Lecture 18

May 31, 2011

Brief Review of last class on Fission

Boiling water reactor

BWR

versus

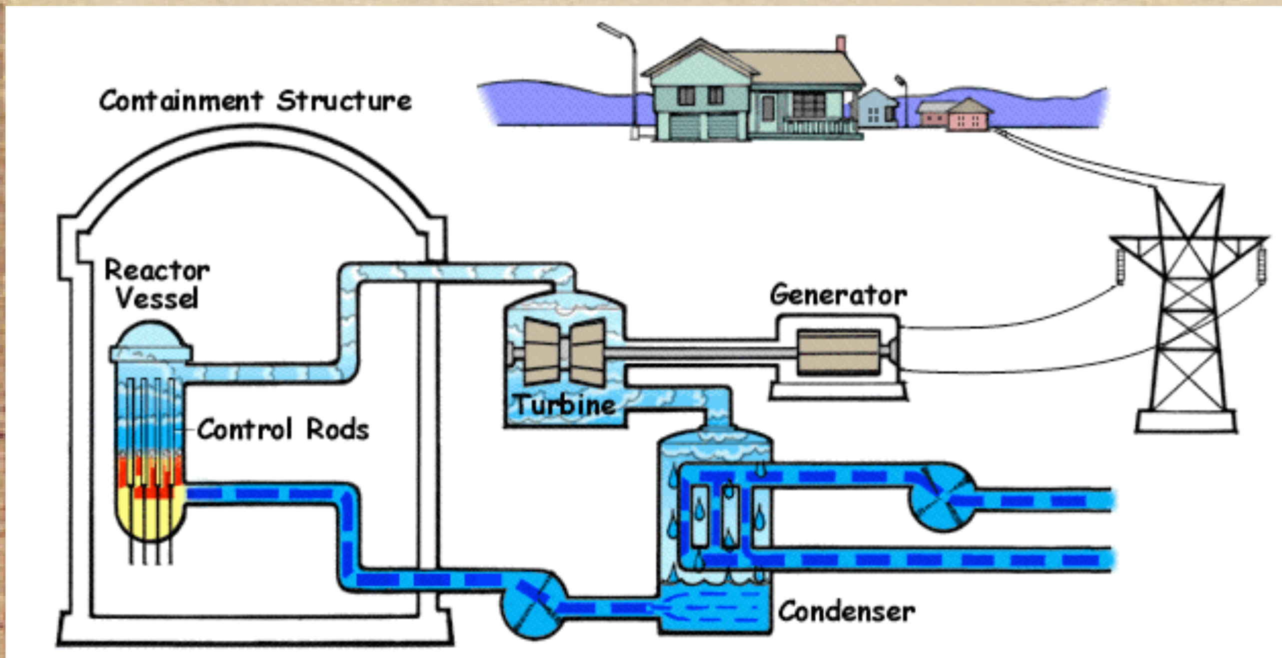
Pressurized Water Reactor

PWR (submarines)

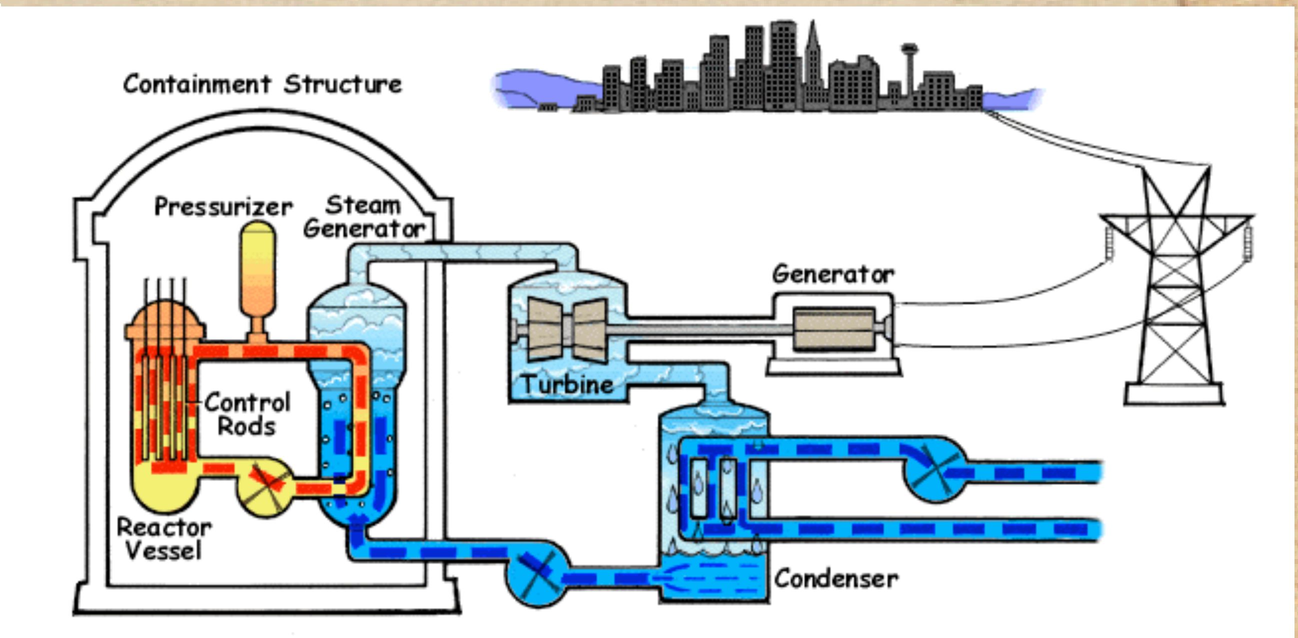
In PWR's water is pressurized to prevent it from boiling. Water gets superhot and outside the reactor, it heats up and boils unpressurized water. Pipes needed to carry this high pressure water around.

Efficiency 34%
Power 1220 MW
342 tons /year
UO_2

Boiling water reactor



Pressurized Water Reactor



Direct fission

Uranium as fuel: Availability / costs aspect.

1.Available 3×10^6 Tons U_3O_8

2.To produce 1 GW.yr need 1Ton ^{235}U or 200 Tons mined U_3O_8

3.Total capacity in USA 97 GW.yr ..Available for 155 years

Breeder tech

Plutonium as fuel:

1. 4200 years

2.Lower grade Uranium is also useful therefore more....

3.Win-Win from this view point. Liquid sodium leaks.+ proliferation issues......

Type of fuel	$ per MWH	Market share 2009
Nuclear Power	51	20.3%
Coal	37	44.9%
Gas turbine combo	35	23.4%
Solar cells	202	
Solar Thermal	158	
Wind	55	
Hydro electric	48-86	7%

Costs of electricity from nuclear power versus other fuels

Disasters:

Three Mile Island (USA)
Chernobyl (USSR)
Fukushima Daiichi (Japan)

Germany: Nuclear power plants to close by 2022

Germany's coalition government has announced a reversal of policy that will see all the country's nuclear power plants phased out by 2022.

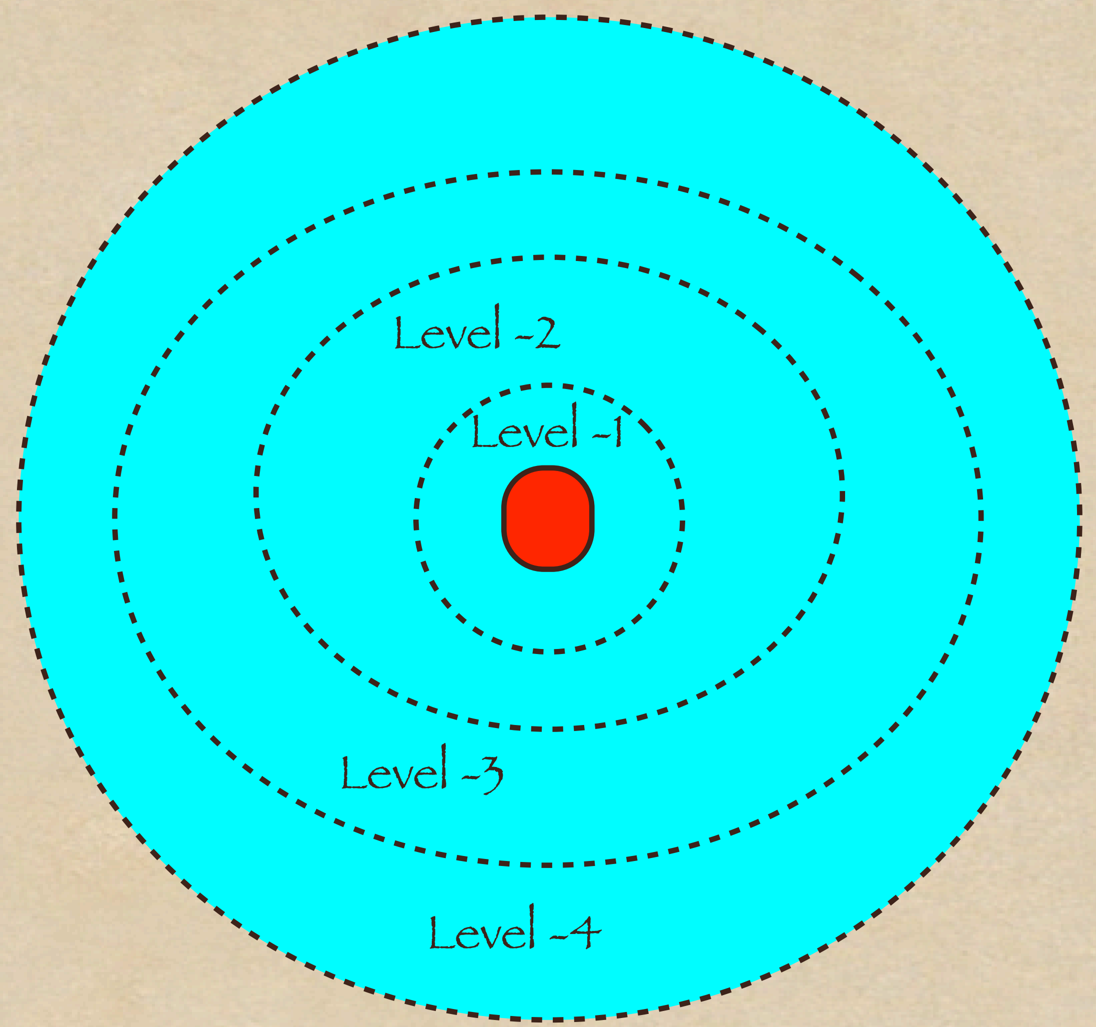
The decision makes Germany the biggest industrial power to announce plans to give up nuclear energy.

Environment Minister Norbert Rottgen made the announcement following late-night talks.

Chancellor Angela Merkel set up a panel to review nuclear power following the crisis at Fukushima in Japan.

There have been mass anti-nuclear protests across Germany in the wake of March's Fukushima crisis, triggered by an earthquake and tsunami.

'Sustainable energy'
Before the meeting Chancellor Angela Merkel said: "I think we're on a good path but very, very many questions have to be considered.
"If you want to exit something, you also have to prove how the change will work and how we can enter into a durable and sustainable energy provision." Ministers said they needed to keep nuclear energy as a "bridging technology" to a greener future.



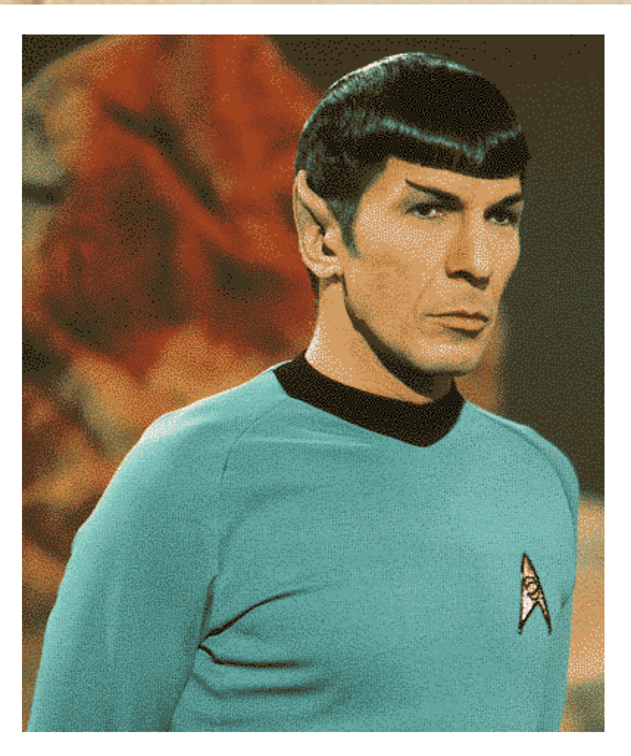
Vision for future security:
Need multiple redundancy
Say 4 levels of confinement
At each level, assume that all previous levels have failed.
Also small is beautiful- forget economy of scale

Expense of reactors will increase due to this confinement security, but pays off.

Fusion

Fusion and its issues

Dilithium could be found on only a few planets in the galaxy, and was therefore a rare and valuable substance. Notable sources of dilithium included Coridan and Elas in the Federation, as well as Rura Penthe in the Klingon Empire and Remus in the Romulan Star Empire. (TOS: "Journey to Babel", "Elaan of Troyius"; Star Trek VI: The Undiscovered Country; DS9: "One Little Ship"; Star Trek Nemesis) It could also be found on Troyius, where it was known as radan, and had a variety of different uses, including jewelry. (TOS: "Elaan of Troyius")



As all Trekkies know:

TOS = The Original Series

DS9= Deep Space 9

Scientifically, use of the prefix "di-" denotes two atoms, suggesting dilithium consists of two atoms of lithium. However, lithium, being a metal, should not be able to exist in this state, as metals cannot form diatomic molecules. "Real" dilithium (two lithium atoms in a covalent bond) is only currently known to exist as a gas.

And now for some real science

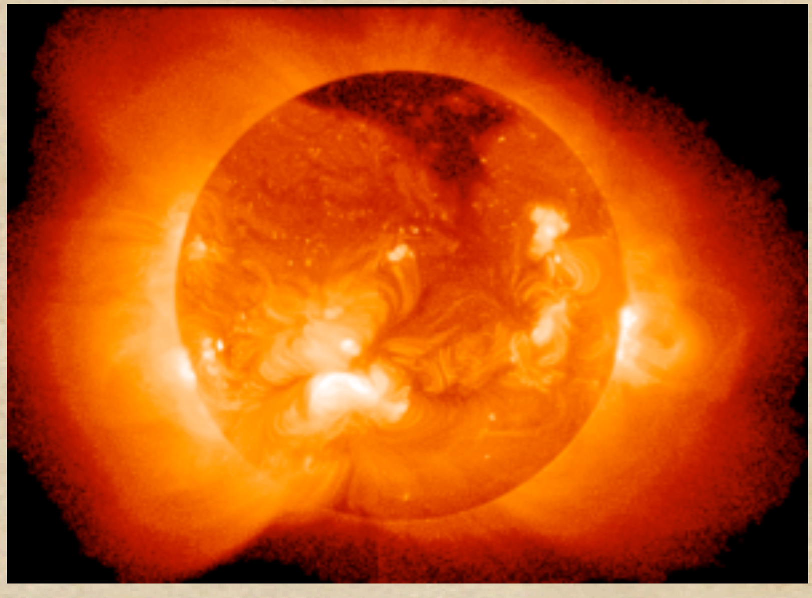
$${}^2_1H_1 + {}^3_1H_2 \rightarrow {}^4_2He_2 + n + 17.6\ Mev$$

This is the process for a schematic DT fusion reactor.

Breeding Tritium for cycling

$$n + {}^6Li \rightarrow \alpha + {}^3_1H_2 + \ energy$$

But first some light on the Sun:



Total energy produced by the sun ~ $3.6\text{x}10^{31}$ J per day

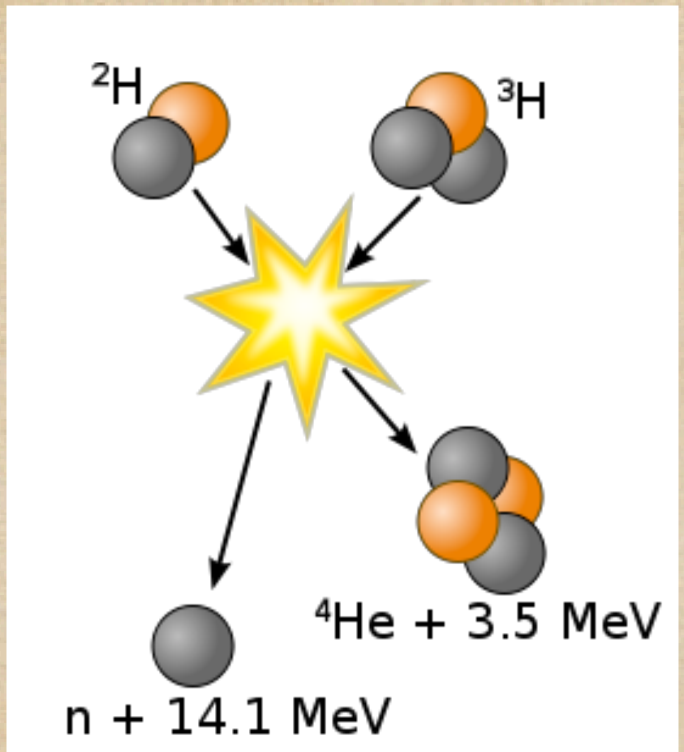
~10^{13} Quad per day!!

Basic reactions:
DT
DD

Code: D = Deuterium $^2{}_1H_1$
T = Tritium $^3{}_1H_2$

D= Deutron =1proton + 1 neutron= $^2{}_1H_1$

T= Tritium= 1 proton + 2 neutrons = $^3{}_1H_2$



DT reaction

$$^2_1H_1 +^3_1 H_2 \rightarrow^4_2 He_2 + n + 17.6\ Mev$$

This means we can bring (standard) abundant Hydrogen with tritium to produce Helium and energy. However, tritium is not naturally occuring. Need breeder to grow that isotope. Lithium is needed for that.

$$^1_0n +^6_3 Li \rightarrow^3_1 T +^4_2 He$$

$$^1_0n +^7_3 Li \rightarrow^3_1 T +^4_2 He +^1_0 n$$

A bit of ^{7}Li produces neutrons needed for keeping this going.

Need confinement to fire fusion.

Either magnetic confinement or some other "plasma" type effects.

Experimental- nothing "proven" yet.

This and the next slide are informational only- not part of our exam related course

Hydrogen Burning: Hans Bethe (1939)

- None of the two-particle reactions between the major species in juvenile H +He matter produce a stable product:
  - $^{1}H + {}^{1}H = {}^{2}He$ (unstable) $= {}^{1}H + {}^{1}H$
  - $^{1}H + {}^{4}He = {}^{5}Li$ (unstable) $= {}^{1}H + {}^{4}He$
  - $^{4}He + {}^{4}He = {}^{8}Be$ (unstable) $= {}^{4}He + {}^{4}He$
- However, Hans Bethe (1939) showed how hydrogen burning can begin with the exothermic formation of deuterium:
  - $^{1}H + {}^{1}H = {}^{2}D + \beta^{+} + \nu + 1.442$ MeV
- This reaction initiates the PPI chain:

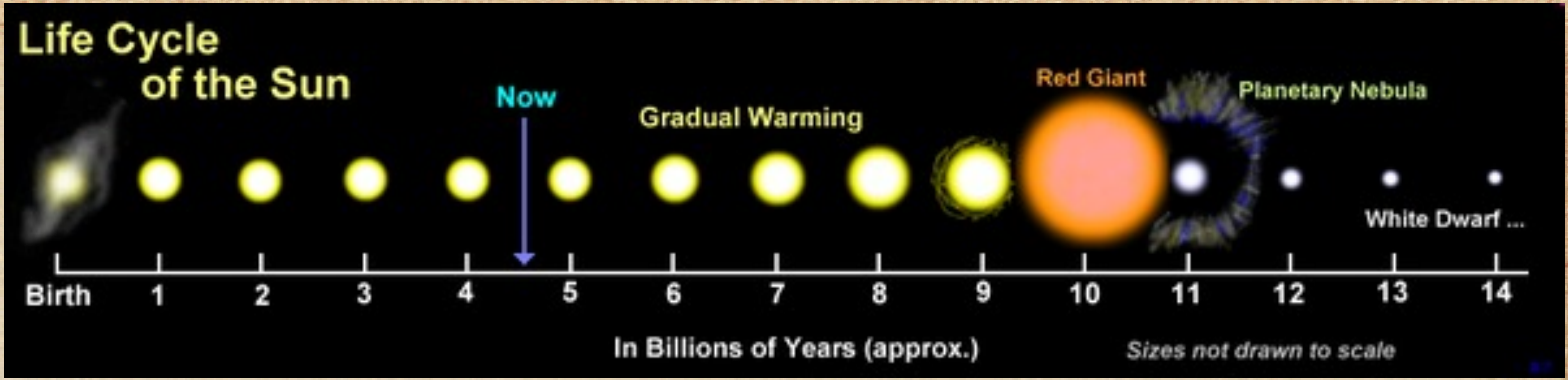
$$2\ ({}^{1}H + {}^{1}H = {}^{2}D + \beta^{+} + \nu)$$

$$2\ ({}^{1}H + {}^{2}D = {}^{3}He + \gamma)$$

$$^{3}He + {}^{3}He = {}^{4}He + 2\ {}^{1}H$$

$$\text{Net: } 4\ {}^{1}H = {}^{4}He + 2\nu + \gamma$$

- $^{2}D/^{1}H$ quickly approaches equilibrium value, but this is 10^{13} times smaller than the terrestrial value…terrestrial ^{2}D is made elsewhere!



- Most stars produce energy by ^{1}H burning – first generation stars produce ^{4}He by proton-proton-chain process: fusion

- Second generation stars have already incorporated other elements beyond ^{4}He and ^{1}H burning takes place by C-N-O cycle: four protons fuse using carbon, nitrogen and oxygen isotopes as a catalyst to produce one alpha particle (^{4}He), two positrons and two electron neutrinos. Fusion processes (He burning, C burning, O burning, Si burning can form elements up to mass ^{40}Ca)

- Eventually all H will be fused to He (our sun has fused 10-20% of its H)

- If the star is < ~8 solar masses, the star will undergo swelling to form a red giant, followed by gravitational collapse to a white dwarf.

Final Topic

Conserving energy at home and work

- Energy spent: where does it all go?
- Conduction, convection and radiation
- Conduction proper and analogy with electricity

Doing better than predictions: thanks to conservation efforts

Predicted energy usage (1970 predcition for 2003) was 160 QBTu,
we are at 98 QBTu

Energy consumption/GDP ratio:
1970: 27000 BTU/$
2004: 8400 BTU/$

Is it sensible to take ratios of two dimensional things?
In Physics we are very careful to define dimensionless ratios as far as possible
Not so in other fields.

Usage levels of energy Total 98 QBTu

- Household 22%
- Transport 27%
- Industry 33%
- Commercial uses 18%

Household uses:

- Space heating: 47%   4.4 QBTu
- Water heating 16%   2.1 QBTu
- Appliances 22%
- Rest 25%

Thermal conduction: 50-60%
Convection: 30-40%
Radiation: 5-10%

Conduction goes out through walls (37%), windows(16%), floors(1%), doors (3%), ceilings(5%)
Cracks in walls windows and doors (38%)

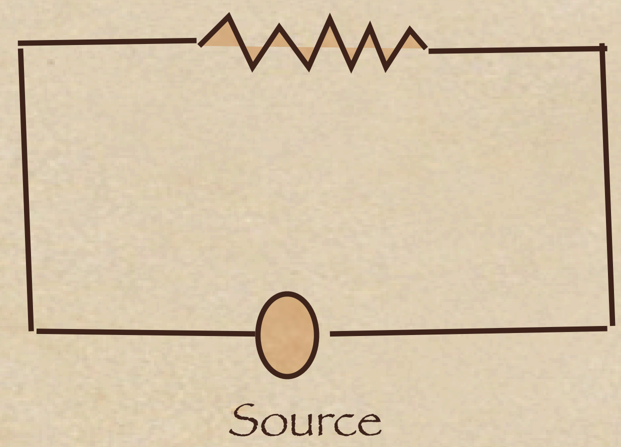
Good designs help, especially for newer houses.

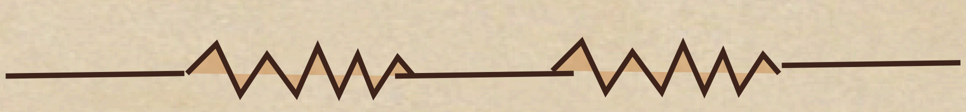
Analogy between electrical current and thermal energy transport

$$I = \frac{Q_e}{t}$$

$$I = \frac{V}{r_e}$$

r_e





$$r_{tot} = r_1 + r_2$$

L = length or resistor

A = Cross section of resistor

σ = electrical conductivity

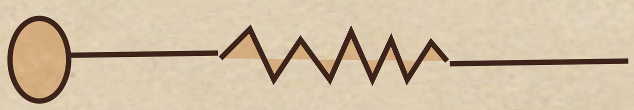
$$r_e \propto L$$

$$r_e \propto \frac{1}{A}$$

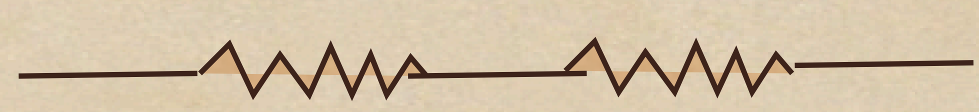
$$r_e = \frac{L}{A\sigma}$$

thermal energy transport

$$I_H = \frac{Q_H}{t}$$



$$I_H = \frac{T_H - T_C}{r_H}$$



$$r_H \propto L$$

$$r_{tot} = r_1 + r_2$$

L = length of insulator

A = Cross section of insulator

κ= thermal conductivity

$$r_H \propto \frac{1}{A}$$

$$r_H = \frac{L}{A\kappa}$$

Basic Equation for Heat conduction:

$$I_H = \frac{Q_H}{t}$$

$$I_H = \frac{T_H - T_C}{r_H}$$

Combining these:

$$\frac{Q_H}{t} = \frac{(T_H - T_C)A\ \kappa}{L}$$

Dimensions of various things:

$$[\frac{Q_H}{t}] = \frac{BTu}{Hour}$$

$$[\kappa] = \frac{BTu \times inch}{Hour \times ft^2 \times^0 F}$$

Usually express this as

$$Q = \frac{A \times \Delta T \times t}{R}$$

$$\because \frac{\kappa}{L} \to R$$

Traders use the so called R value defined above

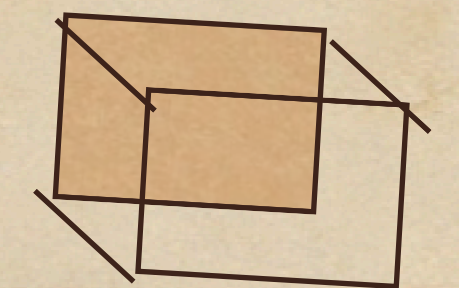
Thermal Resistance of materials is usually expressed in terms that are slightly different from r_H

$$r_H = \frac{L}{\kappa A} = \frac{R}{A}$$

$$R \equiv \frac{L}{\kappa}$$

$$[R] = \frac{hr \times {}^0F \times ft^2}{BTu}$$

$$Q = \frac{A \times \Delta T \times t}{R}$$



$$\Delta T \times t = degree - days$$

We can use this to add resistances and achieve the insulation needed.

$$Q = 24\frac{A}{R_{total}} \times degree - days$$

Typical R-values

Material	R (hr ^{0}F ft^2) / BTu
Plywood 3/4"	0.94
Polyurethane	6.25
Brick	0.2
Stone	0.08
Concrete	1.28
Glass 1/8"	0.03
Air layer (outside)	0.17
Air layer (inside home)	0.68

Concept of Degree Days is useful.
Each day we can calculate temp difference x hours
In a given (winter) season we can add up the daily figs.

Degree days

Example:
Temp 65^0 with outside temp 17^{0}F
What is the dd in 150 days?

Degree days = (65-17) x150 days = 7200 deg days

- Barrow Alaska 19990
- NJ 4810
- SF 3070
- Miami 170

$$Q = 24 \frac{A}{R_{total}} \times degree - days$$

$$R_T = R_1 + R_2 + R_3 + ..$$
$$= \frac{l_1}{\kappa_1} + \frac{l_2}{\kappa_2} + ..$$

As an example, a double glass window is a better insulator than a single glass window since we have two sheets separated by air gap. The air gap also has a significant R value:
From last table: we see that the
inside air layer has R=0.68 (Outside layer has less R=0.17)
glass pane (1/8)th inch R=.03 .

Hence for a single pane glass R= 0.68+.03+.17 = ~ 1

Double pane glass gets 3 inner layers R=3x0.68+.03+.17 = 2

Much better deal