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Introduction to Alternative and Renewable Energy

EST1830

2. Basic Engineering Science for Energy

Overview

Overview Topics

2.1 Physics

- SI Units
- Force, Energy, Power
- Forms of energy
  1. Motion,
  2. Gravitational and mechanical
  3. Electrical Energy
     - Faraday's Law of Induction
     - Voltage, current
  4. Radiant Energy
     - Electromagnetism
  5. Thermal energy

2.2 Thermodynamics

- First Law
- Second Law

2.3 Chemistry

- Periodic Table of elements
- Stoichiometry

2.1 SI Units- again

- Electromagnetic Units
  - Charge: Coulomb (C)
  - Current: Amperes (A)
  - Electrostatic potential: Volts (V)
  - Resistance: Ohms (Ω)
- Thermal Units
  - ^oF, ^oC, Kelvin (K)

- Meter (m), Kilogram (Kg), Second (S)

- Derived units
  - Force: Newtons (N)
  - Energy: Joules (J)
  - Power: Watts (W)

Reminder of SI units

2.1 Force, Energy, Power

Example- dimensional analysis

[Velocity] v = length/time = meters/second = m/s

<u>Newton' Second Law</u>

Force = mass x acceleration

Dimensionally

Force = [mass] [velocity/second]

= [mass] [(length/time)/time]

= [Kg] [m/s^2] = Kg m/s^2

= Newton (N)

So, the force of gravity on us

$F_{gravity}$= mg = [80kg][9.8 m/s^2]= 784 N

2.1 Force, Energy, Power

Example- dimensional analysis

[Velocity] v = length/time = meters/second = m/s

<u>Kinetic Energy</u>

Energy = ½ mass x velocity^2

Dimensionally

Energy = [mass] [velocity]^2

= Kg m^2/s^2

= [Kg m/s^2][m]

= Newton-meter (N-m)

= Joule

So, your Kinetic Energy walking at 3 mph

$$E_{\text{kinetic}} = \frac{1}{2}mv^2 = \frac{1}{2}\,80\text{ kg}\left(3\,\frac{\text{miles}}{\text{hour}} \times 1609\,\frac{\text{meters}}{\text{mile}} \times \frac{1}{3600}\,\frac{\text{hours}}{\text{second}}\right)^2 = 72\text{ Joules}$$

MIT OpenCourseWare, 8.21 The Physics of Energy, Fall 2009, http://ocw.mit.edu

2.1 Force, Energy, Power

Power

Power is the rate at which energy is converted from one form to another so it is the change in energy per elapsed time: ΔE/ΔT.

Power = units of Energy per unit time

Dimensionally

Power = [energy]/[time]

= [Kg m^2/s^2]/[s]

= Joule/second (J/s)

= Watt

Power you exert climbing stairs at 0.5 meters per second

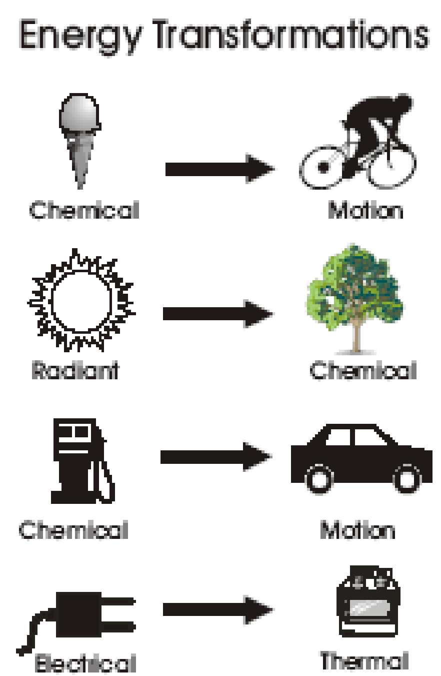
$$\Delta E = mg\Delta h = 80\,\text{kg} \times .5\,\text{m} \times 9.8\,\text{m/s}^2 = 390\,\text{Joules}$$

$$P_{\text{climbing}} = \Delta E/\Delta t = 390\ \text{Joules}\,/1\,\text{second} = 390\,\text{Watts}$$

MIT OpenCourseWare, 8.21 The Physics of Energy, Fall 2009, http://ocw.mit.edu

2.1 Forms of Energy

Potential Energy Potential energy is stored energy and the energy of position — gravitational energy. There are several forms of potential energy.	**Kinetic Energy** Kinetic energy is motion — of waves, molecules, objects, substances, and objects.
Chemical Energy is energy stored in the bonds of atoms and molecules. Biomass, petroleum, natural gas, and coal are examples of stored chemical energy. Chemical energy is converted to thermal energy when we burn wood in a fireplace or burn gasoline in a car's engine.	**Radiant Energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays and radio waves. Light is one type of radiant energy. Sunshine is radiant energy, which provides the fuel and warmth that make life on Earth possible.
Mechanical Energy is energy stored in objects by tension. Compressed springs and stretched rubber bands are examples of stored mechanical energy.	**Thermal Energy**, or heat, is the vibration and movement of the atoms and molecules within substances. As an object is heated up, its atoms and molecules move and collide faster. Geothermal energy is the thermal energy in the Earth.
Nuclear Energy is energy stored in the nucleus of an atom — the energy that holds the nucleus together. Very large amounts of energy can be released when the nuclei are combined or split apart. Nuclear power plants split the nuclei of uranium atoms in a process called fission. The sun combines the nuclei of hydrogen atoms in a process called fusion.	**Motion Energy** is energy stored in the movement of objects. The faster they move, the more energy is stored. It takes energy to get an object moving and energy is released when an object slows down. Wind is an example of motion energy. A dramatic example of motion is a car crash, when the car comes to a total stop and releases all its motion energy at once in an uncontrolled instant.
Gravitational Energy is energy stored in an object's height. The higher and heavier the object, the more gravitational energy is stored. When you ride a bicycle down a steep hill and pick up speed, the gravitational energy is being converted to motion energy. Hydropower is another example of gravitational energy, where the dam "piles" up water from a river into a reservoir.	**Sound** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate — the energy is transferred through the substance in a wave. Typically, the energy in sound is far less than other forms of energy.
Electrical Energy is what is stored in a battery, and can be used to power a cell phone or start a car. Electrical energy is delivered by tiny charged particles called electrons, typically moving through a wire. Lightning is an example of electrical energy in nature, so powerful that it is not confined to a wire.	



http://www.need.org/EnergyInfobooks.php

http://www.eia.doe.gov/kids/energy.cfm?page=about_forms_of_energy-forms

Law of Conservation of Energy: Energy cannot be created or destroyed. But it can change from one form to another. (First Law of Thermodynamics)

2.1 Forms of Energy- the walk

Note on units: All the different forms of energy must have units of mass x (length^2/time^2)

Kinetic

1. Motion Energy

4. Radiant energy
   - Electromagnetic

5. Thermal Energy
   - Conduction
   - Pressure/Volume

Potential

2. Gravitational and Mechanical Energy

3. Electrical Energy

2.1.1 Motion energy

Energy manifested in motion, mostly generalized as Kinetic Energy

Kinetic Energy of a mass m moving at speed v: $E_{\text{kin}} = \frac{1}{2}mv^2$

baseball @ 100 mph

$$E_{\text{kin}} = \frac{1}{2}(5\ \text{oz})\,(100\ \text{mph})^2 \cong \frac{1}{2}(150\ \ \text{g})(160\ \text{km}/3600\ \text{s})^2$$
$$\cong \frac{1}{2}(0.15\ \text{kg})(44\ \text{m/s})^2 \cong 150\ \text{J}$$

100 pitches $\cong$ 15 kJ $\ll$ 10 MJ daily human food energy

Camry w/4 passengers

$$E_{\text{kin}} = \frac{1}{2}(4000\ \text{lb})\,(60\ \text{mph})^2$$
$$\cong \frac{1}{2}(1800\ \ \text{kg})(27\ \text{m/s})^2 \cong 700\ \text{kJ}$$

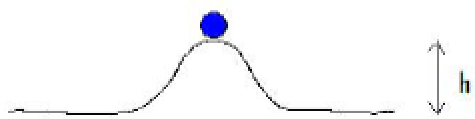
2.1.2 Gravitation and mechanical energy

When a **force** acts on an object over a **distance** it does **work** that can show up as kinetic energy or be stored as potential energy.

Work = [Force] x [Distance]

Motion against a force (*e.g.* roll ball uphill)

kinetic energy → potential energy



$$U = mgh \; (g = 9.8 \text{ m/s}^2)$$

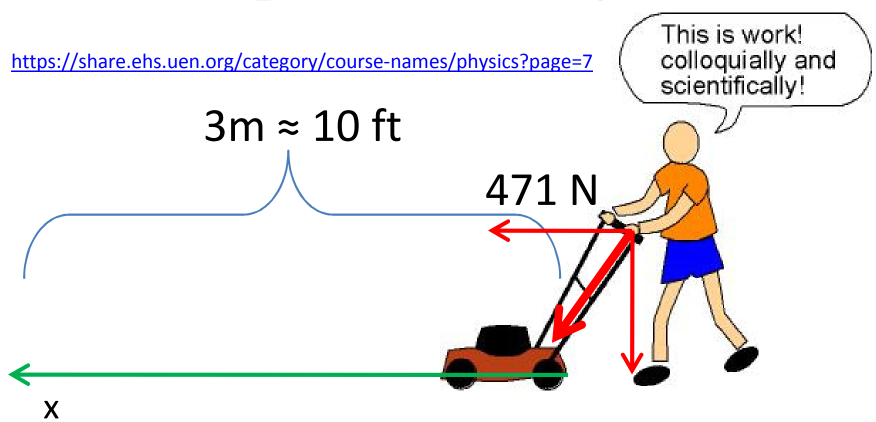
Force Distance

- Force points in direction of decreasing potential energy

A person exerting a force of 471 N in the x direction over 3meters could do work.

W= [471N] [3m] = 1413 J

https://share.ehs.uen.org/category/course-names/physics?page=7



Question: Is it potential or kinetic energy ?

MIT OpenCourseWare, 8.21 The Physics of Energy, Fall 2009, http://ocw.mit.edu

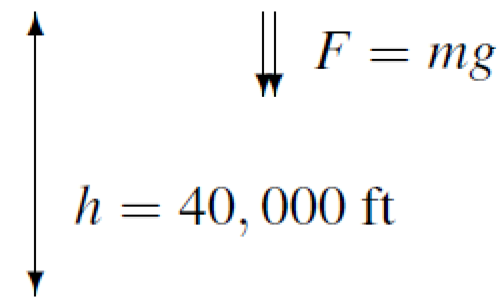
2.1.2 Gravitation and mechanical energy

Work = [Force] x [Distance]

- Airplane at altitude

747 at 900 km/h has $E_{\text{kin}} \cong \frac{1}{2}(350,000\ \text{kg})(250\ \text{m}/\text{s})^2 \cong 11\ \text{GJ}$

How about potential energy?



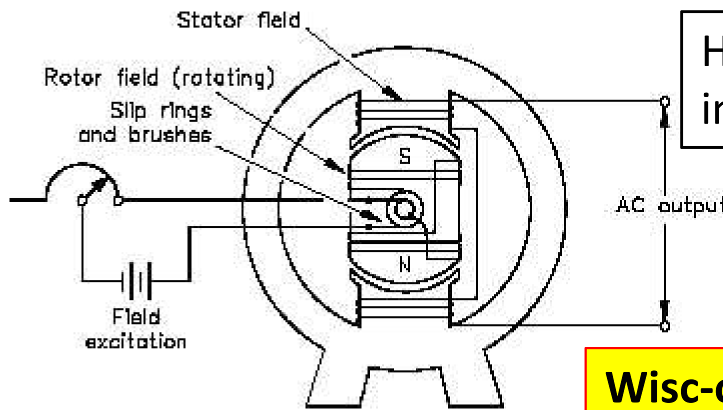
$$U = mgh \cong (350,000\ \text{kg})(9.8\ \text{m}/\text{s}^2)(12,000\ \text{m}) \cong 41\ \text{GJ}$$

Other examples of potential energy applications:

- Pump water uphill for storage

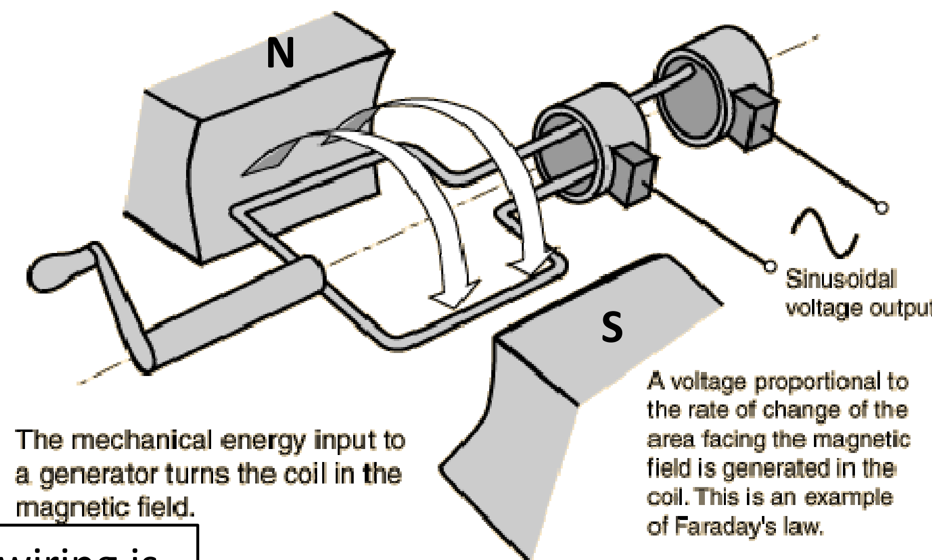
2.1.3 Electrical energy

- Faraday's Law of Induction
  - Any change in the magnetic flux through a coil of conducting wire will cause a voltage **(EMF)** to be induced in the coil.



Here, wiring is in the stator

Wisc-online 3-phase generator

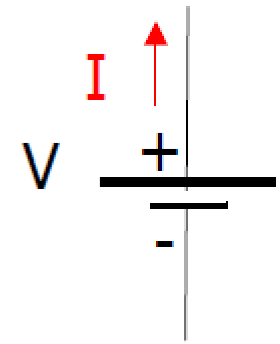


Here, wiring is in the rotor

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/motorac.html#c2

2.1.3 Electrical energy

- We indicate EMF with this symbol:
  - Long side: + terminal
  - Short side: - terminal



- The current flows from + to –
  - Counterintuitive if you think about it in terms of electrons…

Visual tutorial:
http://micro.magnet.fsu.edu/electromag/java/generator/ac.html

MIT OpenCourseWare, 8.02 , Physics II: Electricity and Magnetism, G. Sciolla, Fall 2004, http://ocw.mit.edu

2.1.3 Electrical energy

Faraday's Law of Induction

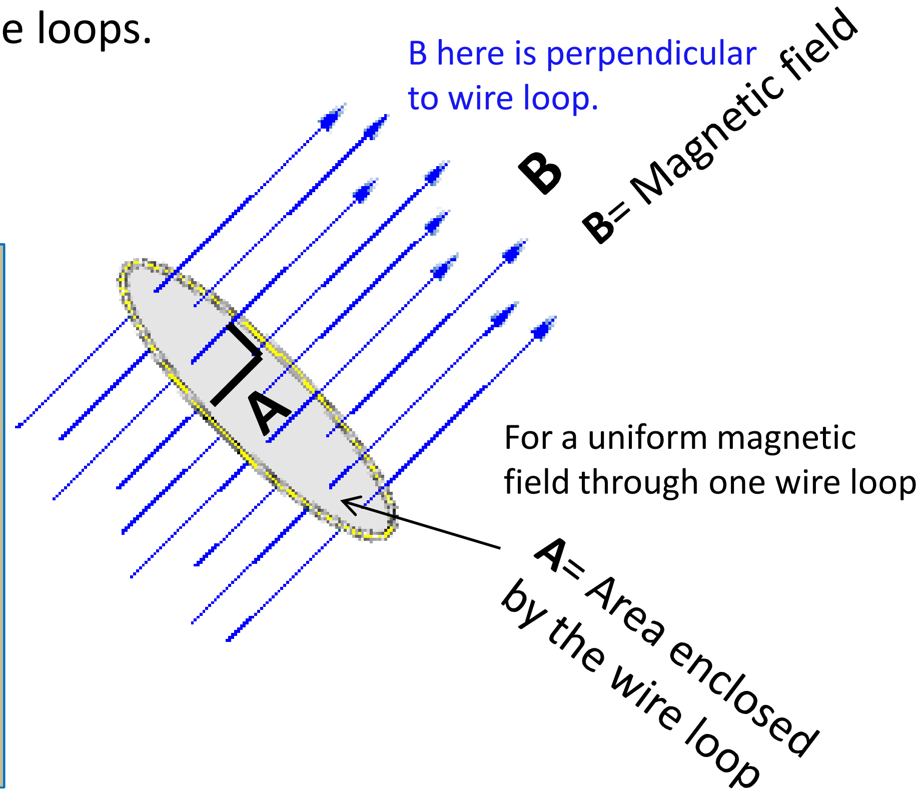
$$\text{Voltage generated} = -N\frac{\Delta(BA)}{\Delta t}$$

Faraday's Law

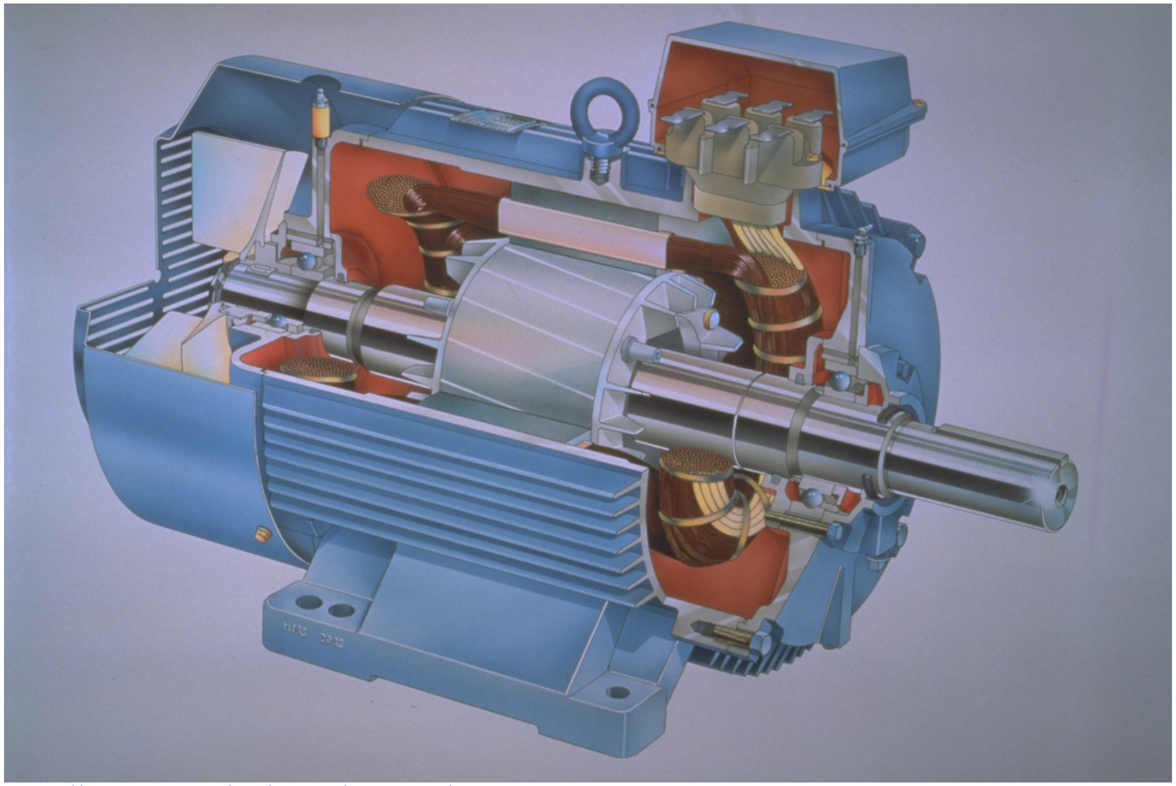
N is the number of turns of identical single wire loops assuming each loop has the same amount of induced EMF. So this relation is for multiple loops.

$$\Phi_B = B_{\perp}A = BA\cos\theta$$

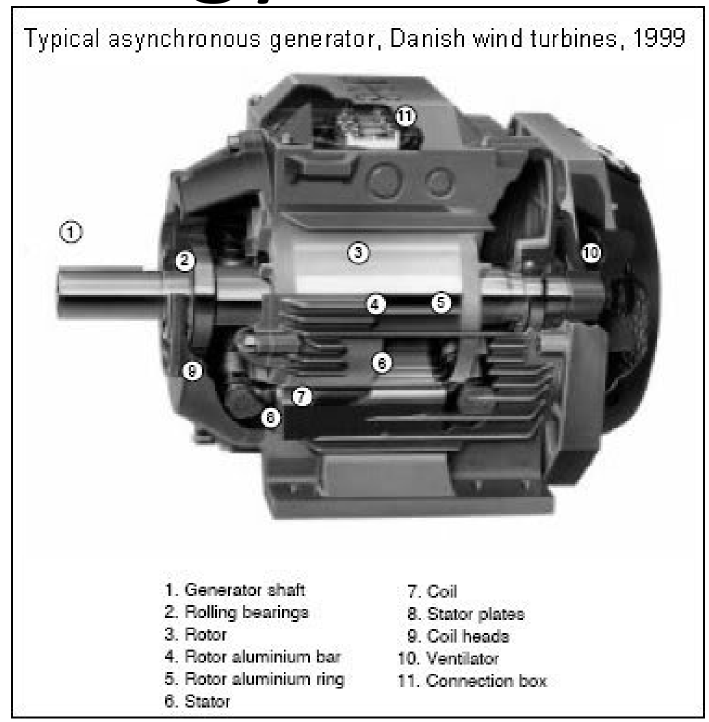
- EMF= electromotive force in Volts
- Φ = magnetic flux
  - SI unit: weber [W]= (Volt-second)
- B = magnetic field
  - Tesla (T)=weber/m^2
  - 1T=10,000gauss
  - B_{earth} = 0.3 gauss
- A = Area enclosed by the wire loop (m^2)
- t= time



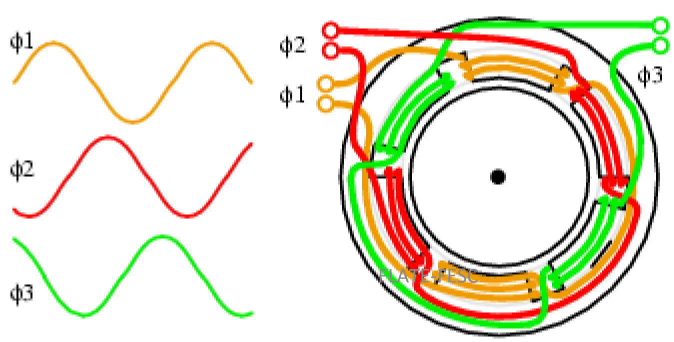
2.1.3 Electrical energy

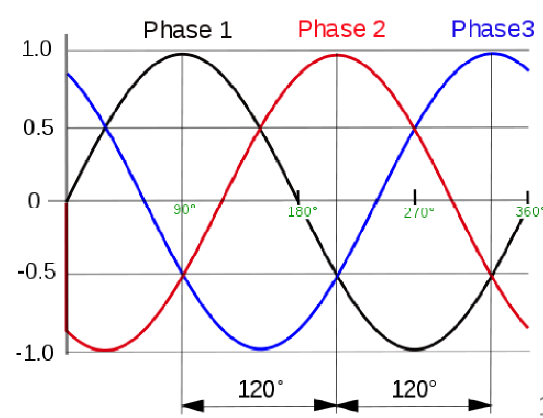


http://users.telenet.be/b0y/content/gen_techin/Induction.Motor.cutaway.jpg

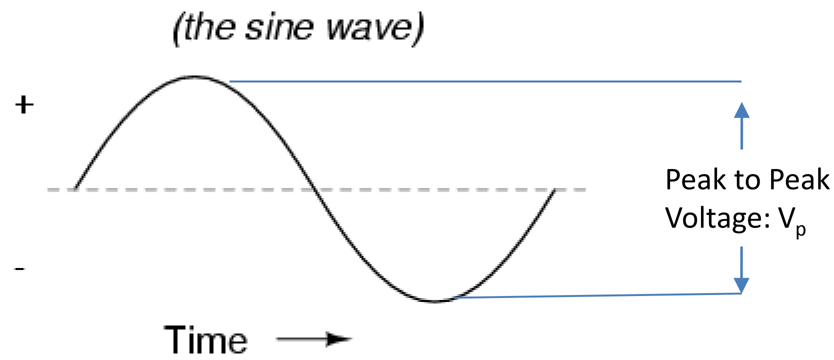


Faraday's Law of Induction





2.1.3 Electrical energy



$$\text{Frequency in Hertz} = \frac{1}{\text{Period in seconds}}$$

$$V_{\mathrm{RMS}} = \frac{V_{\mathrm{p}}}{\sqrt{2}}.$$

$$V_{rms} = 0.7071 * V_p$$

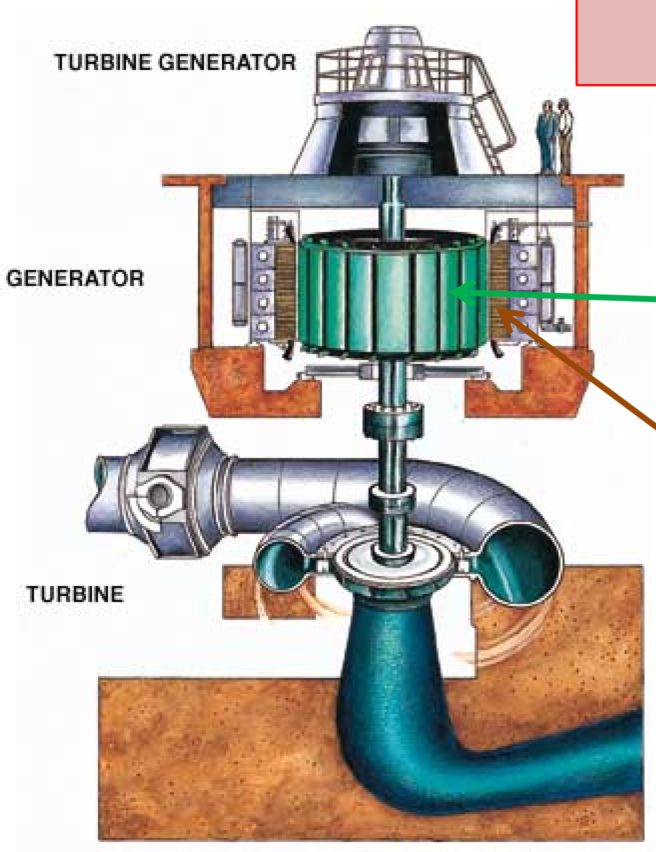
RMS voltage is the most common way to measure/quantify AC voltage. Because AC voltage is constantly changing and is at or near the highest and lowest points in the cycle for only a tiny fraction of the cycle, the peak voltage is not a good way to determine how much work can be done by an AC power source (e.g. your amplifier, a wall outlet in your house...).

In North America, most homes have 110 to 120 Volts AC electricity. (120 volts is the most commonly used term) This 120 VAC is the RMS value; so the AC electricity is equivalent in power to 120 VDC. AC with an RMS of 120 volts actually goes from peaks of +170 volts to -170 volts.

http://www.allaboutcircuits.com/vol_2/chpt_1/2.html

2.1.3 Electrical energy

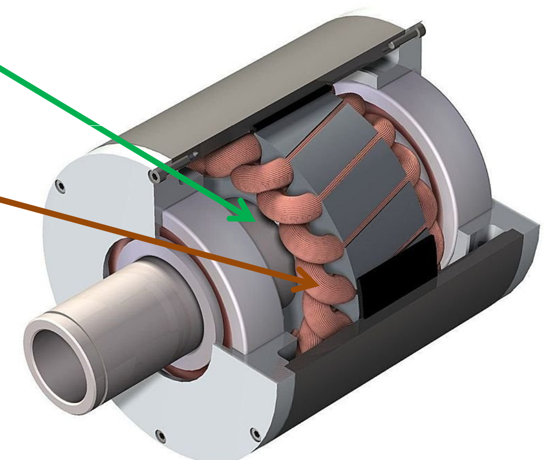
Typical Generators



http://www.rise.org.au/info/Tech/hydro/image003.jpg

Rotor: Magnets

Stator: Wires



Small Wind Turbine generator using NeFeB magnets: 400W to 5kW; 16 poles (8N/8S)

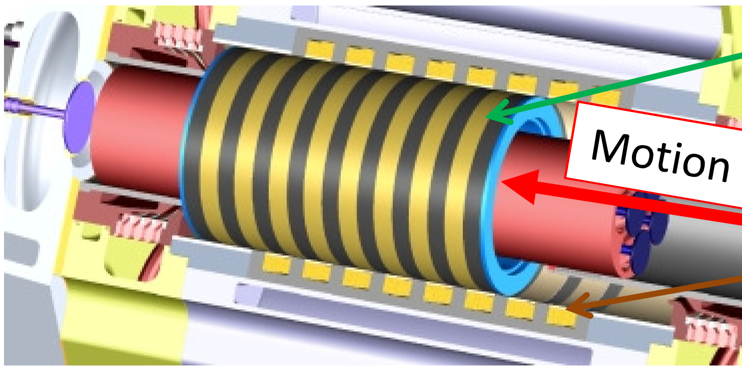
http://news.directindustry.com/press/meccalte/micro-wind-turbine-generator-58473-37321.html

Faraday's Law of Induction

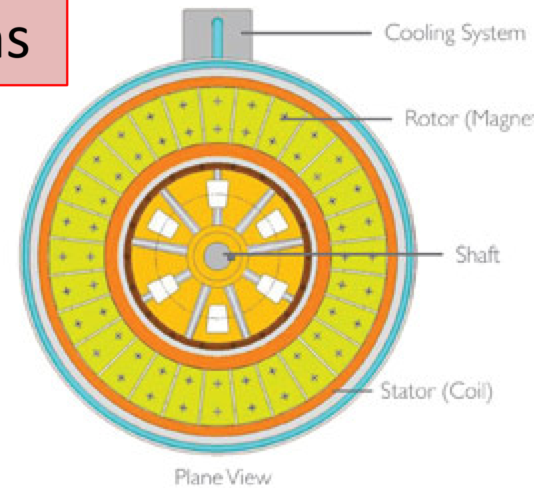
2.1.3 Electrical energy

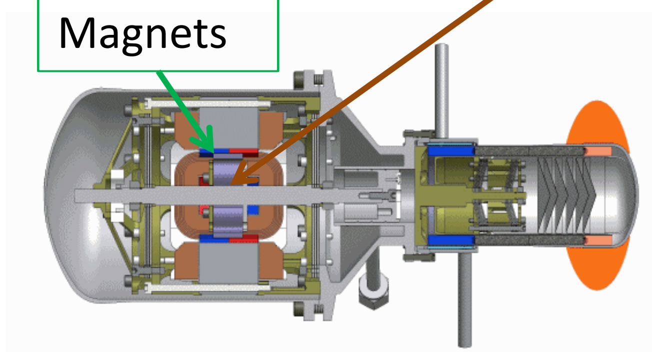
Other Generator Configurations

http://www.freepistonpower.com/fp3.aspx



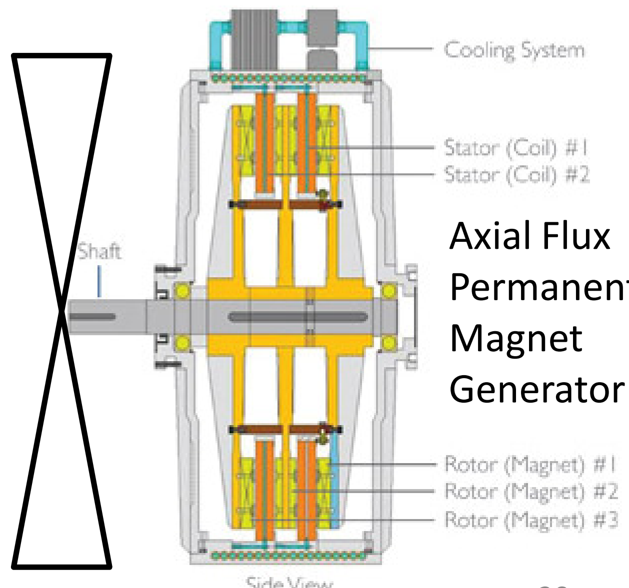
Linear generator consisting of eight ring-shaped NeFeB permanent magnets located on the moving assembly and an eight coil stator.





Stirling Engine Linear Generator

http://www.photology.fr/stirling/stirlinglinear.html



Axial Flux Permanent Magnet Generator

http://www.cleanenergytechnologies.net/axial_flux_technology.html

Faraday's Law of Induction

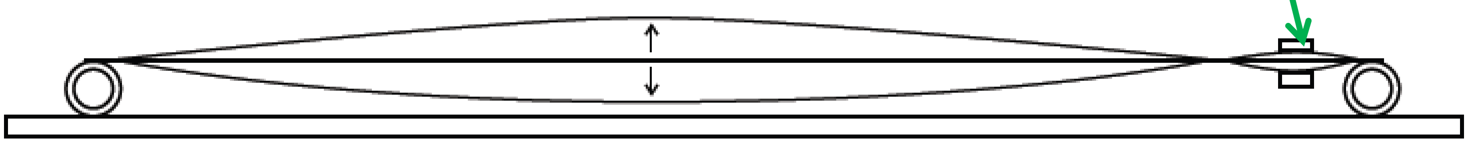
2.1.3 Electrical energy

Other Generator Configurations

Stator: Wires

Magnets

Demonstration Video or Lab.



http://www.kidwind.org/xcart/product.php?productid=167&cat=4

2.1.3 Electrical energy

Faraday's Law of Induction: Also makes possible the design of Step-up and Step-down transformers.

http://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/

Step-up AC transmission substation

Step-down power transformer

Step Up Transformer

Step-down power transformer

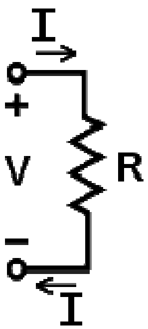
Transformer efficiency typically > 98%

http://www.temcotransformer.com/step-up-transformers.html

2.1.3 Electrical energy

What is electrical power ?

To explain it we must understand Ohm's law



Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference or voltage across the two points, and inversely proportional to the resistance between them.

http://en.wikipedia.org/wiki/Ohm%27s_law

$$I = \frac{V}{R} \quad \text{or} \quad V = IR \quad \text{or} \quad R = \frac{V}{I}$$

2.1.3 Electrical energy

What is electrical power ?

$$P = IV$$

So substituting Ohm's law into the relation above, Power becomes…

$$P = I^2 R = \frac{V^2}{R}$$

Where

P is the instantaneous power (W)
V is the voltage drop (V)
I is the current (A)
R is the resistance (Ohms) or (Ω)

Using the first set of power equations…. → $I = P/V$

Example: Transmission lines

An average of 120 kW of electric power is sent from a power plant. The transmission lines have a total resistance of 0.40 Ω. Calculate the power loss if the power is sent at (a) 240 V, and (b) 24,000 V.

(a) $$I = \frac{P}{V} = \frac{1.2 \times 10^5 W}{2.4 \times 10^2 V} = 500 A$$

$$P_L = I^2 R = (500 A)^2 (0.40 \Omega) = 100 kW$$

83% loss!!

This is why electricity is transmitted at very high voltages.

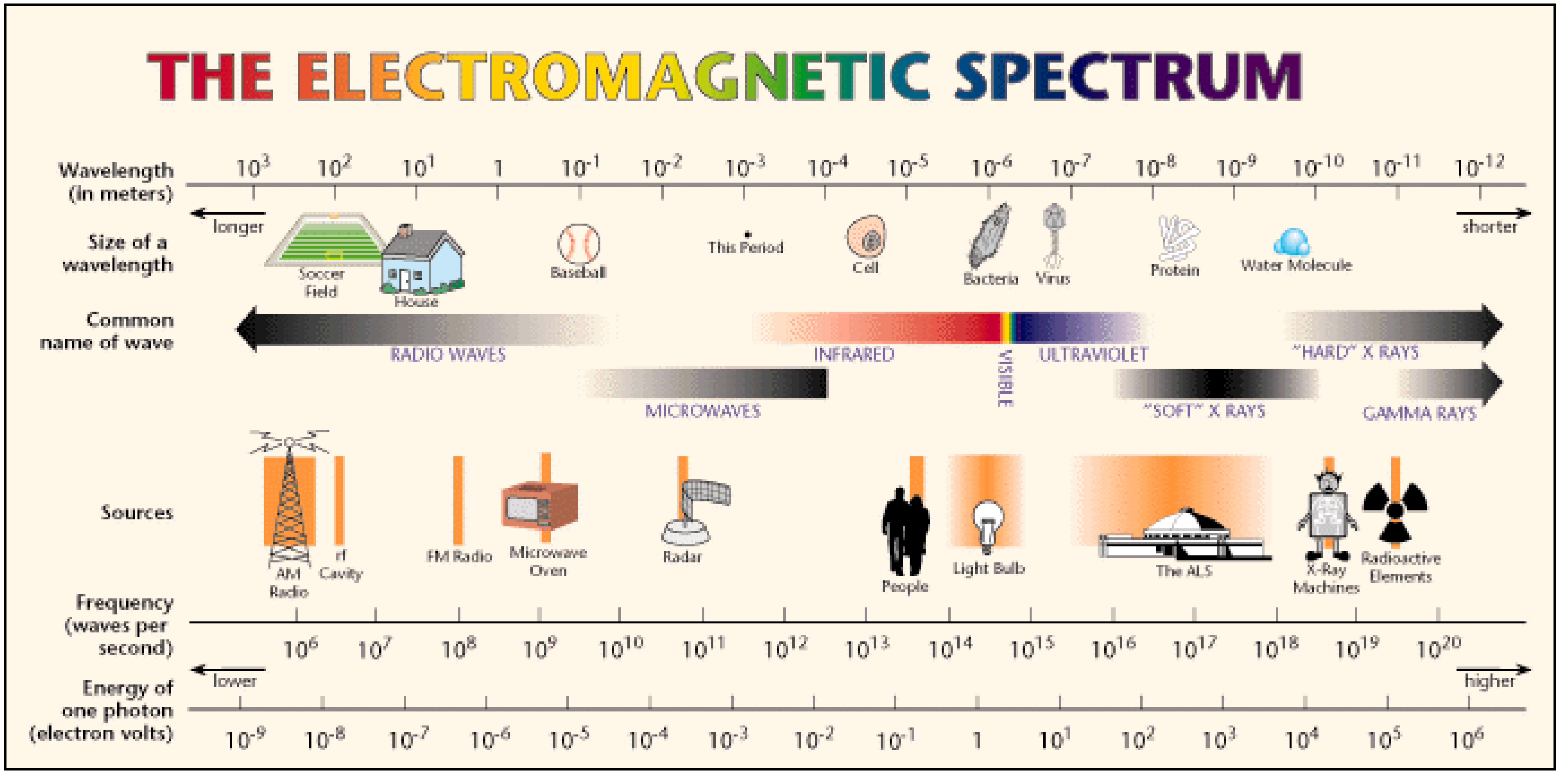
(b) $$I = \frac{P}{V} = \frac{1.2 \times 10^5 W}{2.4 \times 10^4 V} = 5.0 A$$

$$P_L = I^2 R = (5.0 A)^2 (0.40 \Omega) = 10 W$$

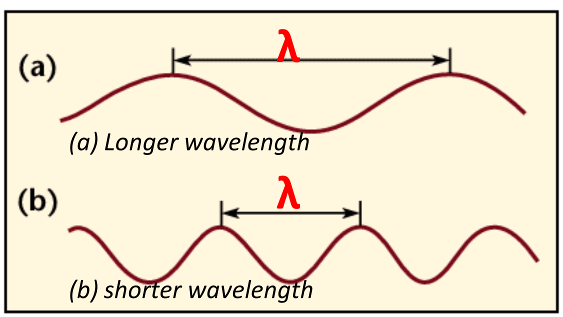
0.0083% loss

2.1.4 Radiant energy

(a)



(b)



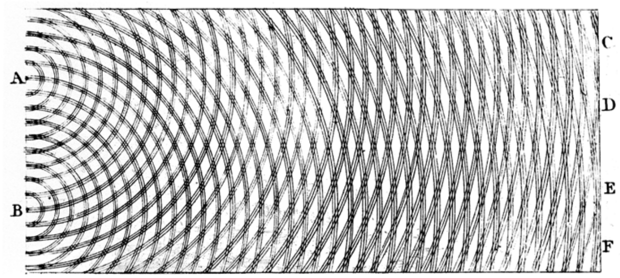
(a) Lower frequency

(b) Higher frequency

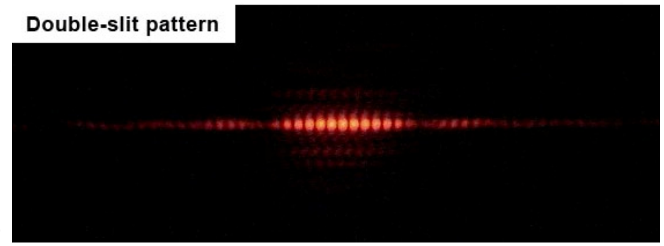
http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

2.1.4 Radiant energy

Double-slit experiment by Thomas Young confirmed **light is a wave.**



http://en.wikipedia.org/wiki/Wave%E2%80%93particle_duality



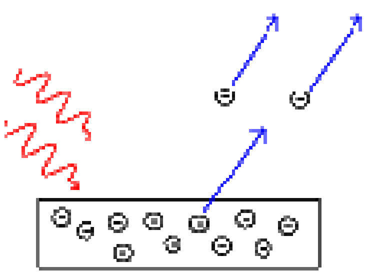
http://en.wikipedia.org/wiki/Double-slit_experiment

So we know light behaves as a wave…

……..**but not so fast….**

We have the photoelectric effect….

E=hυ



http://en.wikipedia.org/wiki/File:Photoelectric_effect.svg

•The photoelectric effect is a phenomenon in which electrons are emitted from matter (metals and non-metallic solids, liquids, or gases) after the absorption of energy from electromagnetic radiation such as X-rays or **visible light**.

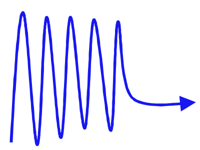
•In order to explain the photoelectric effect, Einstein assumed that **light is a particle,** called a photon, with quantized energy of ***E=hυ***

2.1.4 Radiant energy

Speed of light → $c = \lambda\, \nu$

Speed of light: c (m/s)
Wavelength: λ (m)
Frequency: ν (1/s)

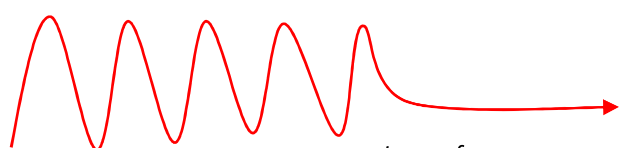
High Energy Photon for Blue Light



Higher frequency

Energy of a Photon $E = h\nu$ **Or also** $E = \frac{hc}{\lambda}$

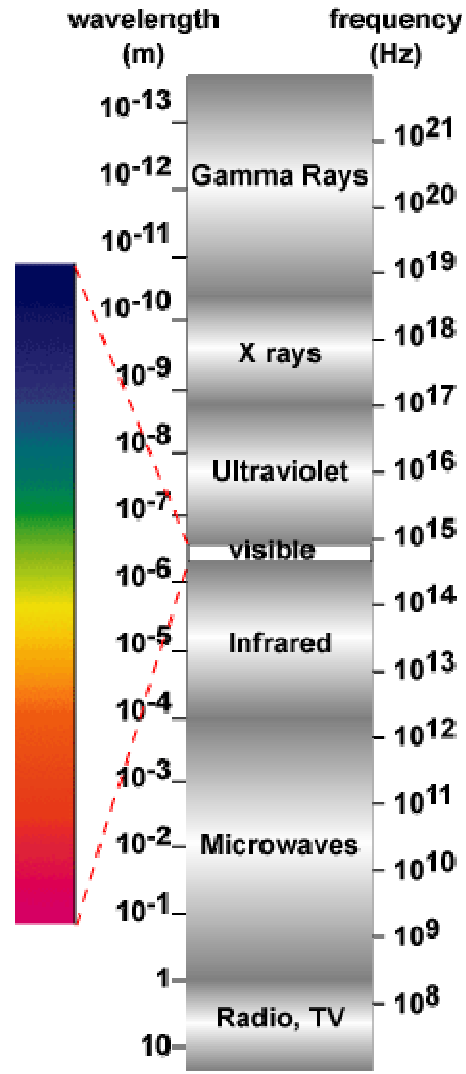
Low Energy Photon for Red Light



Lower frequency

Planck's Constant: $h = 6.626 \times 10^{-34}$ Joule·second

Typically , when dealing with particles such as photons or electrons the units to use are electron volts (eV). But, we will stick to Joules.



http://pvcdrom.pveducation.org/index.html

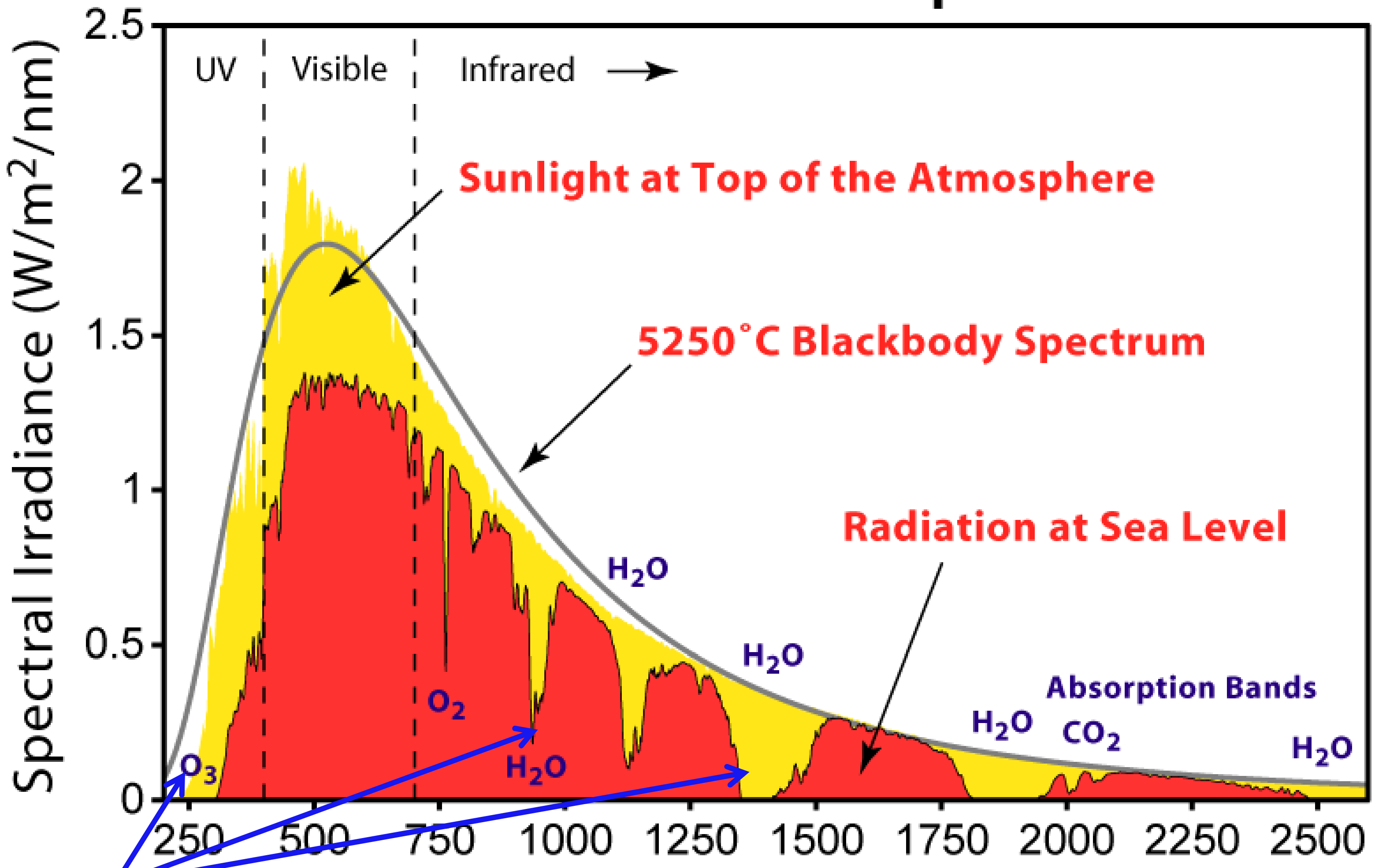
2.1.4 Radiant energy

So light behaves both as a wave and a particle:
Wave-Particle Duality

- Light as a WAVE
  - Solar Thermal Systems
  - Convective Systems
    - Wind Energy
    - Ocean Thermal
  - Geothermal
- Light as a PARTICLE
  - Photovoltaics
  - Photosynthesis
  - LEDs (Light Emitting Diodes)
  - Nuclear
    - Fission
    - Fusion
  - Atmospheric absorption

2.1.4 Radiant energy

Solar Radiation Spectrum



Note how some of the solar radiation is absorbed by ozone (O3) and water.

http://physweb.bgu.ac.il/COURSES/Astronomy1/Graphics/solar_spectrum.png

2.1.4 Radiant energy

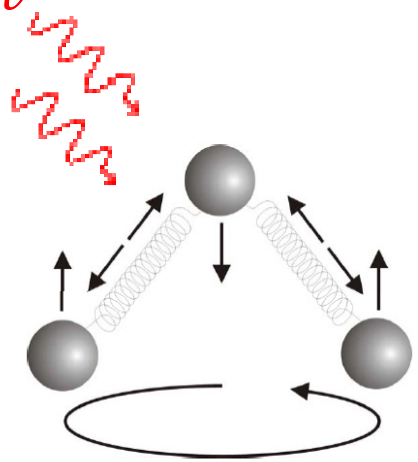
Light as a PARTICLE: Atmosphere (molecules)

Why are some wavelengths of lights absorbed by water and not others?

The water molecule absorbs only certain specific photons of energy. That energy is translated into motion of the molecule.

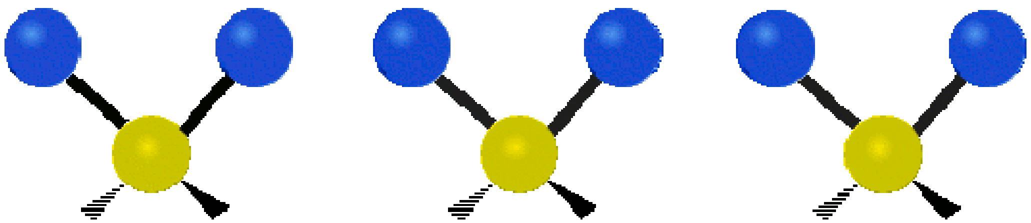
Photon of sun light

$E=h\upsilon$



H_2O

In addition to rotational mode, there are three fundamental molecular vibrational modes in water:



V1: symmetric stretch V2: bending V3: asymmetric stretch

http://en.wikipedia.org/wiki/Electromagnetic_absorption_by_water

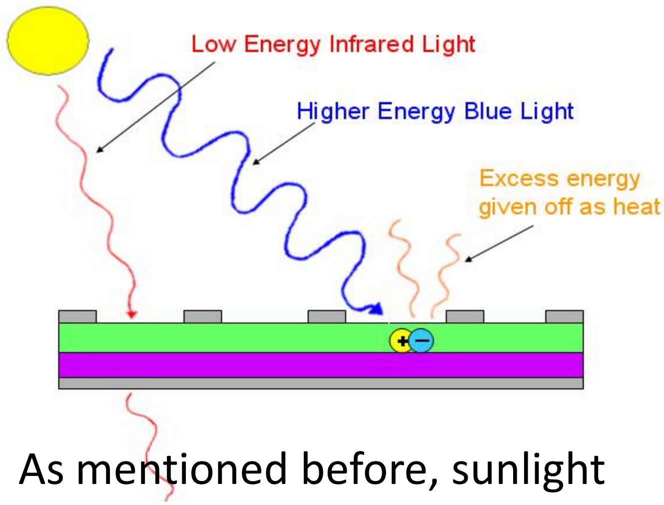
- Absorption near 970 nm is attributed to a 2V1 + V3 combination
- near 1200 nm to a V1 + V2 + V3 combination
- near 1450 nm to a V1 + V3 combination
- near 1950 nm to a V2 + V3 combination

So those wavelengths do not reach the earth when trapped by water molecules.

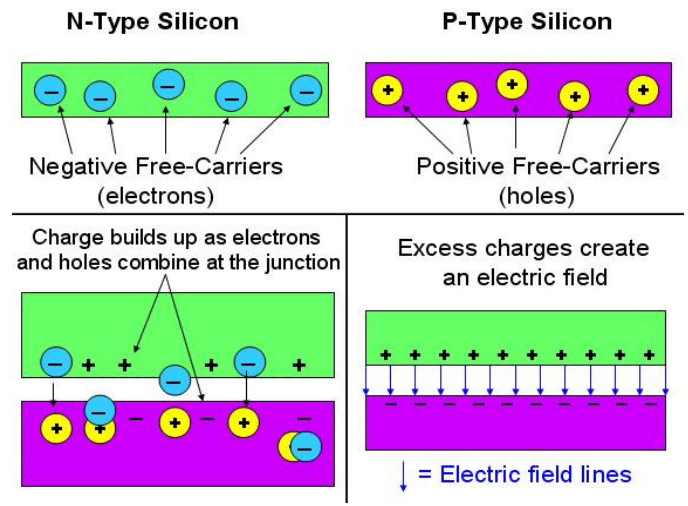
2.1.4 Radiant energy

Light as a PARTICLE: Photovoltaics

Solar Cell Mechanism



As mentioned before, sunlight is made of light with a broad range of energies spanning from infrared to ultraviolet light. Low-energy light doesn't have the energy required to release electrons; too-high energy light wastes the excess energy as heat.



N-type silicon has negative free-carriers (electrons), while P-type silicon has positive free-carriers (holes). When the two materials are put together, a junction is formed. At this PN Junction, electrons are attracted to holes and move to the P-type silicon via a conductor.

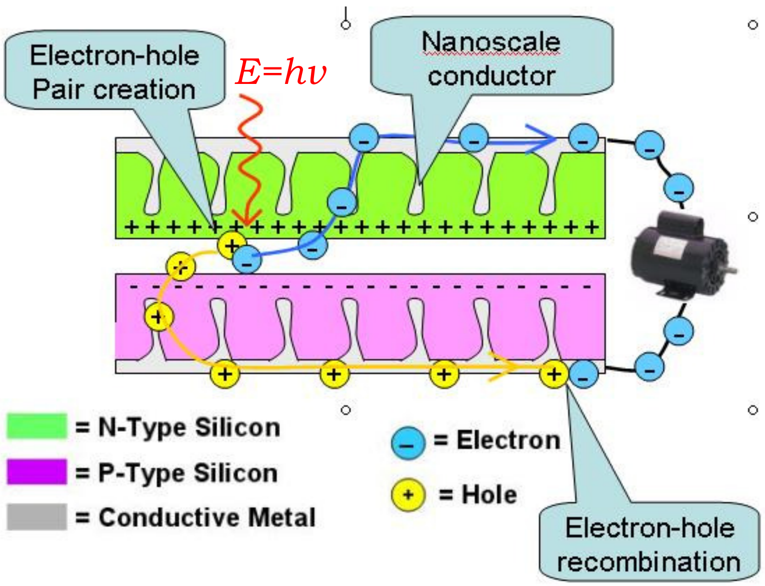
http://nanopedia.case.edu/NWPage.php?page=solar.cell.efficiency

http://nanopedia.case.edu/NWPage.php?page=solar.cells.pre-nano

2.1.4 Radiant energy

Light as a PARTICLE: Photovoltaics

Solar Cell Mechanism



http://nanopedia.case.edu/NWPage.php?page=nano.solar.cells

Light excites an electon-hole pair in a pn junction that has a voltage difference across it. Electrons are swept out to do useful work (like turn on a light bulb or run a motor). This creates DC voltages…so inverters that turn DC voltages to AC voltages are typically needed to run home appliances.

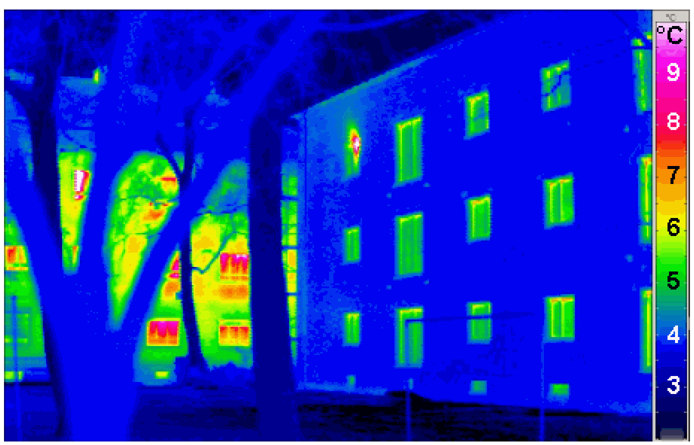
2.1.4 Radiant energy

Light as a WAVE

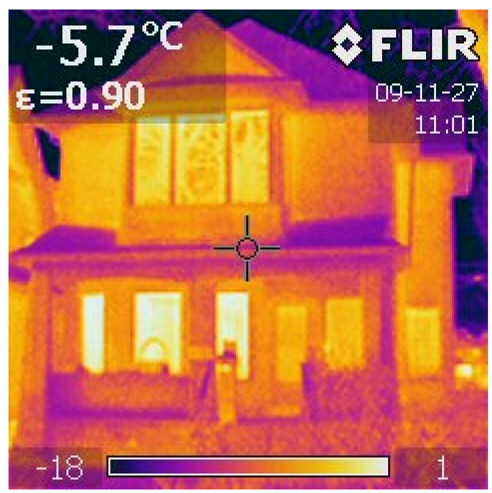
Infrared radiation from people. Wavelength in the range of 0.7 to 300µm . False colors.

http://en.wikipedia.org/wiki/Infrared

- People give off infrared radiation.
- Buildings also give off infrared radiation.
  - This gives rise to a field of home inspection known as Thermography Inspection



http://upload.wikimedia.org/wikipedia/commons/f/f2/Passivhaus_thermogram_gedaemmt_ungedaemmt.png



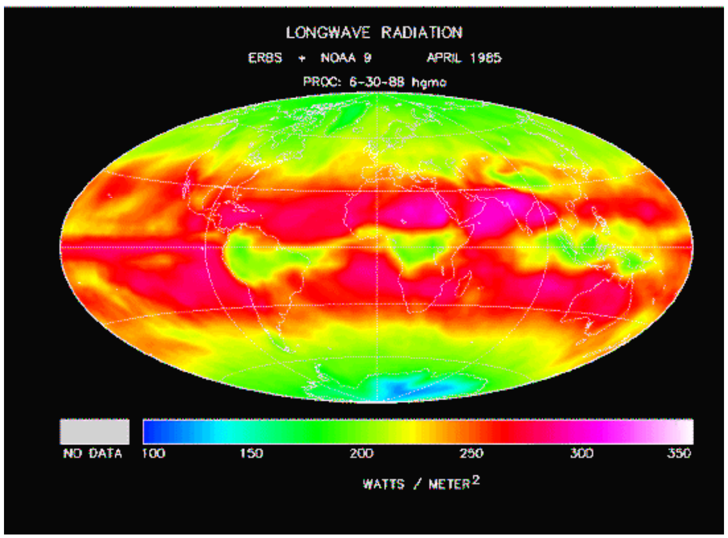
http://www.homecrafters.net/pics/IR0122.jpg

One of the tools of home thermography: Duracam 320 P-Series IR Thermal Imaging Camera

http://www.infraredcamerasinc.com/infrared-camera-duracam.html

2.1.4 Radiant energy

Light as a WAVE



http://en.wikipedia.org/wiki/Black_body

Infrared radiation from earth. False colors.

- The earth also gives off infrared radiation.
  - Some gets captured by atmosphere, particularly by greenhouse gases.
- **Energy** radiated by a "blackbody" radiator per second per unit area is proportional to the fourth power of the absolute temperature and is given by Stefan-Boltzmann law

$$j^* = \sigma T^4$$

where

$j^* = P/A$ (power per unit area [w/m^2])

$\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4} Stefan-Boltzmann constant

T = temperature in Kelvin [K]

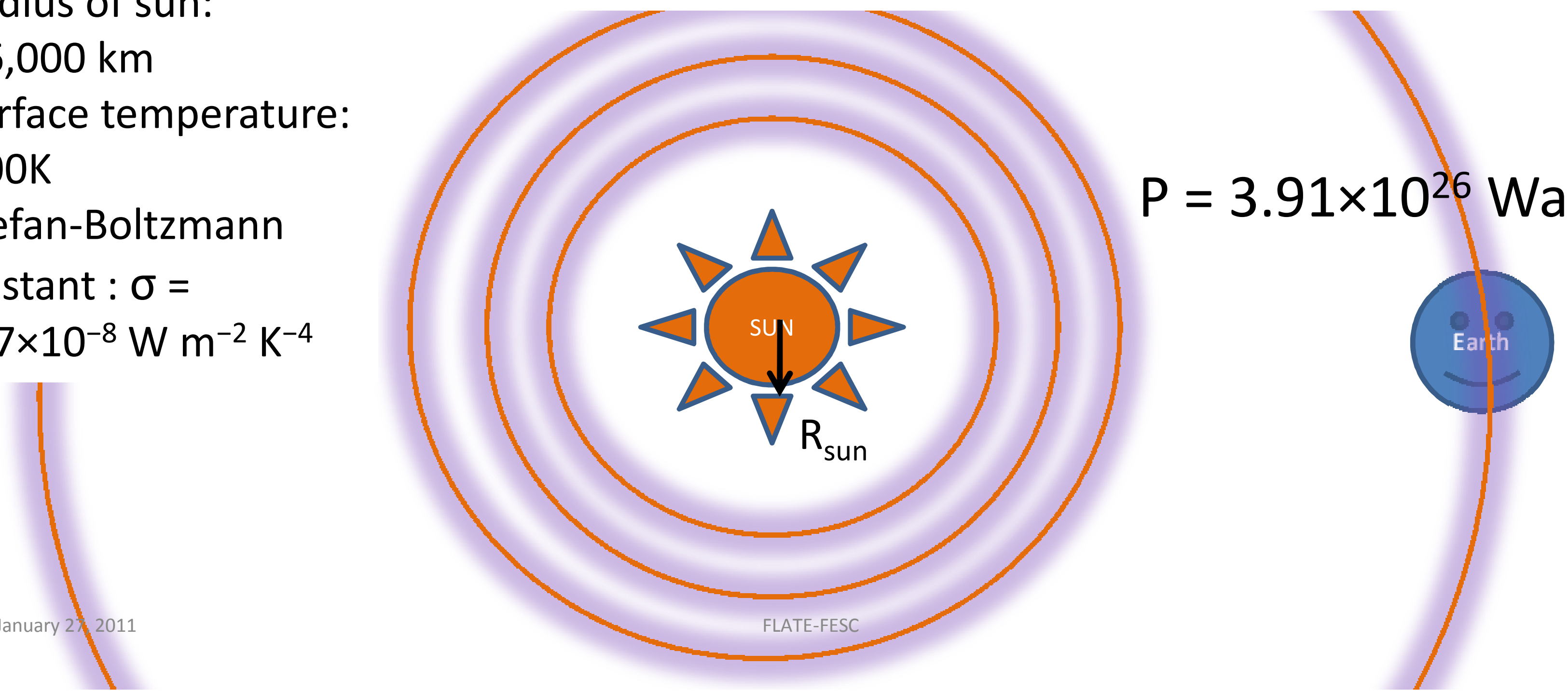
2.1.4 Radiant energy

Light as a WAVE

- So what is the power incident on the earth by the Sun (aka: irradiance)?
- If we approximate the sun as a sphere and assume the power from the sun is evenly radiated outward in all directions.
  - Surface area of sphere: $A=4\pi R^2$
- Stefan-Boltzmann law gives us the irradiance of the sun in Watts.

$$P= A\sigma T^4 = (4\pi R^2_{sun})\sigma T^4_{sun}$$

- Radius of sun: 696,000 km
- Surface temperature: 5800K
- Stefan-Boltzmann constant : $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}

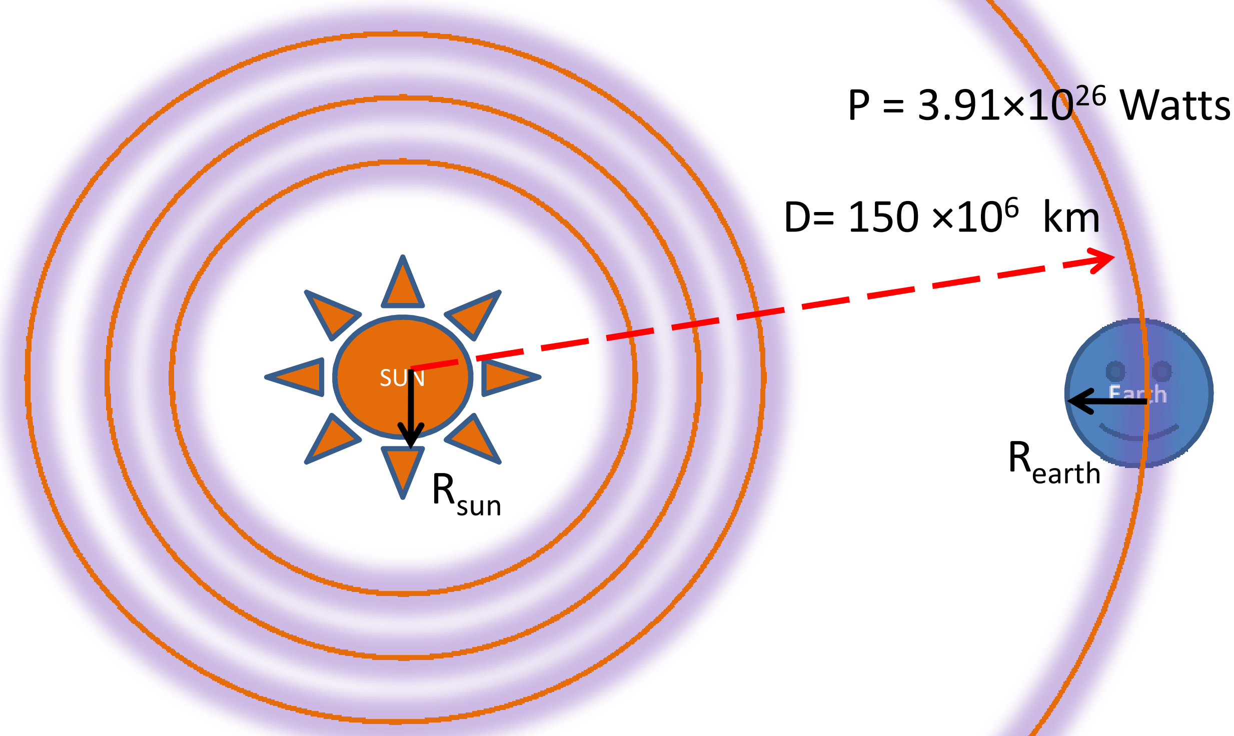


$P = 3.91\times10^{26}$ Watts

2.1.4 Radiant energy

Light as a WAVE

- So now we know the sun puts out 3.91×10^{26} W
- Distance from sun to earth: ~150×10^{6} km
- Radius of earth: ~6400 km

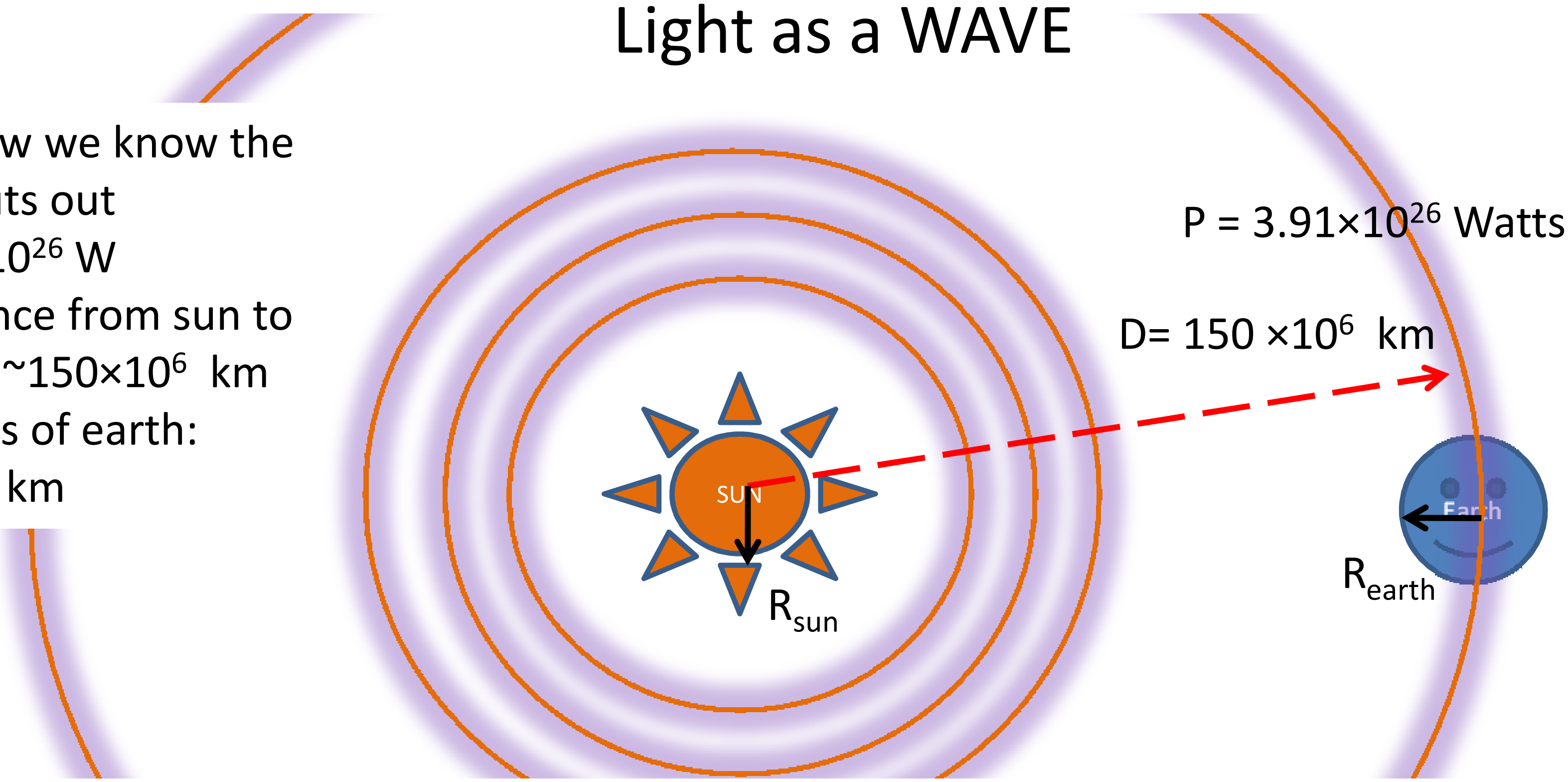


At the Earth's distance from the sun, the total solar power is spread over the area of a sphere of radius 150,000,000km, but the Earth covers only a circle of radius 6400km out of all that area, so we must know what fraction of the total area the earth covers….intuitively it should be a small fraction….

2.1.4 Radiant energy

Light as a WAVE

- So now we know the sun puts out 3.91×10^{26} W
- Distance from sun to earth: $\sim 150 \times 10^{6}$ km
- Radius of earth: ~6400 km



Ratio of earth's area (circle) to the area of the sun's irradiance (sphere)

$$A_{earth}/A_{sun} = \pi R^2_e / 4\pi D^2 = 4.55 \times 10^{-10}$$

This is the fraction of the sun's power intersected by the earth.

So earth receives about $P = (4.55 \times 10^{-10})(3.91 \times 10^{26}\ W) = 1.78 \times 10^{17}$ W at the outer atmosphere. Or per unit area: Irradiance $= 1.78 \times 10^{17}\ W / \pi(6400 \times 10^3 m)^2 = 1383\ W/m^2$. But, most calculations use **1366 W/m²** as the yearly average sun's incident solar radiation (insolation) on the earth. This is known as the solar constant.

2.1.5 Thermal Energy: Heat Conduction

- Heat is transported in three ways
  1. Conduction
     - Hotplate on a stove
  2. Convection
     - A two story house is warmer on the second floor
  3. Radiation
     - SPF40 (or more) while at the beach
- We have covered radiation in section 2.1.4. Convection will be left up to the student to review.

MIT OpenCourseWare, 8.21 The Physics of Energy, Fall 2009, http://ocw.mit.edu

2.1.5 Thermal Energy: Heat Conduction

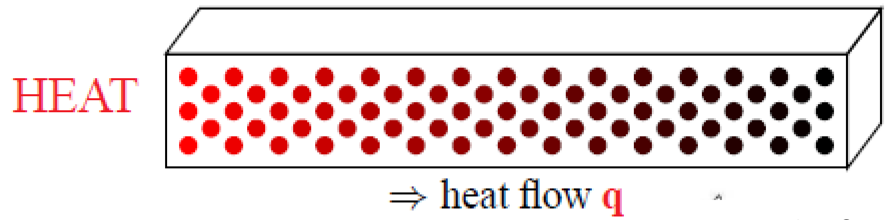
Heat Conduction

- For many simple applications, Fourier's law is used in its one-dimensional form.

$$q_x = -k\frac{dT}{dx}$$

- Or in non-differential form…

$$q = -k\frac{\Delta T}{L}$$



$\mathbf{q}$ = heat current density [J/m^{2}s] = W/m^2

heat flowing per second through ⊥ surface

Fourier law: $\mathbf{q} = -k\nabla T$

Note: this is in vector form

∇T = temperature gradient [K/m]

k: thermal conductivity [W/mK]

-Different for different materials

-Can be temperature dependent

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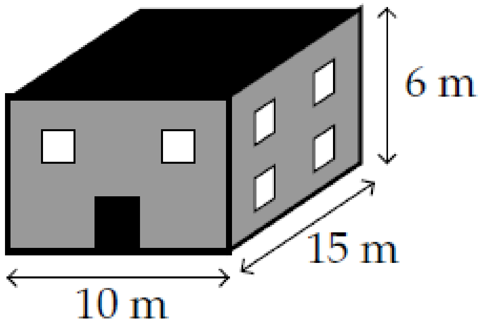
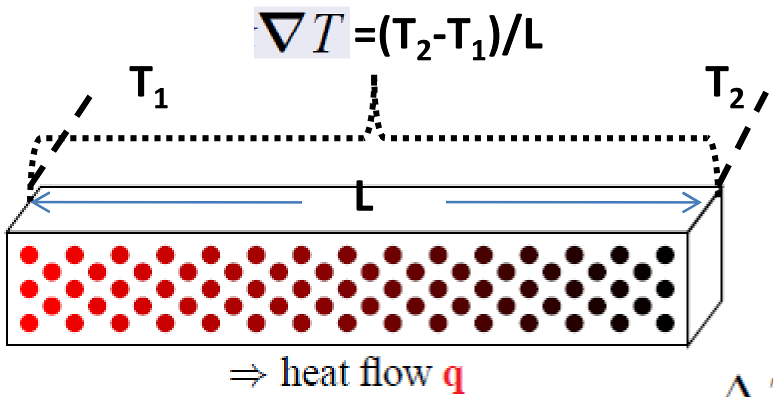
2.1.5 Thermal Energy: Heat Conduction

What is the heat loss if inside is 20°C and outside is 0°C through 0.2m concrete?





$$q = -k\frac{\Delta T}{L}$$

$$(1.4\ \mathrm{W/mK})(20\ \mathrm{K}/0.2\ \mathrm{m}) = 140\ \mathrm{W/m^2}$$

$$\text{area} = 300\ \mathrm{m^2} + 150\ \mathrm{m^2} = 450\ \mathrm{m^2}$$

$$\Rightarrow 60\ \mathrm{kW}\ \times 24\ \text{hours} \cong 1500\ \mathrm{kWh}$$

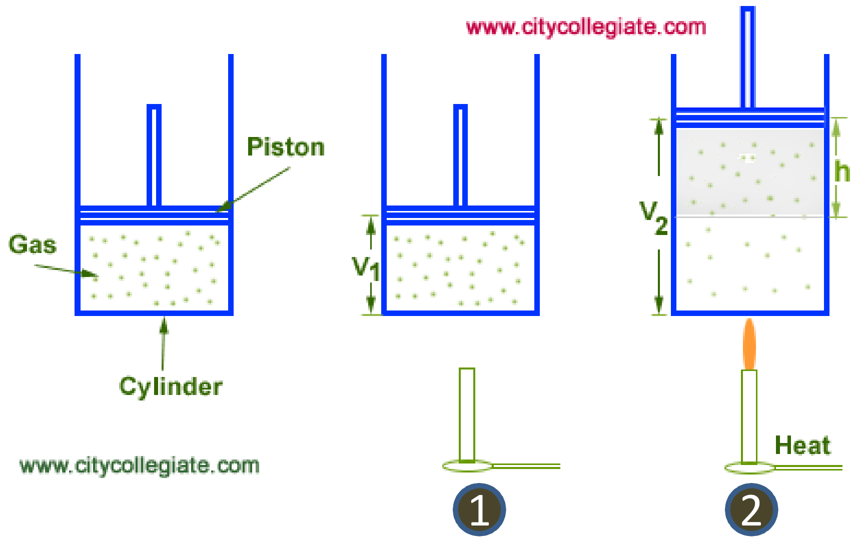
material	k [W/mK]
air	0.026
fiberglass insulation	0.043
hard wood	0.16
concrete	1.4
steel	52

Roughly 5 GJ/day!

Wood: $\times \frac{0.16}{1.4} \Rightarrow \sim 500\ \mathrm{MJ/day}$

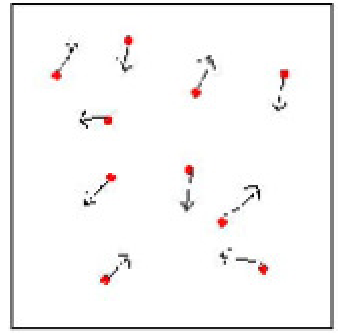
2.1.5 Thermal Energy: Pressure/Volume

In the diagram below , what is supplying the force?



1. In step one we have a system at equilibrium with its environment, but…
2. In step 2, heat (Q) is added to the system…

Microscopically, thermal energy from a chemical reaction (combustion) was transferred to gas molecules in the piston…this transferred thermal energy is known as **heat (Q)**.



The gas is composed of several molecules. Each particle having its own kinetic/potential E…..this gives rise to Thermal Energy

Pressure: Bouncing molecules → force on piston

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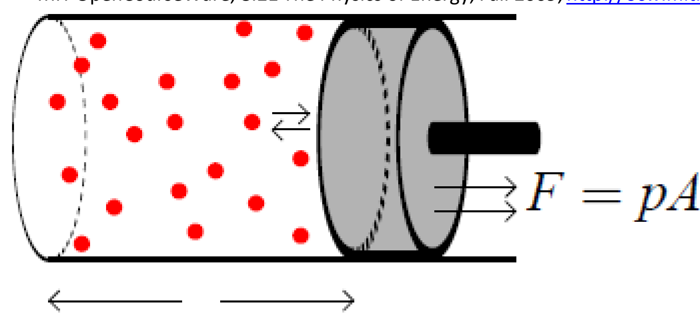


When heat is added, the molecules gain kinetic energy, which in turn causes more bouncing and more force on the piston.

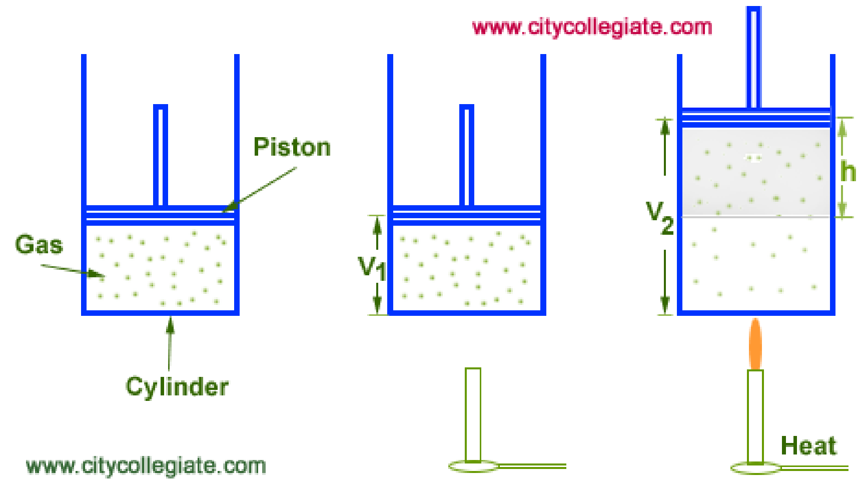
2.1.5 Thermal Energy: Pressure/Volume

- Pressure is a force per unit area. So in SI units it is in the form of Newtons per square meter. [N/m^2]
- Work done by pressure takes the form of displacing a certain amount of volume by that pressure….. So…

Work = Pressure x Δvolume

- This turns out to be the same work definition as we had before:

W = force x distance



Pressure = force per unit area => **P= [F]/[A]**
rearranging…. **F=[P][A]**

Since W = F x d, in the piston above the distance is the height change of the piston (displacement)..so Δh is the distance for our work relation.

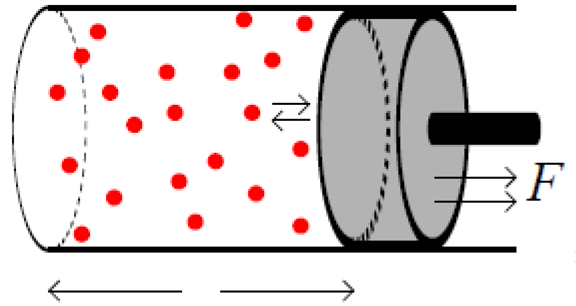
Means…. **W=[P][A][Δh]….**and from high school we know that volume is area times height…so that we end up with

W = P x ΔV

http://www.citycollegiate.com/thermodynamicsXII_first.htm

2.1.5 Thermal Energy: Pressure/Volume

- If the gas in the piston behaves as an ideal gas
  - Ideal gas: point-like particles, elastic collisions
- Then work can be related to the number of molecules and the temperature in the gas so that ..



Work = Pressure x Δvolume = pΔV

pΔV or just pV leads to

pV= NRT

- N — number of moles
- R — the gas constant $R = 8.31447 \ \frac{\text{Joules}}{\text{mole K}}$
- T — temperature in Kelvins

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Overview Topics

2.1 Physics

- SI Units
- Force, Energy, Power
- Forms of energy
  1. Motion,
  2. Gravitational and mechanical
  3. Electrical Energy
     - Faraday's Law of Induction
     - Voltage, current
  4. Radiant Energy
     - Electromagnetism
  5. Thermal energy

2.2 Thermodynamics

- First Law
- Second Law

2.3 Chemistry

- Periodic Table of elements
- Stoichiometry

2.2.1 Thermodynamics- 1st Law

- First Law of Thermodynamics tells us that energy is neither created nor destroyed, thus the energy of the universe is a **constant.**
- Energy can, however, be transformed from one form of energy to another form of energy.
- In order to understand the system's change in energy we must set boundaries.

2.2.1 Thermodynamics- 1st Law

- So if we think in terms of the pressure/volume concept discussed in section 2.1.5.
  - The change in energy of the molecules (kinetic energy in this case) is directly related to the heat we added to the piston minus the work done by the piston as it expanded and moved out.
  - So the piston reached a new equilibrium after heat was added.
  - And the energy just changed from one form to another, but it performed work!
- So we can take most forms of energy and covert them to some type of work!! ☺ ....think alternative energy

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

$$\Delta U = Q - W$$

Change in internal energy — Heat added to the system — Work done by the system

http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/firlaw.html

⟷ **Unfortunately, in real systems some of the energy is lost as heat or other forms and it is not fully converted to work!!** ☹

Which leads us to the Second Law of Thermodynamics

2.2.2 Thermodynamics- 2nd Law

Unfortunately, in real systems some of the energy is lost as heat or other forms and it is not fully converted to work!! ☹

There are two aspects to the Second Law of Thermodynamics.

1. It places a constraint on the attainable efficiencies of heat engines.

   In a general sense, energy efficiency can be defined as:
   η = useful energy out/energy in

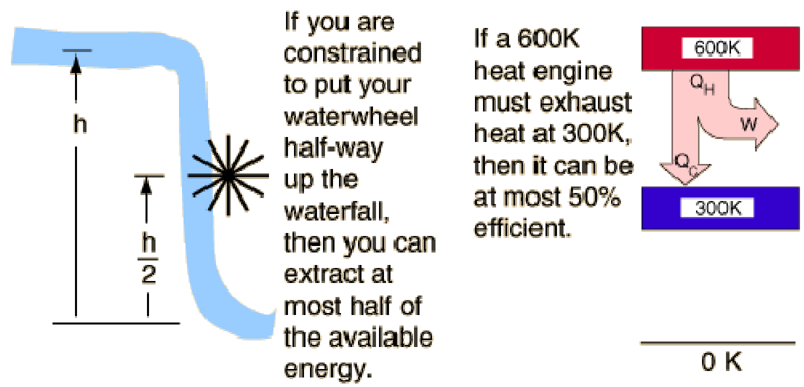
2. It places a direction on energy transfer.
   - Think in terms of heat conduction explained in section 2.1.5. Heat flowed from hot to cold.
   - One can boil water using a hot flame, but one cannot generate a hot flame by gathering all the boiled molecules and reversing the process.

   The above statements are measured in terms of Entropy (S)
   $\Delta S = \Delta Q/T$

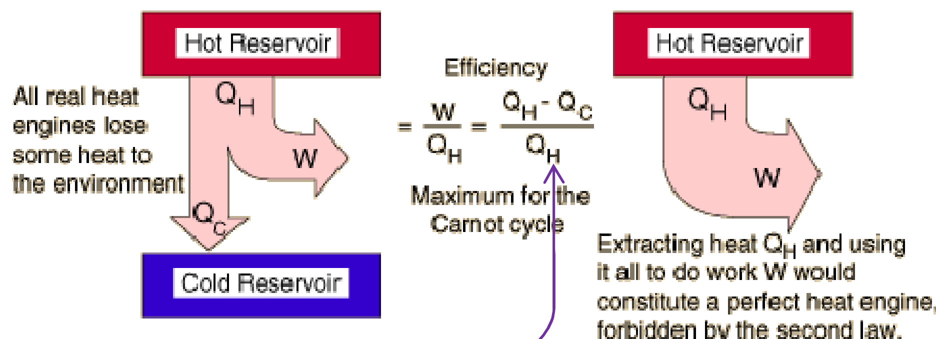
2.2.2 Thermodynamics- 2^{nd} Law (1)

- The efficiency constraint combined with the energy direction constraint precludes the existence of perpetual motion machines.
- Perpetual motion machines are thought to operate in such a way that once started they will continue operating forever.
- Don’t buy one!

Visualization of efficiency limitations

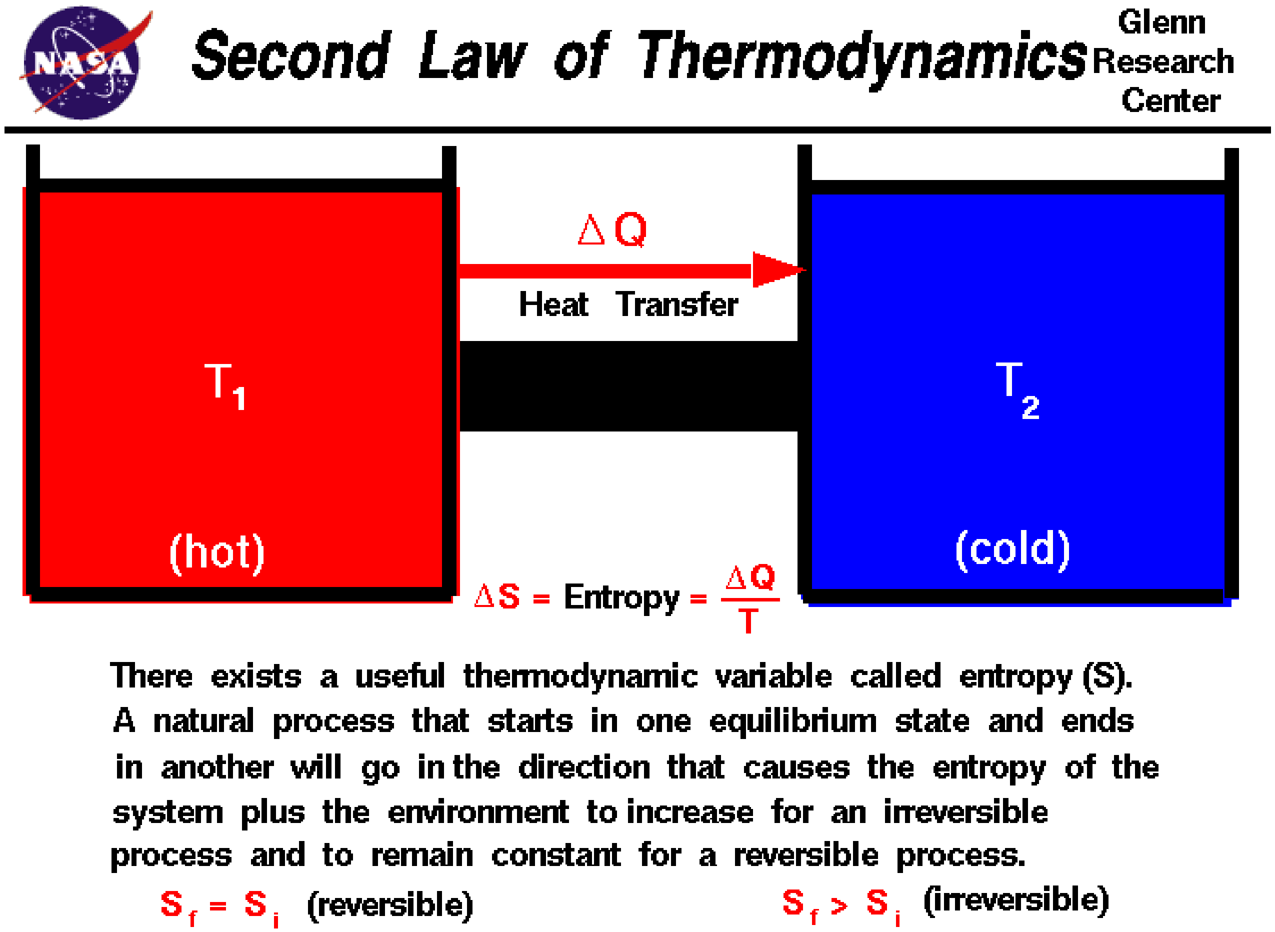


http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/seclaw.html#c1



Maximum efficiency is the Carnot Efficiency (but is theoretical…does not exist in reality.)

2.2.2 Thermodynamics- 2nd Law (2)



http://www.grc.nasa.gov/WWW/K-12/airplane/thermo2.html

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  4. Radiant Energy
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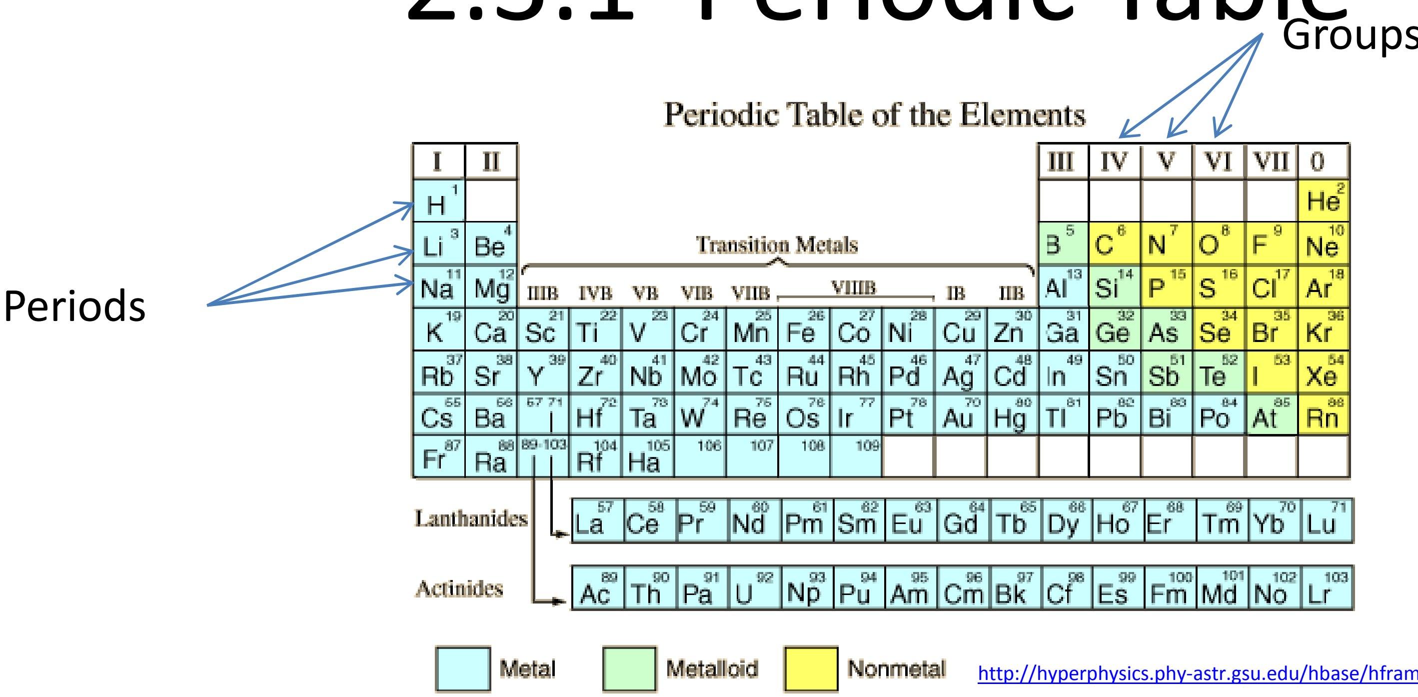
2.3.1 Periodic Table



http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

- In order of Atomic Number: number of protons(Z^+) in nucleus, which have positive charge.
- For the atom to remain neutral, it must have the same number of electrons (e^-).

2.3.2 Stoichiometry

Several Important Chemical Reactions

Balanced Chemical Reactions

Fuel combustion

- $CH_4 + 2\,O_2 = CO_2 + 2\,H_2O$ – natural gas
- $C_8H_{12} + 11O_2 = 8\,CO_2 + 6\,H_2O$ – gasoline
- $C_6H_{12}O_6 + 6O_2 = 6\,CO_2 + 6\,H_2O$– cellulosic biomass

Hydrogen production

- $CH_4 + H_2O = CO + 3H_2$ – steam reforming of methane
- $CO + H_2O = CO_2 + H_2$ – water gas shift reaction

Hydrogen fuel cell

- $H_2 + ½\,O_2 = H_2O$ + electricity – overall reaction

MIT OpenCourseWare, 3.564J Sustainable Energy, Spring 2005, http://ocw.mit.edu

Basic Engineering Science

- Now that we covered some of the basics, we can start looking into several Renewable Energy Technologies.
  - Solar Energy
    - Photovoltaics
    - Solar Thermal
  - Wind Energy
  - Biomass
  - Water Energy
  - Fuel Cells
- New Directions in Alternative Energy
- Energy Storage
- Energy Efficient Products