Lecture 19

Pre- final Review

June 2, 2011

Current, Voltage, Resistance
Joule Heating.

Electric Energy Concepts

Electrical Laws (Ohm's law, Joule Heating)

Faraday's law and the Generation of electricity

Transmission of electricity (transformers)

Water	Electricity
Total water in tank	Charge Q in battery [Coulomb]
Rate of flow of water in a pipe	Current I [Amperes]
Height of tank	Potential V [Volts]
Height difference	Potential difference
Constriction of pipe carrying water	Resistance R [Ohms]
Work done in forcing water through a pipe	Work done in pushing charge through a circuit
Rate of doing work is power {watts}	Rate of doing work is power P {watts}

$$I = \frac{Q}{\Delta t}$$

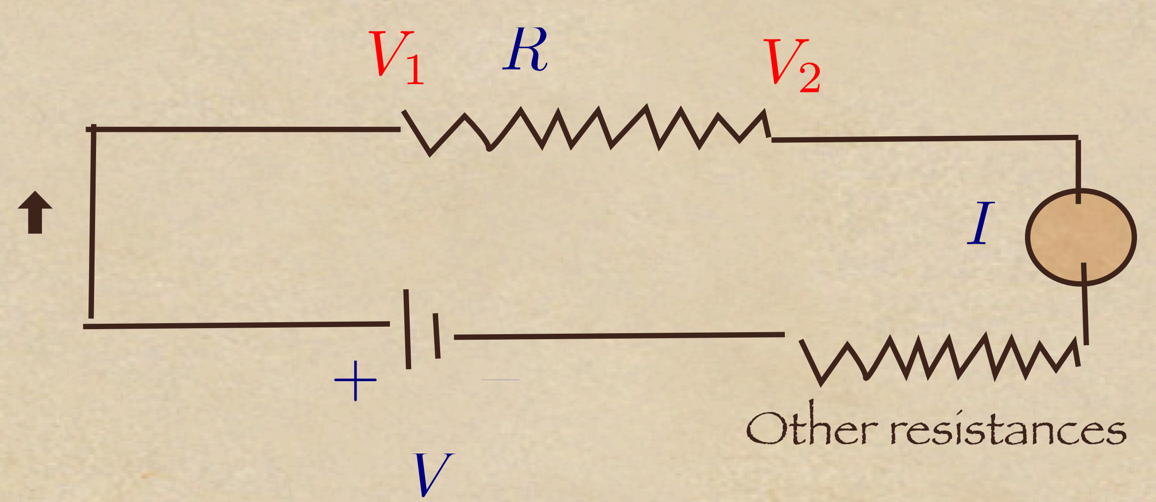
$$V = V_1 - V_2$$

$$V = I \times R$$

$$W = V \times Q$$

$$P = I \times V$$

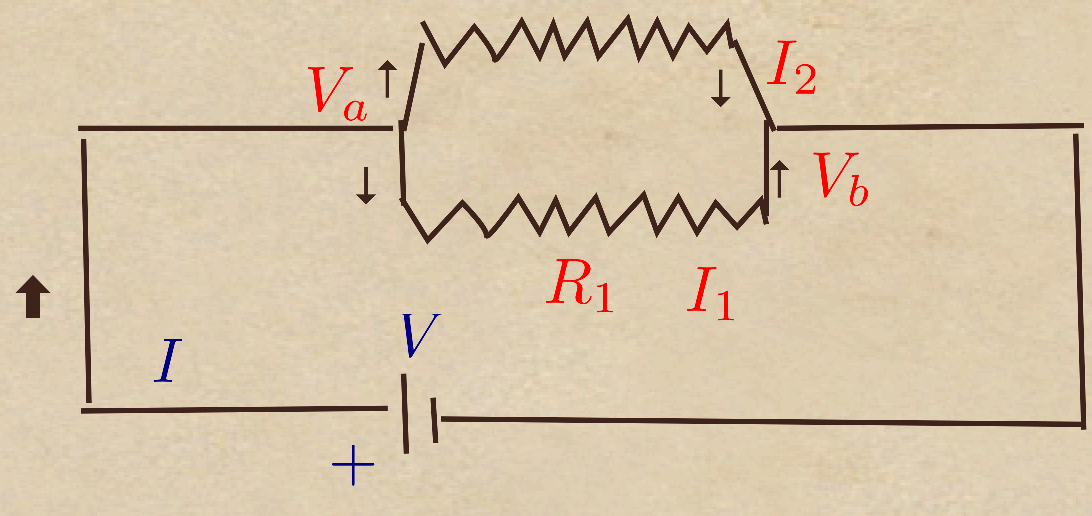
Resistance and Ohm's law



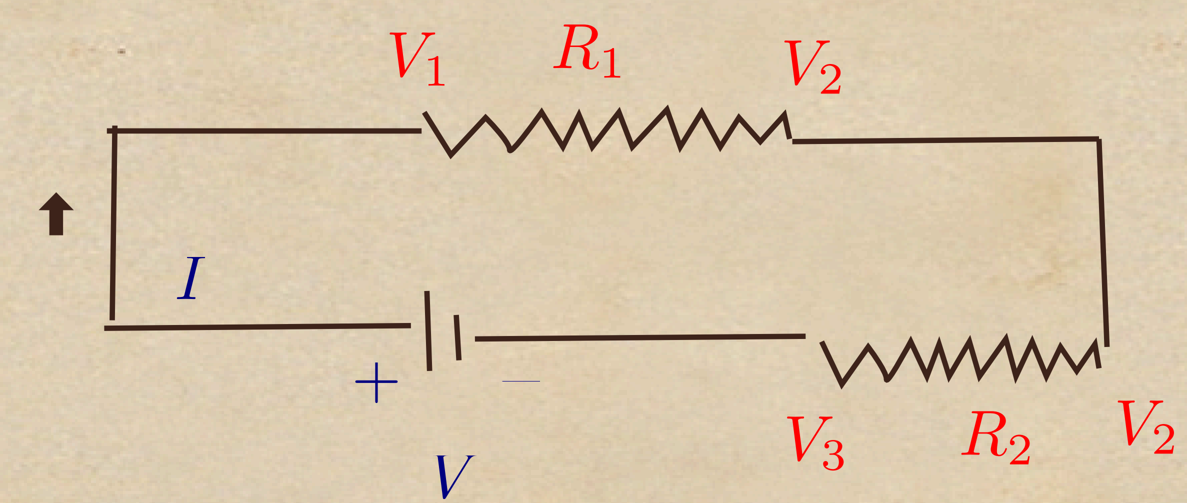
$$[R] = Ohms \rightarrow \Omega$$

$V_1 - V_2 = I \times R$ Potential drop across R and current I are connected by Ohm's law

$P = (V_1 - V_2) \times I = I^2 \times R$ Power dissipated in (Joule) heating across R



Resistors in “parallel”



Resistors in “series”

Note that the current I
is common to both resistances.

Comparing the two

Series

If we take

R_1/R_2=very small

Parallel

$$R_T = R_1 + R_2$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2}, \quad (6)$$

$$P_1 = V^2 \frac{R_1}{R_T^2}, \longleftarrow \text{small}$$

most of power used $\longrightarrow$

$$P_1 = V \times I_1 = \frac{V^2}{R_1}, \quad (7)$$

$$P_2 = V^2 \frac{R_2}{R_T^2}, \longleftarrow \text{most of power used}$$

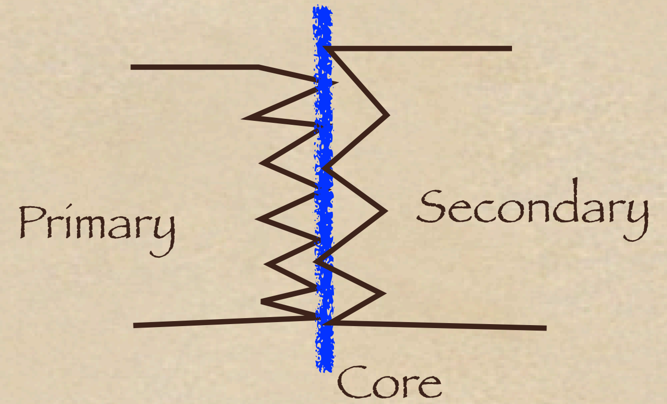
small $\longrightarrow$

$$P_2 = V \times I_2 = \frac{V^2}{R_2}, \quad (8)$$

Transformers

In all power generation schemes, the mechanical energy obtained by one of several means, is used to rotate the coils in a fixed magnetic field, and hence produce current.

Transformers:



Two loops of AC (not DC) current in close proximity transform voltages according to number of loops

$$V_p/N_p = V_s/N_s$$

Primary coil V_p is voltage and N_p is # of loops

Secondary coil V_s is voltage and N_s is # of loops

$$V_s = V_p \times N_s/N_p$$

We can choose N_p and N_s and thereby manipulate voltages!

Big V is the solution. $$P_{Joule} = P^2_{Generated} \times \frac{R}{V^2}$$

Wrong formula

$$V = I \times R$$

Correct formula

$$V_i - V_f = I \times R$$

to calculate I from the given line voltage V and resistance R.

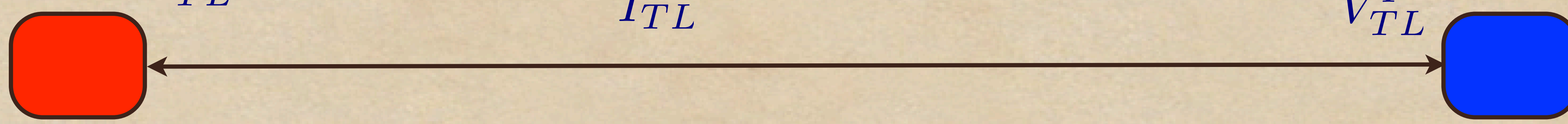
Key point is that the voltage line has a potential drop across its length:

$$\Delta V = V_{TL}^{I} - V_{TL}^{F}$$

R_{TL}

V_{TL}^{I} $\quad$ I_{TL} $\quad$ V_{TL}^{F}

P_{P-P}



T-L

P-P
(Power Plant)

Transmission Line

User

$$P_{P-P} = V_{P-P} \times I_{P-P}$$

$$\mathrm{V}_{P-P} = 12,500V$$
$$I_{P-} = 1000A$$
$$P_{P-P} = 12.5MW$$

$$\mathrm{R}_{TL} = 2\ \Omega\ (Ohm)$$

Sun/Earth:

Solar Constant = 2 cal/min/ cm^2 (averaged over the 24 hr day)

Effective Solar Constant = 0.5 cal/min/ cm^2

Losses in atmosphere due to absorption amount to 53% so we get about 47% of that

For an 8 hour day @ noon

$$600\ W/m^2\ \sim 190 \frac{Btu}{ft^2\ hr}$$

Insolation is defined as energy in a 8 hour day
e.g. in place X it is ~ 1520 BTU/ft^2 or 4.5 kWH/m^2

Units of Insolation: Energy/Area= Power x time/Area
Often given as kWH/m^2

A Sample Example:
Given that the daily insolation is 1000 Btu/ft^2, how much area do we need of solar panel to heat up 100 gallons water by 70^0 F?

Recall: 1 Btu heats one pound of water by 1^0 Farenheit, and one gallon weighs 8 pounds hence heat needed is

$$100\frac{gallon}{day} \times \frac{8\ lb}{1\ gallon} \times 1\frac{Btu}{{}^0F \cdot lb} \times 70^0 F = 56,000\ \frac{Btu}{day}$$

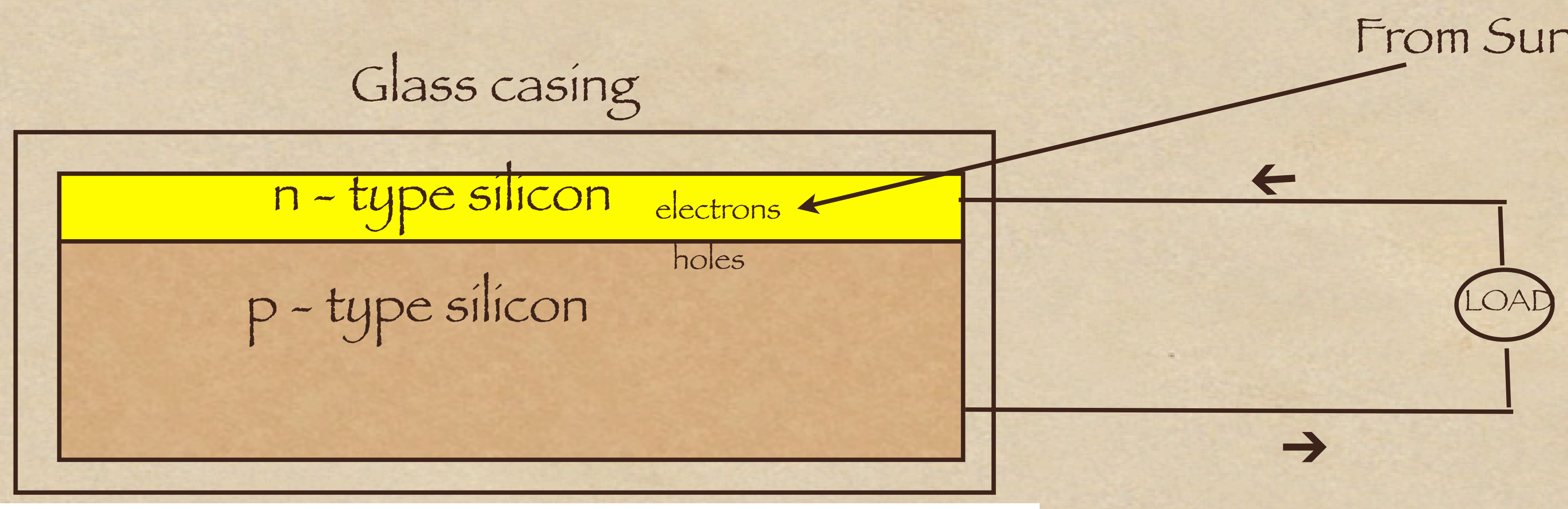
Need 56 Sq ft. Usually efficiency is 50% so need 112 Sq ft.

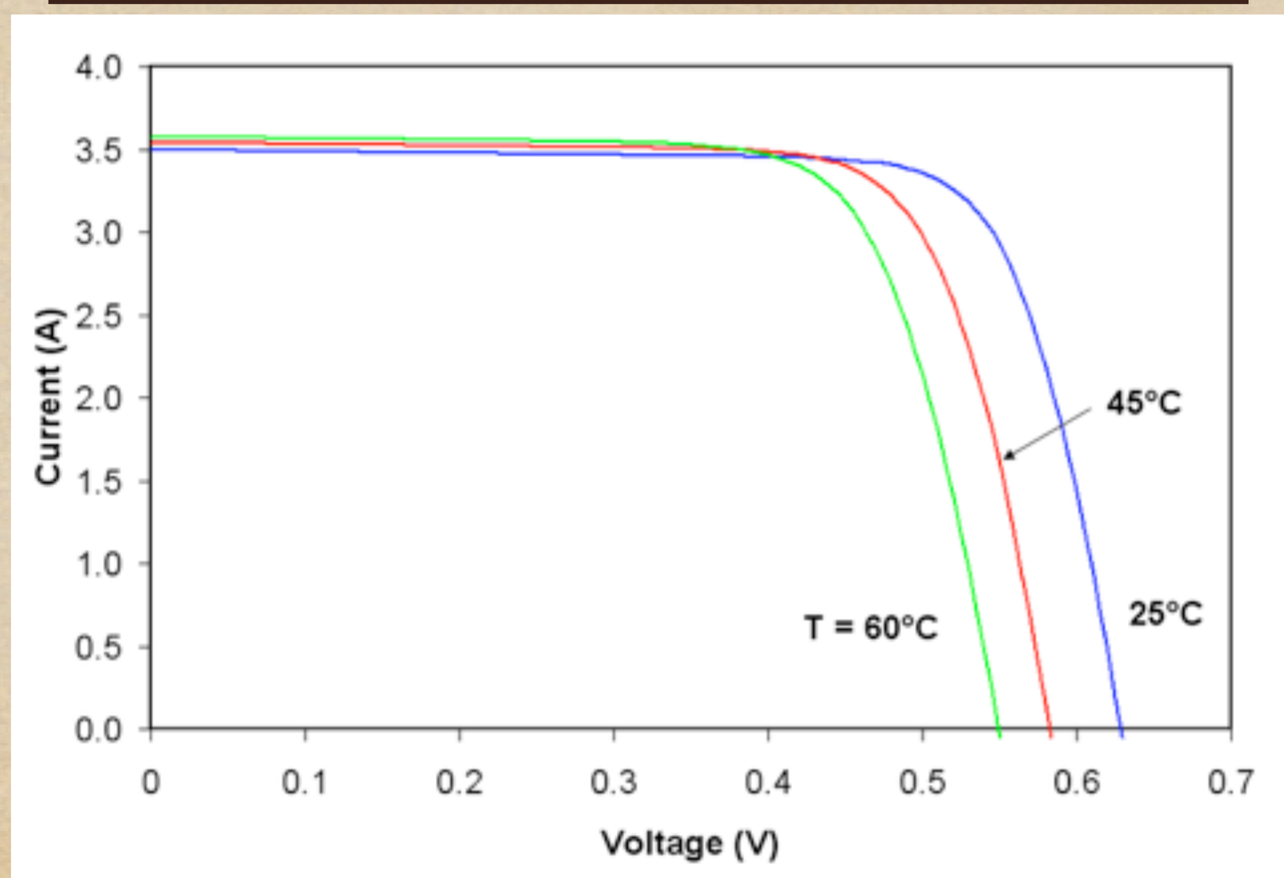
Further ideas involve

- Tracking the sun to maximize input
- Focussing light on pipes that carry liquids rather than flat panels. This way we utilize all the light.
- Converting solar energy to electricity.
- Converting solar energy to produce H_2, O and CO using catalysis.

Photoelectric effect and p-n junctions and Photovoltaics

Each cell ~ 2" dia and 1/16" thick- stack up some 50 of them to get a voltage of 20/25 volts





Water power is conversion of potential energy of water to electrical energy, e.g. by turning a turbine.

- 80% to 90% efficient
- Cyclical and weather (precipitation) dependent
- In USA currently less than 7% of total usage from 30% in post war years

Head= "h" the height of water

$$E = Mgh$$

Potential energy of water

$$g = 9.8 \text{ meter}/\text{sec}^2$$

Example: Water drops in a hydel project with a head of 90 meters. How much water flow is needed to produce 10 kW power, assuming 80% conversion efficiency?

Let x liters of water flow per second.

Hence mass flow is x kg/sec (using density of water - d =1 kg/Liter)

Power = energy /time = M gh/t = (M/t) g h

$$\begin{aligned} Power &= x(kg/sec) \times 9.8(m/sec^2) \times 90m \\ &= x \times 882\ kg\ m^2/sec^3 \\ &= x \times 882\ watts \end{aligned}$$

$$\text{Watt} = \text{kg}\ meter^2/\text{sec}^3$$

Next equate these:

$$0.8 \times x \times 882\ watts = 10^4\ watts \qquad x = 14.17\ Litres\ /sec$$

River discharge rates:

Amazon = 219 Million Litres/sec

= 219,000 m^3 /sec (1 m^3= 10^3 L)

= 219 Mil L/sec

Ganges = 42 Mil L /sec

St Lawrence = 10 M L/s

Ohio - Missisippi = 8 ML/s

Problem:

If we can drop the Ohio river by 10 meters, what is the generated power?

$$Power = 8 \times 10^6 \ (kg/sec) \ \times 9.8 \times (m/sec^2) \ \times 10(m)$$
$$= 0.8 \times 10^9 \ Watts$$

~ 1 Gigawatt

$$Total\ energy\ per\ year = Power \times 365 \times 24\ Watt\ hour$$

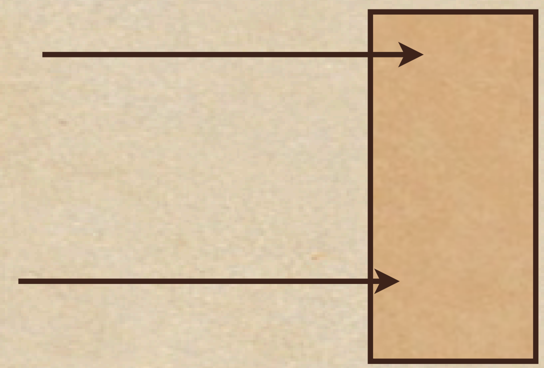
$$Total\ energy\ per\ year = 5.6\ TeraWatt\ hour$$

Annual power generated ~ 4000 TWH

Wind power:

$$P/m^2 = 6.1 \times 10^{-4}\ v^3$$

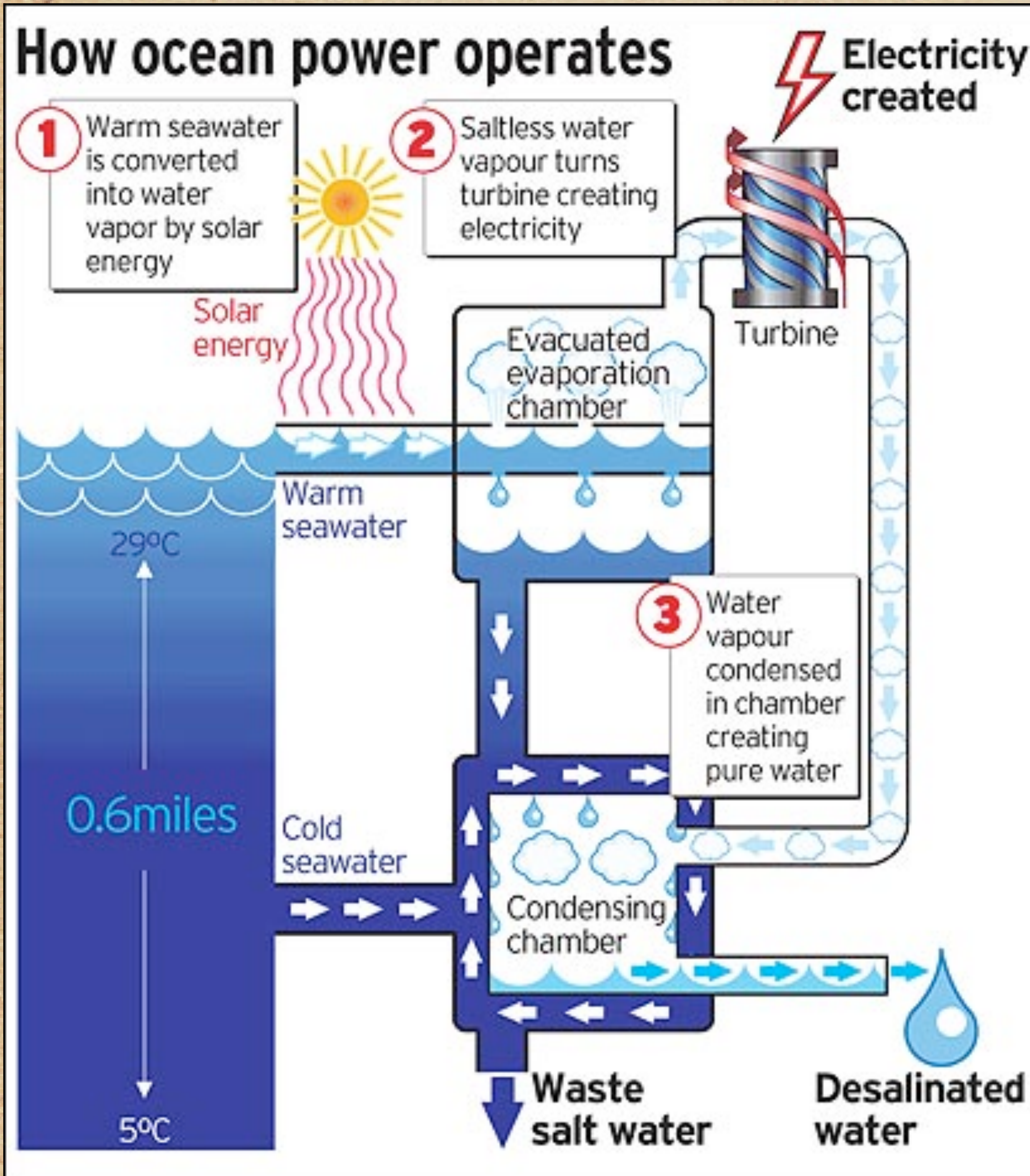
P is the power in kW per square meter
and v the wind velocity in meters per second.
This assumes that the surface is at right angles to the wind



v^2 from kinetic energy and v from amount of wind passing by per second.

$$30\ mph = 48\ kmph = 13.33\ meter/second$$

$$10\ sq\ meters\ gives\ 2.37\ kW$$



$$\eta = \frac{T_H - T_C}{T_H}$$

$$\eta = \frac{15}{300} \sim 5\%$$

If we cool 1000 gallons of water by 2ºC, the power generated is 32 MW.
At 5% efficiency this gives 1.6 MW output as usable power.

Offshore plants could produce Hydrogen that can be transported by ships..

Not a big player as yet, and rather cool response in US to this technology.

Nuclear Energy

- Vast possibilities
- Much worry about safety, partly based on experience
- Further ideas for safer harvesting
- Need to know the basics:

$$^{236}_{92}U \rightarrow ^{90}_{36} Kr + ^{143}_{56} Ba + 3n + \ 199 Mev$$

Fission reaction: Need to understand the symbols and concepts.

$$E_{Binding} = (Total\ energy\ of\ Z\ protons\ and\ N\ neutrons) - (total\ energy\ of\ nucleus)$$

$$\Delta m = (total\ mass\ nucleons) - (mass\ nucleus)$$

Example of $^{14}{}_{7}N$ nitrogen nucleus:

Nuclear Mass - 7 electron mass= 13.9992 u

Mass of nucleii (7 p + 7 n)= (.112356+ 13.9992) u

Mass defect = .112356 u

Binding energy = $1.004\ 10^{13}$ J

10 tons of this substance gives 98 QBTU !!!!

Reactor Issues:

Chain reaction: neutrons + U produces more neutrons
Controlled Chain reaction is a Reactor and is desirable for energy purposes

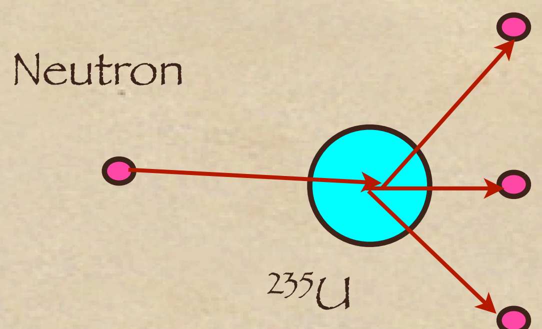
$$^{236}_{92}U \rightarrow ^{90}_{36} Kr + ^{143}_{56} Ba + 3n$$
$$+199\ Mev$$

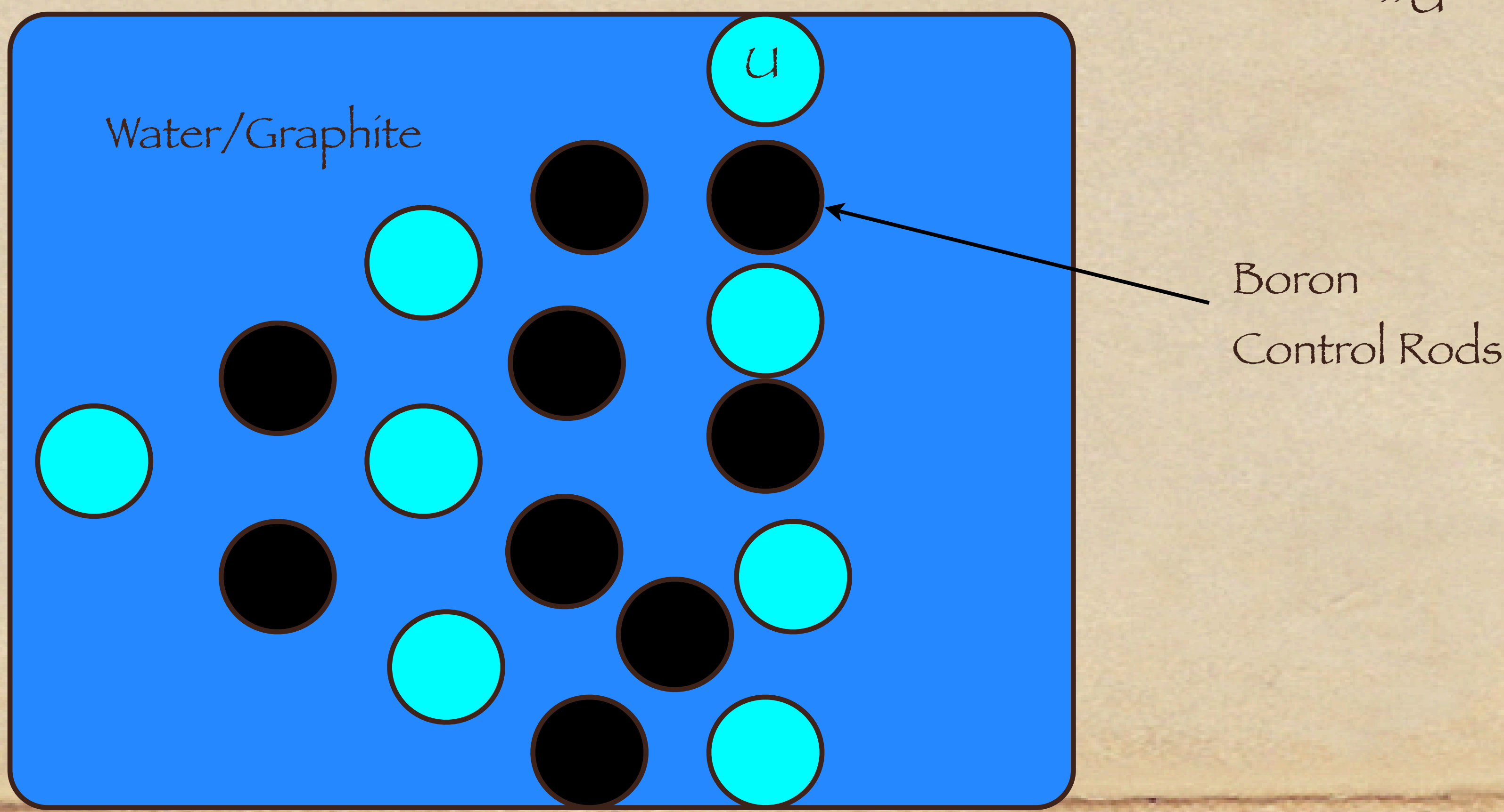
Some decays do not produce neutrons but give photons i.e. gamma rays instead.

A few crucial facts are important to assimilate here:

1. Slow neutrons have a greater chance of fissioning ^{235}U. The probability of fissioning is 1000 times larger for neutrons with energy .025 eV (300K) than with 1 Mev. Therefore the importance of "thermal neutrons".
2. The emitted neutrons are very fast, with energy of O(Mev) and these need to be slowed down, in order to create next generations of fission.
3. Slowing down happens with the help of "moderators". Moderators are material such as heavy water or graphite where the fast neutrons rattle around to get thermalized.
4. Need control rods to absorb neutrons that are produced, to prevent a reactor from blowing up.

1. A moderator is a tank of some material that scatters neutrons without absorbing them. Good candidates are water, graphite, heavy water.
2.Control rods are inserted to soak up neutrons and to stop the processes. Control rod materials are good neutron absorbers- Boron compound work well





Criticality:

Need a certain amount of ^{235}U to sustain a chain reaction.

$$^{235}_{92}U + n \rightarrow ^{236}_{92}U$$

$$^{236}_{92}U \rightarrow ^{90}_{36}Kr + ^{143}_{56}Ba + 3n$$
$$+199\ Mev$$

In breeder tech reactors we also get into

$$n + ^{238}U \rightarrow ^{239}U$$

$$^{239}_{92}U + n \rightarrow ^{239}_{94}Pu + \text{stuff}$$

$$n + ^{239}_{94}Pu \rightarrow \text{fission products} + \text{energy}$$

Different uses weapons or reactors have different requirements of enrichment and criticality.

Practice Finals

1. Two resistors with resistances 2 Ohms and 3 Ohms are connected to a 10 V battery,
   (a) in series
   (b) in parallel.
   For each case find the voltage drop across each, and the amount of Joule heating produced in each resistor.

2. A power plant generates 1000 MW which is transmitted by a power line that carries a current of 500 Amps. If the end voltage is 800,000 V what is the resistance of the line?

3. A hot-tub heater with resistance of 20 Ohms is used in a household with voltage 115 volts, for 2 hour every morning. Assuming that it is used to heat up water at 70% efficiency, and that the temperature boost required is 50^0C, what is the quantity of water used each day? What are the electricity charges for this usage per month? (Assume 25 cents/ kWH charges).

4. A car wash needs 500 gallons of water a day heated from 50^0F to 100^0F. How large a solar collector would be needed to do this? The incident insolation is 1000 Btu/ft^2 and the collector efficiency is 30%.

5. A hydel project has a head of 90 meters. Calculate the rate of flow of the lake needed to obtain 1 MW power working at 80% efficiency. If the velocity of water in flow is 20 kms per hour, what is the area of the lake? Here the volume flow rate is related to the velocity and the area, by imagining that the lake flows at a steady rate with the surface water discharged into the dam.

$$Area \ \times velocity = volume \ /time$$

Physics 2

Elementary Physics of Energy

Practice Final Solutions

1. Two resistors with resistances 2 Ohms and 3 Ohms are connected to a 10 V battery,
(a) in series
(b) in parallel.
For each case find the voltage drop across each, and the amount of Joule heating produced in each resistor.

Solution:

(a) For resistors in series, the current is the same in both. To find the current in the system use the relation $V_1 - V_3 = V = I(R_1 + R_2)$. Since $V = 10$ Volts and $R_1 + R_2 = 5$ Ohms, then $I = V/(R_1 + R_2) = 2$ Amps. Now the voltage drop across each resistor can be found from $V = I \times R$, so it is 4 V and 6 V, for the 2 and 3 Ohm resistors, respectively. Note that the sum of the voltage dropped across the resistors is equal to the voltage of the battery.

The power dissipated across each resistor (Joule heat) is $P = \Delta V \times I$, hence 8 and 12 Watts. (Units: The units of Volts are Joule/Coulomb and Amps are Coulombs/sec)

(b) For resistors in parallel the voltage drop is the same across both, and equal to the battery voltage, i.e. 10 V.

To calculate the power, first find the current through each resistor. The total current in the system is

$$I = V \times (\frac{1}{R_1} + \frac{1}{R_2}) = 8.3\ Amps.$$

Because $V = I_1 R_1 = I_2 R_2$ and $I = I_1 + I_2$,

$$I_1 = I \frac{R_2}{R_1 + R_2} = 8.3 \times \frac{3}{2+3} = 5\ Amps$$

Then $I_2 = I - I_1 = 3.3\ Amps$. So the power is 50 W for the 2 Ohm resistor and 33 W for the 3 Ohm resistor.

2. A power plant generates 1000 MW which is transmitted by a power line that carries a current of 500 Amps. If the end voltage is 800,000 V what is the resistance of the line?

Solution:

First, find the initial voltage:

$$V = P/I = \frac{1 \times 10^9\ W}{500\ A} = 2 \times 10^6\ V = 2\ MV.$$

The voltage dropped across the line is $V_i - V_f = 2,000,000 - 800,000 = 1,200,000\ V = 1.2\ MV$. The resistance can then be found from Ohm's Law, $V = IR$, i.e. $R = V/I = (1.2 \times 10^6\ V)/(500\ A) = 2,400\ Ohms$.

3. A hot-tub heater with resistance of 20 Ohms is used in a household with voltage 115 volts, for 2 hour every morning. Assuming that it is used to heat up water at 70% efficiency, and that the temperature boost required is 50^0C, what is the quantity of water used each day? What are the electricity charges for this usage per month? (Assume 25 cents/kWh charges).

Solution:

Let the mass of water be m kG. Calculate the total amount of heat energy required to increase the water temperature by 50^0 Celsius using the formula $\Delta Q = mass \times heat\ capacity \times temperature\ difference = m\ (kg) \times 4.2\ (kJ)/(kg^0C) \times 50^0C = m \times 210\ kJ$.

By inserting Ohm's Law into the equation for Joule heating one arrives at the formula $P = V^2/R = (115\ V)^2/(20\ Ohms) = 661\ W = 661\ J/sec$. So in two hours the energy used $2\ hours \times 3600\ (sec/hour) \times 661\ W = 4.8 \times 10^6$ J. Since the efficiency is 70%, the amount of heat actually absorbed by the water is $E_{used} = .7 \times 4.8 \times 10^6 = 3.3 \times 10^6$ J.

Then equate the two expressions and solve for the mass:

$E_{used} = 3.3 \times 10^6\ J = m \times 2.10 \times 10^5\ J$, so

$$m = \frac{3.3 \times 10^6}{2.10 \times 10^5} = 15.7\ kg.$$

The cost of usage is found from the energy drawn by the hot tub, i.e. $661\ W = 0.661\ kW$. Thus each day 1.32 kWh are used, so in a month that's $1.32 \times 30 = 39.7\ kWh$. At the given charges this will cost $39.7 \times .25 = 9.92$ \$ per month.

4. A car wash needs 500 gallons of water a day heated from 50^0F to 100^0F. How large a solar collector would be needed to do this? The incident insolation is 1000 Btu/ft^2 and the collector efficiency is 30%.

   Solution:

   Find the amount of energy required to heat the water using the formula $\Delta Q = mc\Delta T$, i. e.

$$\frac{500\ gal}{day} \times \frac{8\ lbs}{gal} \times \frac{1\ Btu}{lb\ \cdot^0 F} \times 50^0 F = 2 \times 10^5\ Btu$$

   where the specific heat was chosen in convenient units. Since the collector is 30% efficient it is only able to capture 300 Btu/ft^2, so the necessary area is $\frac{2\times10^5\ Btu}{300\ Btu/ft^2} = 666.7\ ft^2$.

5. A hydel project has a head of 90 meters. Calculate the rate of flow of the lake needed to obtain 1 MW power working at 80% efficiency. If the velocity of water in flow is 20 km per hour, what is the area of the lake? Here the volume flow rate is related to the velocity and the area, by imagining that the lake flows at a steady rate with the surface water discharged into the dam.

   Solution:

   $Energy = mgh$ and $Power = energy/time = mgh/t = (m/t)gh$ where m/t is mass per unit time, hence the flow rate. So

$$Power = x(kg/sec) \times 9.8(m/sec^2) \times 90\ m.$$

   The actual power required, taking into account the efficiency, is $(1 \times 10^6\ W)/(0.8) = 1.25 \times 10^6\ W$. Put this into the above and solve for the flow rate.

$$x = \frac{1.25 \times 10^6\ W}{9.8(m/sec^2) \times 90\ m} = 1,417\ kg/sec.$$

   Note that the units of Watts are $kg \cdot m^2/sec^3$. The density of water is 1000 kg/m^3 so the flow rate is 1.42 m^3/sec. To find the area divide this by the velocity, which is $\frac{2\times10^4\ m}{hr} \times \frac{1\ hr}{3600\ sec} = 5.6\ m/sec$, so

$$\frac{1.42\ m^3/sec}{5.6\ m/sec} = 0.22\ m^2.$$

Problems from Ristinen & Kraushaar:

Ch. 5 Problems (pg. 167): 6, 8
Multiple Choice Questions: 4, 5

Ch. 6 (pg. 207): 4, 18

Additionally you are advised to review the concepts of specific heat and latent heat from the first half of the course.

Chapter 5 Problems

6.

$$\frac{2.4\,J}{cm^{3\circ}C} \times (\frac{100\,cm}{m})^3 \times 140\,^\circ C = 336 \times 10^6\,J$$

8.

$$(1 - \frac{5+273}{20+273}) \times \frac{1}{3} = 0.017 = 1.7\%$$

Multiple Choice

4. c. $\frac{10{,}000\,kg}{1s} \times 9.8\frac{m}{s^2} \times 150\,m \times 0.85 = 1.25 \times 10^7\,W$ electric, or $12.5\,MW_e$

5. d. The power in the wind is proportional to the speed cubed. If the speed is tripled from 3 mph to 9 mph, the power is increased by 3^3, or 27 times. The new power is thus $27{\times}5\,kW = 135\,kW$

Chapter 6 Problems

4.

$${}^{238}_{92}\mathrm{U}_{146} \rightarrow {}^{140}_{55}\mathrm{Cs}_{85} + {}^{92}_{37}\mathrm{Rb}_{55} + 6\mathrm{n}$$

18. One plant that makes enough plutonium for 20 bombs generates the following energy in a year:

$$1000\,MW \times 1000\frac{kW}{MW} \times \frac{365.3\,day}{yr} \times \frac{24\,hr}{day} \times 1\,yr = 8.77 \times 10^9 kWh/yr$$

Dividing this result into the total energy generated worldwide gives an effective number of 1000 MW power plants, so:

$$20\,bombs \times \frac{24 \times 10^{11}}{8.77 \times 10^9} = 5,475\,bombs!$$