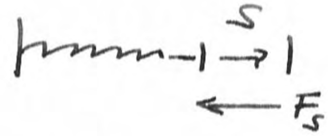
INTERNAL ENERGY

SPRINGS

$F_s = -k_s\, s$



POTENTIAL ENERGY → $F_s = -\dfrac{dU}{ds} = -k_s s$

$$\boxed{U_s = +\frac{k_s s^2}{2}}$$

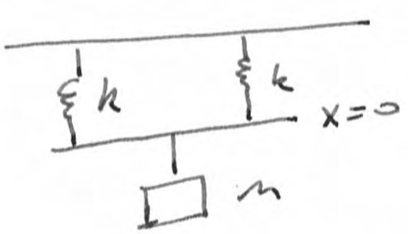
CHECK → $\dfrac{dU_s}{ds} = k_s s$ → $-\dfrac{dU_s}{ds} = -k_s s = F_s$

(Note:
$U_s = \dfrac{k_s s^2}{2}$ + CONSTANT ALSO WORKS, BUT
WE CHOOSE $U_s = 0$ when $s = 0$.)

(Note: $U_s \to \infty$ as $s \to \infty$ so it's hard to define $U(s\to\infty) = 0$ because $U(s=0) = -\infty$!)

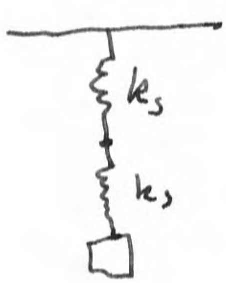
REAL SPRINGS ⇒ COMPRESSION ≠ EXPANSION
ESPECIALLY IF s is "large".

Aside ⇒



$$U_T = \tfrac{1}{2}k_s X^2 + \tfrac{1}{2}k_s X^2$$
$$= k_s X^2 = \tfrac{1}{2}K_{eff}X^2$$

~~Keff~~ $\boxed{K_{eff} = 2k_s}$



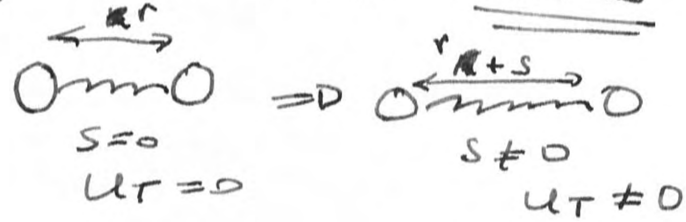
$$U_T = \tfrac{1}{2}k_s\left(\tfrac{\Delta X}{2}\right)^2 + \tfrac{1}{2}k_s\left(\tfrac{\Delta X}{2}\right)^2$$
$$= \tfrac{1}{4}k_s\,\Delta X^2 = \tfrac{1}{2}K_{eff}(\Delta X)^2$$

$$\boxed{K_{eff} = \tfrac{1}{2}k_s}$$

MUCH EASIER TO DEAL WIT U_T

POTENTIAL ENERGY BETWEEN ATOMS ?

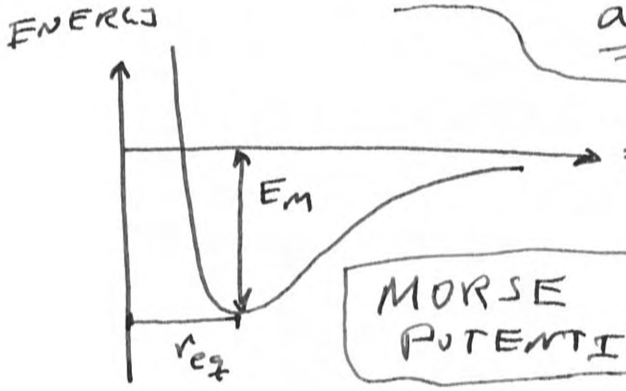
$U_T = \tfrac{1}{2}k s^2$



PROBLEM!

$O_2 \rightarrow 2O$ O_2 can be broken up into 2 O atoms.

$U_T \rightarrow \infty$ as $r \rightarrow \infty$ WHICH DOES NOT ALLOW THIS TO HAPPEN



MORSE POTENTIAL

MORE REALISTIC POTENTIAL

$$U_M = E_M[1 - \exp(-\alpha(r - r_{eq}))]^2 - E_M$$

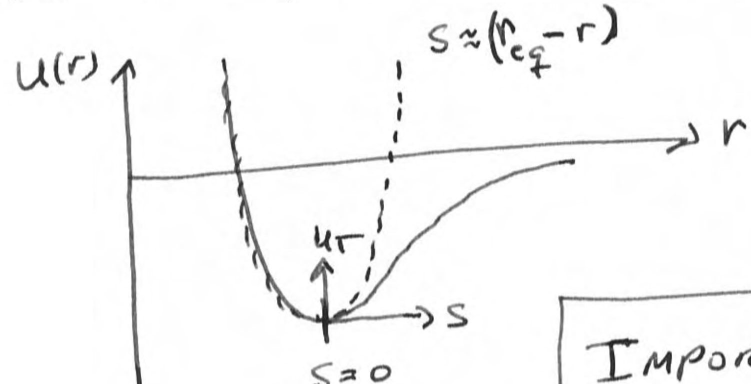
E_M = BINDING ENERGY

r_{eq} = Equilibrium ENERGY

$$U_M(r = r_{eq}) = (E_M)(0) - E_M = -E_M$$

$$U_M(r \rightarrow \infty) = E_M - E_M = 0$$

NOTE: $U_T = \frac{1}{2}k_s s^2$ is ok near $r \approx r_{eq}$.



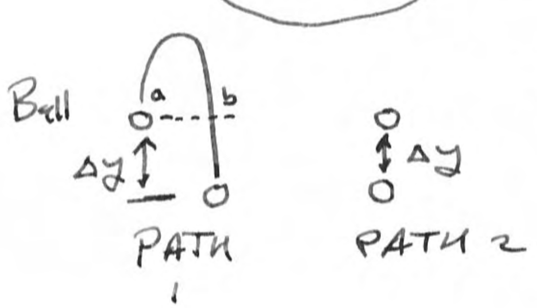
THIS IS NOT A BAD ~~Appro~~ APPROXIMATION FOR $r \approx r_{eq}$.

IMPORTANT PRINCIPLE

ΔU is PATH INDEPENDENT

IN ALL CASES ΔU SAME

$(\Delta U_1 = \Delta U_2 = \Delta U_3)_{A \rightarrow B}$

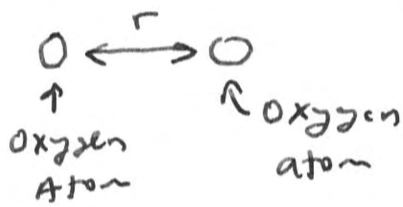


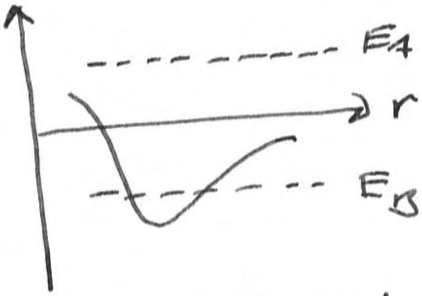
$\Delta U_1 = -mg\,\Delta y \Rightarrow$ PATH #1 $(\text{WORK UP})^{a \rightarrow b} = -(\text{WORK DOWN})^{b \rightarrow a}$

$\Delta U_2 = -mg\,\Delta y$

SO $\Delta W = 0$

$\boxed{\text{EXAMPLES}}$





$E_A = K_A + U_A$

$E_A > 0$

$O_2 \rightarrow O + O$

NOT BOUND!

$\cancel{E_B = K_B + U}$

$E_B = K_B + U_B$

$E_B < 0$ O_2 BOUND

SPRING

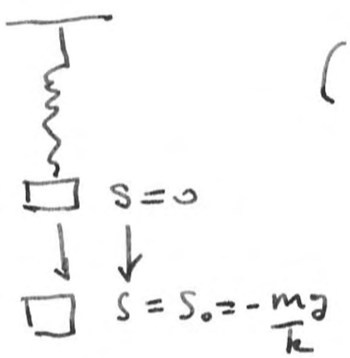
NO MOTION,

But GRAVITY!

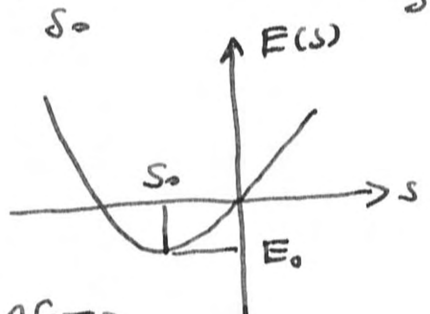
$$E = \underbrace{\tfrac{1}{2}ks^2}_{\text{SPRING}} + \underbrace{mg\Delta y}_{\text{GRAVITY}} = \tfrac{1}{2}ks^2 + mgs$$

Note: $E = U$ w/ $K = 0$

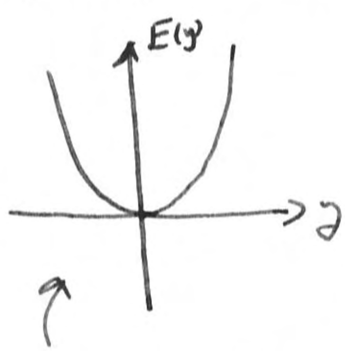
$$F_s = -\frac{dU}{ds} = -(ks + mg) = 0 \qquad \boxed{s_0 = -\frac{mg}{k}}$$



$$(E)_{s=s_0} = \tfrac{1}{2}k\Big[\underbrace{-\frac{mg}{k}}_{s_0}\Big]^2 + mg\Big[\underbrace{-\frac{mg}{k}}_{s_0}\Big] = -\frac{m^2g^2}{2k}$$



VIBRATES THE SAME! But DISPLACED

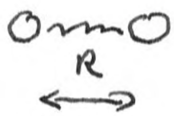


$\cancel{y = s + s_0}$ $\cancel{y(s \rightarrow)}$

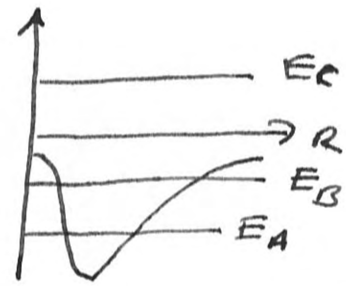
$y = s - s_0$ $\begin{cases} \text{when } s = 0 \\ y = -s_0 = +mg/k \\ \text{when } s = s_0 \\ y = 0 \end{cases}$

$E(y) = \tfrac{1}{2}ky^2 - E_0$

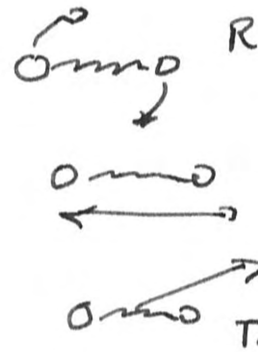
INTERNAL ENERGY



O_2 Molecule



MOLECULES WITH E_B
CONTAIN MORE ENERGY THAN E_A.



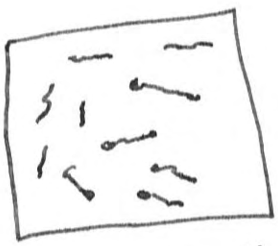
ROTATE

VIBRATE

TRANSLATE

$$E_{INTERNAL} = E_{TRANS} + E_{ROT} + E_{VIB} + E_{THERM} + E_{CHEMICAL} + \dots$$

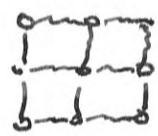
(Electronic)



LIQUID O_2

RANDOM MOTION } "THERMAL"

SOLIDS



Kinetic & POTENTIAL

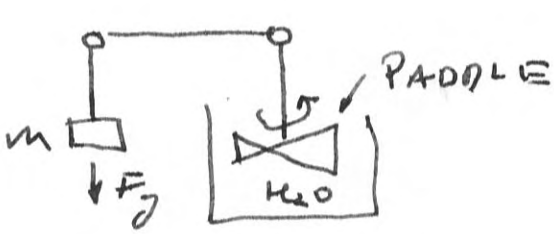
TEMPERATURE = MEASURE OF INTERNAL ENERGY $\Rightarrow$ "THERMAL ENERGY"

HEAT LIQUID $\rightarrow$ EXPANDS

$\uparrow$
Add Energy

MEASURE $\Rightarrow$ HEAT
EXPANSION

Joule's Experiment: 4.2 J WORK $\Rightarrow$ 1K RISE TEMP. H_2O



SPECIFIC HEAT CAPACITY

$$C = \frac{\Delta E_{THERMAL}}{m \Delta T}$$