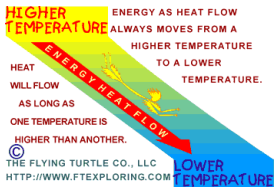
Kinds of Energy

- Radiant Energy -- light
- Kinetic Energy -- motion
- Gravitational Potential Energy -- height
- "Internal Energy"
  - Temperature, Pressure -- hot air
  - Chemical energy
  - Nuclear energy
- Transfers and conversions among different kinds of energy power everything that happens in our climate!

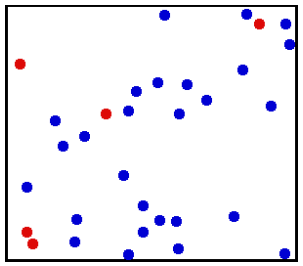
If Energy is Conserved …

then why do we need to "conserve energy?"

- Total energy is conserved (First Law), but not its usefulness!
- Second Law of Thermodynamics: Energy flows "downhill" from highly concentrated (hot) forms to very dilute (cold) forms



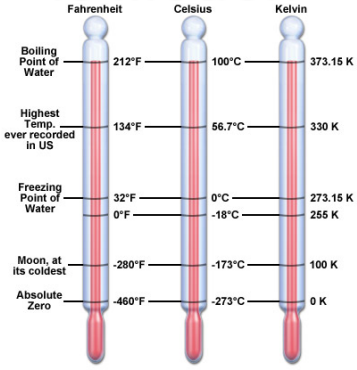
- Gasoline burned in your car (hot) makes it move
- Turbulence and friction of tires on road dissipated as heat
- Heat radiated to space (cold)



Temperature is Motion

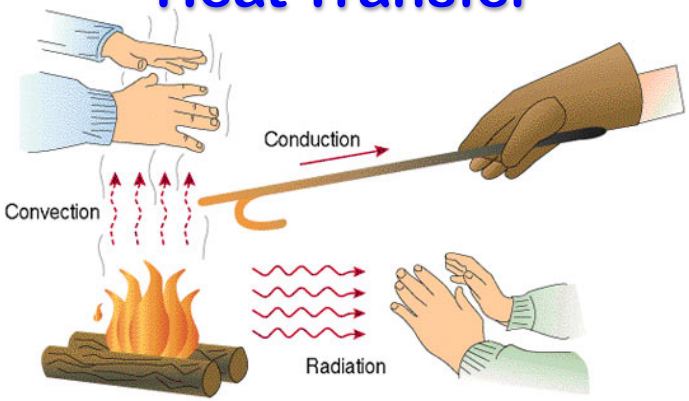
Temperature is a measure of the average kinetic (motion) energy of molecules

- K.E. = ½ mv^2
  m = mass, v = velocity
- So…temperature is a measure of air molecule speed (squared)



Thermometers are speedometers!

Heat Transfer



Conduction is by hot molecules colliding with neighbors
Convection is by hot stuff moving in bulk from place to place

Electromagnetic Radiation

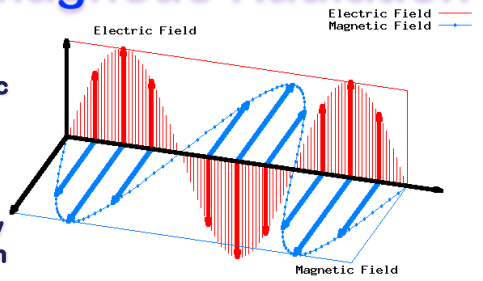
Changing electric fields create changing magnetic fields …

and vice versa!

This makes energy move even through empty space

We can see it, feel it

Plants harvest it directly, and we harvest them!



Travels at 3×10^8 m/s
= 186,000 miles / sec !

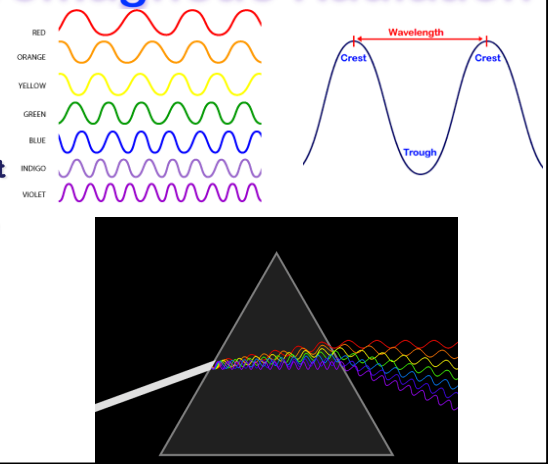
Distance it goes in one cycle is called the wavelength

Electromagnetic Radiation

Radiation travels as waves or photons

Waves do not require molecules to propagate

Shorter waves carry more energy than longer ones



Electromagnetic Radiation

Radiation travels as waves or photons

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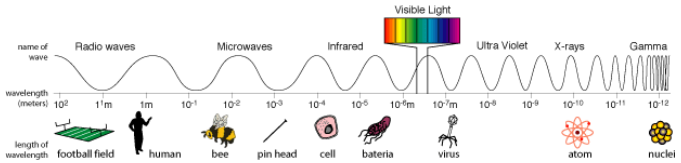
Shorter waves have more energy than longer waves

TYPE OF RADIATION	RELATIVE WAVELENGTH	TYPICAL WAVELENGTH (meters)
AM radio waves		100
Television waves		1
Microwaves		10^{-3}
Infrared waves		10^{-6}
Visible light		5×10^{-7}
Ultraviolet waves		10^{-7}
X rays		10^{-9}

Wavelength

Increasing

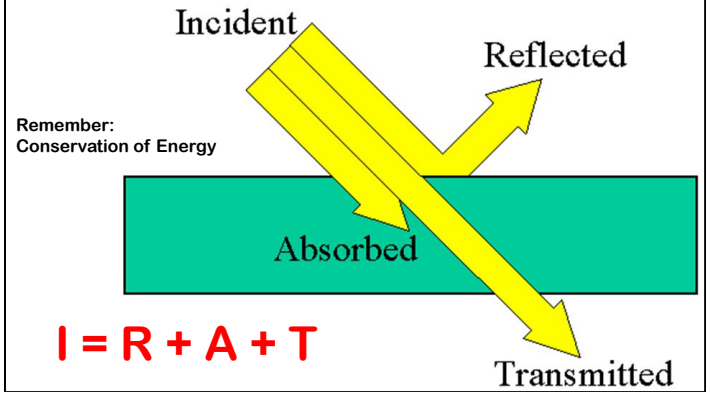
Electromagnetic Radiation Spectrum



Shorter waves carry more energy than longer waves

Electromagnetic waves interact with matter at similar scales (sizes) as the waves

When Radiation Meets Matter



Remember:
Conservation of Energy

$I = R + A + T$

Reflection

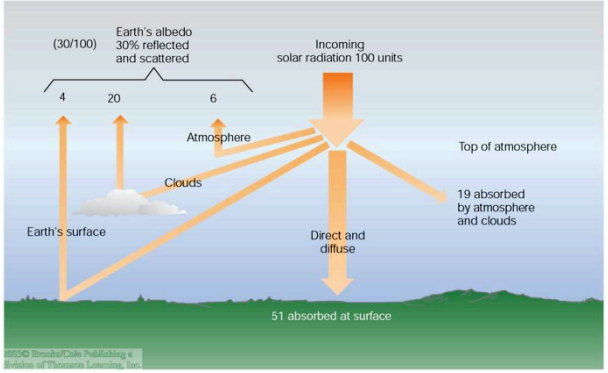
- Albedo: the fraction of incoming radiation that gets reflected
- Surface albedo varies according to the material
  - Spatially
  - Temporally

TABLE 2.3 Typical Albedo of Various Surfaces

SURFACE	ALBEDO (PERCENT)
Fresh snow	75 to 95
Clouds (thick)	60 to 90
Clouds (thin)	30 to 50
Venus	78
Ice	30 to 40
Sand	15 to 45
Earth and atmosphere	30
Mars	17
Grassy field	10 to 30
Dry, plowed field	5 to 20
Water	10*
Forest	3 to 10
Moon	7

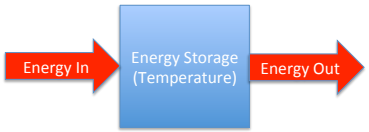
*Daily average.

Solar Radiation



- 30% reflected by clouds, air, dust, and surface
- 19% absorbed by the atmosphere (mostly clouds)
- 51% absorbed at the surface

An Energy Budget

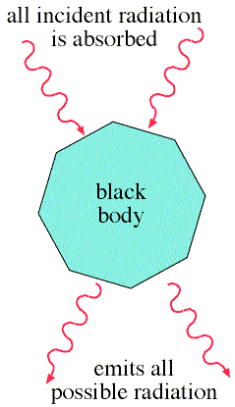


- Total energy is conserved
- Energy in – energy out = change in storage (related to temperature)
- Energy out depends on temperature!

Thermal Radiation

"Everything emits heat"

"Black Body"

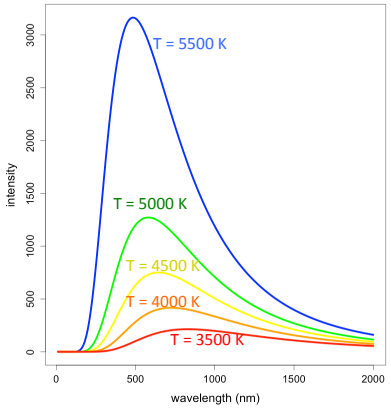


Just an idea, really …

- Idealized object that absorbs all radiation that falls on it
- No transmission, no reflection, just absorption and emission
- Emits energy according to temperature

Blackbody Emission

- Hot objects emit *much* more than cold objects at every wavelength
- Peak emission at shorter waves at higher temperatures

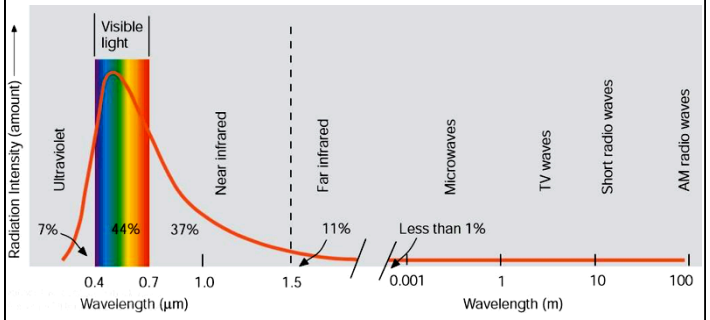


Energy and Power

- Energy is an intrinsic property of an object, measured in Joules
- Power is a rate of transfer of energy, or a flow of energy, measured in Joules per second
- We define:

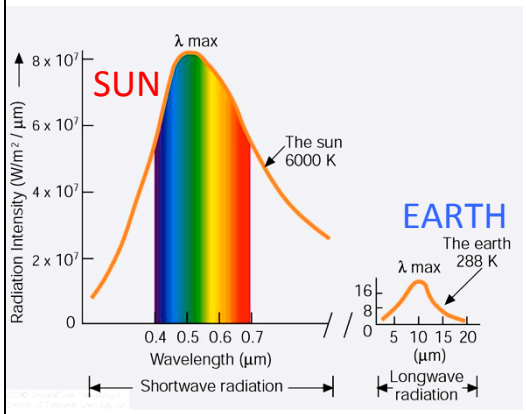
  1 Joule per second = 1 Watt

Solar Emission



Solar radiation has peak intensities in the shorter wavelengths, dominant in the region we know as visible, but extends at low intensity into longwave regions.

Emission: Sun & Earth

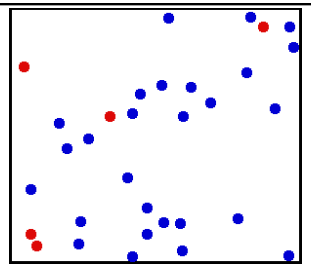


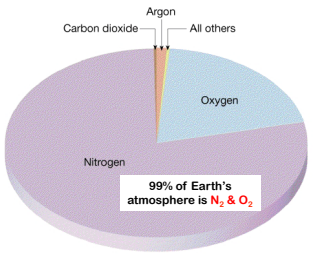
Both are almost perfect blackbodies!

The hot sun radiates at shorter (visible) wavelengths that carry more energy

Energy absorbed by the cooler earth is then re-radiated at longer (thermal infrared) wavelengths

Greenhouse Gases



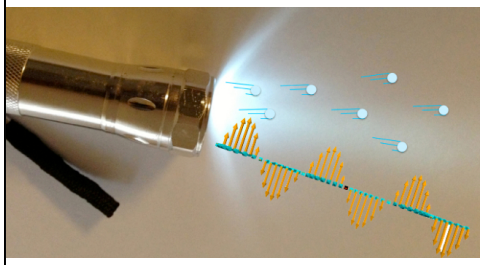


Gases

- Gases are made of moving molecules separated by empty space
- Kinetic energy of molecular motion is proportional to temperature
- Gases don't behave as blackbodies or even graybodies!
- Let's take a look!

Waves *and* Photons

Electromagnetic radiation behaves as both waves and particles!



Long Waves = small photons

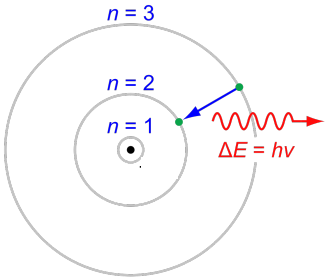
Short Waves = BIG PHOTONS

Experiments show both kinds of behavior:

- Oscillating fields with troughs and crests (waves)
- Individual packets of energy (particles)

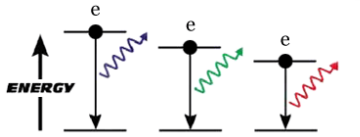
Energy is "Quantized"

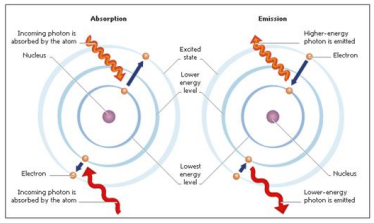
- When radiation interacts with atoms and molecules, only certain "jumps" in energy are possible
- Electrons orbit at specific energy levels above an atomic nucleus
- Absorption of a photon of just the right energy can make them "jump up" to the next level



- Emission of a photon occurs when an electron "falls" down to a level below

UV & Visible Light

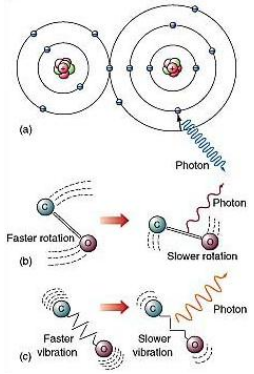




- Big jumps take lots of energy, small jumps take less
- Big drops emit energetic photons (short wavelengths)
- Small drops emit less energetic photons (longer wavelengths)

Most electron transitions in gases absorb/emit visible or UV light

Molecules and IR light

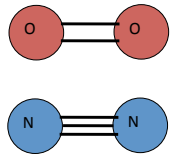


- Molecules are groups of atoms that share electrons (chemical bonds)
- Molecular transitions involve changes in vibration, rotation, bending, and stretching of chemical bonds
- Photons can interact with molecules to change states
- Transitions involve specific amounts of energy, so only certain wavelengths are active

Molecular transitions typically absorb & emit in thermal infrared

Dancing Molecules and Heat Rays!

- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which two atoms of the same element share electrons



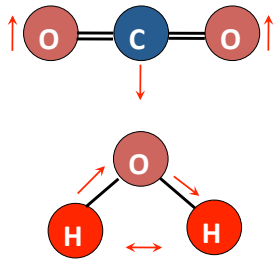
- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well

Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

No electric dipole!

Dancing Molecules and Heat Rays!

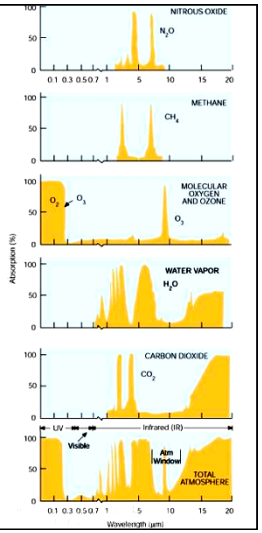
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



Molecules that have many ways to wiggle are called "Greenhouse" molecules

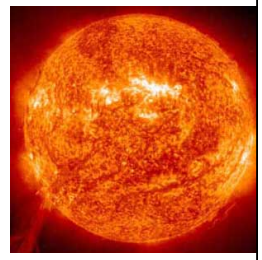
Atmospheric Absorption

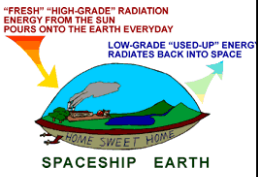
- Visible radiation passes almost freely through Earth's atmosphere
- Earth's emitted thermal energy either fits through a narrow "window" or is absorbed by greenhouse gases and reradiated
- Complete absorption from 5-8 mm (H_2O) and > 14 mm (CO_2)
- Little absorption between about 8 m and 11 mm ("window")



Follow the Energy

- Nuclear fusion in the Sun powers all changes on the Earth!
- Solar energy heats the air, lifts it, blows it around, evaporates water, makes snowstorms
- Conversion of solar energy and downhill dissipation as heat energy drive all weather and climate phenomena
- Energy comes in hot, and goes out cold, at 340 W m^{-2}





Remember

- Energy makes things happen!
- Energy in minus energy out = change in energy
- EM Radiation is the only way for Earth to exchange energy w/ rest of universe
- Sun emits mostly visible radiation, Earth emits mostly thermal infrared
- Atmosphere absorbs & emits in IR too!