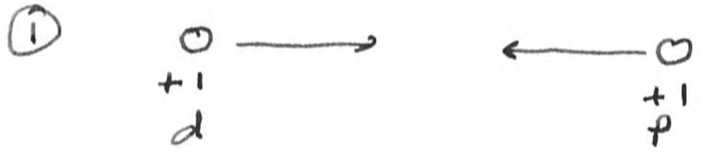
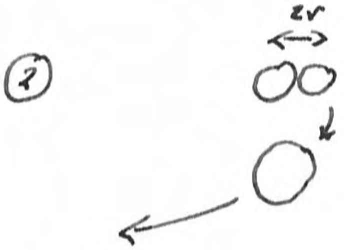
EXAMPLE PROBLEM (WEB ASSIGN)

Proton - deuterium nucleus collide.

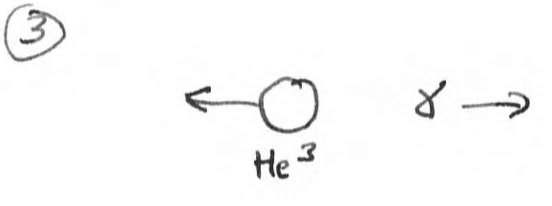
$d = (p,n)$ DEUTERIUM IS A BOUND PROTON-NEUTRON





~~COLLIDE~~ COLLIDE!

Form a He^3



(1) COLLIDE
(2) ~~APPRO~~ APPROACH TO "2r"
(3) Fuse and create He^3
$(2p,n)$ and γ-ray.

NOTE: γ-ray carries energy (kinetic energy) but has ZERO REST MASS (BECAUSE IT NEVER RESTS!)

QUESTIONS

(A) WHAT IS $K_d + K_p$ JUST BEFORE THEY COLLIDE?

INITIAL

$K_d =$ 7.2×10^{-14} J

$K_p =$ 1.44×10^{-13} J

GIVEN!

~~FINALE~~ FINAL

$2r = 1.8\times10^{-15}$ m

$$U_{pd} = +\frac{1}{4\pi\varepsilon_0}\frac{e^2}{(2r)}$$

$$(K_d + K_p)_f = ?$$

CONSERVATION OF ENERGY

$$(K_p + K_d)_{initial} = (K_p + K_d)_{final} + U$$

$$(K_p + K_d)_{final} = (K_p + K_d)_{initial} - U$$

$$= (7.2\times10^{-14} + 1.44\times10^{-13}) - \frac{\overset{e^2}{(1.6022\times10^{-19})^2}}{\underset{2r}{1.8\times10^{-15}}}\underset{\frac{1}{4\pi\varepsilon_0}}{(8.988\times10^{9})}$$

$$\boxed{(K_p + K_d)_f = 8.78\times10^{-14}\ \mathrm{J}}$$

Ⓑ WHAT IS KINETIC ENERGY OF THE PRODUCTS?

$$\underbrace{d + p}_{\text{Know This}} \to \underbrace{He^3 + \gamma}_{?}$$

CHANGE IN TOTAL ENERGY = 0

$$\Delta E = (\Delta E)_{\text{rest mass}} + \Delta K + \Delta U = 0$$

NOTE:
$\Delta U = U_i$
as γ carries no charge

$$\Delta K = -\Delta U - (\Delta E)_{\text{REST MASS}} \Rightarrow (K_{He^3} + K_\gamma) = (K_p + K_d)_f + U_i - (\Delta E)_{\text{REST MASS}}$$

Note:
$(K_p + K_d)_f$

$$\underbrace{(K_{He^3} + K_\gamma) = (K_p + K_d)_i - (\Delta E)_{\text{REST MASS}}}_{\text{THINK ABOUT THIS!}}$$

$(\Delta E)_{\text{REST MASS}}$

p 1.0073 $\quad$ He^3 3.0155
d $\underline{2.0136}$
3.0209

$\Delta m = -0.0054$ a.m.u. (m_p) $\to 1.6605 \times 10^{-27}$ kg

$$(\Delta E)_{\text{REST}} = \Delta m c^2 = (-0.0054)(1.6605 \times 10^{-27})(3 \times 10^8)^2$$
$$= -8.0587 \times 10^{-13} \text{ J}$$

$$(K_{He^3} + K_\gamma) = \underbrace{(7.2 \times 10^{-14} + 1.44 \times 10^{-13})}_{(K_p + K_d)_i \text{ [GIVEN]}} - \underbrace{[-8.0587 \times 10^{-13}]}_{\Delta m c^2}$$

$$\boxed{(K_{He^3} + K_\gamma) = 1.022 \times 10^{-12} \text{ J}}$$

$$\Delta K = -\Delta m c^2 = 8.059 \times 10^{-13} \text{ J}$$

ENERGY PER MOLE $(p + d) \Rightarrow$ ABOUT $\boxed{3g}$

$$\Delta K = (8.059 \times 10^{-13})\text{J}\ (6.02 \times 10^{23})$$
$$= 4.85 \times 10^{11} \text{ J}$$

1 TON TNT = 4.2×10^9 J

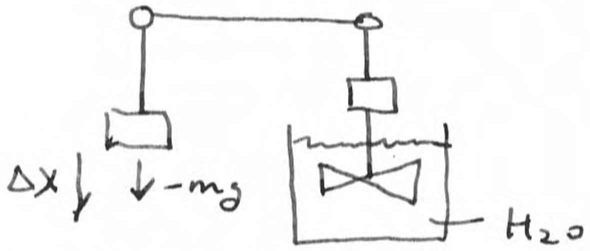
$\Delta K \Rightarrow$ ABOUT <u>100 TONS OF TNT</u>

"3g ⇒ FUSED" = 100 TONS OF TNT !!

TEMPERATURE = MEASURE OF INTERNAL ENERGY

Joule's Expt.

WORK ⇒ THERMAL ENERGY
(HEAT!)



4.2 J (work) ⇒ 1 K RISE OF 1 g of WATER
[HEAT]

TAKES A LOT OF WORK For 1 K rise.

$$W = -mg(-\Delta x) = mg\Delta x$$

HEAT CAPACITY

$$C = \frac{\Delta E_{THERMAL}\,^{(J)}}{\underset{\text{mass (g)}}{m}\ \underset{(K)}{\Delta T}} = 4.2\ J/g\text{-}K \Big\}\ \text{For } \underline{\underline{H_2O}}.$$

↑
SPECIFIC HEAT CAPACITY

ENERGY TRANSFER

HEAT FLOW HOT ⇒ COLD

$$\Delta E_{sys} = \underset{\substack{\uparrow\\ \text{Work}}}{W} + \underset{\nwarrow\ \text{HEAT}}{Q}$$

SIGN CONVENTION

Q – OUT OF system is NEGATIVE

Q – INTO THE SYSTEM is POSITIVE

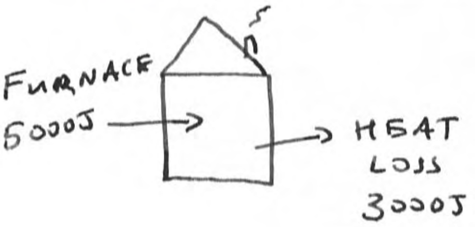
POWER: ENERGY TRANSER PER UNIT TIME

$$P = \vec{F}\cdot\Delta\vec{r}/\Delta t = \vec{F}\cdot\frac{d\vec{r}}{dt} = \vec{F}\cdot\vec{v}$$ [UNIT = WATT]

EXAMPLE: ENERGY TO RUN LIGHT BULB (100 W) for one hr?

$$P \times time = E = 100\frac{J}{s} \times 1hr \times \left(\frac{60\,min}{hr}\right) \times \left(\frac{60\,s}{min}\right) = \underline{3.6\times10^{5}\,J}$$

ENERGY COUNTING & OPEN & CLOSED SYSTEMS

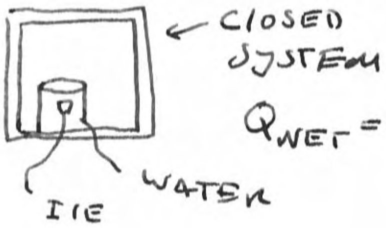


} PRETTY BAD!

NET GAIN BY HOUSE

$Q = +5000 - 3000 = 2000\,J$

CALLED AN OPEN SYSTEM. HEAT FLOWS IN AND OUT.



$Q_{NET} = 0$

HEAT can flow within the system, e.g. from the WATER TO ~~MELT~~ MELT ICE.

READ SECTION 7.9
AT your PERIL!

BE CAREFUL IN DESCRIBING THE SYSTEM ⇒ USUALLY "COMMON SENSE" PAYS.

ENERGY DISSIPATION (FRICTION)

$$F_T = \underbrace{f_{air}}_{\text{FRICTION (VISCOSITY)}} - mg$$

What is fair? ⇒ FALLING AT CONSTANT SPEED occurs IN AIR ⇒ $\boxed{\text{TERMINAL VELOCITY.}}$

Typical Expression ⇒

$$f_{AIR} \cong \frac{1}{2} \underset{\uparrow \text{ CONSTANT}}{C} \rho A v^2$$

ρ ⇒ DENSITY OF AIR

v = velocity

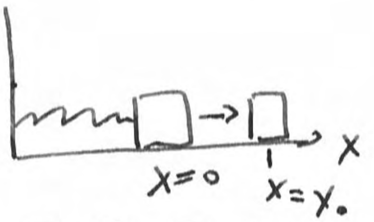
A = AREA OF OBJECT

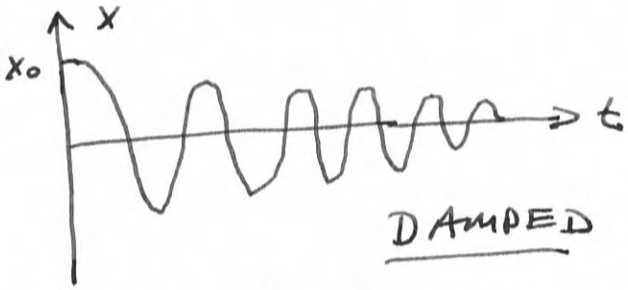
$$\boxed{\vec{F} \cong -\frac{1}{2} C \rho A v^2 \hat{v}} \rightarrow \text{FORCE OPPOSITE TO } \vec{v}.$$

WHAT ABOUT SPRINGS?

$$\vec{f}_{spring} \cong -c\vec{v} \quad \Big\} \rightarrow \text{AGAIN } \vec{f} \text{ opposite to velocity.}$$

SPRING SOLUTION





DAMPED OSCILLATOR

$$X = A \exp(-c/2m\ t) \cos(\omega t)$$

↳ CAN SHOW THIS IS A SOLUTION

$$\boxed{m\frac{d^2x}{dt^2} = -k_s x - c v_x}$$

$$F = F_s + f_{vis}$$

END CHAPTER 7

QUANTIZATION OF ENERGY

PREVIOUSLY →

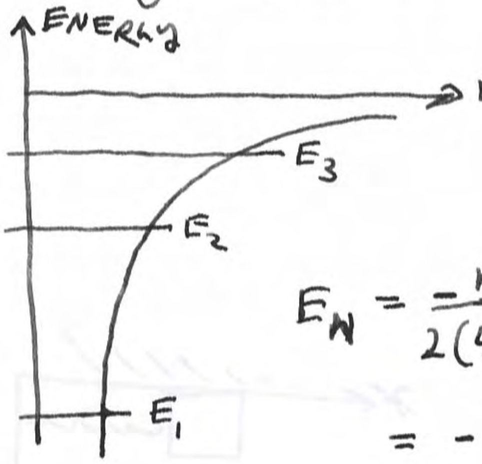
$e^+ + e^- \rightarrow 2\gamma$ ← GAMMA RAYS.

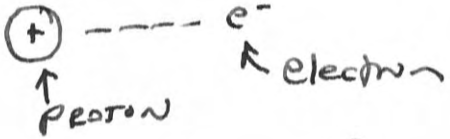
CAN LIGHT TAKE ON ANY VALUE? Not for a reaction like this. Smallest unit of mass → well defined and "quantized" value of energy.

PHOTONS → CARRY ENERGY BUT HAVE NO REST MASS. THEY CANNOT EXIST AT REST.

ENERGY ⇒ H_{atom} + photon ⇒ H^* ← Hydrogen atom with higher internal energy.

ENERGY LEVELS: HYDROGEN ATOM





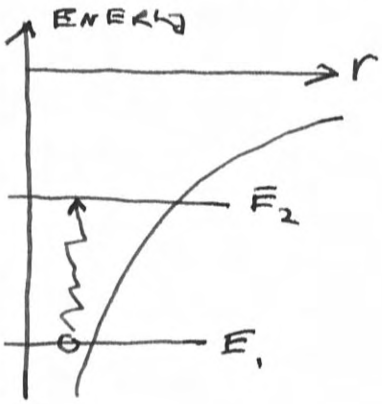
$$U = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$E_N = \frac{-me^4}{2(4\pi\varepsilon_0)^2 N^2 \hbar^2}$$

$$= -\frac{13.6\ eV}{N^2} \qquad N = 1, 2, \ldots$$

Excitations and absorption

Absorb a photon



$$H + \text{photon} \rightarrow H^*$$

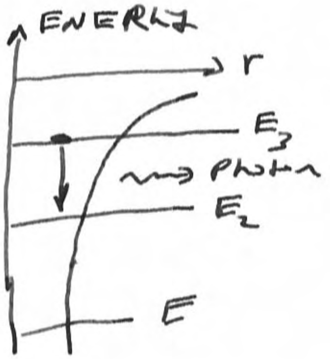
$$E_i + \underset{\text{ENERGY}}{\text{photon}} = E_f$$

$$E_1 + E_{photon} = E_2$$

$$E_{photon} = -\frac{13.6}{4} - \frac{-13.6}{1} = 10.2\text{ eV}$$

$$\text{“}(N=2)^2 \quad \text{“}(N=1)^2$$

Emission



$$E_{photon} = E_3 - E_2$$

$$= \frac{-13.6}{9} - \frac{-13.6}{4}$$

$$= -13.6\left[+\frac{1}{9} - \frac{1}{4}\right]$$

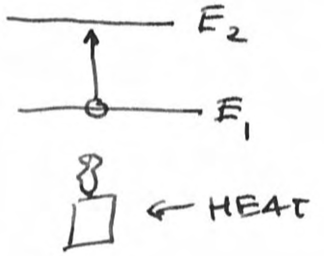
EFFECT OF TEMPERATURE

CAN TEMPERATURE "EXCITE" an atom?

IT CAN!

$N(E_2)$ = # of atoms in E_2

$N(E_1)$ = # of atoms in E_1



$$\frac{N(E_2)}{N(E_1)} = \exp(-(E_2 - E_1)/k_B T)$$

↑ (Boltzmann CONSTANT 1.4×10^{-23} J/K)

Suppose

$E_2 - E_1 = \underline{1\text{ eV}}$

$T = 300K$

$1\text{ eV} = 1.6\times10^{-19}\text{ J}$

$$\frac{N(E_2)}{N(E_1)} = \exp\left(-\frac{1.6\times10^{-19}}{(1.4\times10^{-23})\ (300)}\right) \approx 10^{-17}$$

Effectively <u>all</u> atoms would <u>NOT</u> be excited.