FUNDAMENTAL FORMULA

Physics 115

Work = Force X Distance   e.g. Weight X Height

$W = F \times d$ $\mathcal{W} \times h$

$[W = \text{work} \neq \text{weight} = \mathcal{W}]$

IMPORTANT RATIOS

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

60 mi/hr = 88 ft/sec = 26.8 m/sec

$$\text{Acceleration} = \frac{\text{Speed}}{\text{Time}} = \frac{\text{Distance}}{(\text{Time})^2}$$

$g = 9.8$ m/sec^2

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \left[= \frac{\text{Energy}}{\text{Time}} = \text{Force} \times \text{Speed}\right]$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

(For water : 1000 kg/m^3)

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \left[= \frac{\text{Force X distance}}{\text{Area X distance}} = \frac{\text{Energy}}{\text{Volume}}\right]$$

$$\text{Current} = \frac{\text{Charge}}{\text{Time}}$$

- O V E R -

DISTINCTIONS

In this course you should learn the differences between:

Speed and velocity

Velocity and acceleration

Work and effort

Mass and weight

Force, energy, and power (They don't all just mean "vigor".)

Law and Theorem

Machine, motor, and engine

Motor and generator

Engine and refrigerator

Heat* and temperature ("It's not the heat: it's the temperature".)

Heat* and work

Energy and entropy

Accelerator and reactor

Thermal and fast nuclear reactors

Fission and Fusion

---

* The word "heat" really should be used only as a verb (and not as a noun): "To heat" and object is to add to it energy in random (i.e. disorganized) form, as we shall learn in great detail.

Work is force times distance (in the same direction).

$$W = Fd$$

Energy is stored work $E = W$

Weight times height is one form of work

$$W = \mathcal{W}h = Mgh \qquad (\mathcal{W} = \text{weight} = Mg)$$

$\therefore$ Energy is the stored ability to lift a weight (or to do other mechanical work, such as to drive a generator of electric current.).

Power is the rate of working

$$\text{Power} = P = \frac{\text{work}}{\text{time}} = \frac{W}{t}$$

(how much you do, how quickly).

When lifting

$$P = \frac{\mathcal{W}h}{t} = \mathcal{W} v_{up} \qquad \left(\frac{h}{t} = v_{up}\right)$$

ENERGY, POWER, AND FORCE
have definite and different meanings.

ENERGY QUANTITIES [illegible]

Joule [illegible] = 0.74 foot-pound [illegible]

[illegible]

Calorie = 4184 Joule (1 kilocalorie)

Kilowatt-hour = 3.6 megajoule [illegible]

Therm = energy released by the combustion of 100 [illegible]

of natural gas [illegible]

= 10^5 Btu = 105.5 megajoule [illegible]

[illegible]

ExaJoule = 10^18 Joule [illegible]

One Watt is a power of one Joule/second

Electron-volt = 1.6 x 10^-19 Joule

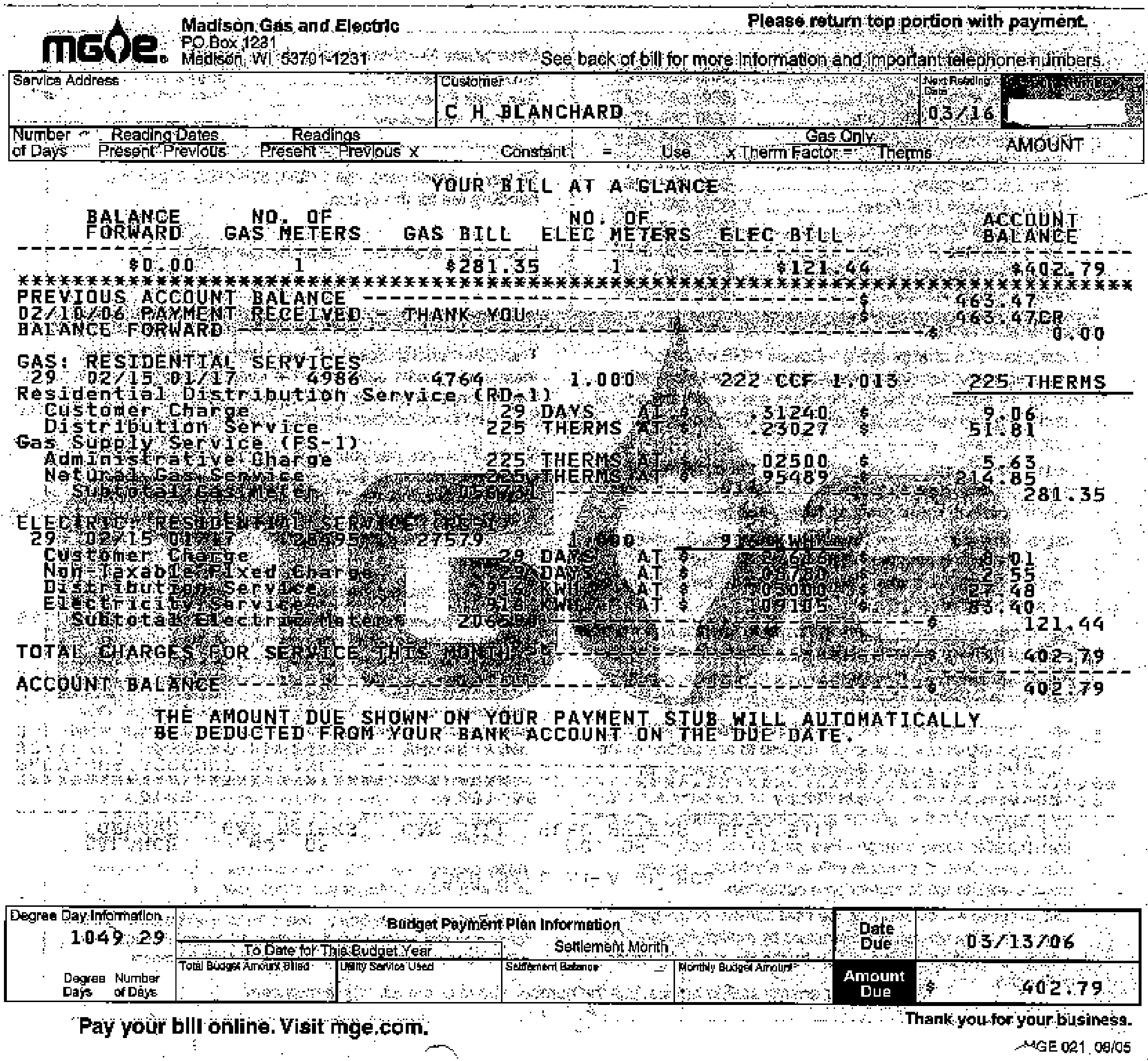
[illegible] energy [illegible]

corresponds to 100 [illegible]

[illegible]

The USA buys about 100 exaJoule (10^{20} J) per year.

That is a power of 3.4 teraWatt (3.4 x 10^{12} W)



mge Madison Gas and Electric
P.O. Box 1231
Madison, WI 53701-1231

Please return top portion with payment.

See back of bill for more information and important telephone numbers.

Service Address	Customer	Next Reading Date	
	C H BLANCHARD	03/16	[redacted]

Number of Days	Reading Dates Present	Reading Dates Previous	Readings Present	Readings Previous	x Constant	= Use	x Therm Factor	= Therms (Gas Only)	AMOUNT

YOUR BILL AT A GLANCE

BALANCE FORWARD	NO. OF GAS METERS	GAS BILL	NO. OF ELEC METERS	ELEC BILL	ACCOUNT BALANCE
$0.00	1	$281.35	1	$121.44	$402.79

```
PREVIOUS ACCOUNT BALANCE ---------------------------------$       463.47
02/10/06 PAYMENT RECEIVED - THANK YOU --------------------$       463.47CR
BALANCE FORWARD ----------------------------------------------$     0.00

GAS: RESIDENTIAL SERVICES
 29  02/15 01/17   4986   4764    1.000    222 CCF 1.013     225 THERMS
Residential Distribution Service (RD-1)
  Customer Charge               29 DAYS    AT $   .31240  $      9.06
  Distribution Service         225 THERMS  AT $   .23027  $     51.81
Gas Supply Service (FS-1)
  Administrative Charge        225 THERMS  AT $   .02500  $      5.63
  Natural Gas Service          225 THERMS  AT $   .95489  $    214.85
    Subtotal Gas Meter [illegible] ----------------------$      281.35

ELECTRIC: RESIDENTIAL SERVICE [illegible]
 29  02/15 01/17  [illegible]  27579    1.000    [illegible] KWHRS
  Customer Charge               29 DAYS    AT $ [illegible] $      8.01
  Non-Taxable Fixed Charge      29 DAYS    AT $ [illegible] $      2.55
  Distribution Service   [illegible] KWH   AT $ [illegible] $     27.48
  Electricity Service    [illegible] KWH   AT $   .09105  $     83.40
    Subtotal Electric Meter [illegible] -----------------$      121.44
TOTAL CHARGES FOR SERVICE THIS MONTH ---------------------$      402.79

ACCOUNT BALANCE ------------------------------------------$      402.79

        THE AMOUNT DUE SHOWN ON YOUR PAYMENT STUB WILL AUTOMATICALLY
        BE DEDUCTED FROM YOUR BANK ACCOUNT ON THE DUE DATE.
```

Degree Day Information	Budget Payment Plan Information				Date Due	03/13/06
1049 29	To Date for This Budget Year		Settlement Month			
Degree Days Number of Days	Total Budget Amount Billed	Utility Service Used	Settlement Balance	Monthly Budget Amount	Amount Due	$ 402.79

Pay your bill online. Visit mge.com.

Thank you for your business.

MGE 021 08/05

NOTE For a given amount of energy, electricity is about three times as expensive as gas:

Electricity	13¢/kWhr
Gas	4.3 ¢/kWhr

(Because gas is "heat" and electricity is "work" !)

Physics 115 Class #1 Wed 25Sep87

$ab = a \cdot b = a \times b$ = a times b (= b times a)

The ratio of a & b is the fraction $\frac{a}{b}$ or a/b

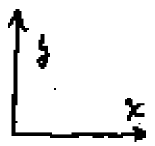
and a/b means $a \div b$ (a divided by b : b divided into a : $b\overline{)a}$)

"of" means "times" : $\frac{1}{2}$ of N is $\frac{1}{2}N = N/2$

"per" means "divided by" or "for every"
percent = for every hundred
per capita = per person (literally: for each head).

"47% of" means "0.47 times"

A graph of y versus x means



$10^2 = 10 \times 10 = 100$
$10^3 = 10 \times 10 \times 10 = 1000$ kilo
$10^6 = 1,000,000$ = one million Mega
$10^9 = 1,000,000,000$ = one billion Giga (G is hard except before E)
$10^1 = 10$
$10^0 = 1$
$10^{-1} = \frac{1}{10} = 0.1$ deci
$10^{-2} = 0.01$ centi
$10^{-3} = 0.001 = \frac{1}{1000}$ milli
$10^{-6} = .000001$ micro

$$60\,\frac{mi}{hr} \times \frac{5280\,ft}{1\,mi} \times \frac{1\,hr}{3600\,sec} = \frac{60 \times 5280}{3600}\,\frac{ft}{sec} = 88\,\frac{ft}{sec}$$

$$= 88\,\frac{ft}{sec}\ \frac{1\,m}{3.28\,ft} = 26.8\ m/sec$$

(OVER)

Area = length × width : how much surface.

Volume = length×width×height : how much space.

Circumference $= C = \pi D = 2\pi R$

$A_{circle} = \pi R^2$

$A_{sphere} = 4\pi R^2$

$V_{sphere} = \frac{4\pi}{3} R^3$

Accuracy of measurements ("significant figures")

$x = 3$ means $2.5 < x < 3.5$ $\Delta x = 1$

$x = 2.7$ means $2.65 < x < 2.75$ $\Delta x = .1$

$x = 2.73$ means $2.725 < x < 2.735$ $\Delta x = .01$

$x = 2.736$ means $2.7355 < x < 2.7365$ $\Delta x = .001$

And

$1.23\ m \times 4.56\ m$ is the area $5.61\ m^2$ (not $5.6088\ m^2$)

DEMOS

Vacuum Pump

Cotton & Penny Falling

Pulleys

1kg mass and 1m stick

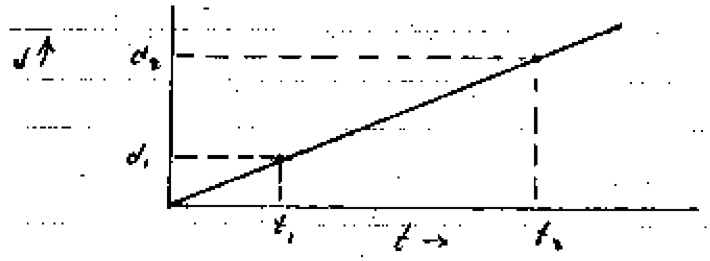
Wheel and axle

MOTION IN A STRAIGHT LINE

$$\begin{cases} \text{velocity} = v = \dfrac{\text{distance}}{\text{time}} = \dfrac{\Delta d}{\Delta t} = \dfrac{d_2 - d_1}{t_2 - t_1} = \text{time rate of change of distance} \\ \text{acceleration} = a = \dfrac{\text{velocity}}{\text{time}} = \dfrac{\Delta v}{\Delta t} = \dfrac{v_2 - v_1}{t_2 - t_1} = \text{time rate of change of velocity} \end{cases}$$

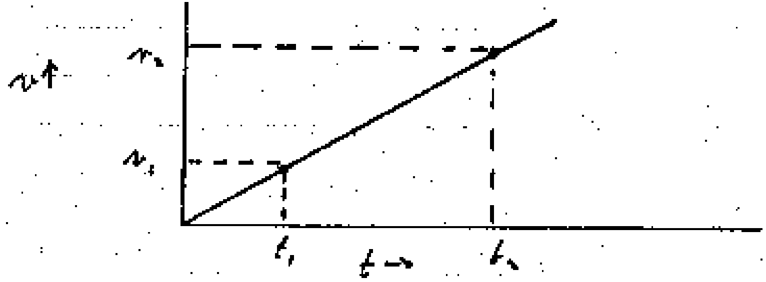
$F = Ma$

If $F = 0$ then (since $M \neq 0$) $a = 0$. Then v = constant and



straight-line graph
slope = $v = \dfrac{d_2 - d_1}{t_2 - t_1}$
and $d = vt$

If F = constant then (since M = constant), a = constant and



straight-line graph
slope = $a = \dfrac{v_2 - v_1}{t_2 - t_1}$
and $v = at$

Average velocity $= \bar{v} = v_{avg} = \frac{1}{2}(v_i + v_f) = \frac{1}{2}(0 + at_f) = \frac{1}{2} a t_f$

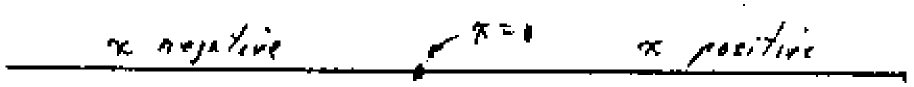
Distance = avg vel × time $= \bar{v} t_f = \frac{1}{2} a t_f^2$ that is $d = \frac{1}{2} a t^2$ (from rest)

Work done by pusher in accelerating a body

$$\text{Work} = W = Fd = Mad = Ma\bar{v}t = M \frac{v_f - v_i}{t} \frac{v_f + v_i}{2} t$$
$$= \frac{1}{2} M (v_f^2 - v_i^2) = \frac{1}{2} M v_f^2 - \frac{1}{2} M v_i^2$$

$\frac{1}{2} M v_f^2 = \frac{1}{2} M v_i^2 + Fd$ Kinetic Energy $\boxed{K.E. = \frac{1}{2} M v^2}$ (OVER)

Distance, Velocity, and Acceleration along a line



S	e.g.	N
W		E
down		up
left		right

v↓ x→	negative	positive
negative	size of x increasing (getting more negative)	size of x decreasing (on right but going left)
positive	size of x decreasing (on left but going right)	size of x increasing (getting more positive)

a↓ v→	negative	positive
negative	speeding up (vel getting more negative)	slowing down (vel getting less positive)
positive	slowing down vel getting less negative	speeding up (vel getting more positive)

BASIC UNITS

System → Quantity ↓	mks (SI)	British Eng'g (fps)	cgs
time	second	second	second
length	meter	foot	centimeter
force	Newton	pound	dyne
mass	kilogram	slug	gram
work or energy	Joule (=Nm)	foot-pound	erg
power	Watt$(=\frac{J}{sec})$	horsepower $(1hp=550\frac{ft\ pd}{sec}=\frac{3}{4}kW)$	erg/sec
g	9.80 m/sec^2	32.2 ft/sec^2	980 cm/sec^2

ENERGY UNIT	Abbrev	Magnitude in Joules
electron volt	eV	1.6×10^{-19}
million electron volt	MeV	1.6×10^{-13}
billion electron volt	GeV	1.6×10^{-10}
erg (cgs unit)		10^{-7}
Joule (mks unit)	J	1
foot pound (fps unit)	ft-pd	1.356
calorie (heat)	cal	4.184
British thermal unit (heat)	Btu	1055
kilocalorie = food calorie = Calorie (heat)	kcal	4184
kiloWatt hour	kWhr	3.6×10^6
therm=10^5 Btu [100 ft^3 methane] (heat)		1.055×10^8
*Quad [=quadrillion (10^{15}) Btu]	Q	1.055×10^{18}

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*Romer's book was written before the definition of the Q was standardized. His Q is 10^{18} Btu.

Free-Fall Experiment — Fri 4 Sep 87

x (cm)	Δx (cm)	Δ(Δx) (cm)
181.46		
	3.43	
178.03		0.96
	4.39	
173.64		1.07
	5.46	
168.18		1.15
	6.61	
161.57		1.07
	7.68	
153.89		1.10
	8.78	
145.11		1.08
	9.86	
135.25		1.09
	10.95	
124.30		1.12
	12.07	
112.23		1.14
	13.21	
99.02		

$9.78/9 = 1.087$

$1.087 \times 900 = 978 \text{ cm/sec}$

frequency = 60 cycles/sec ⇒ 120 dots/sec ⇒ $\frac{1}{30}$ sec for 4 dots

⇒ $\Delta t = \frac{1}{30}$ sec

(OVER)

Mechanics ((Chap 2, 3, & 5)

Newton's Laws (1686)

The 3 laws of motion:

1. Law of Inertia: it takes outside influence to *change* motion.
2. $\vec{F} = M\vec{a}$.
3. Interaction forces are equal & opposite.
4. Universal gravitation. → $F = G \frac{M_1 M_2}{d_{12}^2}$ [eqn (5-2) p 175]

Note that #2 includes #1.

Force = F = a push or a pull

M = Mass = amount of inertia or quantity of matter

W = Weight = the force with which an object is pulled toward the center of the earth by the gravitational attraction.

$$F = Ma \Rightarrow W = Mg$$

g = acceleration of gravity = $9.8 \frac{m/sec}{sec}$

"inertia": lack of art or skill (Kepler)

Work = W = Fd = force × distance in the same direction

Energy is stored work.

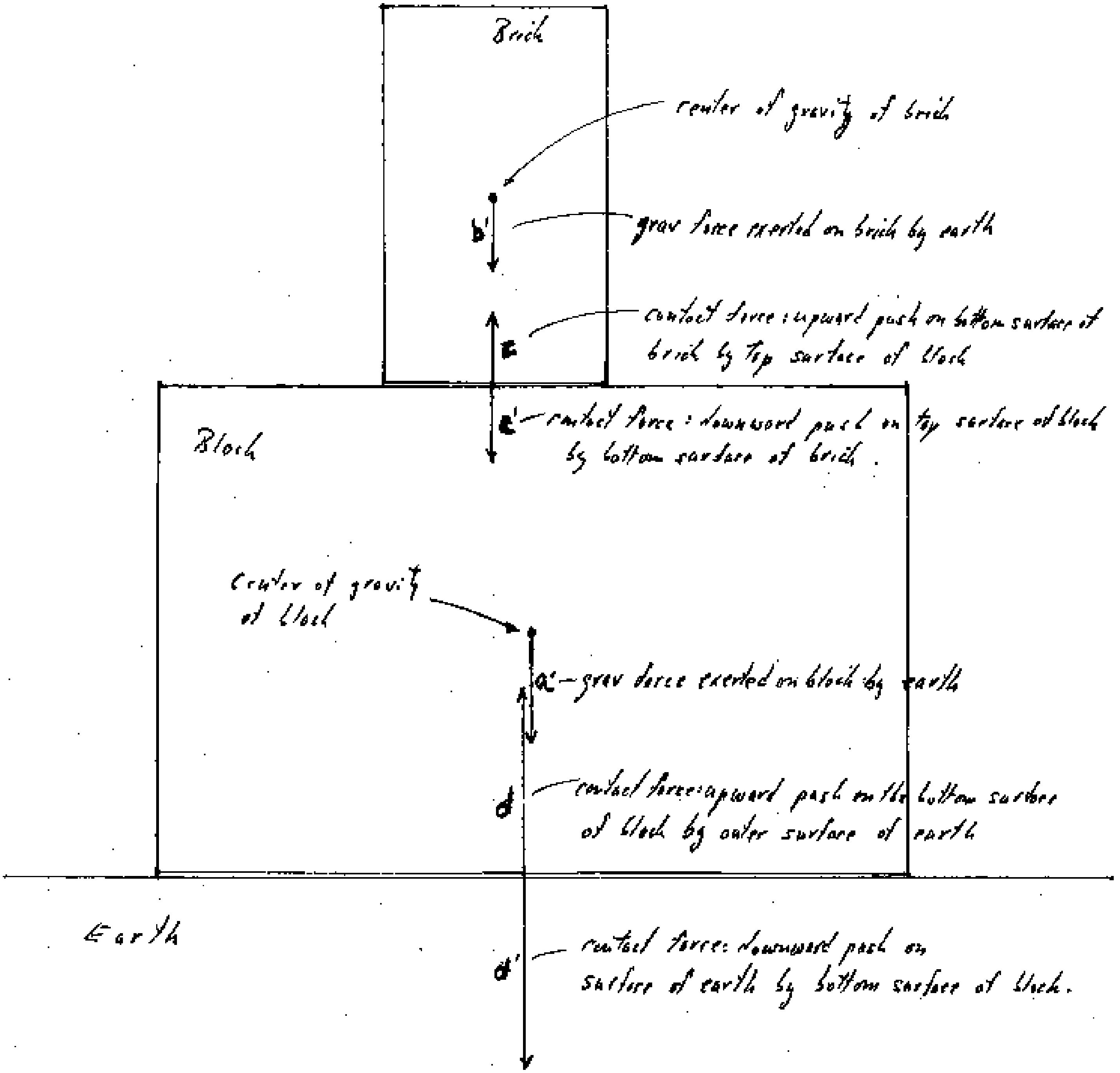
Energy as a practical measure: force × distance = weight × height

Energy as a conserved quantity.

Energy as a controlling function

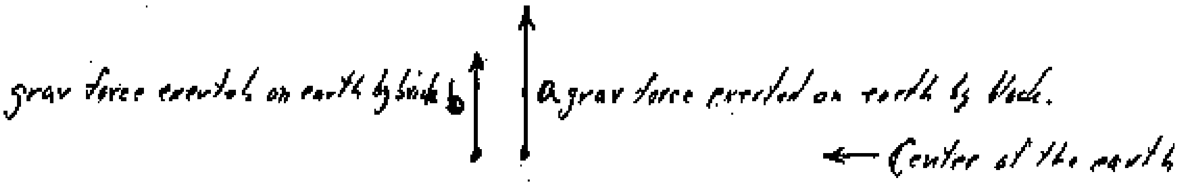
(OVER)

BRICK on a BLOCK on the GROUND



$c = b$

$c + a = d$



Physics 115 Problems Fall 1987

"Physics is thinking very hard about very simple things".

A written solution to each of the following problems is to be completed by each student, by the end of the semester.

Solutions are to be kept in a 8 1/2 x 11 binder, one problem to a page.

You may be asked to show your problem work to date, on short notice.

Solutions put into your binder are to be neat and legible.

It is up to the student to be sure that solutions in her/his binder are correct and complete. (Do not wait for your problems to be corrected: they may be only graded). (You do not understand a problem until you are sure whether or not you have solved it.)

You may ask questions about any problem at any time (and I really do expect you to do so: most students will need help on most of the problems.)

Class #5 Mon 14 Sept 87

Was problems 2, 3, 4, & 5.

Physics 115 problems

(a) was initial speed of gun projectile motion

1. (a) How many feet do you travel each second when you drive at a speed of 30 mi/hr?

   (b) There are 640 acres in a square mile. a mile = 5280 ft. If a plot of ground is square and has an area of 1 acre, how many feet is it on a side?

   (c) The hectare is defined to be an area of 10000 square meters (100m x 100 m). It is sometimes called "the metric acre." How many acres are there in a hectare?

   (d) The 1500-meter race is often called "the metric mile." Is this distance greater or less than a mile? What is the percent difference?

The speed of light (in vacuum or, practically, in air) is 3.00×10^8 m/sec How long would it take to go

   (e) around the earth (radius 6.4 million meter) reflected by mirrors, say?
   (f) from the sun to the earth (1.5×10^{11} meter)?

   (g) When the congress appropriates $1 billion for something, how much money per capita is this in the US?

Physics 115 problems

2. I hold a 5 lb. box at rest.

   (a) What are the magnitude and direction of the force I exert on the box?
   (b) What are the magnitude and direction of the force the box exerts on me?
   (c) What are the magnitude and direction of the force the earth exerts on the box?
   (d) What are the magnitude and direction of the force the box exerts on the earth?
   (e) What are the magnitude and direction of the force the surface of the earth exerts on my feet?
   (f) What is the total force on the box?
   (g) What is the total force on me?

Now instead I lift the box vertically upward by a distance of 3 feet at constant speed.

(h) What are the magnitude and direction of the force I exert on the box?
(i) What are the magnitude and direction of the force the box exerts on me?
(j) How much work do I do on the box?
(k) How much work does the box do on me?

Now I carry the box horizontally for 12 feet at constant speed.

(l) What is the magnitude and direction of the force I exert on the box?
(m) What is the magnitude and direction of the travel of my hand?
(n) How much work does my hand do on the box in this horizontal trip?
(o) How much work does the box do on my hand in this trip?

Finally I lower the box vertically downward at constant speed by 3 feet.

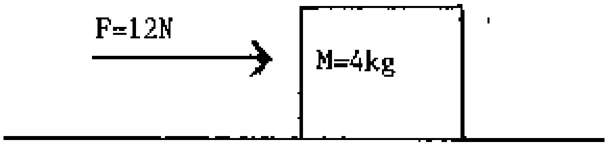
(p) What are the magnitude and direction of the force I exert on the box?
(q) What are the magnitude and direction of the force the box exerts on me?
(r) What are the magnitude and direction of the force the earth exerts on the box?
(s) What are the magnitude and direction of the force the box exerts on the earth?
(t) What are the magnitude and direction of the force the surface of the earth exerts on my feet?
(u) What is the total force on the box?
(v) What is the total force on me?
(w) How much work do I do on the box?
(x) How much work does the box do on me?

Now consider the net result of all of the three above motions.

(y) What is the total work done by my hand?
(z) What is the total work done by the box on my hand?

Physics 115 Problems

3. A 4-kg object is on a smooth (no friction) horizontal surface. A constant horizontal force of 12N is applied to it for a time of 2 seconds. It starts from rest.



   (a) What is its final speed?

   (b) What is its average speed (during the 2 seconds of acceleration)?

   (c) What is the total distance traveled?

   (d) What was the initial kinetic energy?

   (e) What is the final kinetic energy?

   (f) How much work was done by the agent exerting the accelerating force?

   (g) What average power was used?

   At the end of the 2 seconds the force is removed.

   (h) How will the distance, speed, acceleration, and kinetic energy behave from then on?

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4. A 5-kg object falls freely from rest for 2.5 seconds.

   (a) What is its final speed?

   (b) What is its average speed?

   (c) How far does it fall?

   (d) What is its final kinetic energy?

   (e) How much potential energy does it lose?

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5. Estimate the volume of your body by dividing your mass by your density. [Your density is very nearly that of water, since you almost (or just barely float in water.] Are you surprised by size of your answer?

Physics 115 Problems Class #6 Wed 6/9/87 ans. probs 6, 7, & 8

6. A mass of 18 metric tons ($M = 1.8 \times 10^4$ kg) is being raised vertically upward at a constant speed of v = 0.10 m/sec by a lift.

   (a) What is the acceleration of the mass?

   (b) What is the total (or net) force on the mass?

   (c) Is the kinetic energy changing? If not, what is its value?

   (d) Is the potential energy of the mass changing? If it is, what is the rate at which it is changing?

   (e) What is the force exerted on the mass by the lift (magnitude and direction)?

   (f) What is the force exerted on the lift by the mass (magnitude and direction)?

   (g) What is the force exerted on the mass by the earth (magnitude and direction)?

   (h) What is the force exerted on the earth by the mass (magnitude and direction)?

   (i) What is the power being supplied by the lift?

   (j) How can the lift be doing work on the mass if the net force on the mass is zero?

7. A mass M = 2.00 kg starts at rest. An upward force of 39.2 N is applied to it by a lift for 2 seconds, and then the upward force exerted by the lift is decreased to 19.6 N (still upward) and continued for two more seconds.

   20 (a) What is the total (or net) upward force on M during the first two seconds?

   0 (b) What is the total (or net) upward force on M during the second two seconds?

   10 (c) What is the upward acceleration of M during the first two seconds?

   0 (d) What is the upward acceleration of M during the second two seconds?

   10 (e) What is the average upward speed of M during the first two seconds?

   20 (f) What is the average upward speed of M during the second two seconds?

   20 (g) By what height does M rise during the first two seconds?

   40 (h) By what height does M rise during the second two seconds?

   40×10 (i) What is the work done by the lift in the first two seconds?

   20×40 (j) What is the work done by the lift in the second two seconds?

   400 (k) What is the K.E. of M at the end of the first two seconds?

   400 (I) What is the K.E. of M at the end of the second two seconds?

   400 (m) What is the increase of P.E. of M in the first two seconds?

   800 (n) What is the increase of P.E. of M in the second two seconds?

   1600 (o) What is the total change in the energy of M?

   1600 (p) What is the total work done by the lift?

Class #7 Fri 18/9/87

Was Problems 9, 10, 11, 4/2

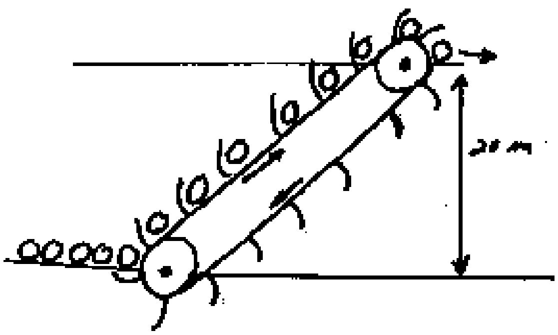
Physics 115 Problems

8. What is the maximum electric power that could be generated at a waterfall with a height of 30 m and a flow of 20 m^3 of water per second? One cubic meter of water has a mass of 1000 kg.

9. A conveyor-belt raises 3-kg balls through a height of 20 m. It delivers 8 balls per minute from the lower level to the higher level. (The balls roll on to the belt at the lower level and roll off at the higher.)

   (a) By how much does the belt increase the potential energy of each ball that it raises?

   (b) What power is the belt-driving motor supplying?



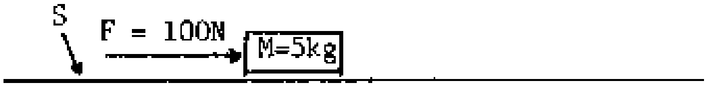
10. An elevator car and its passengers have a total mass of 1500 kg. The elevator car is moving upward at a constant speed of 5 m/sec.

    (a) What is the value of the total kinetic energy?

    (b) How much does the total gravitation potential energy increase each second?

    (c) How much power must be supplied to drive this elevator upward?

11. A mass M = 5kg, starting from rest, is pushed along a frictionless horizontal surface S, by a constant horizontal force F = 100 Newton, through a distance of 2.5 meter.



(a) How much work is done by the force F?

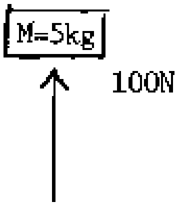
(b) What is the final kinetic energy?

(c) What is the final speed?

(d) What is the value of the acceleration of the mass while being pushed?

(e) By how much does the G.P.E. increase?

Now, instead, the same 5kg mass, starting from rest, has a vertically upward force of 100 N applied to it through a distance of 2.5 meters.



(f) What is the net upward force on the mass?

(g) What is the value of the upward acceleration of the mass?

(h) How much work is done by the force?

(i) How much does the gravitational potential energy of the mass increase?

(j) How much does the kinetic energy of the mass increase?

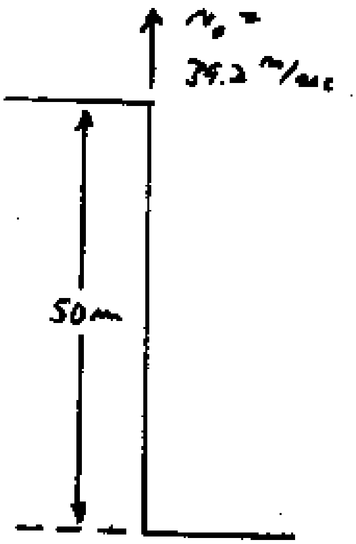
(k) What is the final speed?

12. A object is dropped from rest through a height of h. Prove from the conservation of energy that, if there is no friction (air resistance), then the speed at the bottom is

$$v = \sqrt{2gh}$$

Notice that this speed depends on the height, of course, but it does not depend on the mass of the body!

13. A ½ kg ball is thrown straight up with an initial speed 39.2 m/sec, at the very edge of a 50 m cliff, as shown.



(a) How many seconds later does it stop at the highest point of its flight?

(b) What was its <u>average</u> speed on the way up?

(c) How high does it rise above the top of the cliff?

(d) When will it pass the top of the cliff on the way down?

(e) How fast will it be traveling at that time?

(f) When will it hit the valley floor?

(g) How fast will it be going then?

(h) What are the values of the kinetic energy: at the beginning, at the top, back at the level of the cliff, and on the valley floor?

(i) What are the values of the G.P.E. at these same points?

Suppose now, instead, that the ball had been thrown <u>downward</u> with a speed of 39.2 m/sec from the edge of the cliff.

(a) How long will it take to hit the valley floor?

(b) How fast will it be going then?

(c) What are the values of the kinetic energy at the beginning and on the valley floor?

(d) What are the corresponding values of the G.P.E.?

14. A block of mass M is held on a smooth (no friction, very slippery) incline of height h and length d, as shown.

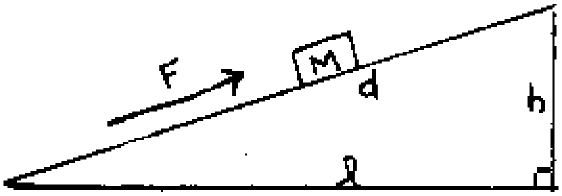
(a) How much force up the incline is required to hold it in place?

(b) How much force up the incline is required to move it up the incline at constant speed?

(c) What is the total work required to move it through the distance d up the incline at constant speed?

(d) What is the work required to lift the block through the height h?

(e) Prove that the answers to (c) and (d) are the same and explain.



Class #8 Mon 21 Sept 87

System of units ✓

$$W = \bar{F}s = Fa\bar{v}t = \Delta(\tfrac{1}{2}mv^2)$$

We reviewed probs 11 + 12

and did probs 13 + 14.

Physics 208 Fall 1987

Week	Sunday	Lab (3323 St)	Tues	Thurs	Fri
1	30 Aug	L2*	X	Chap 20	Grav. Field
2	6 Sept	E1	Chap 21	22	Multipoles
3	13 Sept	E2	23	24	$\rho = \rho_0 e^{-\sigma t/\varepsilon_0}$
4	20 Sept	E3	25	25	EXAM #1 ←
5	27 Sept	E4	26	26	TBA
6	4 Oct	E6	27	27	TBA
7	11 Oct	E7	28	28	Chap 29
8	18 Oct	E8	30	30	EXAM #2 ←
9	25 Oct	E9	31	32	TBA
10	1 Nov	"E10"	34	34	TBA
11	8 Nov	L1	34	35(Rel)	TBA
12	15 Nov	L3	35	36(Quant)	EXAM #3 ←
13	22 Nov	X	36	X	X
14	29 Nov	L8	36	36	TBA
15	6 Dec	L9	37(Nucl)	37	EXAM #4 ←
16	13 Dec	X	37	X	X

Final Exam 7:45 AM Thursday 17 December

*For those who've never done it.

TBA = to be announced

OLD EXAM

PHYSICS 115
Exam #1
Wed 9 Oct 85

NAME ______________________________

Closed book. 50 minutes. 5 questions.

Write your answer to each question directly on these sheets.

Information you might want:

The acceleration of gravity near the surface of the earth is

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

The force of gravitational attraction is

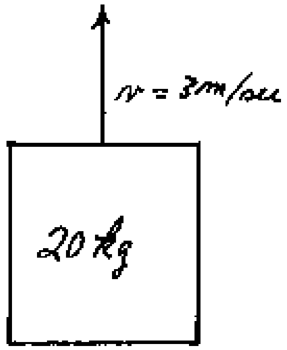
$$F_{grav} = G \frac{M_1 M_2}{(d_{12})^2}$$

and

$$G \approx \frac{2}{3} X \cdot 10^{-10} \text{ in mks units (the ones we use).}$$

Radius of earth	$6.4 \text{ X } 10^6$ m
Mass of earth	$6.0 \text{ X } 10^{24}$ kg
Earth-Sun distance	$1.5 \text{ X } 10^{11}$ m

1. A 20 kg mass is being lifted vertically upward with a constant speed of 3m/sec.



(a) How far upward does it move in one second?

(b) What ~~upward force is required to raise it?~~
is the tension in the rope?

(c) How much does the gravitational potential energy increase in one second?

(d) How much does the kinetic energy increase in one second?

(e) How much work does the raising force do in one second?

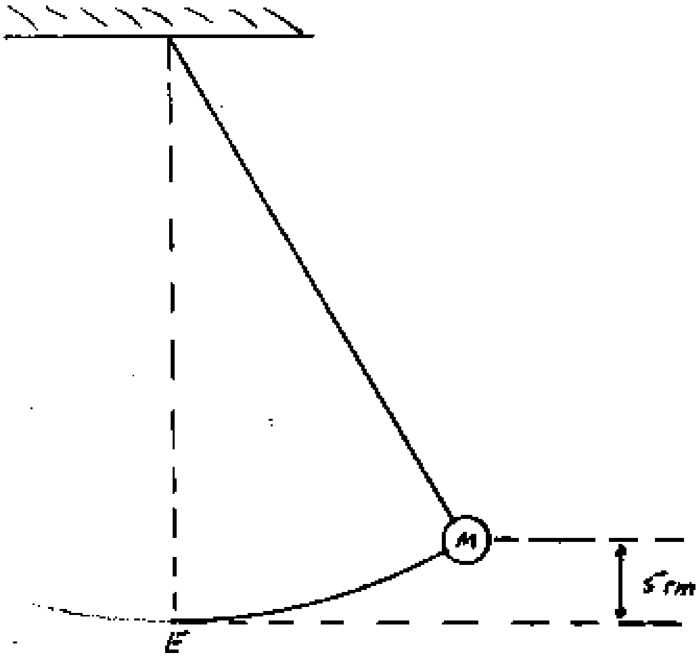
(f) What power is required for the lifting?

2. A baseball is hit straight up from the ground, starting up with a speed of 35m/sec. Neglect the effects of air resistance.

(a) How high does it go?

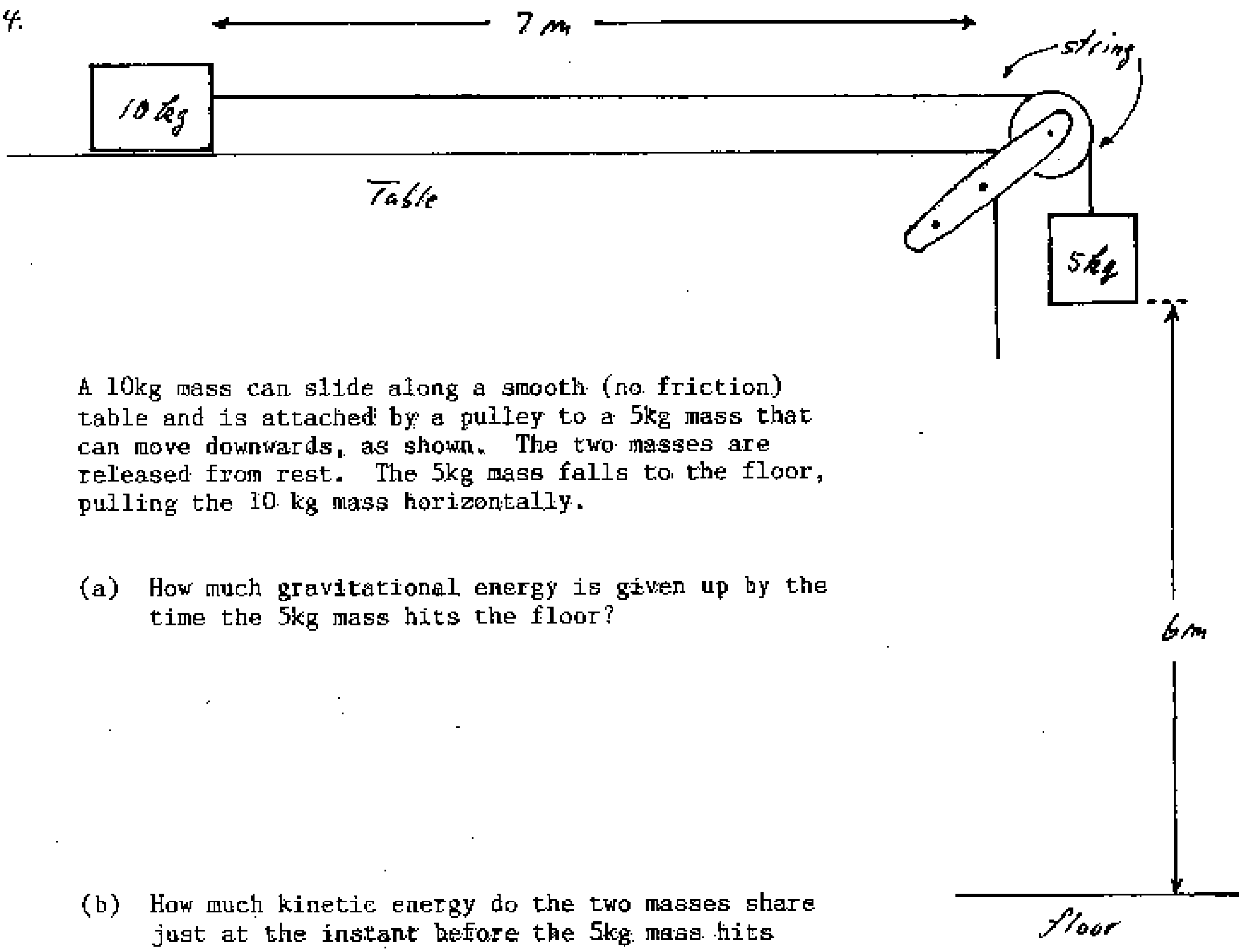
(b) How long a time does ~~it take to return to the ground?~~ the whole trip take (time up + time down)?

3.



A simple pendulum is pulled out from its equilibrium position E (at the bottom of the swing) to a position where its height is 5 cm, as shown. The pendulum is released from rest at this position. With what speed will it pass through the equilibrium point, E?

4.



A 10kg mass can slide along a smooth (no friction) table and is attached by a pulley to a 5kg mass that can move downwards, as shown. The two masses are released from rest. The 5kg mass falls to the floor, pulling the 10 kg mass horizontally.

(a) How much gravitational energy is given up by the time the 5kg mass hits the floor?

(b) How much kinetic energy do the two masses share just at the instant before the 5kg mass hits the floor?

(c) What is their speed just before the 5kg mass hits the floor?

5. The Earth travels around the Sun in a nearly-circular orbit of radius 1.5×10^{11}.

(a) What is the speed of the Earth in this orbit?

(b) What is the <u>magnitude</u> of the Earth's acceleration?

(c) What is the <u>direction</u> of the Earth's acceleration?

(d) What force supplies this acceleration?

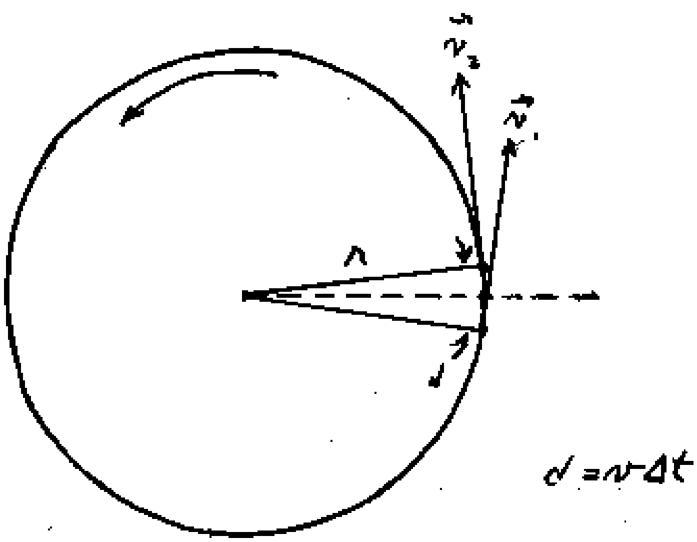
Class #9 Wed 23/9/87

Physics 115

Centripetal Acceleration

(Romer, p114)

Motion in a circle at constant speed.



Similar triangles : $\frac{d}{r} = \frac{\Delta v}{v}$

$$\frac{v\Delta t}{r} = \frac{\Delta v}{v}$$

$$a = \frac{\Delta v}{\Delta t} = \frac{v^2}{r}$$

The acceleration $a = \frac{v^2}{r}$ has inward direction.

(Always turning to left).

Low-altitude earth-satellite orbit $(r \doteq R_E)$

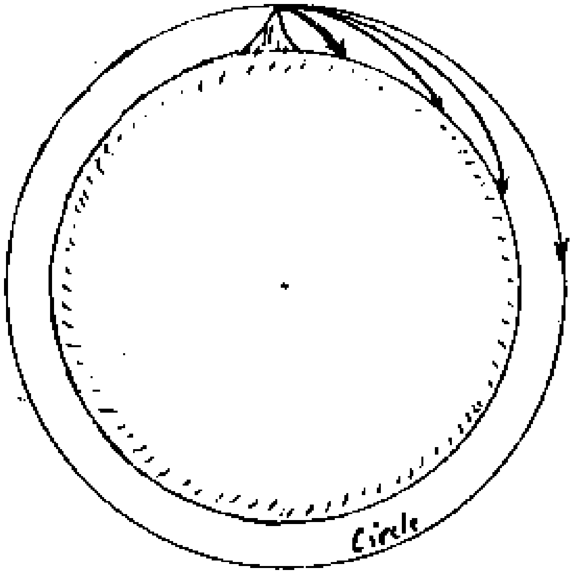
$$\frac{v^2}{R_E} = g \quad \left\{ \begin{array}{l} \text{84 minutes} \\ 18 \times 10^3 \text{ mi/hr} \end{array} \right.$$

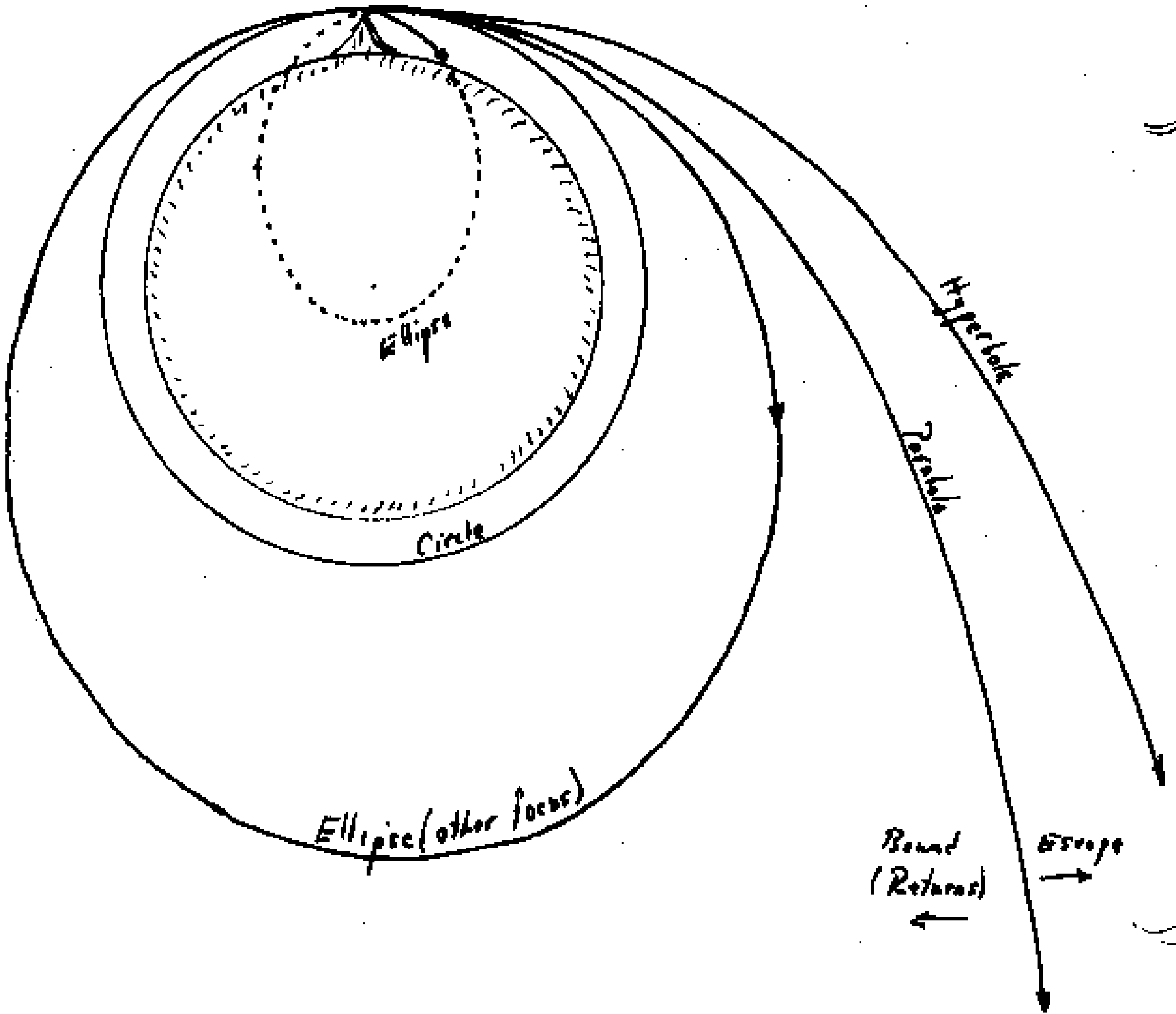
Foucault Pendulum

Centripetal & Centrifugal

Class #10 Fri 25 Sept 87

NEWTON'S PICTURE





(OVER)

Class #11 Mon 28 Sept

Newton's Universal Gravitation

$$F_{attr} = G \frac{M_1 M_2}{d_{12}^2}$$ eqn (5.7) on p175

$$G = \frac{2}{3} \times 10^{-10} \frac{N m^2}{(kg)^2}$$

$$F = Ma$$

$$G \frac{M M_E}{R_E^2} = W = weight = Mg$$

$$g = \frac{G M_E}{R_E^2} = 9.8 \ m/sec^2$$

Low-altitude circular orbit

$$\frac{v^2}{R_E} = g \quad \Rightarrow \quad v = \sqrt{g R_E} = \sqrt{9.8 \times 6.4 \times 10^6}$$

$$= 7900 \ m/sec \doteq 18000 \ \frac{mi}{hr}$$

Circular orbit at altitude h

$$\frac{G M M_E}{r^2} = M \frac{v^2}{r} \qquad with \quad r = R_E + h$$

$$\Rightarrow \quad v = \sqrt{\frac{G M_E}{R_E + h}}$$

Synchronous Orbit

Synchronous Orbit

$$G\frac{\cancel{m}M_E}{r^2} = \cancel{m}\frac{v^2}{r}$$

$$v = \frac{\text{circumference}}{\text{day}} = \frac{2\pi r}{24\times3600}$$

$$\frac{GM_E}{r^2} = \frac{1}{r}\left(\frac{2\pi r}{24\times3600}\right)^2 \Rightarrow r = 6.6\,R_E \qquad (h = 5.6\,R_E)$$

$$F_{attr} = G\frac{M_1M_2}{r^2} \Rightarrow G.P.E. = -G\frac{M_1M_2}{r} \quad (5.12)\text{ m p }188$$

Escape velocity

$$K.E. + G.P.E. = 0$$

$$K.E. = -G.P.E.$$

$$\frac{1}{2}Mv^2 = G\frac{MM_E}{R_E}$$

$$v = \sqrt{2\frac{GM_E}{R_E}} = \sqrt{2gR_E} = 11\times10^3\ \text{m/sec}$$

$$= 26\ \text{thousand}\ \frac{\text{mi}}{\text{hr}}$$

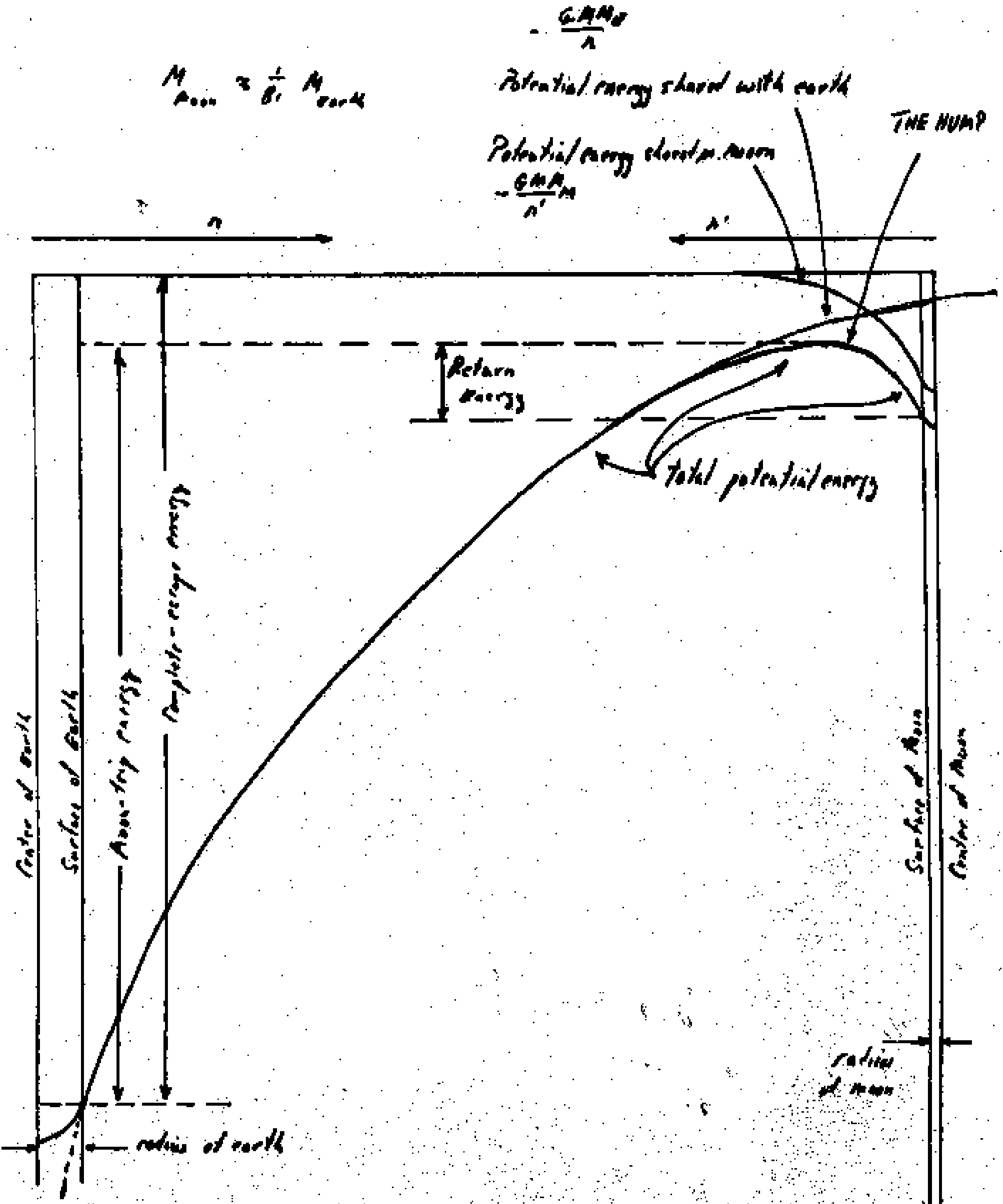
$$F_{attr} = W = Mg = G\frac{MM_E}{R_E^2}$$

(OVER)

$$\therefore\ g = G\frac{M_E}{R_E^2}$$

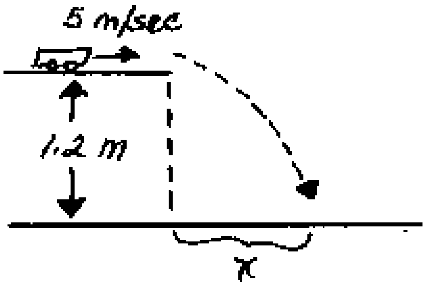
and $$Mgh = MG\frac{M_E}{R_E^2}h = \frac{GMM_E}{R_E}\frac{h}{R_E}$$

ENERGETICS OF A TRIP TO THE MOON

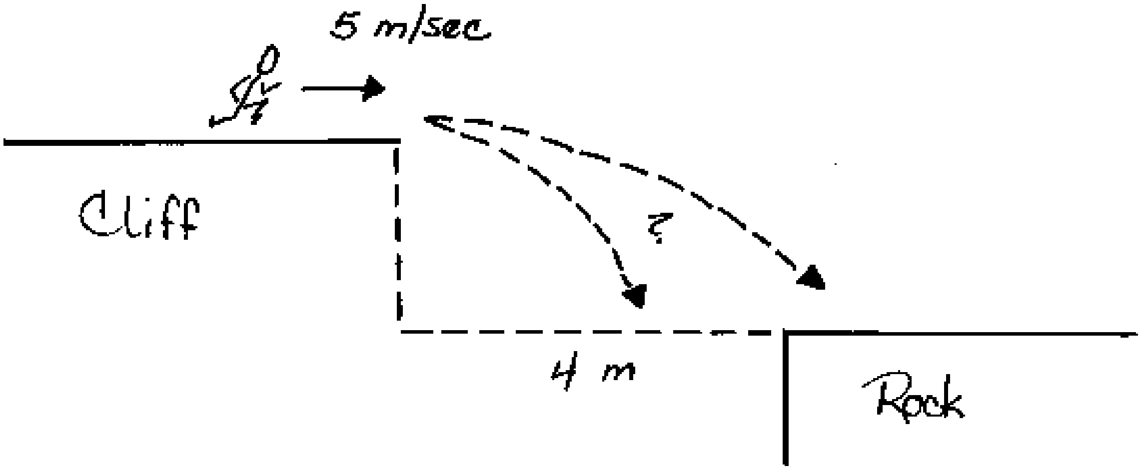


Not to scale.

15. A cart moving with a speed of 5 m/sec rolls off the edge of a horizontal table 1.2 m high, as shown. What is the horizontal distance (x) travelled before it hits the floor?



16.



A person runs with a speed of 5 m/sec horizontally off the edge of a cliff, hoping to land on a rock 2 m below and 4 m away (horizontally), as shown.

(a) What time will the horizontal travel from cliff to rock take?

(b) How far does the person fall (vertically) in this time?

(c) Does he make it?

(d) How can he do better?

Physics 115 Problems

17. (a) Find the speed and period of a low-altitude earth satellite.

(b) Find the speed and altitude of a synchronous earth satellite.

18. What is the speed of the Earth in its orbit around the Sun?

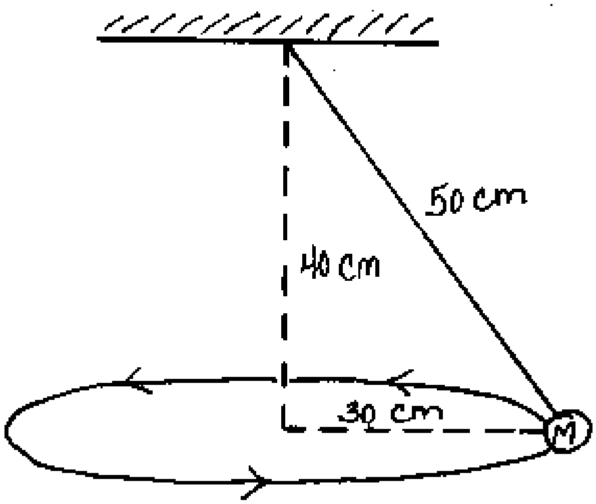
19. (a) Find the escape speed of a projectile from (the surface of) the earth.

(b) Find the escape energy of a 100 kg projectile from the surface of the earth.

(c) Estimate the minimum energy required to get a 100kg payload from the Earth to the Moon.

Did these class #12

20. A mass M moves in a horizontal circle of radius 30 cm at the end of a light 50 cm string attached to the ceiling, as shown.



(a) How much vertical acceleration does the mass have?

(b) How much tangential acceleration does the mass have?

(c) How much radial acceleration does the mass have?

(d) What is the speed of M in its circular motion?

(e) What is the <u>period</u> of the motion?

(f) Is the kinetic energy of M constant?

(g) Is the potential energy of M constant?

(h) Is the total energy of M constant?

21. Why are races run <u>counterclockwise</u> (looking down) around a track?

22. Consider a 100-Watt, 115-Volt incandescent lamp (light bulb).

    What is the current through the lamp?

    What is the resistance of the lamp?

    Answer the same two questions for a 50-Watt, 115-Volt lamp.

23. What is the cost, at 7¢/kWhr, to leave a 100-Watt light on for 24 hours? How much energy did you use up?

24. How fast can a 10 kg object be raised, at constant speed, by the power from 2 Amp of current at 110 Volts?

PHYSICS 115
Exam #1
Fri 2 Oct 87

NAME ______________________________

This was an exceptionally poor exam. Errors and should have had a circular motion problem instead of 4 or 5

Closed book. 50 minutes. 5 questions.

Write your answer to each question directly on these sheets.

Information you might want:

The acceleration of gravity near the surface of the earth is

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

The force of gravitational attraction is

$$F_{grav} = G\frac{M_1M_2}{(d_{12})^2}$$

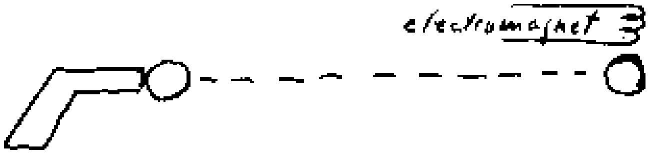
and

$$G = \frac{2}{3} \times 10^{-10} \text{ in mks units (the ones we use).}$$

Radius of earth	6.4×10^6 m
Mass of earth	6.0×10^{24} kg
Earth-Sun distance	1.5×10^{11} m

1 mile = 1609 m

1. In class you saw a ball fired from a gun aimed directly at another ball.



(a) What happened?

(b) Why did it happen? (What is the point of this demonstration?)

(c) How was it arranged that the two balls started at the same time?

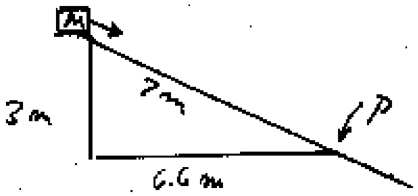
2. A ball is launched from the ground with a horizontal speed of 40 m/sec and a vertically upward speed of 30 m/sec.

(a) How much time is taken for the ball to reach its highest point?

before it returns to the ground

(b) How far does it travel horizontally? ^

3.



A mass slides from rest down a smooth plane past a point P.

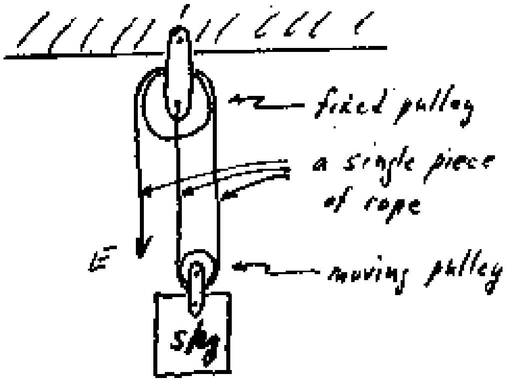
Total distance travelled = 7 m
Horizontal distance travelled = 6.3 m
Vertical distance travelled = 3 m

give mass

(a) How much potential energy was lost when the point P was passed?

(b) With what speed did the mass pass point P?

4. (a) How far up will the 5 kg mass move when the end E of the rope is pulled down 4 meters?



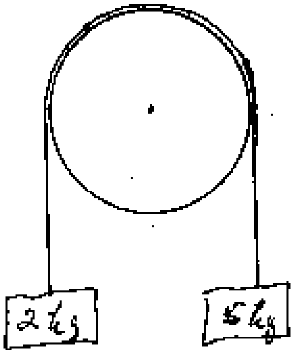
(b) What downward force applied to the end E of the rope will be required to hold the 5 kg mass at constant height (if there is no friction)?

(c) What downward force applied to the end E of the rope will be required to maintain the 5 kg in uniform upward motion with a speed of 2 m/sec?

(d) What is the value of the input power (at E) in part (c)?

(e) What is the output power (to the 5 kg mass) in part (c)?

5.



Masses are connected by a rope R over a weightless and frictionless wheel W that is free to turn, as shown. The masses are brought to rest and then released.

(a) Which way will the 5 kg move? (up or down?)

(b) Which way will the 2 kg move?

(c) When the 5 kg moves by 2 meter, how far does the 2 kg move?

(d) When the 5 kg moves by 2 meter how much does its potential energy change <u>and</u> which way (increase or decrease)?

(e) When the 2 kg moves by 2 meter how much does its potential energy change <u>and</u> which way (increase or decrease)?

(f) How much <u>and</u> which way does the total potential energy change (when the 5 kg moves by 2 m)?

(g) How much <u>and</u> which way does the total kinetic energy change (when the 5 kg moves by 2 m)?

(h) What is the speed of the 5 kg after it has moved 2 meter from rest?

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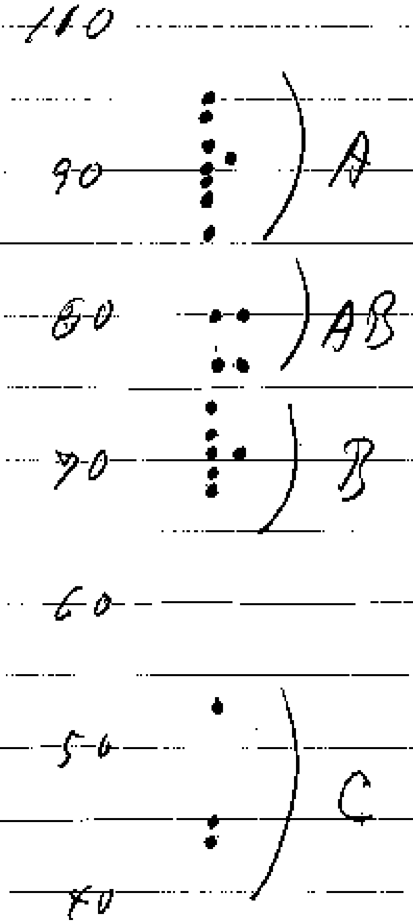


Physics 115
Class #12
Wed 30 Sept 87

SIMPLE MACHINES (not in book)

Force multipliers (Force isn't conserved)

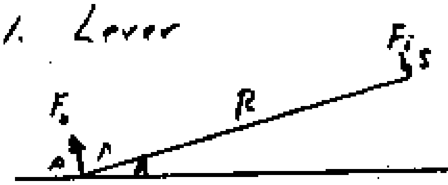
Mechanical to mechanical (e.g. bicycle, nail puller, block+tackle, etc.)

Energy is conserved, and so

$$[\text{Force} \times \text{Distance}]_{out} \leq [\text{Force} \times \text{Distance}]_{in}$$ (Equality without friction)

Mechanical advantage $= \frac{F_{out}}{F_{in}} = \frac{D_{in}}{D_{out}}$

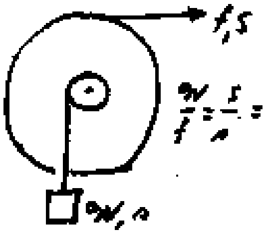
1. Lever



$sF_o = SF_i$

$\frac{F_o}{F_i} = \frac{S}{s} = \frac{R}{r}$

or Wheel+Axle

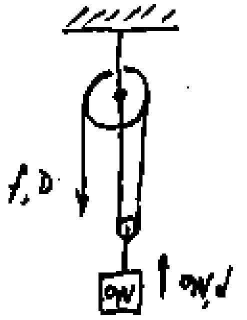


$\frac{W}{f} = \frac{S}{s} = \frac{R}{r}$

2. Inclined plane (or screw or jack)

$fl = Wh$ $\frac{W}{f} = \frac{l}{h}$

3. Pulley



$fD = Wd$ $\frac{W}{f} = \frac{D}{d} = 2$

4. Hydraulic jack or press

$\frac{F}{A} = p = \frac{f}{a}$

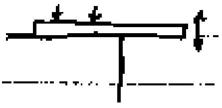
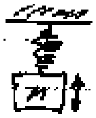
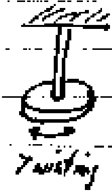
$aD = V = Ad$

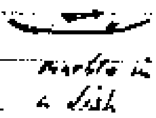
$\frac{F}{f} = \frac{A}{a} = \frac{D}{d}$

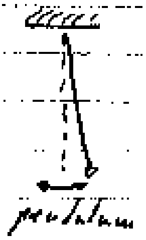
(OVER)

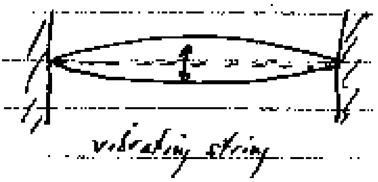
VIBRATIONS OR OSCILLATIONS

Repetitive motion back & forth along a line



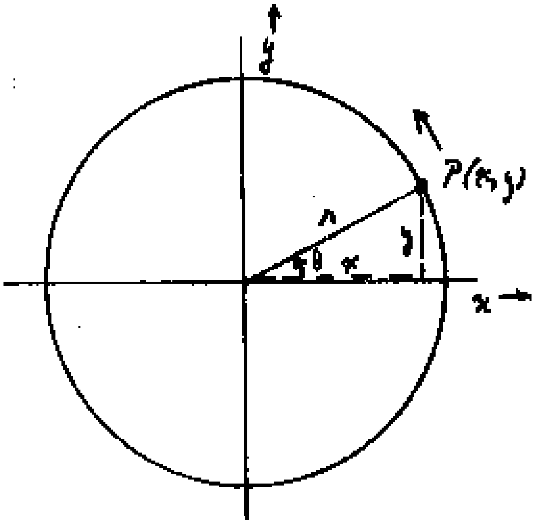




Small vibrations are normally sinusoidal that is harmonic

sine or cosine function of time

a pure musical tone



side opposite to θ is y

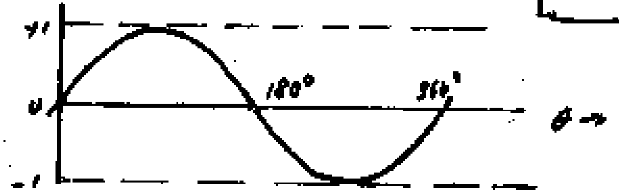
side adjacent to θ is x

hypotenuse is r

A propagating vibration is a wave eg sound

$$\sin\theta = \frac{opp}{hyp} = \frac{y}{r}$$

$$\cos\theta = \frac{adja}{hyp} = \frac{x}{r}$$



Period = T = seconds for one full cycle (there & back)

Frequency = $\nu = \frac{1}{T}$ cycles per second : Musical pitch (ν = 8k Hz)

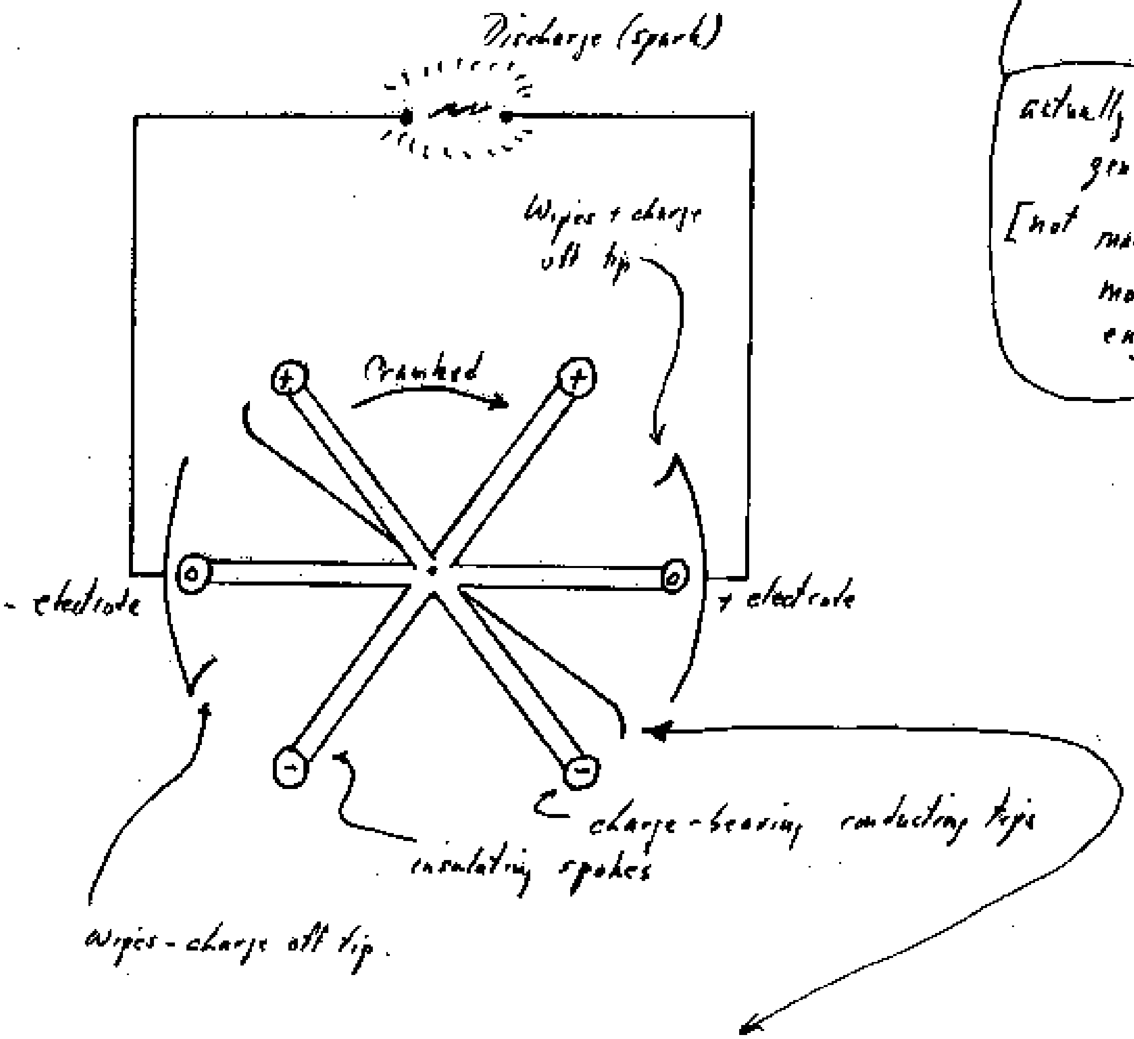
Amplitude : Maximum displacement (to either side).

Middle C : $\nu = 262$ cycles/sec (or H_z)

Class #15 Wed 7 Oct 87

actually generator [not machine motor engine]

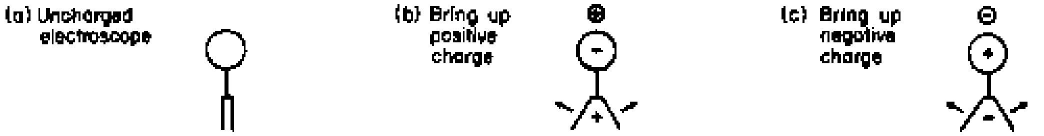
Induction Charging in an Electrostatic "Machine"



Fixed conductor that temporarily connects opposite tips while they are still near the electrodes. Tip near the negative electrode goes positive and the tip near the positive electrode goes negative. [i.e. electrons flow from upper left to lower right.]

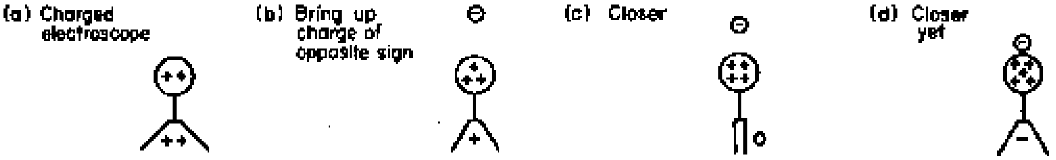
(over)

1.

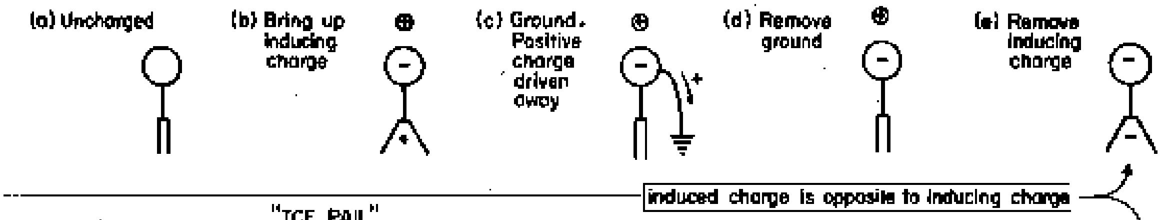


2.

3.

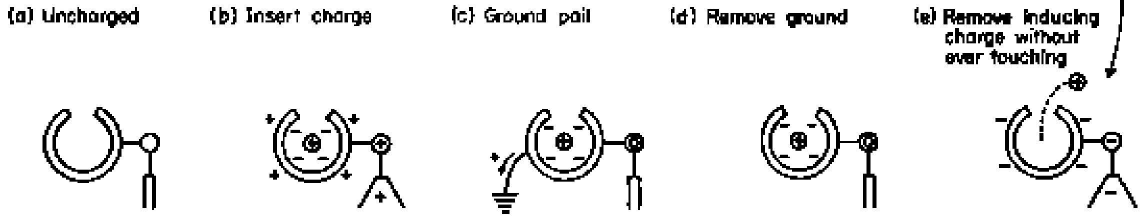


4. Charge electroscope "by Induction"

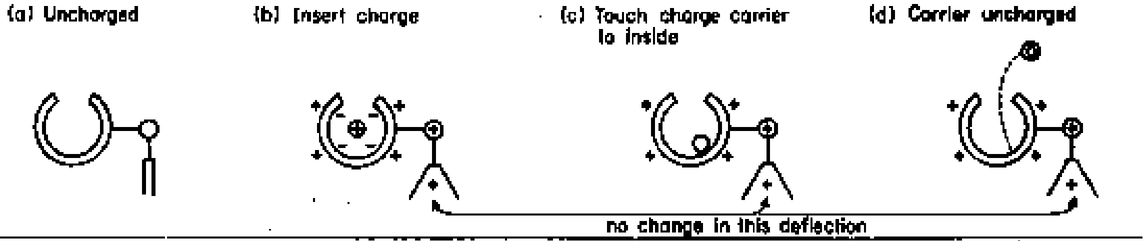


"ICE PAIL"

5. Charge "by induction"



6.



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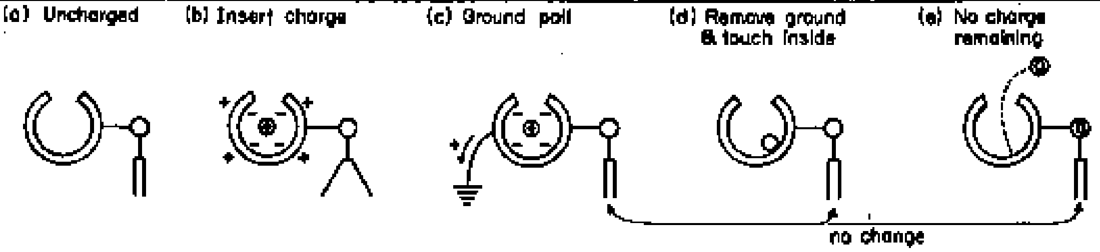


Class #16 Fri 7 Oct 87

Electromagnetism (Chap 8 & 9)

Coulomb's Law $F_{elec} = k_e \frac{q_1 q_2}{(d_{12})^2}$ [eqn (8.1) on p 275]

$k_e = 9.0 \times 10^9 \frac{Nm^2}{Coul}$

Like charges repel (opposite of gravitation!)

Electric field (p 279)

Outward from positive point, line, plane (Faraday)

$\vec{E} = \frac{\vec{F}}{q}$: force per charge

Electric current = $\frac{\text{charge}}{\text{time}}$ $I = \frac{Q}{T}$

Electric voltage = $\frac{\text{work}}{\text{charge}}$ $V = \frac{W}{Q} = \frac{E.P.E.}{Q}$

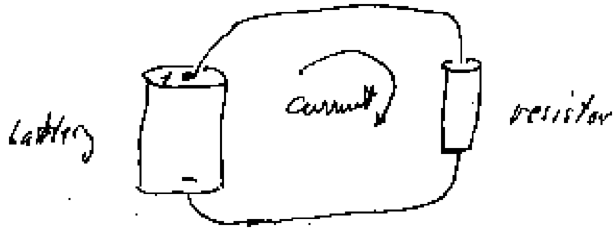
Power = $\frac{\text{work}}{\text{time}}$ $P = \frac{QV}{T} = IV$ = current × voltage $\boxed{P = IV}$

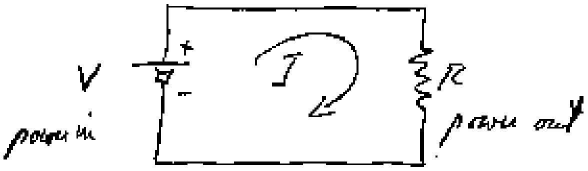
Ohm's Law $I = \frac{V}{R}$ $\boxed{I = \frac{V}{R}}$

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

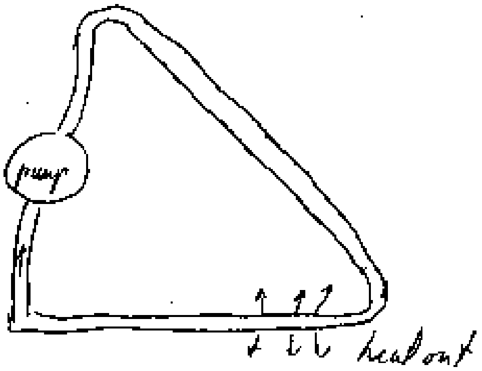
E.P.E. for two charges is $E.P.E. = k_e \frac{q_1 q_2}{d_{12}}$

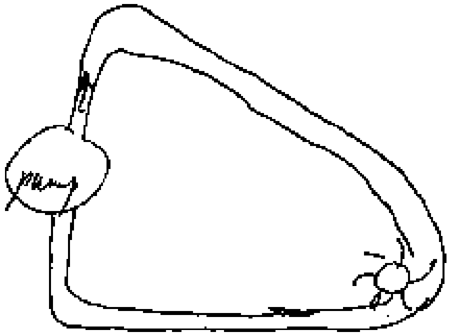
(OVER)


battery
+
−
current
resistor


V
+
−
power in
I
R
power out

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

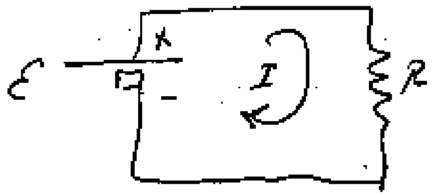

pump
heat out


pump

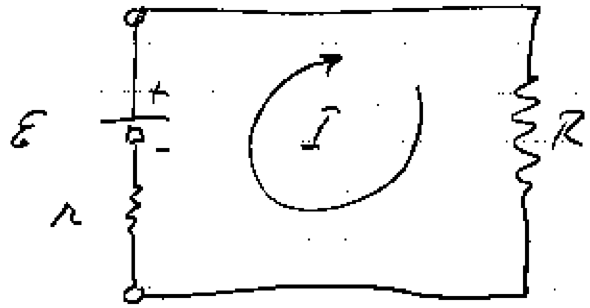
EMF = $\mathcal{E}$ = input voltage = V_{in}

= input work per charge

[Not a force!]



$$I = \frac{\mathcal{E}}{R}$$



$$I = \frac{\mathcal{E}}{r+R}$$

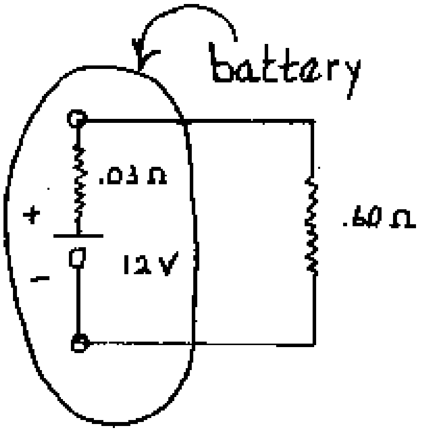
$$V_{battery} = \mathcal{E} - Ir = \mathcal{E} - \frac{\mathcal{E} r}{r+R}$$

$$= \frac{r+R-r}{r+R}\mathcal{E}$$

$$= \frac{R}{R+r}\mathcal{E} = \frac{\mathcal{E}}{1+\frac{r}{R}}$$

EMF = $\mathcal{E}$ = input wk/charge = V_{in} = $V_{open\ ckt}$

29. A battery has 0.03Ω internal resistance. If it is attached across an external .60 ohm resistor, as shown, then:



(a) How much current flows in the circuit?

(b) How much voltage drop is there across the external load resistor?

(c) What fraction of the battery's power is going into the load?

(d) What voltage applied to the terminals is required to charge the battery with a current of 10 Amp?

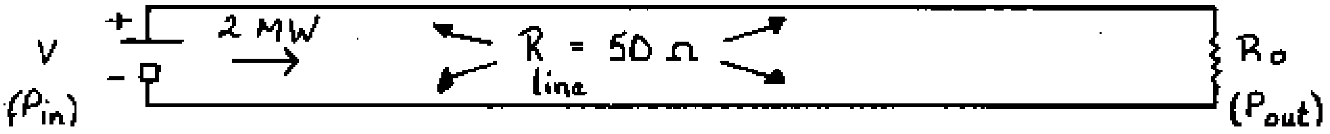
(e) Power f~~rom charging battery~~? required in recharging.

Fix

(f) Power to .03Ω?

(g) Power to ~~charge~~ the battery? in recharging

30.



A long transmission has a total (round trip) resistance of 50Ω. The input power from the voltage V at the left end is 2 Mega Watt.

(a) If V = 40kV, what fraction of the input power is dissipated by the resistance of the line?

(b) Answer again if V = 400kV.

31. An electron is moving at speed $v = 3 \times 10^5$m/sec perpendicular to a magnetic field $B = 3 \times 10^{-2}$ Tesla. What is the radius of its "cyclotron motion"? [charge = -1.6×10^{-19} Coul, mass = 9.1×10^{-31}kg]

32. A waterfall has a height of 60 meters and a total water flow of 1500 cubic meters per hour. How many amperes of current at a voltage of 50kV could be generated by this fall?

33. How many kiloWatt hours of electric energy is required to heat 8 liters of water from 68F to 120F?

115 #19

Fri 16 Oct 87

① Field from current RHR

② Force on current in field RHR

Circular motion of charged particle moving
perpendicular to [unif & const] mag field } →

③ Motor and generator ④

#18 Wed 14 Oct 87

Ckt problems and then….:

Magnetic compasses and magnetic fields (North <u>seeking</u> etc)
Dip needle

[charges fields forces charges, and]
currents field forces currents

Iron filings

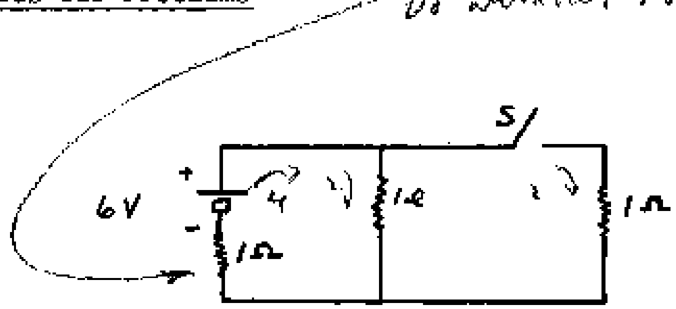
Current in magnet
> [Stream of charged particles ↔ current ?
Deflect electron beam with magnet.

Force on moving charge

Motion in a circle (cyclotron motion)

Do without this R first.

25.



(a) How much current flows through the middle one-ohm resistor when the switch S is open, as shown?

Now the switch S is closed.

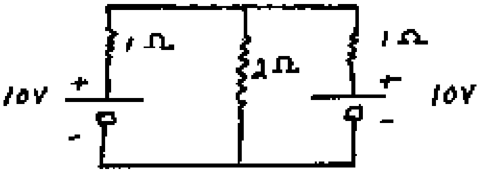
(b) How much current flows through the middle resistor?

(c) How much current flows through the right resistor?

(d) How much current flows through the battery?

(e) What power is supplied by the battery and what power dissipated in each resistance?

26. (a)

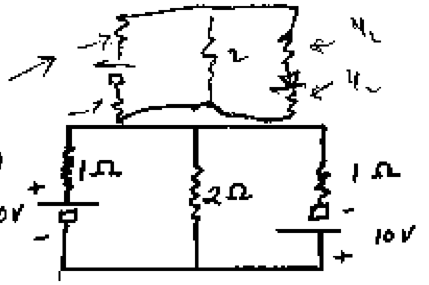


(a) Find the current in each resistor.

(b) Power from each battery.

(c) Power to each resistor.

(b)

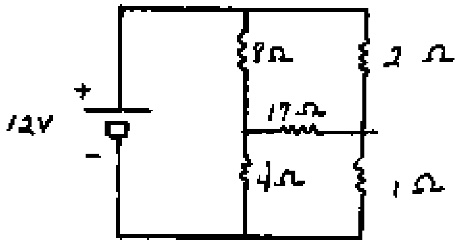


(a) Find the current in each resistor.

(b) Power from each battery.

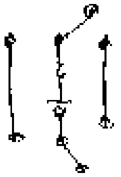
(c) Power to each resistor.

27. (Optional Harder Problem)

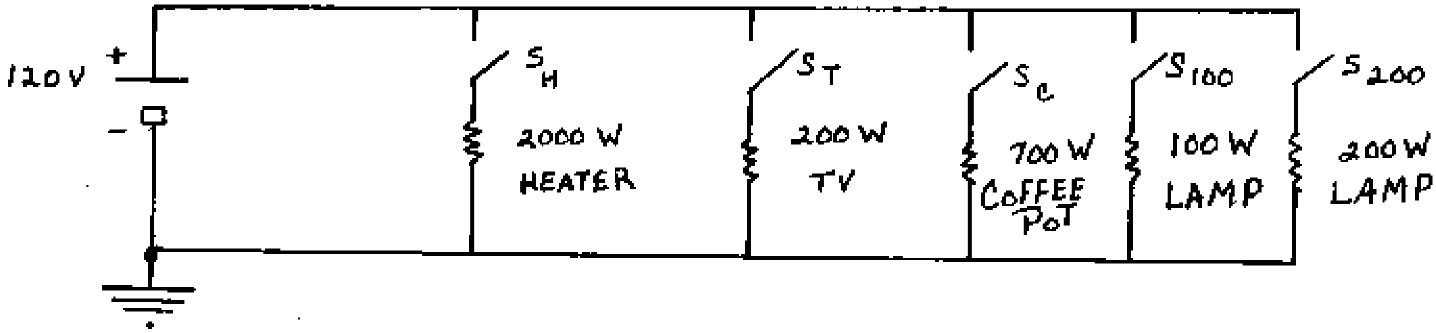


Find the current in each resistor and all powers.

2%.5



28.



Find the resistance of each appliance and the total current through the battery when:

(a) Each switch (alone) is closed.

(b) When any two are closed.

(c) When all five are closed.

115 #20 Mon 19 Oct 87

1. Circular motion of charged particle perpendicular to a magnetic field (constant + uniform).

2. Faraday's law of electromagnetic induction
Romer Sections 9.3 and 9.4

3. Changing magnetic field (through a circuit) gives an electric current (in that circuit).

4. Nikola Tesla 10 July 1856 – 7 Jan 1943
a.c. – and Edison (GE)
– and Westinghouse (a.c.)

5. "a.c." : $I = I(t) = I_m \sin \omega t$ "sinusoidal"

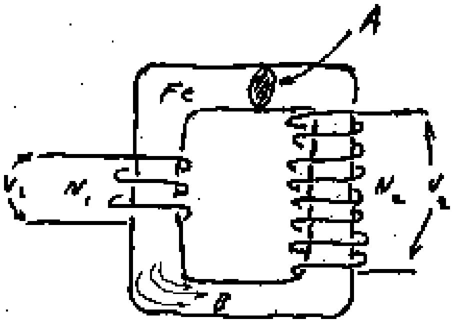
$(\omega = 2\pi f \quad , \quad f = \frac{1}{T})$

6. Transformer (a.c. only!)

$I_1 \Rightarrow BA = \Phi \propto N_1 I_1$

$$V_2 = N_2 \frac{\Delta \Phi}{\Delta t}$$

$$V_1 = N_1 \frac{\Delta \Phi}{\Delta t}$$



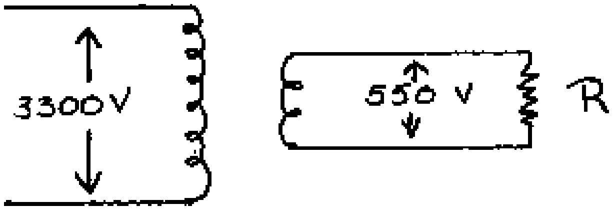
$$\frac{V_2}{N_2} = \frac{\Delta \Phi}{\Delta t} = \frac{V_1}{N_1} \qquad \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

$P_1 = I_1 V_1 = I_2 V_2 = P_2$ (power in = power out)

34. If a battery contains 10 kilomole of energy-storing chemical, that is 6 x 10^{27} molecules; and if each molecule can store 1/5 electron-Volt (1eV = 1.6 x 10^{-19} Joule) of energy, for how long a time can this battery supply 25kW of power?

35. A large "step-down" (in voltage) transformer has input power 2000kW at primary voltage 3300V. The secondary feeds a resistive load at 550V.



If energy losses can be neglected, then what are:

(a) Input (primary) current?

(b) Turns ratio?

(c) Secondary current?

(d) Resistance of load?

36. Why do you get a worse burn from picking up a piece of hot metal than a piece of wood at the same temperature?

37. Methane flame is 2240K. Fe melts at 1808K. Why then doesn't your iron frying pan melt on your gas stove?

38. [Problem 6.17 on p 237:] How much is the temperature of the water in Niagara Falls (190 ft) raised by the conversion of G.P.E. into K.E. and then into T.E.?

39. How much thermal energy is there in 1 m^3 of He (gas) at 1 atmosphere ($p = 1.0 \times 10^5 N/m^2$) and 20 C?

40. Find the total mass of the earth's atmosphere. [Hint: You need the values of (1) atmospheric pressure, (2) surface area of the earth, and (3) acceleration of gravity.]

41. How does a hot-air balloon work? [Hint: The "skin" of the balloon is "limp"; the pressure is the same inside and outside.]

NOTE: The connection between problems 41 & 42

42. Consider heating the air ($pV = Nk_BT$) in your house. You turn on the furnace and the temperature goes up. However, p remains at 1 atmosphere and V changes only negligibly. Thus pV stays the same, but T goes up. How can this be?!

The thermal energy in the house air

$$\text{T.E.} = \frac{3}{2} p V$$

remains unchanged!

Where did the thermal energy from the furnace go? Why did you turn on the furnace?

"It's not the heat, it's the temperature."

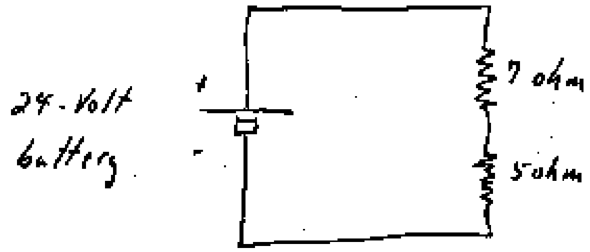
Old Exam

Physics 115
Exam #2
7 Nov. 84

NAME________________________________

acceleration of gravity = 9.8 m/sec^2

1.



(a) How much electric current is flowing in this circuit?

(b) How much voltage is across the 5-ohm resistor?

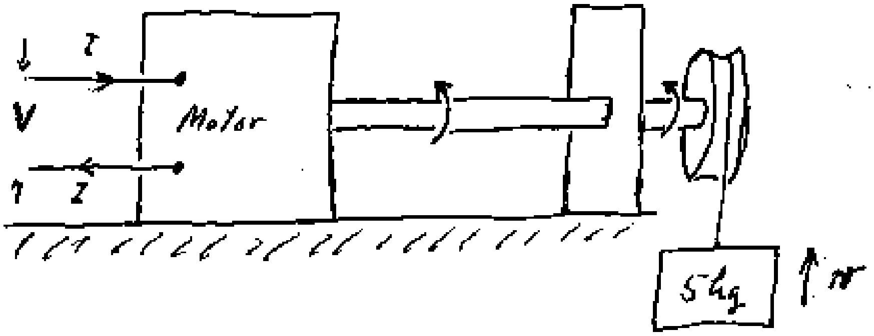
(c) How much power is the battery supplying?

(d) How much power is being consumed in heating the 7-ohm resistor?

2. (a) What is the distinction between an electric <u>motor</u> and an electric <u>generator</u>?

(b) Describe, as well as you can, how an electrical generator works. (It's OK to base your discussion on the demonstration in which we cranked a loop of wire around between two magnets.)

3.



An electric motor is being used to lift a 5-kg mass, as shown.
The power input to the motor is 60 Watt, and the input voltage V is 120 volts.
You may assume that the motor itself wastes no energy.

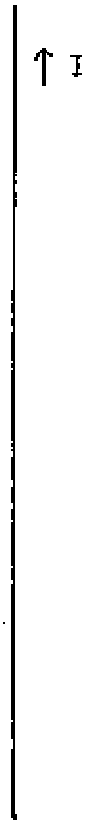
(a) What is the value of the electric current being fed into the motor?

(b) What is the speed v with which the 5-kg mass is being raised?

5. Consider an 800-Watt hair dryer. How much does it cost you to use it for 20 minutes, if a kWhr of electric power costs 7 cents?

4. (a) At right is a point charge Q. Sketch directly on the diagram the direction and size of the <u>electric</u> field from this charge in the space around it.
(Comment as you see fit.)

(b) At right is a long straight wire carrying a steady electric current I upward. Sketch directly on the diagram the magnetic field from this current.
(Comment as you see fit.)



The five "states of matter"

1 plasma (hottest)
2 gas
The classical three → { 3 liquid ↑ Higher temperature
4 solid
5 superfluid (coldest)

Plasmas and superfluids do not occur at "ordinary" temperatures and pressures.

The gaseous state is, by far, the simplest; because in that state each molecule is by itself most of the time. (That's not true of a plasma, because the plasma involves a mixture of positively and negatively charged particles and these charges can exert forces on one another through long distances.)

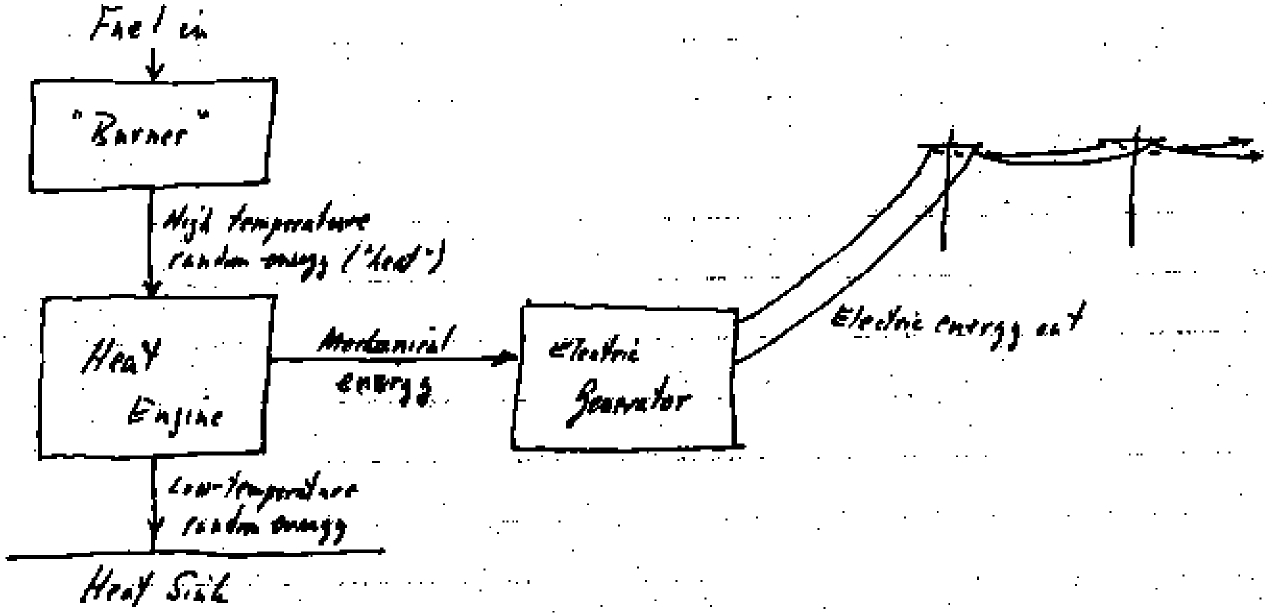
Superfluids are HeII and superconductors.

"System" and "State": two very common and general words in physics.

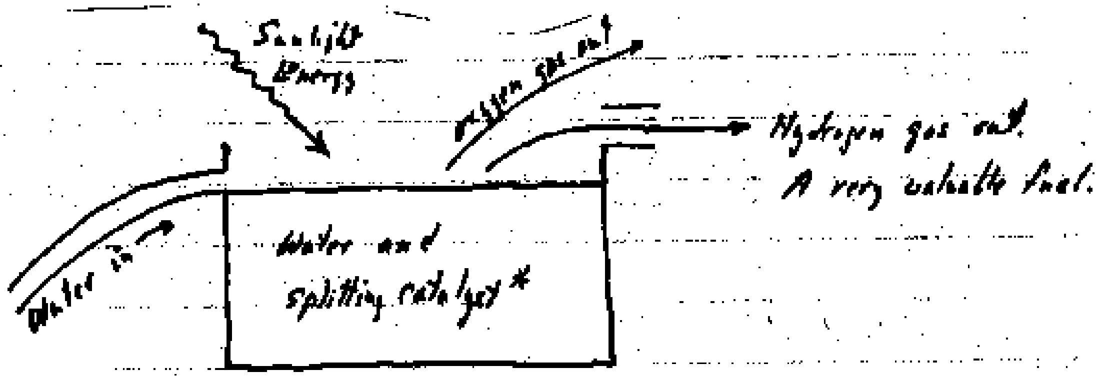
System: The entire physical object you are discussing.

State: When you give the "state of a system" to tell all you know about the precise condition it is in.

Various kinds of energy: Kinetic, Gravitational Potential Energy, Electric Potential Energy, Mechanical Potential Energy (as in a spring), Chemical Energy, Nuclear Energy, Thermal Energy.



THE DREAM : WATER SPLITTING



* No one has found it, yet...

(OVER)

The Laws of Thermodynamics

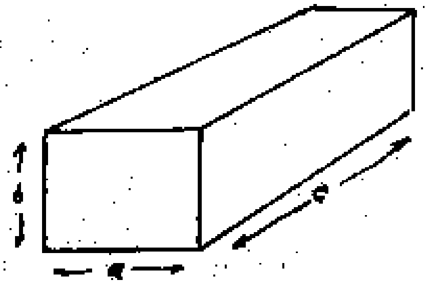
0th Thermodynamic equilibrium is transitive.
There is a unique measure of hotness and coldness.
There is such a thing as a thermometer.
∃ Temperature

1st Energy is conserved (provided that all forms are considered).
∃ Energy

2nd Work can be wholly converted to heat, but the reverse is not true.
Distinguishes between organized (coherent) energy and disorganized (random) energy.
∃ Entropy

[3rd Deals with special properties of matter at temperatures near absolute zero.]

Kinetic Theory of Pressure



Rectangular box full of gas molecules.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} = P$$

$$F = Ma = M\frac{\Delta v}{\Delta t} = \frac{\Delta(Mv)}{\Delta t}$$

In collision with wall $\Delta(Mv) = 2Mv$ (important difficult point)

$$P = \frac{1}{A}\,\frac{N}{3}\,\frac{2Mv}{\frac{2c}{v}} = \frac{1}{ab}\,\frac{N}{3}\,\frac{Mv^2}{c} = \frac{2}{3}N\,\frac{\frac{1}{2}Mv^2}{abc} = \frac{2}{3}N\,\frac{\frac{1}{2}Mv^2}{V}$$

$$\therefore \quad PV = N\frac{2}{3}\,\overline{K.E.}$$

But experimentally

$PV = Nk_BT$ (eq. 6.10, p220) Ideal Gas Law

$\therefore \quad \frac{2}{3}\,\overline{K.E.} = k_BT \Rightarrow \overline{K.E.} = \frac{3}{2}k_BT$ <u>Meaning</u> of Temperature!

$$\left[\frac{1}{2}M(\overline{v_x^2+v_y^2+v_z^2}) = \frac{3}{2}k_BT \Rightarrow \frac{1}{2}M\overline{v_x^2} = \frac{1}{2}M\overline{v_y^2} = \frac{1}{2}M\overline{v_z^2} = \frac{1}{2}k_BT\right]$$

This was derivation of Ideal Gas Law. (Can be done much better!)

Meaning of absolute temperature. Very important.

For ideal gas $T.E. = N\frac{3}{2}k_BT$ $\begin{cases} \text{depends only on Temperature (not on P or V)} \\ = \frac{3}{2}PV \end{cases}$

$_1H$ $_6C$ $_7N$ $_8O$ are the major elements in biology.

Zoology (animals) get energy by the oxidation of hydrocarbons.

e.g. (simplest) $\underset{\text{methane (natural gas)}}{CH_4} + 2\underset{\text{20\% of air}}{O_2} \longrightarrow CO_2 + 2H_2O + \text{Energy}$

And so animals need hydrocarbons and oxygen.
Everything you eat comes directly or indirectly from plants (except pure water and inorganic additives, like salt), & thus from solar energy.

Botany (plants, including trees) does the reverse by photosynthesis

$\underset{\text{Sunlight}}{\text{Energy}} + CO_2 + H_2O \xrightarrow[\text{Chlorophyll}]{} CH_2O + O_2$ complicated two-step reaction

Trees consume carbon dioxide and water, and give off oxygen.

CO_2 is an important "Greenhouse Gas"

The oceans contain 60 times as much CO_2 as does the atmosphere.
The solubility of CO_2 in water decreases as the temperature increases.

Acid rain and the greenhouse effect are both important, and are not very closely related to eachother. (Of course, everything is related to everything else in the ecology of the environment, and so we can't say they are unrelated.)

Acid rain is new and clearly man made.

The greenhouse effect has been in operation for 10s or 100s of million years (humans for about 2 million), and, without it, life as we know it would be impossible. The question is whether man is increasing it to a dangerous extent.

Physics 115
Fri 30 Oct 87

MGE
MADISON GAS AND ELECTRIC

P.O. BOX 1231
MADISON, WISCONSIN 53701-1231
FOR INFORMATION ABOUT
THIS BILL CALL: 252-7222

KEEP BOTTOM PORTION FOR YOUR RECORDS

SERVICE ADDRESS	CUSTOMER	NEXT SCHEDULED READING DATE	ACCOUNT NUMBER
2021 VAN HISE AV	C H BLANCHARD	11/16	10711950

NUMBER OF DAYS — READING DATES: PRESENT, PREVIOUS — READINGS: PRESENT — PREVIOUS X CONSTANT = USE — GAS ONLY: X THERM FACTOR = THERMS — AMOUNT

PREVIOUS ACCOUNT BALANCE	$	62.62
10/06/87 CASH PAYMENT - THANK YOU	$	62.62CR
BALANCE FORWARD	$	0.00
GAS: RESIDENTIAL SERVICE		
31 10/19 09/18 2754 2682	1.000 72 CCF 0.997	72 THERMS
CUSTOMER CHARGE (MONTHLY)	$	3.50
ENERGY CHARGE	* 72 THERMS AT $ .60760 $	43.75
SURCHARGE	$47.25 AT 0.769% $	0.36
PURCHASED GAS ADJUSTMENT	72 THERMS AT $ .00057CR$	0.04CR
WISCONSIN SALES TAX: $47.57	TAXABLE AMOUNT AT 5.0% $	2.38
SUBTOTAL: CHARGES ON GAS METER	058688 $	49.95
ELECTRIC: RESIDENTIAL SERVICE	***CUSTOMER READING***	
31 10/19 09/18 9252 8800	1.000 452 KWH	
CUSTOMER CHARGE (MONTHLY)	$	3.25
ENERGY CHARGE	452 KWH AT $ .06040 $	27.30
SURCHARGE	$30.55 AT 1.530% $	0.47
WISCONSIN SALES TAX: $31.02	TAXABLE AMOUNT AT 5.0% $	1.55
SUBTOTAL: CHARGES ON ELECTRIC METER	072747 $	32.57
TOTAL CHARGES FOR SERVICE THIS MONTH	$	82.52
ACCOUNT BALANCE	$	82.52

* 1 therm = 10^5 Btu (= heat energy from 100 ft^3 of methane).

DEGREE DAY INFORMATION

	DEGREE DAYS	NUMBER OF DAYS
THIS YEAR	441	31
LAST YEAR	301	29

BUDGET BILLING INFORMATION

TO DATE FOR THIS BUDGET YEAR: TOTAL BUDGET AMOUNT BILLED	UTILITY SERVICE USED	BUDGET AMOUNT IN ARREARS	MONTHLY BUDGET AMOUNT

DATE DUE	11/06/87
AMOUNT DUE	$ 82.52

FOR MORE INFORMATION, SEE THE BACK OF THE BILL.

(OVER)

Low-cost, no-cost ways to save energy dollars

Winter's on the way. That means it's time to have your furnace checked by a professional, caulk and weather strip doors and windows, and put on storm windows. These are proven energy-saving actions you probably take every fall.

We'd like to suggest a dozen more low-cost, no-cost actions that add up to greater energy savings. Include them on your "Get Ready for Winter" list.

1. Place your waterbed where the winter sun will shine on it to help warm the water naturally.
2. Insulate your waterbed.
3. Seal your room air conditioner using temporary caulk and plastic or a special cover.
4. Vent the electric dryer to the inside.
5. Check the dryer vent on the outside to make sure it's not stuck open.
6. Insulate your standard model water heater.
7. Install low-flow shower head and faucet aerators.
8. Insulate the first five feet of water heater pipes or install heat traps.
9. Dust all light bulbs.
10. Replace older light bulbs with new ones that are more energy efficient.
11. Check the glazing compound around windows for cracks, missing sections and loose-fitting glass. Replace the compound if you find problems.
12. Make sure heat registers and cold-air returns are not blocked by furniture or drapes.

If you need advice on how to do any of these tasks, stop at the MGE Energy Center at 5 N. Pinckney St. or call 252-7095. Stay warm!

Hurry to apply for gas conversion rebates

If you've thought about converting to natural gas for space heating or water heating, act now.

There is still time to buy and install energy-efficient equipment and apply for cash rebates from MGE—$150 for a furnace or boiler and $50 for a water heater.

But hurry! To be eligible, you must convert to natural gas and buy the furnace, boiler or water heater between June 1 and Nov. 30. The equipment must be installed by Dec. 11.

Gas furnaces must have an AFUE of at least 83%; gas boilers, an AFUE of at least 78%; and gas water heaters, ASHRAE Standard 90 model. In addition, homes must pass a natural gas conversion checkup to be eligible.

If you received a rebate for one type of equipment in the past, you may still qualify for a rebate on other equipment this year.

For more information, call 252-7222.

CUSTOMER INFORMATION CORNER

Q. When are heating degree days shown on MGE bills?

A. Heating degree day information is printed in the lower left corner of your bill beginning in October and continuing throughout the heating season.

Heating degree days indicate how cold the weather has been during a specific time span. They can be used to evaluate the effect of weather on the amount of energy used.

Generally, you will use more gas and electricity for heating as the number of degree days increases. However, other factors such as wind, sunshine, lifestyle and conservation measures also affect the amount of energy you use.

(over

Switching to time-of-use rates may save on electric bills

Most MGE residential customers can choose between two electric rate schedules: standard rates and time-of-use rates. For many customers, time-of-use rates have meant lower electric bills.

With standard rates, one rate is charged for all the electricity used during the billing period.

Time-of-use pricing uses two different rates, depending on when the electricity is used. The higher of the two rates is in effect for peak periods when total electricity demand is high. The lower rate is charged during low-demand, or off-peak, times. Rates can be lower during off-peak times because electricity production costs are lower then.

For MGE, peak hours are from 10 a.m. to 9 p.m. Monday through Friday. All other times, including entire weekends and holidays, are in the off-peak period.

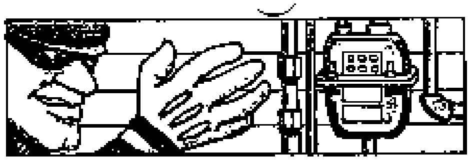
Generally, you can benefit from time-of-use rates if you have a number of large electric appliances and are able to shift some of their use from peak to off-peak times.

For example, delay using your dishwasher until after 9 p.m. weekdays when the off-peak period begins. You can shift about 30 kilowatt-hours of electricity per month to off-peak hours when the lower rate is in effect.

A general rule of thumb is, if you can limit your peak-period electricity use to about a third of your total use, you probably would save with time-of-use rates.

To help you decide if you could benefit from switching to time-of-use electric rates, we've revised our booklet "Living With Time-of-Use Electric Rates." The booklet compares typical bills using both time-of-use and standard rates. It also contains guidelines for switching appliance use and shows you how to determine if time-of-use rates would cut your electricity costs. Other requirements, such as special metering, are described.

You can get a free copy of the booklet by calling 252-7222 or by returning the coupon above in your bill payment envelope.



Meter tampering is illegal, can be dangerous, fatal

Anyone making an unauthorized adjustment of electric meters is risking serious electrical shock and even death.

Tampering with gas meters or piping is also very dangerous. Doing so could permit gas to escape. If undetected, this could result in an explosion or fire.

Under Wisconsin law it is illegal to tap or bypass electric, gas and water meters. Anyone convicted is subject to a fine, imprisonment or both. In addition, the person convicted must pay for service fraudulently obtained as well as for the cost of the utility's investigation.

If you see a gas or electric meter that appears to have been tampered with, please report it to MGE at once. During general business hours, call us at 252-7222. During evenings, weekends or holidays, call us at 252-7111. The meter could pose a serious hazard for anyone near it.

MGE Speakers Bureau available for programs

Need program ideas for your organization's meetings this fall? Call the MGE Speakers Bureau.

The Speakers Bureau offers free programs on a wide variety of energy topics—from "Acid Rain" to "Window Treatments." Your group might want to know about new services for MGE customers . . . or how a Good Cents home is built to save energy . . . or how weatherizing your home can save on both heating and cooling costs.

Most programs last about a half hour, which includes a question-and-answer period.

If you want more information about programs available, call 252-7909. To schedule a program, please contact us at least two weeks before your meeting date.

We're putting energy into our community

Physics 115 #24
Fri 30 Oct 87

Brownian Motion

Experimental "ideal-gas" law

$$\underset{\text{pressure}\,(N/m^2)}{P}\ \underset{\text{volume}\,(m^3)}{V} = \underset{\text{total number of molecules}}{N}\ \underset{\text{Boltzmann's constant} = 1.38\times10^{-23}\,(J/k)}{k_B}\ \overset{\text{absolute temperature}\,(K)}{T}$$

— good approximation for any gas at low pressure

— says $T = 0$ is temperature at which pressure is zero.

Theoretically

$$PV = \frac{1}{3} N \overset{\text{mass of one molecule}}{m} \overset{\text{average}}{\overline{v^2}} = \frac{2}{3} N \overline{\frac{1}{2} m v^2} = \frac{2}{3} N \overline{K.E.}$$

v = molecular speed

Comparing $\quad \frac{2}{3} N \overline{K.E.} = PV = N k_B T$

that is $\quad \overline{K.E.} = \frac{3}{2} k_B T \quad$ (avg K.E. per molecule)

This is the <u>meaning</u> of absolute temperature.

Very important.

The molecules of matter at temperature T have

$$\text{avg K.E.} = \frac{3}{2} k_B T$$

Molecular motion stops <u>only</u> at $T = 0$.

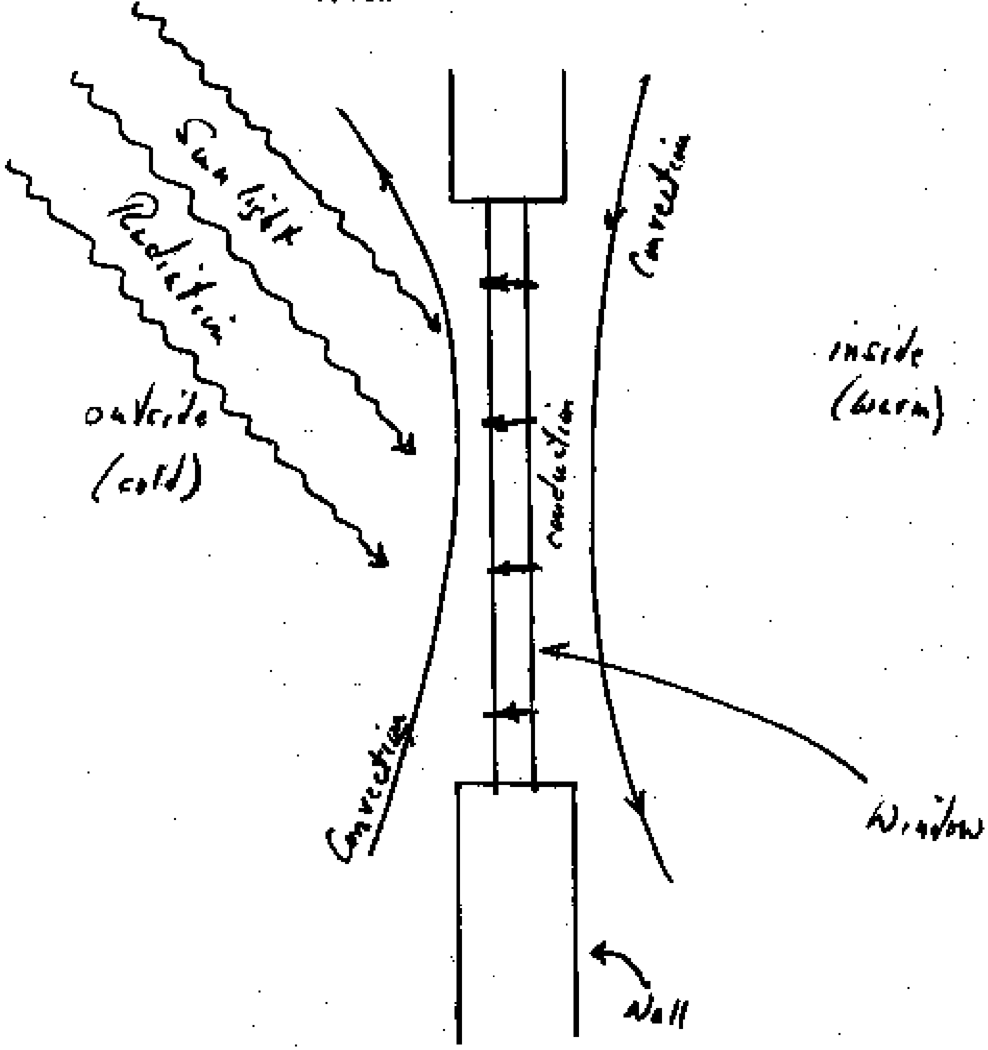
(OVER)

"Heat Transfer" : the transport of random energy①

Conduction② : $H = k A \frac{\Delta T}{\Delta x} t$

Convection

Radiation



① p 205

② also p 166

NYT Tues 27/10/87

Indispensable Helium Is Routinely Squandered

New concern centers on how to husband a gas with unique properties.

By MALCOLM W. BROWNE

As its potential uses proliferate, scientists, government agencies and private interests are wrestling anew with the problem of husbanding an irreplaceable but widely wasted resource: helium.

Although it is most commonly known as the lighter-than-air gas that keeps balloons of all sizes afloat, helium is indispensable to many fields of scientific research and to a host of promising new technologies. Although cheap helium is abundant now, vast amounts of it are wasted each year.

Dr. Roger Dickson, a physicist at the Fermi National Accelerator Laboratory in Batavia, Ill., noted that many helium conservation measures are considered too costly. "Conservation won't seem cost-effective until we start running out of helium," he said. "By then we will have thrown away most of our supply."

The United States produces about 90 percent of the world's supply, much of it a byproduct of natural gas production in Texas, Wyoming and several nearby states. But Government experts estimate that about three-quarters of the helium brought up from gas wells is vented into the air and lost. The Government maintains a strategic stockpile of helium, but the Reagan Administration has proposed closing it as a cost-cutting move, creating further uncertainties about the long-term supply.

Helium, a product of the nuclear fusion of hydrogen, is invisible, odorless and so difficult to discern in the everyday world that it was first discovered by astronomers in 1868 as a constituent of the sun's atmosphere. (The name helium is derived from helios, the Greek word for sun.) Only in 1895 was helium found to exist on the earth, as a decay product of radioactive minerals.

The second lightest of the elements after hydrogen, helium is vital to many new technologies and fields of research requiring temperatures close to absolute zero, or minus 459.4 degrees Fahrenheit.

Only with liquid helium can researchers create such cold. And unlike such other

Continued on Page 16

OVER

Concern Rises Over Indispensible Helium, an Often Squandered Resource

Continued From Page 15

nonrenewable resources as petroleum, helium has other qualities that cannot be duplicated by any other substance.

Since World War I, when gas-filled zeppelins served as strategic bombers, Washington has regarded noninflammable helium as a strategic resource. Airships no longer play important military roles, but helium's unique properties have found many other applications, including advanced weaponry and spacecraft.

Major Reason for Waste

The main problem in conserving helium is that the rate at which it is extracted from the ground depends on the demand for natural fuel gas rather than for the helium itself. When the demand for helium is low but the natural gas market is strong, most of the helium brought up and separated from the gas must be discarded for lack of storage space.

The price of helium sold by the Government is now fixed at $37.50 per thousand cubic feet, about enough to fill a 12-foot balloon. Many conservationists say this price is much too low to protect reserves.

In 1963, the Bureau of Mines began to pump helium into a partly depleted natural gas field in porous rock thousands of feet underground near Amarillo, Tex. This Federal stockpile contains 34.6 billion cubic feet of crude helium.

But in his last budget message, President Reagan called on the Government to abandon its helium operations. The Bureau of Mines has commissioned John Campbell & Associates of Lexington, Mass., to study the effects of such a move. The results of the study are due in December.

Scientists, engineers and Government officials agreed in interviews that helium reserves are adequate for the indefinite future. The major source of world helium supplies since 1929, the Cliffside field in the Texas panhandle, is approaching depletion, according to Armond A. Sonnek, director of helium operations for the Bureau of Mines.

But a helium-rich gas field has been discovered in southwestern Wyoming, from which the Exxon Corporation began extracting helium last year at the rate of about 800 million cubic feet per year, virtually doubling American production.

Apprehensions about helium resources were also reduced somewhat this year by the discovery of high-temperature superconductors, which conduct electricity with no loss to resistance. Superconductors are vital to advanced electricity transmission, powerful magnets and other advanced electrical devices.

Until recently, the only known superconductors had to be chilled to temperatures around minus 452 degrees, an extreme that can be produced only by liquefying helium. The recent advances in superconductivity suggest to some scientists and government officials that helium may not be as crucial to future superconductor technology as had been thought.

But others note that high-temperature superconductors have yet to be made into practical devices. Furthermore, cooling for superconductors is only one use to which helium is put.

Scientists designing the proposed superconducting super collider, a nuclear particle accelerator that would be more than 50 miles in circumference and would cost about $4 billion, believe that liquid helium will be essential to the machine.

10,000 Giant Magnets

The collider would contain around 10,000 gigantic magnets to contain and accelerate an intense beam of particles whipped around the huge circle at nearly the speed of light. Physicists seeking to understand the fundamental interactions of matter and energy regard the collider as an essential tool for achieving the immense energies needed for the research.

The collider's magnets, in common with those already in use at the new Tevatron accelerator at Fermilab, will be based on superconducting material.

Dr. Michael S. McAshan, a member of the design group working at the University of California at Berkeley on the super collider, said the accelerator would require the gas equivalent of 50 million cubic feet of helium to cool the magnets making up its underground ring, and that about 25 percent of this amount will have to be replaced each year because of leaks and other losses.

Dr. McAshan, Dr. Chris Quigg and other physicists designing the collider agree that despite the current euphoria occasioned by the discovery of high-temperature superconductors, ultra-cold helium will still be needed for the collider.

"It took us decades to develop the superconducting wire used in the Tevatron magnets," Dr. Quigg said. "No one is even close to fabricating the new high-temperature superconductors into anything like that."

Other accelerator experts say the intense cold of liquid helium serves another important purpose: It helps to create the ultra-high vacuum that must be maintained in the beam line to prevent speeding particles from colliding inadvertently with air molecules. Without liquid helium, another and more expensive means of evacuating the beam tube would have to be developed.

The helium atom, whose lone shell of electrons is completely filled by two orbital electrons, is uniquely resistant to forming compounds with other chemical elements. The innermost electron shell of an atom is limited to two electrons, and if the shell is completely filled, the chemical bonds that might be formed by borrowed, lent or shared electrons are ruled out.

Only recently did scientists find a way using intense X-ray radiation to unite helium with hydrogen, thereby creating a compound known as an excimer. Excimers, which can produce very high-energy laser beams, are under intense study by laboratories working for President Reagan's anti-missile program, the Strategic Defense Initiative.

Helium's extreme resistance to any type of chemical reaction led to "heliarc" welding, in which the flame of a welding torch is surrounded by a sheath of flowing helium. This prevents atmospheric oxygen and other gases from reacting with the hot metal being welded, and makes possible the high-temperature welding of stainless steel, aluminum and other metals. Roughly one-quarter of the nation's helium consumption is for welding.

Helium's atomic structure prevents liquefaction of the gas until its temperature is lowered to minus 452 degrees; at temperatures below those at which all other gases are converted into liquids or solids, helium remains gaseous.

This makes helium the only possible pressurizing gas in a rocket fuel tank containing liquid hydrogen at minus 423 degrees. Even at this temperature, the gaseous helium can drive the liquid hydrogen from the tank to the rocket engine pumps, and large amounts of helium are essential to the space shuttle propulsion system.

Helium is used to replace nitrogen in the air mixtures used in deep scuba dives to protect divers from the decompression sickness produced by nitrogen dissolved in blood. Liquid helium chills the nuclear magnetic resonance machines used to image organs within the human body without X-rays, and it cools the infrared telescopes needed to map vast parts of the universe invisible in ordinary light. Interest in airships appears to be rekindling, and the Navy recently contracted to purchase the first of a new line of helium-filled blimps from a British-based company.

But scientists prize helium most of all for the light it sheds on the subtle interactions of matter and the mysterious roles of quantum mechanics that govern the microscopic universe.

When it is prepared by successive cycles of compression and expansion, liquid helium has a temperature only 4.2 degrees on the kelvin scale above the absolute zero. But by pumping away the more energetic atoms in the liquid, scientists can reduce its temperature to a fraction of a degree above absolute zero.

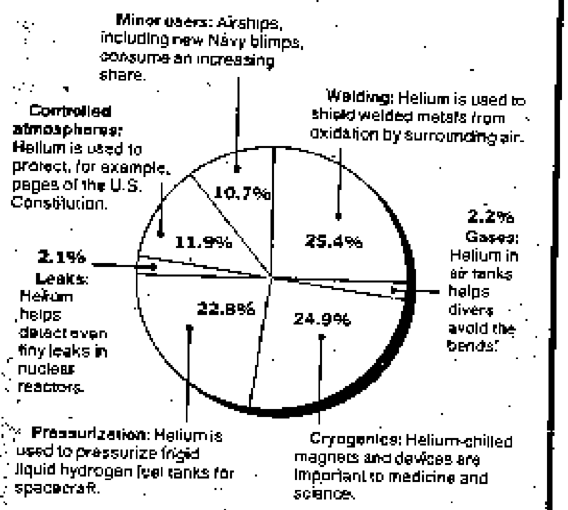
Below 2.17 degrees kelvin, liquid helium becomes superfluid: that is, it flows without friction. A ring-shaped current of superfluid helium set in motion within a larger volume of superfluid helium will rotate forever if left undisturbed.

Superfluid liquid helium behaves in strange ways, offering a unique opportunity to see into the world of quantum mechanics from the human vantage point.

When a rotating container of superfluid helium is gradually speeded up, vortexes form in the liquid. At discrete points in the speeding-up process, the liquid undergoes quantum jumps and new vortexes form. The rate of rotation and the number of vortexes that are created are related by Planck's Constant, a fundamental value underlying quantum mechanics.

Helium: A Diversity of Uses

The demands of scientific research and new technologies are increasing demand for world supplies of irreplaceable helium. Shown are uses of helium in the United States in 1986.



Minor users: Airships, including new Navy blimps, consume an increasing share.

Welding: Helium is used to shield welded metals from oxidation by surrounding air.

Controlled atmospheres: Helium is used to protect, for example, pages of the U.S. Constitution.

Gases: Helium in air tanks helps divers avoid the bends.

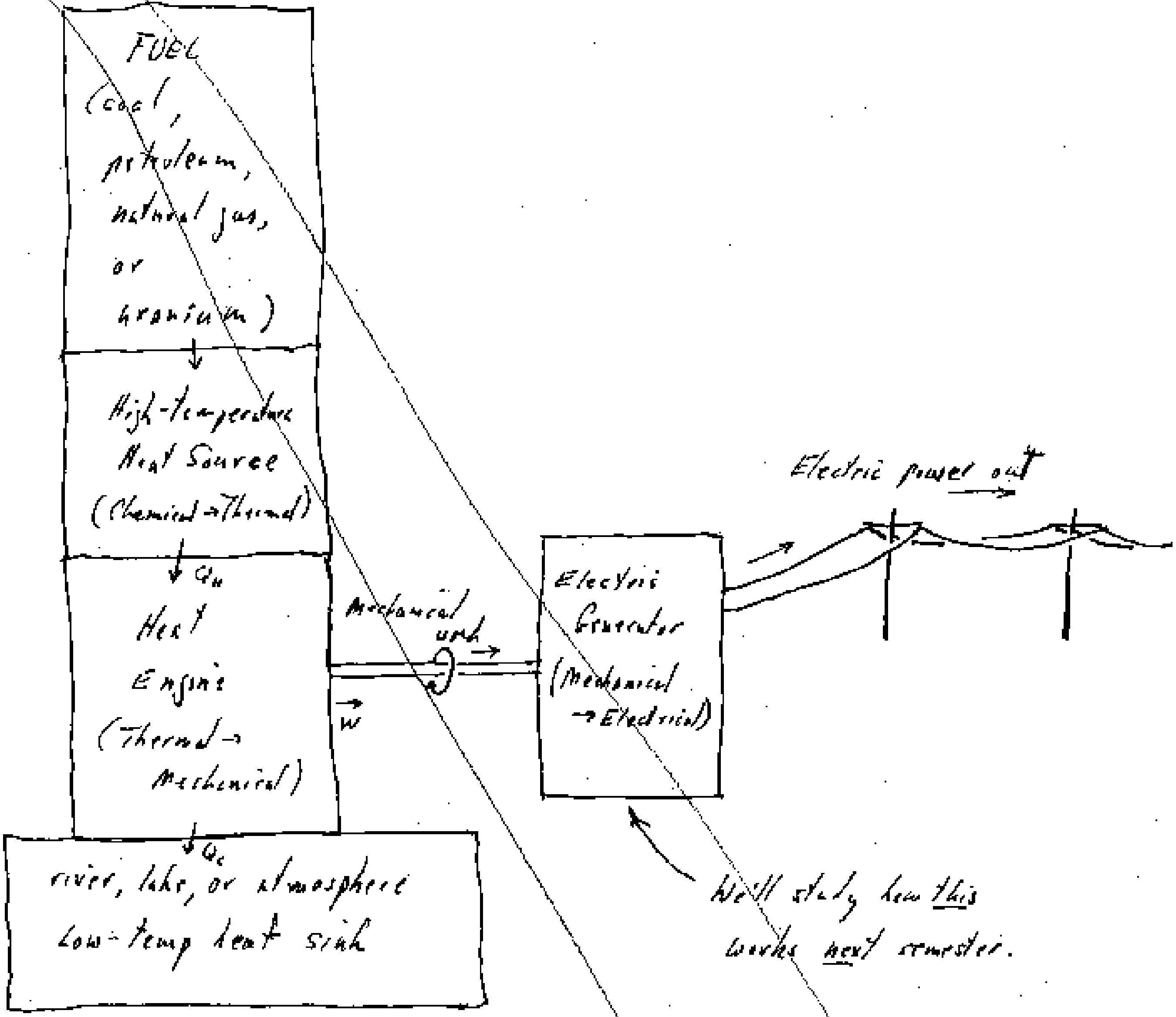
Leaks: Helium helps detect even tiny leaks in nuclear reactors.

Pressurization: Helium is used to pressurize frigid liquid hydrogen fuel tanks for spacecraft.

Cryogenics: Helium-chilled magnets and devices are important to medicine and science.

The New York Times/October 27, 1987; Source: Bureau of Mines

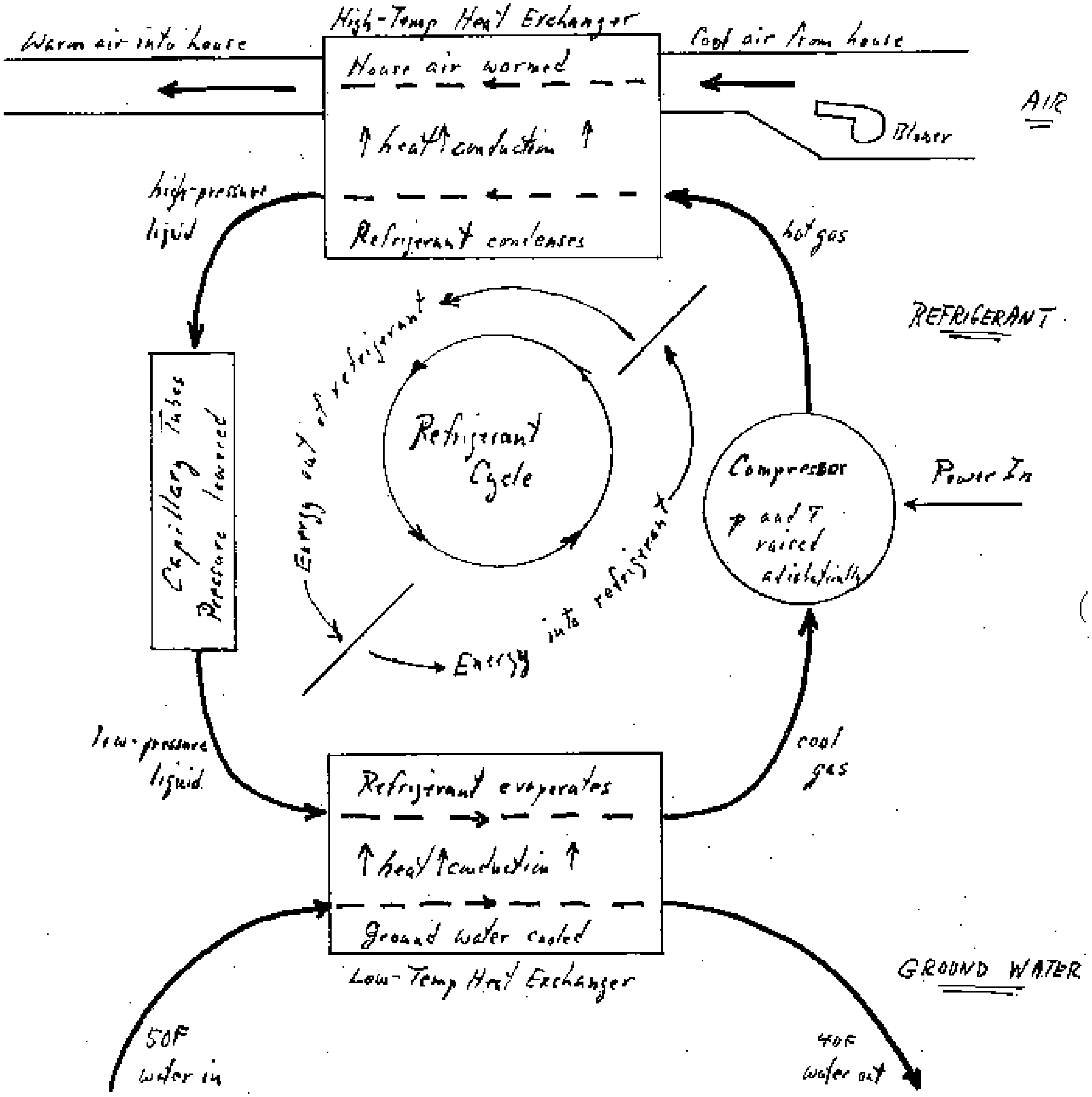
ELECTRIC POWER GENERATION



We'll study how this works next semester.

Hydroelectric has no fuel or heat engine, but drives the generator directly from the mechanical power of the falling water.

GROUND-WATER HEAT PUMP



Refrigerant is fluid with low boiling point temperature

e.g.	b.p.(C)
ammonia NH_3	-38
sulfur dioxide SO_2	-10
freon CCl_2F_2	-29

CHB (NwP)

Ideal or Carnot Engine

All heat in at the highest temperature (H_H in at T_H)
All heat out at the lowest temperature ($|H_c|$ out at T_c)

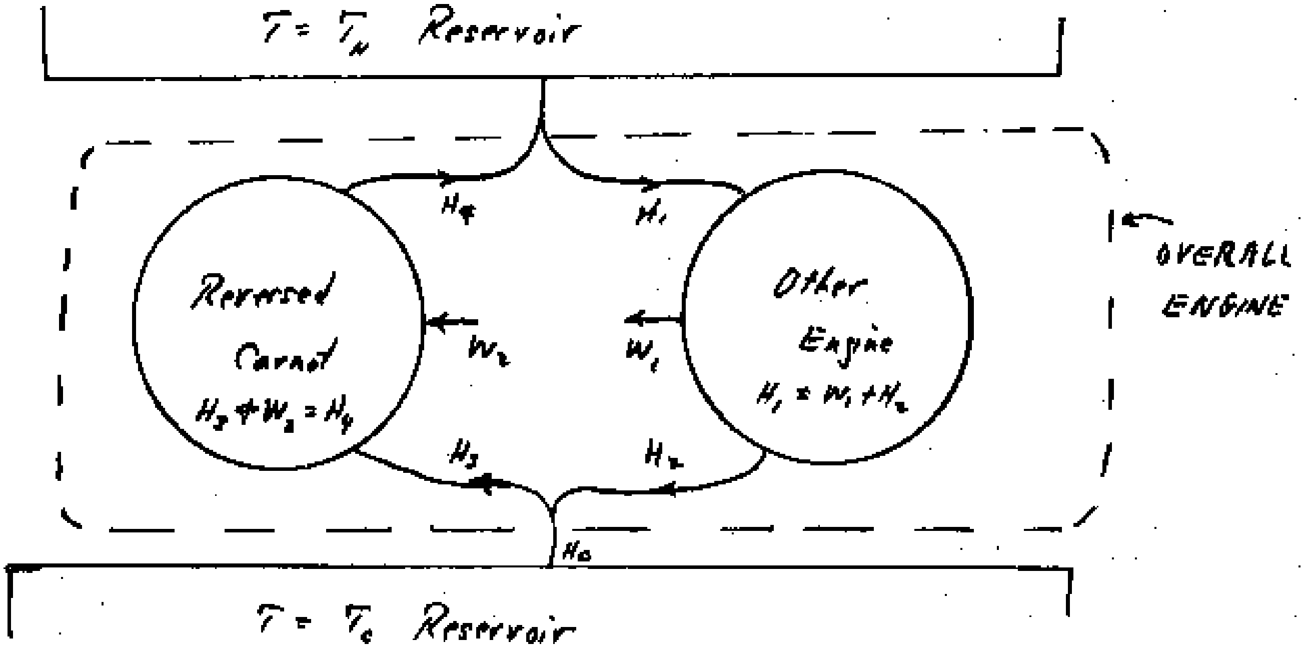
Reversible (equilibrium)

For such engine i.e. b.s.t.

$$\frac{H_H}{T_H} = \frac{|H_c|}{T_c}$$

Then $\Delta S = \frac{H_H}{T_H} + \frac{H_c}{T_c} = \frac{H_H}{T_H} - \frac{|H_c|}{T_c} = 0$

SECOND-LAW EQUIVALENCES



If the other engine were more efficient than Carnot then

$$\frac{H_2}{H_1} < \frac{H_3}{H_4} \qquad \underline{\text{and}} \qquad \frac{W_1}{H_1} > \frac{W_2}{H_4}$$

(a) If we adjust things so that $H_3 = H_2$

then (1) cold reservoir not used ($H_c = 0$)

(2) $H_4 - W_2 = H_1 - W_1 \Rightarrow W_1 - W_2 = H_1 - H_4 > 0$: All heat converted to work.

KELVIN VIOLATION

(b) If (instead) we adjust so that $W_1 = W_2$

(1) no external work (in <u>or</u> out)

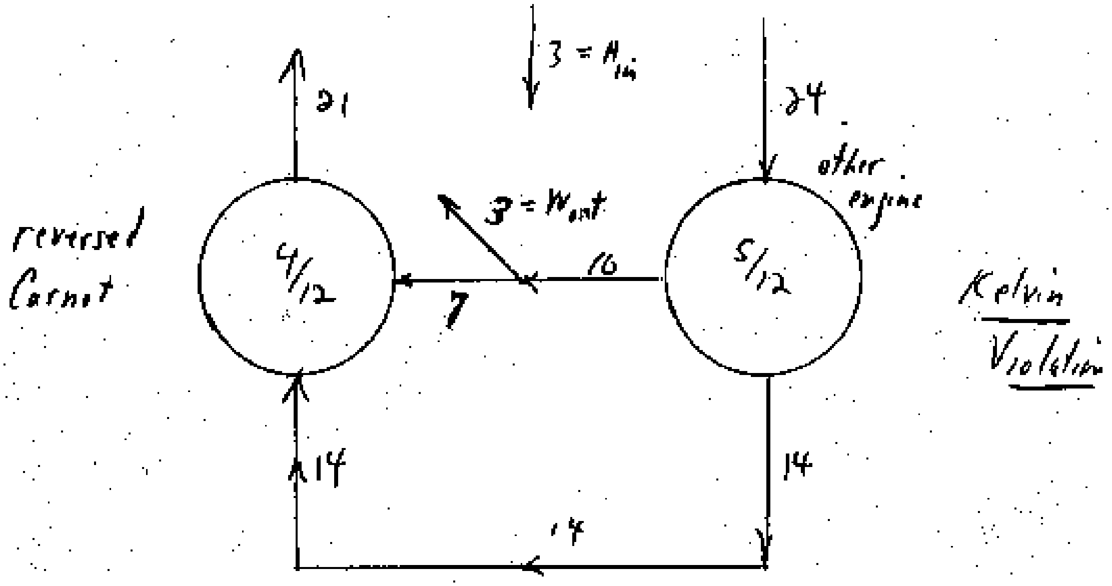
(2) $H_1 - H_2 = H_4 - H_3 \Rightarrow H_3 - H_2 = H_4 - H_1 > 0$

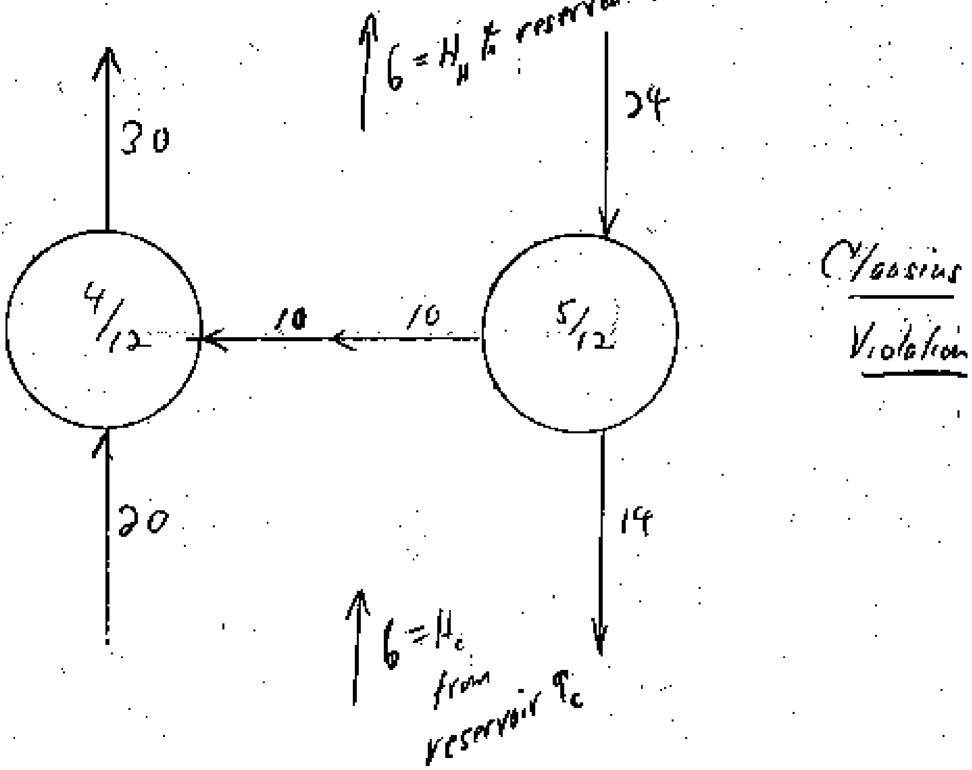
Heat from T_c to T_H without work input.

CLAUSIUS VIOLATION

∴ No engine can have thermo eff greater than Carnot.
[Carnot : reversible, between T_H and T_c]

(OVER)


3 = H_in
21
24
other engine
reversed Carnot
4/12
3 = W_out
10
7
5/12
Kelvin Violation
14
14
14


6 = H_H to reservoir T_H
24
30
4/12
10
10
5/12
Clausius Violation
20
14
6 = H_c from reservoir T_c

36. Why do you get a worse burn from picking up a piece of hot metal than a piece of wood at the same temperature?

37. Methane flame is 2240K. Fe melts at 1808K. Why then doesn't your iron frying pan melt on your gas stove?

38. [Problem 6.17 on p 237:] How much is the temperature of the water in Niagara Falls (190 ft) raised by the conversion of G.P.E. into K.E. and then into T.E.?

39. How much thermal energy is there in 1 m^3 of He (gas) at 1 atmosphere ($p = 1.0 \times 10^5 N/m^2$) and 20 C?

40. Find the total mass of the earth's atmosphere. [Hint: You need the values of (1) atmospheric pressure, (2) surface area of the earth, and (3) acceleration of gravity.]

41. How does a hot-air balloon work? [Hint: The "skin" of the balloon is "limp"; the pressure is the same inside and outside.]

NOTE: The connection between problems 41 & 42

42. Consider heating the air ($pV = Nk_BT$) in your house. You turn on the furnace and the temperature goes up. However, p remains at 1 atmosphere and V changes only negligibly. Thus pV stays the same, but T goes up. How can this be?!

The thermal energy in the house air

$$T.E. = \frac{3}{2} p V$$

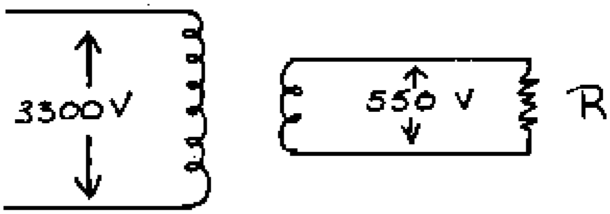
remains unchanged!

Where did the thermal energy from the furnace go? Why did you turn on the furnace?

"It's not the heat, it's the temperature."

34. If a battery contains 10 kilomole of energy-storing chemical, that is 6 x 10^{27} molecules; and if each molecule can store 1/5 electron-Volt (1eV = 1.6 x 10^{-19} Joule) of energy, for how long a time can this battery supply 25kW of power?

35. A large "step-down" (in voltage) transformer has input power 2000kW at primary voltage 3300V. The secondary feeds a resistive load at 550V.



If energy losses can be neglected, then what are:

(a) Input (primary) current?

(b) Turns ratio?

(c) Secondary current?

(d) Resistance of load?

115 Wed 11 Nov 87 #28

Waves Chap 11

EM, sound

$\lambda\nu = v$

{ Scope
{ of waves

EM radiation and string shaking.

Thermal radiation

Black Body { pure
{ real

black box
black hole
black Body

Bestiary

Binding energy (ionization energy)

Physics 115   Class #31   Fri 13 Nov 87

Waves $\lambda\nu = v$

String wave

Sound wave : Slinky

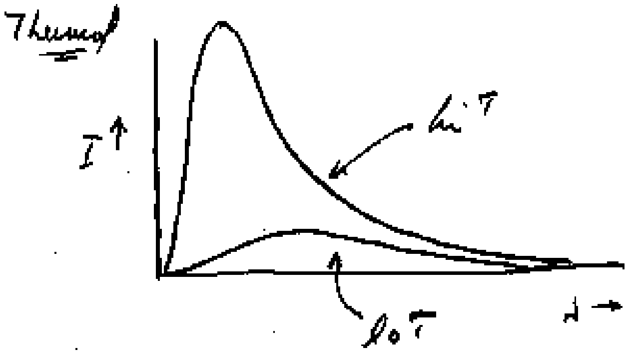
EM wave : μ wave

Prism and "white" light

Thermal Radiation

Laser Radiation

Discrete Spectra



p 374 + 535

Black body $P = \sigma A T^4$ $\left(\sigma = 5.67\times10^{-8}\,\frac{W}{m^2K^4}\right)$

$S = 1360\ \frac{W}{m^2}$

$T_s \approx 5800\,K$

$R_s = 6.9\times10^{8}\ m$

$R_E = 6.4\times10^{6}\ m$

$R_{SE} = 1.5\times10^{11}\ m$

Equilib temp of Earth

$$\pi R_E^2 S = 4\pi R_E^2 \sigma T_E^4$$

$$T_E^4 = \frac{S}{4\sigma}$$

$$T_E = \sqrt{\sqrt{\frac{S}{4\sigma}}} = 278 \text{ K}$$

– Sounds low

But wait! albedo $= \alpha = 0.34$

$$(1-\alpha)\pi R_E^2 S = 4\pi R_E^2 \sigma T_E^4$$

$$\Rightarrow T_E = 253\text{K} = -20\text{ C}$$

– Clearly wrong.

Earth does not act like a black body.
It is warmer than that.
This is the "green house effect".
It is <u>not</u> how a green house works!

Philos. Mag. 17 319 (1909)

XXIV. *Note on the Theory of the Greenhouse.*

By Professor R. W. Wood[*].

THERE appears to be a widespread belief that the comparatively high temperature produced within a closed space covered with glass, and exposed to solar radiation, results from a transformation of wave-length, that is, that the heat waves from the sun, which are able to penetrate the glass, fall upon the walls of the enclosure and raise its temperature: the heat energy is re-emitted by the walls in the form of much longer waves, which are unable to penetrate the glass, the greenhouse acting as a radiation trap.

I have always felt some doubt as to whether this action played any very large part in the elevation of temperature. It appeared much more probable that the part played by the glass was the prevention of the escape of the warm air heated by the ground within the enclosure. If we open the doors of a greenhouse on a cold and windy day, the trapping of radiation appears to lose much of its efficacy. As a matter of fact I am of the opinion that a greenhouse made of a glass transparent to waves of every possible length would show a temperature nearly, if not quite, as high as that observed in a glass house. The transparent screen allows the solar radiation to warm the ground, and the ground in turn warms the air, but only the limited amount within the enclosure. In the "open," the ground is continually brought into contact with cold air by convection currents.

To test the matter I constructed two enclosures of dead black cardboard, one covered with a glass plate, the other with a plate of rock-salt of equal thickness. The bulb of a thermometer was inserted in each enclosure and the whole packed in cotton, with the exception of the transparent plates which were exposed. When exposed to sunlight the temperature rose gradually to 65° C., the enclosure covered with the salt plate keeping a little ahead of the other, owing to the fact that it transmitted the longer waves from the sun, which were stopped by the glass. In order to eliminate this action the sunlight was first passed through a glass plate.

There was now scarcely a difference of one degree between the temperatures of the two enclosures. The maximum temperature reached was about 55° C. From what we know about the distribution of energy in the spectrum of the radiation emitted by a body at 55°, it is clear that the rock-salt plate is capable of transmitting practically all of it, while the glass plate stops it entirely. This shows us that small in comparison to the loss by convection, in other words that we gain very little from the circumstance that the radiation is trapped.

Sthg missing here

Is it therefore necessary to pay much attention to trapped radiation in deducing the temperature of a planet as affected by its atmosphere? The solar rays penetrate the atmosphere, warm the ground which in turn warms the atmosphere by contact and by convection currents. The heat received is thus stored up in the atmosphere, remaining there on account of the very low radiating power of a gas. It seems to me very doubtful if the atmosphere is warmed to any great extent by absorbing the radiation from the ground, even under the most favourable conditions.

I do not pretend to have gone very deeply into the matter, and publish this note merely to draw attention to the fact that trapped radiation appears to play but a very small part in the actual cases with which we are familiar.

---

[*] Communicated by the Author.

Physics 115 Class #33 Wed 18 Nov 87

Greenhouse effect

Wind + Wave power

Photovoltaics (Notes)

Photoelectric Effect (Demonstrate)

max KE = const + $h\nu$

Planck + Probability

PROBLEMS

NYT Tues 17 Nov 87

Turning Point Nears In Production of Fuel For Hydrogen Bombs

U.S. must decide how — or even whether — to produce more tritium.

By MATTHEW L. WALD

WITH aging, faltering plants its sole source of supply, the Federal Government must soon decide whether to build expensive new facilities to produce tritium, a vital and perishable ingredient of nuclear bombs.

The poor condition of the production reactors — two are broken down and the other three are limited to half power — makes possible an interruption in supply. Such a halt would leave nuclear warheads losing potency in their silos, as batteries lose their charge on a supermarket shelf. Adding to the sense of urgency, a recent study by the National Academy of Sciences said that it may take as long to build a new production reactor as the surviving three will last.

The Department of Energy is expected to seek funds soon to build one or two new reactors to produce tritium, a radioactive form of hydrogen, and plutonium, another bomb fuel produced in the same reactors. But each new plant would cost billions, and some experts question whether they are necessary.

The Department is expected to argue that the expense is required for national security. But some arms control advocates, joined by environmentalists who say that production of these bomb fuels is dangerous and polluting, argue that an agreement with the Soviet Union to limit nuclear arms could render the investment unnecessary.

Even limited arms reductions, such as those in the treaty on nuclear forces in Europe now under negotiation, could reduce the need for fresh tritium since supplies could be scavenged from disassembled weapons, some experts say.

Some experts even suggest that by halting tritium production, the East and West could achieve disarmament. With no new supplies, the argument goes, nations would have to steadily reduce arsenals to keep potent tritium in the remaining weapons.

While plutonium production is required to expand the nuclear arsenal, tritium production is needed simply to maintain existing weapons. This is because tritium breaks down naturally at the rate of about 5.5 percent per year. Plutonium, in contrast, is eternal, at least on the human timescale, and the nation's stockpile is believed to be substantial.

Thus tritium, even more than plutonium, is becoming the focus of concern in Congress, which will have to decide on Administration proposals to build the costly new plants.

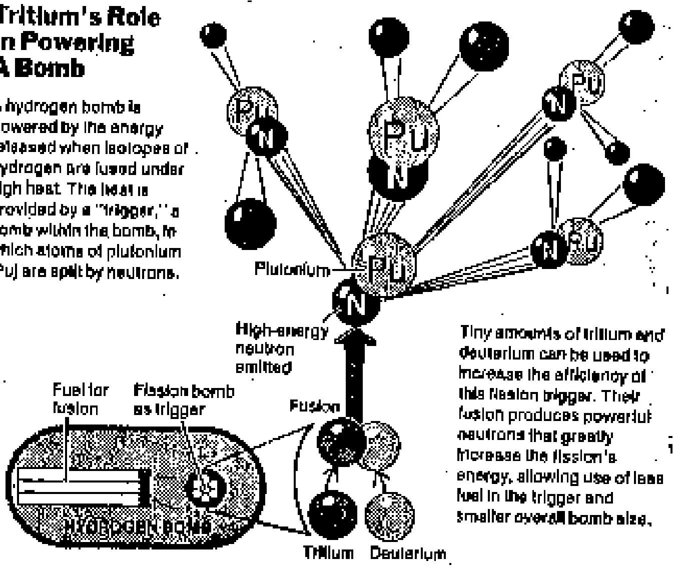
"It's very clear that tritium is the main event, rather than plutonium," said Rep. Ron Wyden, Democrat of Oregon. His district is downstream along the Columbia River from the Federal Government's plutonium-producing reactor at Hanford, Wash., which is closed for safety improvements.

Tritium has become increasingly important to the nuclear arsenal. As a "booster" in the trigger portion of a hydrogen bomb, tritium is essential to reducing the size of warheads, allowing more warheads per missile, or warheads on smaller missiles.

Tritium is a variant or isotope of hydrogen. In nature, the common form of the hydrogen atom has a nucleus of a single proton. A naturally occurring isotope is deuterium. Each deuterium nucleus contains one proton and one neutron; one in 6,000 hydrogen atoms is deuterium.

Tritium, the third isotope, has a nucleus with one proton and two neutrons. It does not occur naturally; it is made in reactors by fir-

Continued on Page 25



Tritium's Role In Powering A Bomb

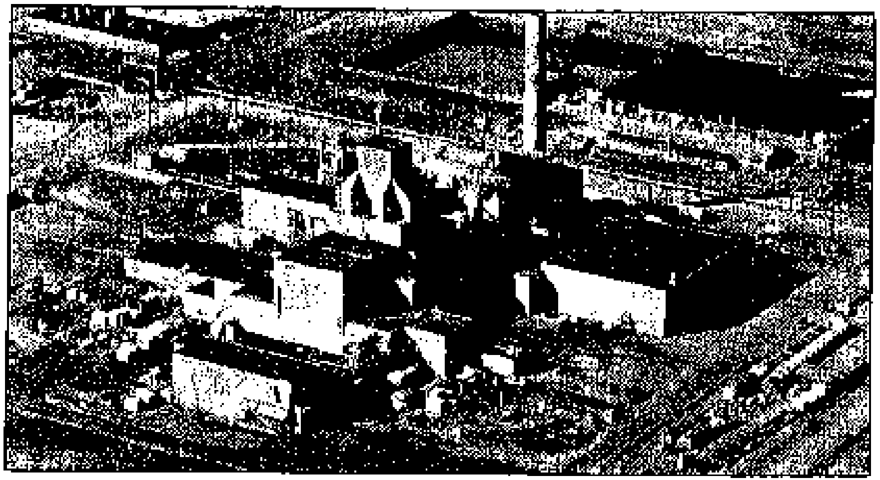
A hydrogen bomb is powered by the energy released when isotopes of hydrogen are fused under high heat. The heat is provided by a "trigger," a bomb within the bomb, in which atoms of plutonium (Pu) are split by neutrons.

Tiny amounts of tritium and deuterium can be used to increase the efficiency of this fission trigger. Their fusion produces powerful neutrons that greatly increase the fission's energy, allowing use of less fuel in the trigger and smaller overall bomb size.

The New York Times

(OVER)

Continued From Page 21



Picture Group/Wade Spees

A reactor that produces plutonium and tritium at the Savannah River Plant near Aiken, S.C.

ing a neutron at the nucleus of lithium-6, which consists of three protons and three neutrons. When a neutron is added, the atom throws off two neutrons and two protons. This leaves one proton and two neutrons, which is tritium.

The three active tritium-producing reactors are all at least 30 years old and all at the Energy Department's Savannah River Plant near Aiken, S.C. These can also produce plutonium. Environmentalists and worker-safety advocates have argued that plant wastes, which are toxic as well as radioactive, are poorly handled. Recently, the Energy Department has acknowledged some problems.

Adding to the worries, E. I. du Pont De Nemours & Company, which built and operates the plants under contract, recently announced that it would give up the work. No replacement has been announced.

The newest production reactor, a plutonium-producing reactor at the Hanford nuclear reservation in southeastern Washington, commissioned by President Kennedy in 1963 and intended to run for 20 years, was used briefly a few years ago to make tritium, with disappointing results. The reactor has been closed since the beginning of the year for safety improvements.

The General Accounting Office reported in March that the situation at Savannah River, coupled with uncertainties about the future operation of the reactor at Hanford, "raises questions about DOE's ability to meet production requirements."

A recent report by the National Academy of Sciences drew attention to the fragile status of tritium production capacity as well as the safety concerns raised by plants used to produce tritium and plutonium. The Energy Department is planning to respond to the report by the end of the year, and its response will discuss plans for one or two new production reactors for making the two bomb fuels, according to a spokeswoman, Chris Sankey.

Roles for Tritium

Tritium has two roles in nuclear weapons: in the fusion that causes the main explosion and, in the latest weapons, in the fission trigger.

In the fusion of a hydrogen bomb, an atom of deuterium and an atom of tritium are forced together under extremely high heat provided by a fission trigger. Bombs are designed to produce the tritium for this stage internally, using neutrons from the fission trigger, in a process much like that in a reactor.

But tritium must be supplied for use as the booster in the bomb trigger, where its function is to rapidly multiply the number of neutrons, subatomic particles that sustain a fission reaction.

Fission, the splitting of atoms in a chain reaction, is the process that powers civilian power reactors as well as bombs like those dropped on Hiroshima and Nagasaki.

In a simple chain reaction, as in a civilian power reactor, a neutron is fired at the nucleus of a uranium atom, splitting it. The split nucleus releases energy and a small number of neutrons. Some are absorbed by non-fissionable material. In a power reactor at equilibrium, each split nucleus gives off, on average, one neutron that inter splits another nucleus.

Doubling the Nuclei

When a fission trigger is fueled by uranium or plutonium, enough neutrons are freed in each generation of fissioning to double the number of nuclei split in the next generation; in microseconds, one fissioning produces two more fissions, which produce four, then eight and so on.

But this process can only occur when there are enough atoms compressed in a "critical mass" of fuel. Usually, chemical explosives are used to get this process started. But as fission progresses, the critical mass tends to blow apart, stopping the process. Theodore B. Taylor, a weapons designer at Los Alamos National Laboratory in the 1950's and now a private consultant, said some bombs would fission no more than one-half of 1 percent of the available fuel before exploding.

This is where tritium comes in. When tritium and deuterium fuse, they emit a neutron whose energy is much higher than those emitted in fission. Each high energy neutron, when it strikes another nucleus, produces four, not two, neutrons. So the "fission" trigger that incorporates the fusion of tiny amounts of deuterium and tritium produces the same power from much less fuel.

> The Government is expected to seek funds for one or two new reactors to produce tritium.

"If the boosting starts early enough in the fission chain reaction, then it releases a lot of neutrons at a time when the chain reaction is multiplying the neutron population very rapidly," Mr. Taylor said. "A neutron injected at that time is worth more than one fission; it is worth easily 10 times as many fissions."

Role in Neutron Bombs

Tritium is also used in the production of neutron bombs, weapons intended to kill people with radiation rather than destroy targets with shock wave. In such a bomb, tritium helps produce a greater number of neutrons from the same amount of plutonium. The Government has apparently dropped plans to produce large numbers of neutron bombs.

The volume of tritium used in triggers is probably small. The Nuclear Weapons Databook, a 1987 publication of the Natural Resources Defense Council, a nonprofit environmental group, estimated the Energy Department tritium inventory at 80 kilograms; with about 20,000 warheads, that means less than four grams per warhead.

Since the bombs are not refueled daily, their tritium reservoirs must have a surplus built in to allow for natural decay. In addition, the Energy Department has a central stockpile, which itself is disappearing at the rate of 5.5 percent a year. Tritium decays into a form of helium.

How often the bombs must be recharged, and how long the stockpile would suffice before the arsenal began to degrade, are classified information, according to the spokeswoman for the Energy Department, Ms. Sankey.

Maintaining the Stockpile

David Albright, senior staff scientist of the Federation of American Scientists, an arms-control group, said that without a negotiated arms reduction, maintaining the nuclear stockpile would require about 10 kilograms of tritium per year. Mr. Albright's estimate is part of an article he is preparing with Mr. Taylor for the January issue of the Bulletin of the Atomic Scientists on the subject of nuclear materials production.

Mr. Taylor, the former weapons designer, said it would take some time without new tritium before weapons were significantly weakened.

"I find it hard to believe there would be a dramatic change in yields if none of them were re-supplied for three or four years," he said. "That's not to say that some people would not feel nervous about it, but the nervousness starts from a fairly high level of confidence."

Another nonprofit group in Washington concerned with nuclear disarmament, the Nuclear Control Institute, proposed earlier this year using the decay of tritium as a tool for mutual disarmament.

"Both superpowers are now faced with the same choice: to maintain and modernize their aging and unsafe nuclear-weapons production reactors if the nuclear arms race continues, or to shut down these dangerous facilities if both sides can agree on verifiable reductions in the numbers and types of nuclear weapons that will make further production of weapons materials unnecessary for the foreseeable future," the institute said.

Monitoring at Issue

Others argue that disarmament through tritium decay would not be as effective as a ban on plutonium and weapons-grade uranium production, in part because it is easier to monitor those metals.

Thomas B. Cochran, senior staff scientist of the Natural Resources Defense Council, said in a telephone interview that "It would be very difficult to retire warheads, even in an optimistic arms control scenario, at a rate in excess of tritium decay." With about 20,000 warheads in the nation's stockpile, he said, matching tritium decay would require eliminating 1,250 warheads the first year. In contrast, the recent negotiations with the Soviet Union on intermediate-range nuclear forces call for a reduction of 500 weapons over five years.

However, he added, if plutonium production is frozen and the three surviving reactors were needed only for tritium, they might survive longer with a reduced workload.

Dr. Cochran's organization, together with other environmental and arms controls groups and prominent individuals, called Nov. 5 for a two-year moratorium on the production of plutonium and for negotiations with the Soviet Union on the banning of such production, along with the production of bomb-grade uranium.

PHOTOVOLTAICS

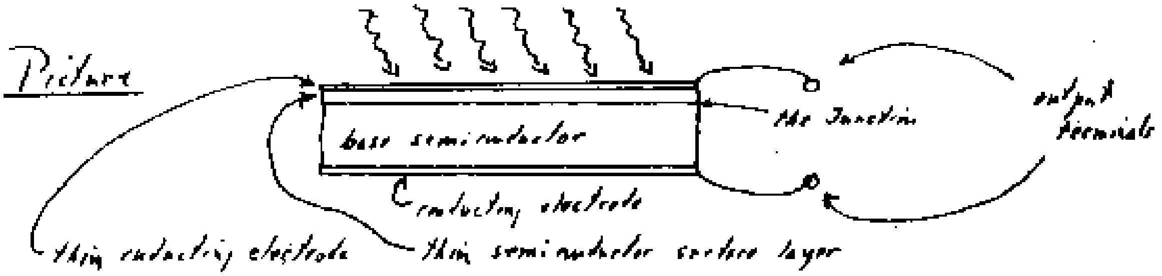
Direct conversion of insolation to electric energy.
10 to 20% efficiency (electric power out / sunlight power in)

Photovoltaic Effect Absorption of photons whose energy then "produces" (separates) negative and positive charges (electrons and "holes") in such a configuration that these charges have to flow in an external circuit in order to recombine.

This is done at (configuration) a semiconductor junction.
e.g. Silicon (Si) or Gallium Arsenide (GaAs).

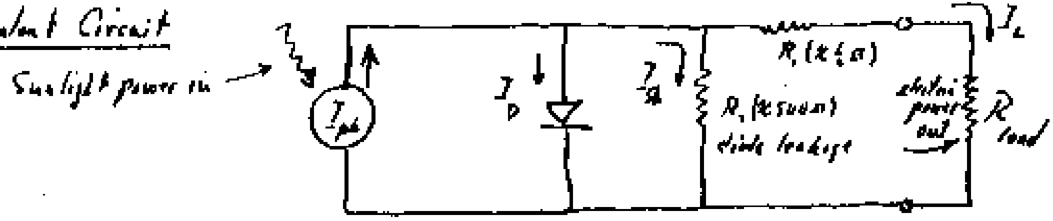
Successful materials now known are expensive (when prepared in the purity required). Have been used so far only in small installations where cost is not a factor (space-vehicle power).

Picture



The surface layer and the base are two differently-prepared semiconductors. The upper conducting electrode and the surface layer of semiconductor are so thin that the sunlight penetrates in to the Junction, where the photovoltaic action takes place.

Equivalent Circuit



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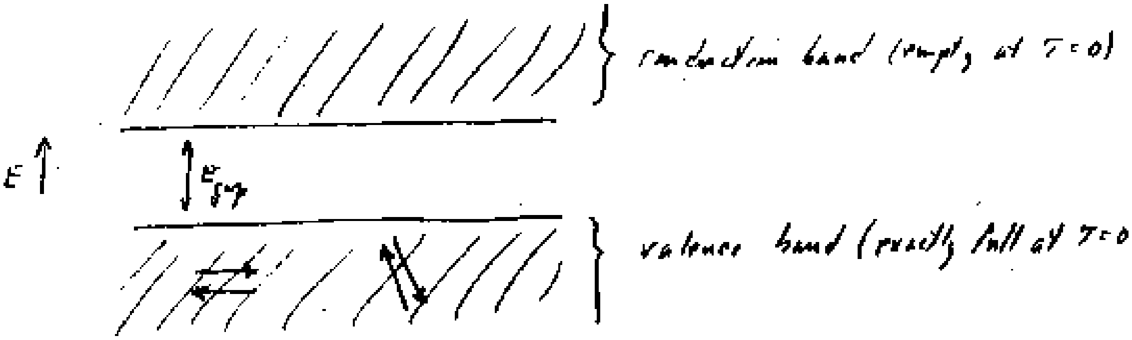
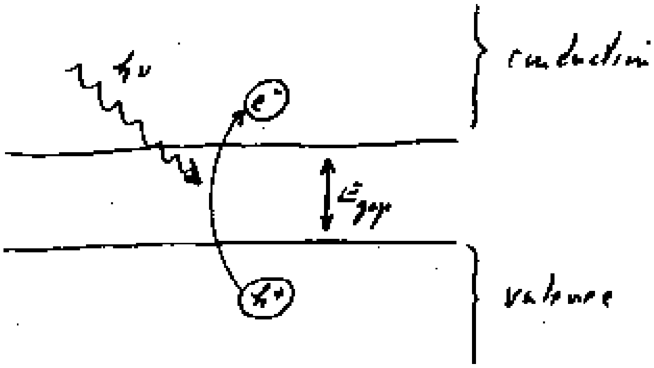


Insulator : $E_{gap} >> k_B T$

Semiconductor : $E_{gap} \gtrsim k_B T$

Conductor : conduction band partly full at $T = 0$

$E_{gap} = 1.12$ eV for Silicon



$h\nu < E_{gap} \Rightarrow$ no charge separation (don't want E_{gap} too high)

$h\nu - E_{gap}$ is wasted (don't want E_{gap} too low)

Physics 115 Problems

43. Use the equation $pV = Nk_BT$ to find how much volume is occupied by 1 mole of an ideal gas at 1 atmosphere and 0C (273 K).

44. In 1921, someone named Betz, using a somewhat simplified model, calculated that a windmill can capture as much as 16/27 of the kinetic energy of the wind that passes through an area the size of the windmill-blade circle.

(a) Use this Betz result to estimate the power expected at sea level with a wind of 30 km/hr and a blade length of 10m. (The density of air is 1.3 kg/m^3)

(b) How does this power vary with wind speed?

45. A truck has to push air out of the way in going down the highway. This is "air resistance". Assuming the truck has cross sectional area A and sets the air it displaces into motion at the speed v of the truck, the power required is

$$P = \tfrac{1}{2}\rho vAv^2 = \tfrac{1}{2}\rho Av^3$$

Take $A = 10 m^2$

Where the density of air is $\rho = 1.3 kg/m^3$. Estimate the power required at 40 mph and at 60 mph.

46. A glass window pane has area 1 m^2 and thickness 2 mm. Its inside surface is at a temperature of 20 C and its outside is at -10 C.

How many calories of heat are conducted outside in one hour?

47. Double Glazing: How many calories per hour of heat are conducted with two panes separated by 7 cm of air (+20 C on inside of inner and -10 C on outside of outer)?

Now assume $\Delta T_{air} = 30$ C and both $\Delta T_{glass} = .03$ C. Why?

48. A house has dimensions 13m x 7m x 3m (height). Its walls and roof are 10cm thick and have the same conductivity as brick. When the outside temperature is -10C:

(a) How many calories per hour are lost through the walls and roof by conduction?

(b) How many cu ft of natural gas must be burned per hour to maintain this heat flow?

49. A coal-fired electrical generating plant operates between temperatures of 450C and 10C, and generates 2.0 kiloMegaWatts of electrical power. Its fuel is coal, giving 29 x 10^6 Joule of thermal energy per kg of coal.

(a) What is the ideal (Carnot) efficiency?

(b) What is the practical efficiency expected? $\left(1 - \sqrt{\frac{T_c}{T_H}}\right)$

(c) How many metric tons (metric ton = tonne = 1000kg) of coal are required per day?

(d) How many cubic meters of water could be warmed 5 C by the discarded heat per day?

115 #35 Mon 23 Nov 87

Rayleigh-Jeans (u.v. catastrophe)

Photoelectric effect

BB spectrum via $\Delta E = h\nu$

Reason that $\Delta E = h\nu$ fixes u.v. catas. ✓

Physics

Tues 24 Nov 87

Black box, black hole, black body.

$\Delta E = h\nu = \frac{\hbar}{2\pi} 2\pi\nu = \hbar\omega$ fixes it
→ how?

Photoelectric effect - confirms

Phys 115

#36 Wed 25 Nov 87

Photons ("light quanta")

Spectra & Energy levels

Bohr Atom

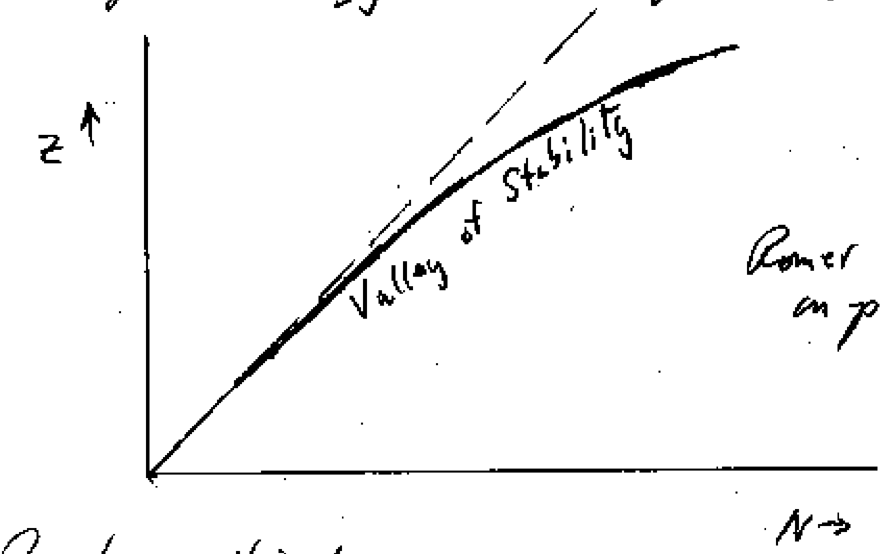
$$\begin{cases} m\frac{v^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} \\ rmv = n\hbar \end{cases}$$

Two slits and probability

#115 #37 Mon 30 Nov 87

Spectra & Energy levels (Romer Sec 12.2)

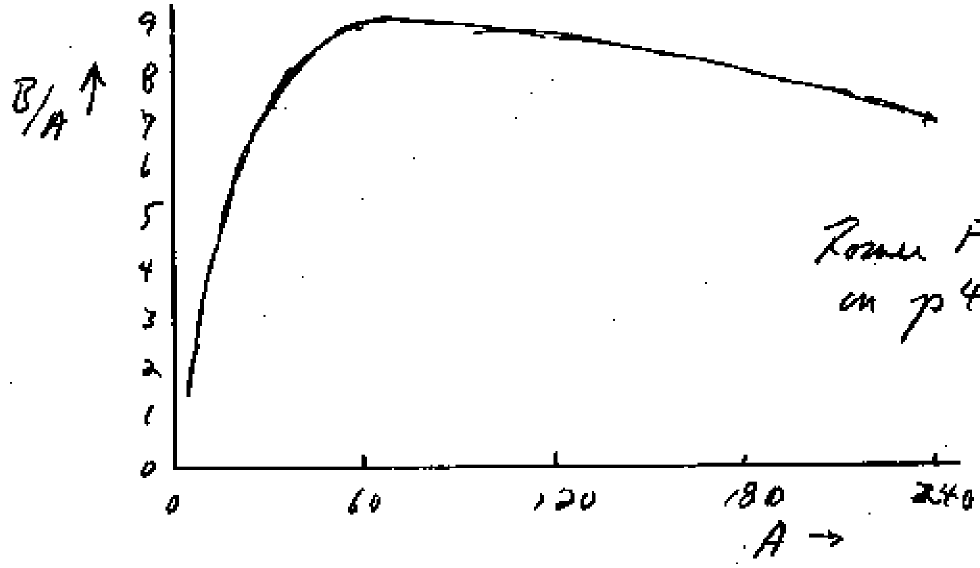
Ionization energy and binding energy



Z+N = A

Romer Fig 13.11
on p 434

Radioactivity



Romer Fig 14.1
on p 459

Fig 4.2 p 98

Physics 115 #38 Wed 2 Dec 87

Next time: Reactor Lab 141 Mech Eng'g.

Binding energy

Fission

Energy release — as K.E.

Randomness of the split

Chain reaction – self sustaining
– neutron economy.

Like a fire (but perpetuator and product are different)

Control – control "rods" or "blades" (neutron absorbers)
– natural negative "temp coeff"

Core, moderator, "biological" shield.

Thermal (as opposed to fast) reactor
and Fissile Fuel

Enriched (in ^{235}U) {enriched U and ordinary water
normal U and heavy water

PWR, BWR

RA of products spent fuel has a lot of β and γ
– SOUTH POLE.

Dec
3 [illegible] 87

Physics 115

Problem #61

Supply of power from solar energy.

What is the area of ground needed to supply a power of 2kW to each of 3×10^6 people?

The solar constant is $\frac{4}{3} \times 10^3 \frac{\text{Watt}}{m^2}$ (at the top of the atmosphere).

Assume that the efficiency of conversion of sunlight energy to usable power is

$$\underbrace{\tfrac{1}{2}}_{\text{atmosphere}} \times \underbrace{\tfrac{1}{2}}_{\text{night \& day}} \times \underbrace{\tfrac{1}{2}}_{\text{weather}} \times \underbrace{\tfrac{1}{2}}_{\text{obliquity}} \times \underbrace{\tfrac{1}{5}}_{\text{photovoltaic efficiency}} = \frac{1}{80}$$

115 #40 Mon 7 Dec 87

Exam oral & individual (by appt)
bring worked problems
one real question the course has raised in your mind

Disposal and South Pole

Dosage

Breeding (next page →)

Fusion

Practical thermo eff $1-\sqrt{\frac{T_c}{T_a}}$
Heat Pump

115 #41 Wed 9 Dec 87

Breeding

$$\left\{\begin{array}{l} {}^{238}_{92}U(n,\gamma)\,{}^{239}_{92}U\ \underset{24\text{ min}}{(\beta^-)}\ {}^{239}_{93}Np\ \underset{2.4\text{ day}}{(\beta^-)}\ {}^{239}_{94}Pu \quad \text{fissile} \\ {}^{232}_{90}Th\,(n,\gamma)\,{}^{233}_{90}Th\ \underset{23.5\text{ min}}{(\beta^-)}\ {}^{233}_{91}Pa\ \underset{27\text{ day}}{(\beta^-)}\ {}^{233}_{92}U \quad \text{fissile} \end{array}\right.$$

Natural ${}^{235}_{92}U$ is increasing in price.

Almost certainly fast.

Like wet wood near the fire.

Physics 115 # 42 Friday 11 Dec 87

Practical thermodynamic efficiency $= 1 - \sqrt{\frac{T_c}{T_H}}$

Heat pump If $W = \frac{1}{3} H_H$ (as engine)

then $H_H = W + H_c = W + \frac{2}{3} H_H \Rightarrow H_H = 3W$

Fission-fragment RA and RA disposal and Antarctica

Solar energy and Hydrogen Economy

Penetrating and Non penetrating radiations
Rad'n Dose rem $\frac{1}{100} \frac{J}{kg}$ $\left(= \frac{1}{7} \, m/sec = .3 \, mph\right)$

$${}^{238}_{92}U\,(n,\gamma)\,{}^{239}_{92}U\,(\beta^-)\,{}^{239}_{93}Np\,(\beta^-)\,{}^{239}_{94}Pu \quad \text{fissile}$$

23 min 2.4 day 24000 yr

$${}^{232}_{90}Th\,(n,\gamma)\,{}^{233}_{90}Th\,(\beta^-)\,{}^{233}_{91}Pa\,(\beta^-)\,{}^{233}_{92}U \quad \text{fissile}$$

23 min 27 day 158000 yr

Natural U - graphite

Enriched U - ordinary water (US)

Natural U - heavy water (CANDU)

Scientific American
June 1975

The Fossil Reactors of Gabon

Two, and probably three, nuclear-fission reactors were assembled by geological processes about 1.7 billion years ago in a region of Africa that is now a part of the Gabon Republic. With enriched uranium 235 as a fuel and light water as a moderator, the natural reactors operated at power levels of several kilowatts more or less continuously for at least 100,000 years and possibly for more than a million. At least as surprising as the existence of the "fossil" reactors is the fact that the geological site has been so little disturbed by tectonic processes in the intervening aeons that French investigators have been able to establish the precise dimensions of the reaction centers (*foyers de reactions*) and the general physicochemical factors that brought the reactors to criticality and controlled their power levels for millenniums on end.

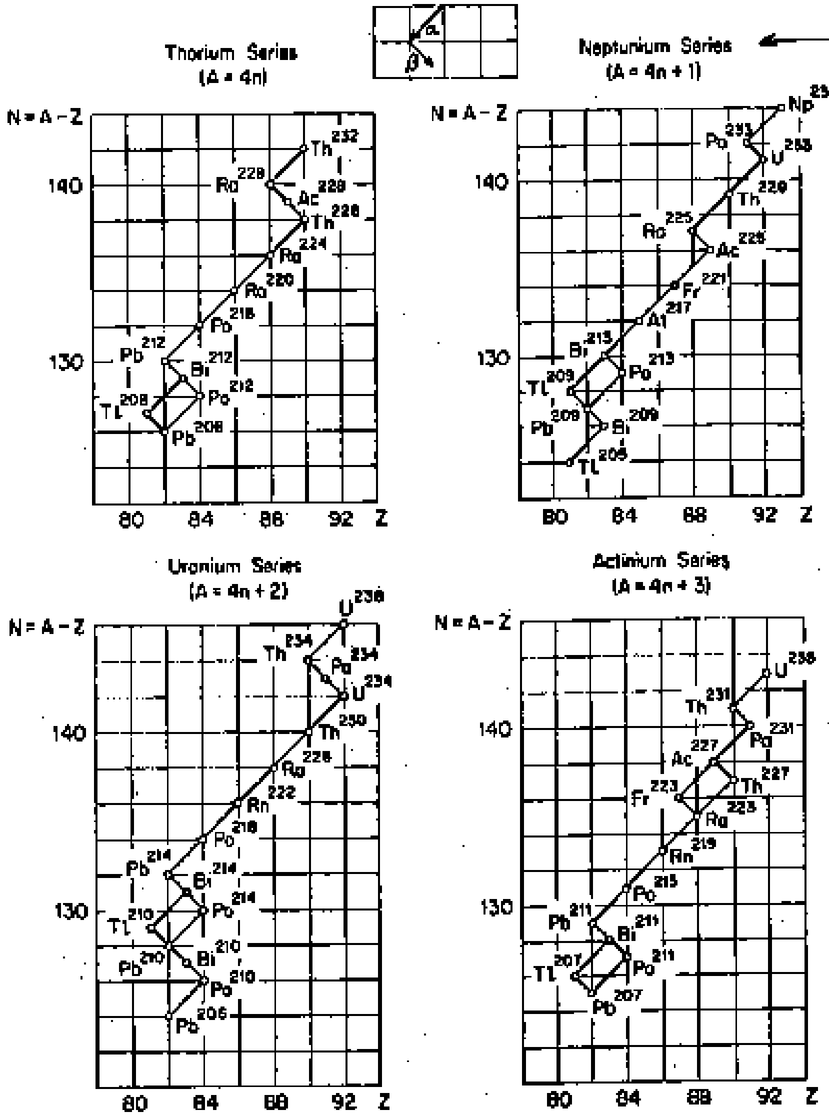
The existence of the natural reactors first came to light three years ago at the French gaseous-diffusion plant at Pierrelatte, when a laboratory preparation of uranium hexafluoride, to be used as a secondary control standard, showed a slight deficit in the expected content of uranium 235: a value of .7171 percent instead of the normal and universal value of .7202. Workers tracking down the discrepancy eventually found that more than 700 tons of uranium shipped from a mine north of Oklo in Gabon was depleted in U-235, representing a total deficit of 200 kilograms of the desirable isotope. A reanalysis of core samples taken some years earlier revealed one sample with a U-235 content as low as .440 percent. The only plausible hypothesis was that some of the U-235 at the site of the mine had been consumed as fuel in a natural nuclear reaction.

The hypothesis was quickly confirmed by identifying the zones of greatest U-235 depletion and examining the ratios of particular isotopes that would have appeared as fission fragments if the nuclear reaction had actually taken place. The ratios carried the proper "signature." In the course of this study one sample was found in which the U-235 reached a record low value of .296 percent. In general the two principal reaction centers showed an impoverishment of U-235 proportional to the total uranium content up to a value of about 30 percent. In still richer samples there was less depletion of U-235, indicating that the optimum value for a sustained chain reaction was a uranium content of between 20 and 25 percent. Overall nearly 500 tons of uranium in the two fossil reactors was strongly depleted in U-235. Taking account of the fact that a certain fraction of the abundant isotope U-238 would have been converted into fissionable plutonium 239, the total production of energy in the two fossil reactors is estimated to have been about 10,000 megawatt-years, equivalent to the output of a 10-kilowatt reactor running for a million years.

Two things were essential for the chain reaction to have occurred: a sufficient enrichment of U-235 above the normal value and a moderator, such as water, to slow down the fast neutrons released by spontaneous fission so that they would support a chain reaction among other nuclei of U-235. Since U-235 spontaneously disintegrates with a half-life of .7 billion years (giving rise to an isotope of thorium), one can calculate that 1.7 billion years ago the Gabon deposits contained about 3 percent U-235, or about the level of enrichment commonly found in the fuel of commercial nuclear reactors. There is also geological evidence that the uranium, in the form of its oxide, was well mixed with a variety of hydrated minerals, so that the reaction centers contained about 15 percent water, at least some of it in liquid form, saturating the mineral bed. The ratio of water to uranium oxide was about the same as it is in a typical man-made light-water reactor. Finally, the reaction centers had to be reasonably free of any well-known nuclear-reaction "poisons," such as boron, which have a voracious appetite for neutrons and would have made a chain reaction impossible.

A volume of something less than a cubic meter is needed to sustain a chain reaction in a water-moderated reactor with a fuel containing 3 percent U-235. Each of the two fossil reaction centers contains at least 300 times the minimum volume. The French investigators conjecture, therefore, that each center consisted of a number of weakly coupled reactors, probably not all functioning at the same time. The details of the control mechanism are still a matter of speculation, but it is clear that variations both in the water content and in the concentration of nuclear-reaction poisons, as the chain reaction proceeded, must have played a major role. A full description of the fossil reactors appears in *Bulletin d'Informations Scientifiques et Techniques*, published by the French Atomic Energy Commission.

(OVER)



Thorium Series (A = 4n)

Neptunium Series (A = 4n + 1)

Uranium Series (A = 4n + 2)

Actinium Series (A = 4n + 3)

all same

Fig. 11. Decay schemes of the four families of natural radioactivity.

50. A heat pump is used to warm a building. The outside temperature is -10C and the temperature inside the building is +20C. (You may use the Carnot formulas for answering the following questions.)

    Heat is to be supplied to the inside of the building at the rate of 1000 cal/sec.

    (a) What will be the rate at which heat is to be taken from the outside environment?

    (b) Express your answer to part (a) in Watts.

    (c) What electric power will be required to operate this heat pump?

    (d) Repeat (a-c) for $T_{outside}$ = +10C (ground water).

51. What is the hottest a surface can get under (unconcentrated) sunlight (1.38 kW/m^2 : assuming no absorption or reflection by the atmosphere)? Could you ever "fry an egg on the sidewalk"?

52. Photovoltaic Power.

    Suppose 1kW/m^2 of sunlight is collected by a 10 ft^2 surface. Assume average photon wavelength is 700 nm. Assume one photon in 10 raises an electron through 1/2 Volt. What are the output current and power? ←

53. For A = 240 the binding energy per nucleon is 7.6 MeV.
For A = 120 the binding energy per nucleon is 8.4 MeV.

(a) What is the total binding energy of a nucleus of mass number A = 240?

(b) What is the total binding energy of a nucleus of mass number A = 120?

(c) What is the total binding energy of <u>two</u> (separate) nuclei of mass number A = 120?

(d) What is the energy release in the fission 240 ⟶ 120 + 120?

54. An ordinary-water enriched-Uranium thermal fission reactor is used to supply heat to drive an electrical-generating plant. The plant puts out 2.0 kiloMegaWatts of electrical power. The plant operates between temperatures of 450C and 10C. Each ^{235}U fission releases 200 MeV (million electron volt) of energy.

(a) What is the ideal (Carnot) efficiency?

(b) What is the practical efficiency expected?

(c) How many kilogram of ^{235}U are required <u>per year</u> (of steady operation)?

55. What is the value of the ratio

$$\frac{\text{Sun energy intercepted by the Earth/year}}{\text{Energy bought by Americans/year}} \quad ?$$

56. Consider the particular fission

$$n + {}^{235}_{92}U \longrightarrow {}^{133}_{52}X + {}^{100}_{40}Y + 3\ n$$

(a) What are the elements "X" and "Y"?

(b) Show where they are relative to the valley of stability.

(c) For each give the equation for its expected radioactive decay.

57. Find the value of each of the following energies in Joules and put them in one sequence of increasing size.

(a) energy release of one ^{235}U fission.

(b) average kinetic energy of N_2 molecule in air at room temperature.

(c) energy of a "green" photon.

(d) energy release of a d + t fusion.

(e) heat of combustion of methane per molecule.

(f) energy of a photon of FM radio.

58\. Binding energies:

$^{2}_{1}\mathrm{H}_{1}$	2.225 MeV
$^{3}_{1}\mathrm{H}_{2}$	8.48 MeV
$^{4}_{2}\mathrm{He}_{2}$	28.30 MeV

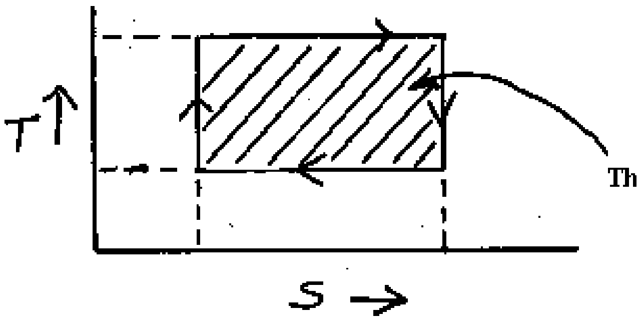
From these data, find the energy release of the $d + t \rightarrow \alpha + n$ reaction.

59\. How much $^{2}\mathrm{H}$ is there in the oceans? (Assume the oceans are 4 miles deep and cover 4/5 of earth's surface.)

60\. (Optional) S = entropy = amount of disorder $\Delta S = \frac{Q}{T}$

In Carnot <u>Cycle</u> $\Delta S = 0 \Rightarrow \Sigma \frac{Q}{T} = 0 \Rightarrow \frac{H_H}{T_H} - \frac{H_c}{T_c} = 0$

And so $\frac{H_H}{T_H} = \frac{H_c}{T_c}$ or $\frac{H_H}{H_c} = \frac{T_H}{T_c}$



Carnot Cycle is rectangle in ST plane.

This area is $H_H - H_c = Q_{net}$