# CHAPTER 8

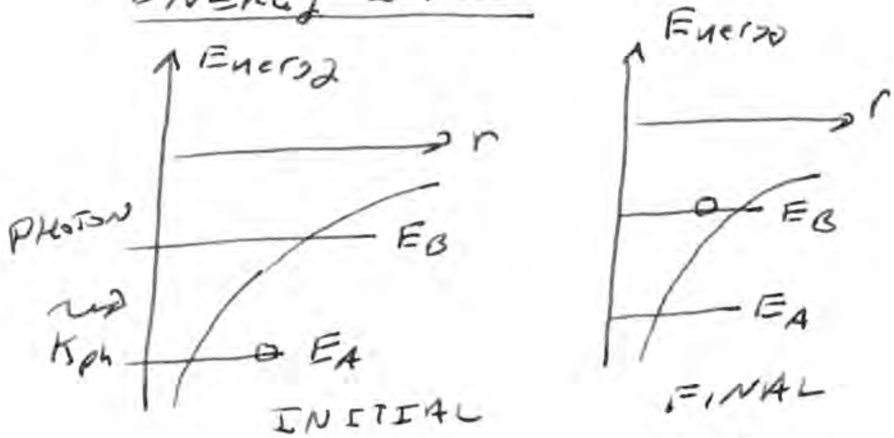

Light can be ~~absorbed~~ or emitted by matter
absorbed

Example

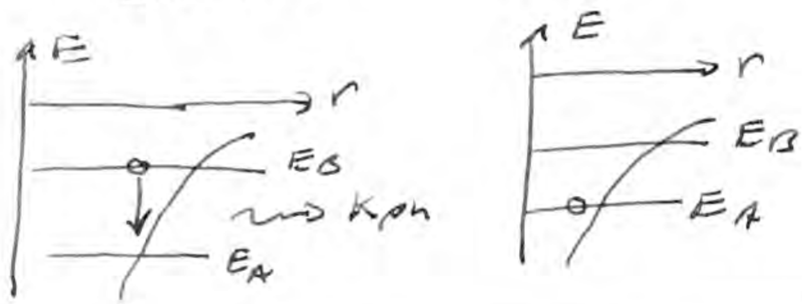
$\rightsquigarrow H \Rightarrow H^*$ ← excited } absorption
atom

$H^* \Rightarrow H + \rightsquigarrow$ } Emission

## ENERGY Levels




$K_{photon} = E_A - E_B$
ONLY PHOTONS WITH THIS PRECISE ENERGY WILL BE ABSORBED




PHOTONS NOT WITH THIS ENERGY CANNOT BE EMITTED OR ~~AB~~ ABSORBED

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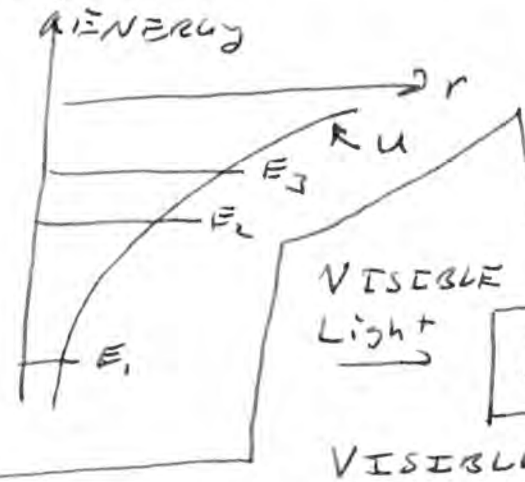
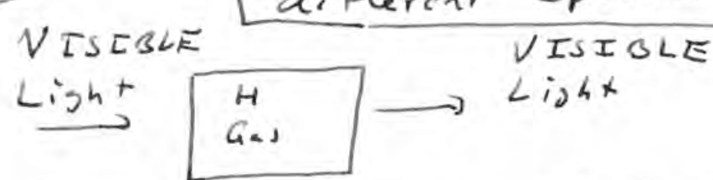
## HYDROGEN ATOM




$$E_N = -\frac{13.6}{N^2}\ (eV)$$

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

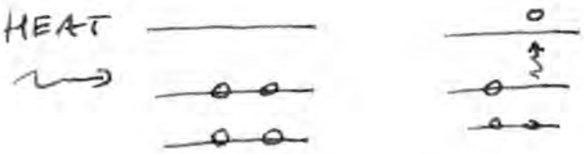
Other atoms also have energy levels, but with different spacings.




VISIBLE LIGHT 1.5 - 3 eV Cannot be absorbed or emitted

ASIDE: TEMPERATURE $\Rightarrow$ CAN ALSO EX

HEAT



FOR "NORMAL" TEMPERATURES THIS IS NOT A LARGE EFFECT

STATISTICAL DISTRIBUTION $\Rightarrow$ Many atoms
($\approx 10^{23}$ is "MANY, MANY..." ATOMS!)

$E_B$

$\Delta E = E_B - E_A$

$E_A$

$N(E_A)$ = NUMBER OF ATOMS WITH ENERGY $E_A$
$N(E_B)$ = NUMBER WITH $E_B$

$$\frac{N(E_B)}{N(E_A)} = \exp(-\Delta E/k_B T)$$

$k_B = 1.38 \times 10^{-23}$ J/K
$T$ = Temp. in K

EXAMPLE

$\Delta E = 1\,\text{eV}$  1 eV  $T = 300\,\text{K}$

$1\,\text{eV} = 1.6 \times 10^{-19}$ J

$$\frac{N(E_B)}{N(E_A)} = \exp\left(-\frac{1.6 \times 10^{-19}}{(1.4 \times 10^{-23})(300)}\right)$$

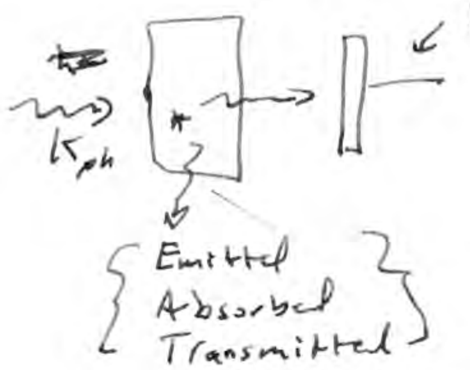
$$= \exp(-38) = 3 \times 10^{-17}$$

Suppose
$N(E_A) = 1$ mole  $N(B) \cong 2 \times 10^{7}$ atoms
[REALLY SMALL NUMBER RELATIVE TO $10^{23}$, BUT NOT ZERO]

Suppose
$T = 5000\,\text{K}$

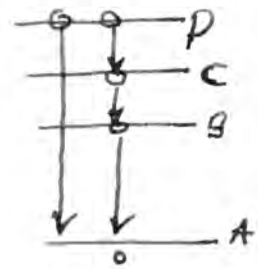
$N(E_B) = 0.1$ mole  $N(E_A) = 1$ mole

# MEASURING ABSORPTION



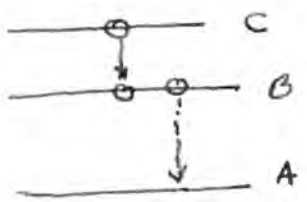

LIGHT ABSORBED CAN HEAT UP THE SOLID

MULTIPLE EMISSION




PHOTONS → $E_{AB}$, $E_{BC}$, $E_{CD}$ CAN BE OBSERVED.

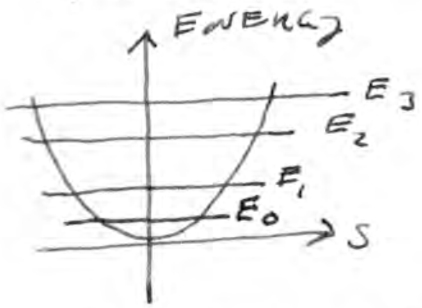
~~Also~~ ALSO $E_{AD}$




SELECTION RULES: SOME TRANSITIONS ARE MORE LIKELY TO OCCUR

THIS IS A GEOMETRY ISSUE (Physics is mostly symmetry and energy!)

## VIBRATION ENERGY LEVELS




$$E = \frac{1}{2} m v^2 + \frac{1}{2} k_s S^2$$

DEFINE $\omega_0 = \sqrt{\frac{k_s}{m}}$

$$E_N = N \hbar \omega_0 + \frac{1}{2} \hbar \omega_0$$

$$= \left(N + \frac{1}{2}\right) \hbar \omega_0 \quad , \quad N = 0, 1, 2, 3, \ldots$$

ENERGY LEVELS UNIFORMLY SPACED

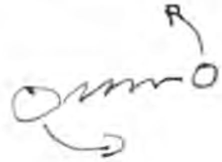
$\hbar$ = Planck's CONSTANT (h) ~~devid~~ divided by $2\pi$. [called "h-bar"]

$$\boxed{\begin{aligned} \hbar &= \frac{h}{2\pi} = 1.05 \times 10^{-34} \text{ J-s} \\ h &= 6.6 \times 10^{-34} \text{ J}\cdot\text{s} \end{aligned}}$$

$\hbar$ is VERY SMALL, BUT IF $\hbar = 0$ NO QUANTUM MECHANICS.

WEIRD RESULT: EVEN AT TEMPERATURE = Zero, PARTICLES WITH VIBRATIONAL ENERGY LEVELS ARE STILL MOVING! $E_N > 0$ !

ROTATIONAL ENERGY




MOLECULE CAN ROTATE
LEVELS CLOSELY <u>SPACED</u>
AND INCREASE AS ENERGY INCREASES


Electronic ~ 1eV  $\sim 10^{0}-10^{1}$ eV
Vibrational ~ 0.01eV  $\sim 10^{-1}$ eV
ROTATIONAL ~ 0.0001 eV  $\sim 10^{-4}$ eV

END CHAPTER 8

READ 8.6, 8.7

START CHPT. 9

MULTIPARTICLE SYSTEMS

RECALL

$$\frac{d\vec{P}_{sys}}{dt} = \vec{F}_{NET}$$

For v << c
$$\vec{P}_{sys} = m_T \vec{v}_{cm}$$

REVIEW

$$\vec{r}_{cm} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + \cdots}{M_T} \; ; \; M_T = m_1 + m_2 + \cdots$$

REARRANGE AND TAKE DERIVATIVE

$$m_T\vec{r}_{cm} = m_1\vec{r}_1 + m_2\vec{r}_2 + m_3\vec{r}_3 + \cdots$$

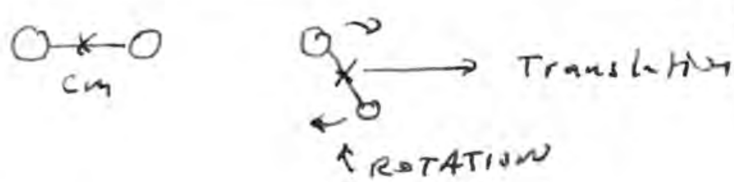
$$m_T\vec{v}_{cm} = m_1\vec{v}_1 + m_2\vec{v}_2 + m_3\vec{v}_3 + \cdots \quad \vec{P}_{sys}$$

CAN DO THIS SUM IN "BUNCHES" OF ATOMS


$$r_{cm} = \frac{(m_{11}\vec{r}_{11} + m_{12}\vec{r}_{12} + \cdots) + (m_{21}\vec{r}_{21} + m_{22}\vec{r}_{22} + \cdots) + (m_{31}\vec{r}_{31} + m_{32}\vec{r}_{32} + \cdots)}{(m_{11} + m_{12} + \cdots) + (m_{21} + m_{22} + \cdots) + (m_{31} + m_{32} + \cdots)}$$

$$\boxed{\vec{r}_{cm} = \frac{M_1\vec{R}_1 + M_2\vec{R}_2 + M_3\vec{R}_3 + \cdots}{M_1 + M_2 + M_3 + \cdots}}$$

KINETIC ENERGY
⇒ ROTATIONAL + TRANSLATIONAL
+ VIBRATIONAL ENERGY




[FOR MOST OBJECTS → BASEBALL ⇒ FAST BALL + CURVE BALL]

$$\boxed{K_{Trans} = \frac{1}{2} M_T v_{cm}^2 = \frac{p_{sys}^2}{2M_T}}$$

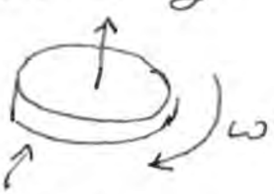
POTENTIAL ENERGY

$$\boxed{U_g = M_T g y_{cm}}$$

WE HAVE BEEN DOING THIS ALL ALONG

$$\left[\begin{aligned} U_g &= m_1 g y_1 + m_2 g y_2 + \dots \\ &= g\underbrace{(m_1 y_1 + m_2 y_2 + \dots)}_{M_T y_{cm}} \end{aligned}\right]$$

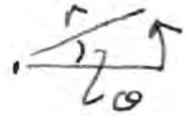
ROTATIONAL KINETIC ENERGY




Uniform disk spinning

$\omega = \frac{2\pi}{T}$ ← PERIOD FOR ONE ROTATIONAL

$\omega r = \frac{2\pi r}{T} = v$ ← angular speed




$\theta = \frac{s}{r}$ (θ in RADIANS)

$\theta r = s$

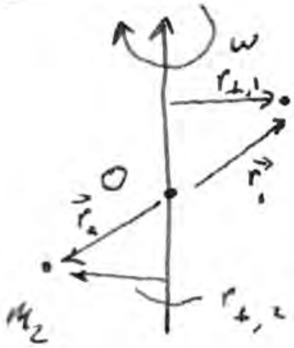
$\frac{d(\theta r)}{dt} = \frac{ds}{dt}$

CONSTANT $r$ →

$r \frac{d\theta}{dt} = v$

$r\omega = v$

~~UNIF~~




$v_1 = \omega r_{\perp 1}$

$v_2 = \omega r_{\perp 2}$

KINETIC ENERGY

$K_{rot} = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 + \frac{1}{2} m_3 v_3^2 + \dots$

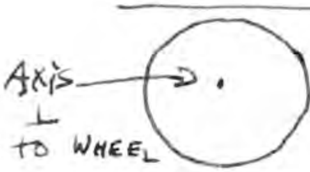
$K_{rot} = \frac{1}{2} m_1 r_{\perp 1}^2 \omega^2 + \frac{1}{2} m_2 r_{\perp 2}^2 \omega^2 + \frac{1}{2} m_3 r_{\perp 3}^2 \omega^2 + \dots$

$= \frac{1}{2} I \omega^2$ $I$ = MOMENT OF INERTIA

$$\boxed{I = m_1 r_{\perp 1}^2 + m_2 r_{\perp 2}^2 + m_3 r_{\perp 3}^2 + \dots}$$

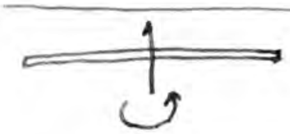
$$\boxed{K_{rot} = \frac{1}{2} I \omega^2}$$

EXAMPLES

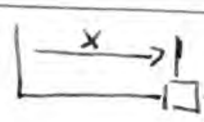



$I = R^2(m_1 + m_2 + m_3 + \dots)$ (HOOP)

$$\boxed{I = MR^2}$$




$\rho = \frac{M}{L}$ } UNIFORM




$\boxed{\Delta m = \rho \Delta x}$

$$\boxed{I = \sum_i \Delta m_i x_i^2}$$

$\Delta m_i = \Delta m = \rho \Delta x$ (UNIFORM)

$I = \frac{M}{L} \sum_i x_i^2 \Delta x$

$$I = \frac{M}{L} \sum_i x_i^2 \Delta x \Big\} \text{ WHAT IS THIS?}$$

$\Delta x \to 0$
(INTEGRAL)

$$= \frac{M}{L} \int_{-L/2}^{+L/2} x^2 \, dx$$

THIN ROD $\longrightarrow$ $\boxed{I = \frac{1}{12} ML^2}$

$$= \frac{M}{L} \left. \frac{x^3}{3} \right]_{-L/2}^{+L/2} = \frac{M}{L} \left[ \frac{L^3}{24} - \frac{(-L)^3}{24} \right] = \frac{1}{12} ML^2$$

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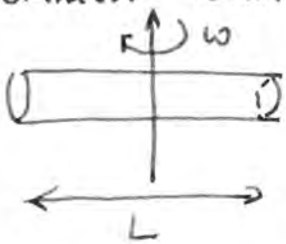
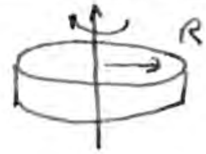
COMMON SHAPES



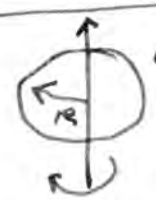

CYLINDER

$$\boxed{I = \frac{1}{12} ML^2 + \frac{1}{4} MR^2}$$




CYLINDER

$$\boxed{I = \frac{1}{2} MR^2}$$




SPHERE

$$\boxed{I = \frac{2}{5} MR^2}$$

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STRIP AREA $= \pi[R_2^2 - R_1^2]$ Let $R_2 = (R_1 + \Delta R)$

Let $\Delta R \to 0$ $\longrightarrow$ $R_2^2 = R_1^2 + 2\Delta R_1 R_1 + \Delta R^2$

AREA $= \pi \, 2\Delta R_1 R_1$ $\qquad R_2^2 = R_1^2 + 2\Delta R_1 R_1$

$dA = 2\pi r \, dr$ $\qquad \rho = \dfrac{M}{\pi R^2}$


$dm = \rho \, dA$

$$I = \sum_i \Delta m_i r_i^2 \Longrightarrow \frac{M}{\pi R^2} \int_0^R r^2 \, 2\pi r \, dr$$

↑ mass of strip

$$= \frac{2M}{R^2} \left. \frac{r^4}{4} \right]_0^R = \frac{MR^2}{2}$$

$$\boxed{I = \frac{MR^2}{2}}$$

OTHERS DONE THE SAME WAY