Day 4

1) Metallic platinum requires V_1 volt to serve as stopping potential for light of wavelength, λ_1 and if wavelength is λ_2, then V_2 volt is required. (assume, $V_2 > V_1$). h/e can be given by
   A) $(V_2 \times V_1) \times (\lambda_1^2/[\lambda_1 - \lambda_2])$
   B) $[V_2 - V_1] \times (\lambda_1 \lambda_2/[c[\lambda_1 - \lambda_2])$
   C) $(V_2 \times V_1) \times (\lambda_1/\lambda_2)$
   D) $(V_2/V_1) \times (\lambda_1 - \lambda_2)$
2) The work function of two metals are A and B are 2.5 eV and 4.5 eV respectively. Suppose you want to device a visible light detector photocell. Which of the two metals will you use?
3) When two ultraviolet beams of wavelengths $\lambda_1 = 80$ nm and $\lambda_2 = 110$ nm fall on a lead surface, they produce photoelectrons with maximum energies 11.390 eV and 7.154 eV, respectively.
   (a) Estimate the numerical value of the Planck constant.
   (b) Calculate the work-function, the cut-off frequency, and the cut-off wavelength of lead.
4) A certain photo-tube requires 1 volt to serve as the stopping potential for light of wavelength 5000Å. If the light has the wavelength of 3750Å the stopping potential is 1.82 volts. Calculate h/e from this data.
5) Show that, de Broglie's wavelength for an electron (of mass 'm'), accelerated with a potential difference 'V' is inversely proportional to the potential difference. [assume the velocity of the accelerated electron is <<velocity of light]. Which instrument was developed, based on the outcome of your Result-Briefly explain!

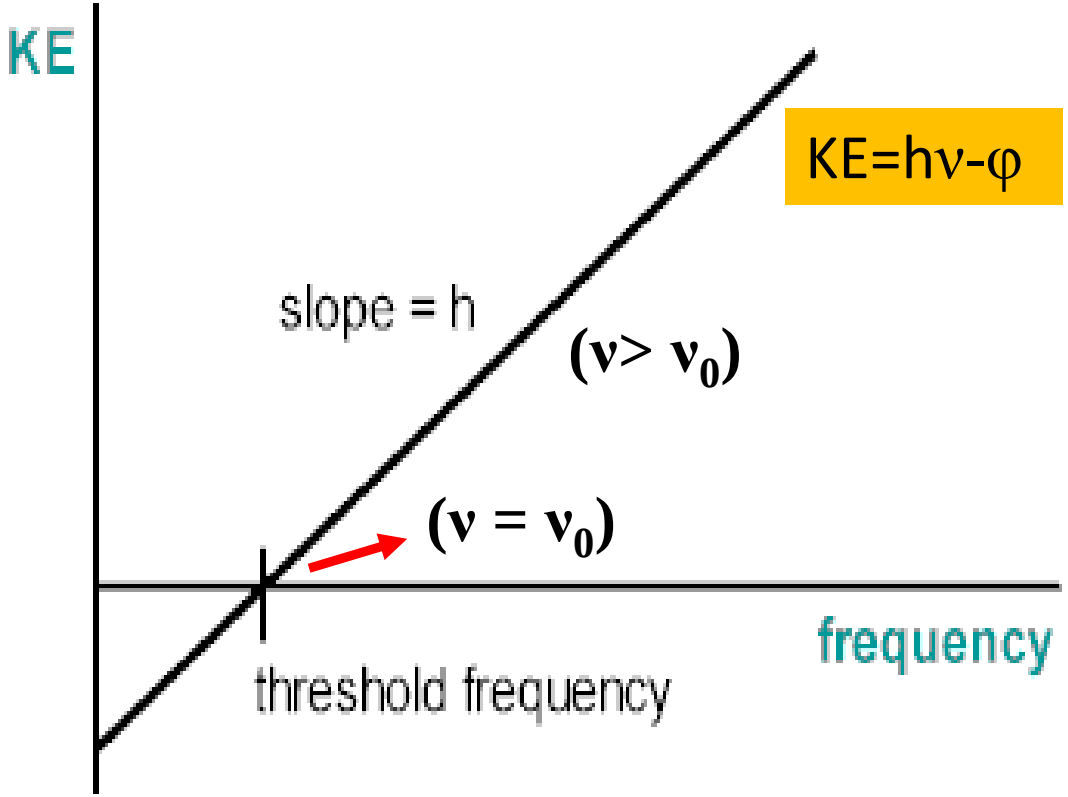
- ✓ **The electrons in a metal posses potential energy which must have to overcome before removal of the metal surface and this energy is called work function of the electrons.**

From conservation of energy:

Total energy of electrons = E_{Photon} = KE of electron + Pot. energy

$$h\nu = \frac{1}{2} mV^2 + \text{Work-function}$$

$$\frac{1}{2} mV^2 = h\nu - \text{Work-function}$$



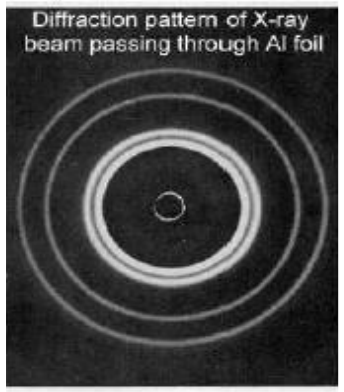
Total energy of electrons = KE + Pot. energy

hν = ½ mV²+Work-function

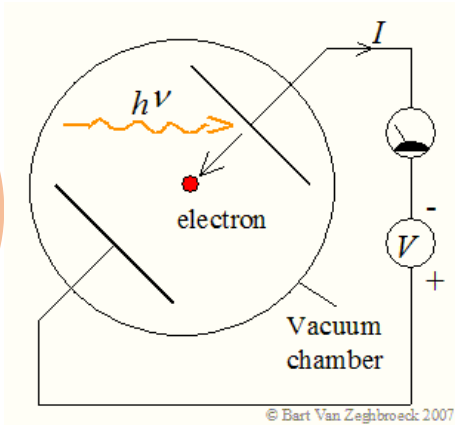
The slope of the straight line obtained by plotting the kinetic energy as a function of frequency above the threshold frequency is just Planck's constant, and the x-intercept, where $(1/2)mv^2=0$, is just the work function of the metal, $\Phi=h\nu_0$.

Summary of Day 3

de Broglie's equation



$$\lambda = h/P$$



Heisenberg's Uncertainty Principle

$$\Delta X \times \Delta P_x \geq h/4\pi$$

…… to see an electron using microscope!!

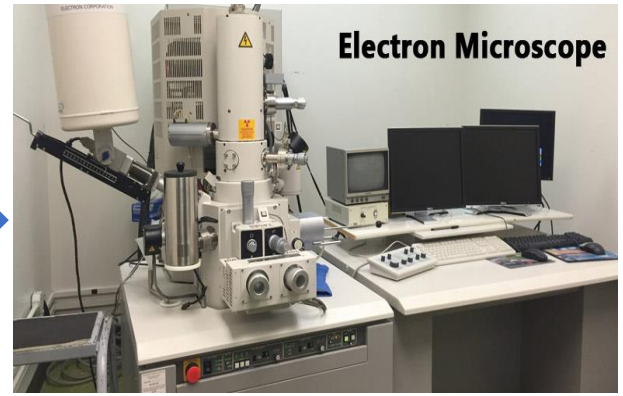
'wave' nature and 'particle' nature have been superimposed!

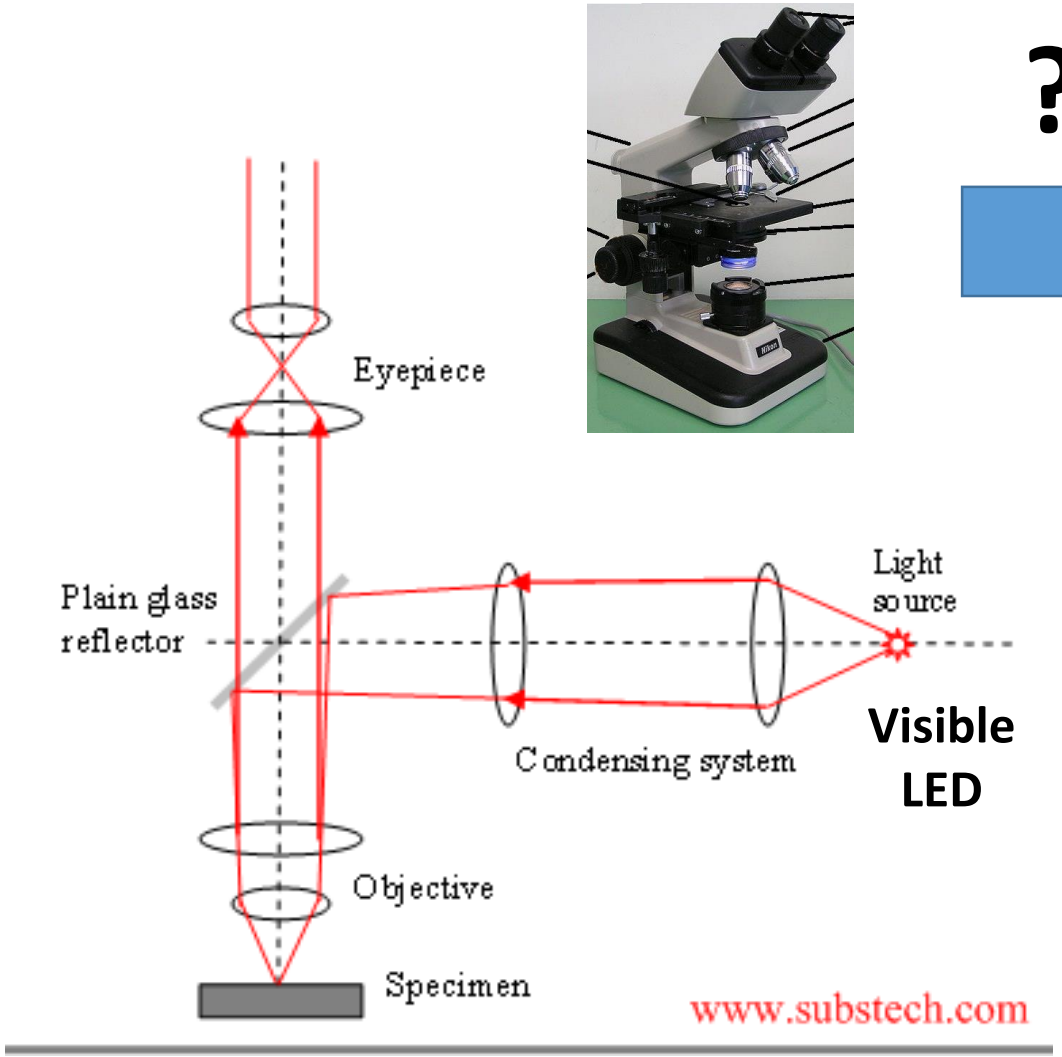
Only applicable to sub-atomic word
No significance in real world!!

"Electrons are particles in the form of wave"
-Chemical Bonding

Considering an electron, passing through a tube with voltage V_1 with a velocity v

$$\lambda = h/\sqrt{(2eV_1m)}$$





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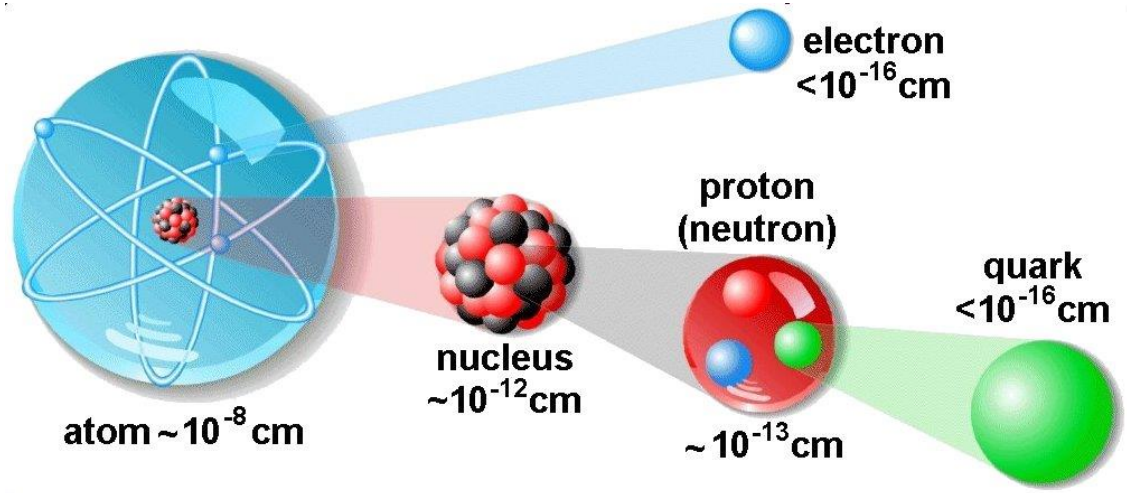
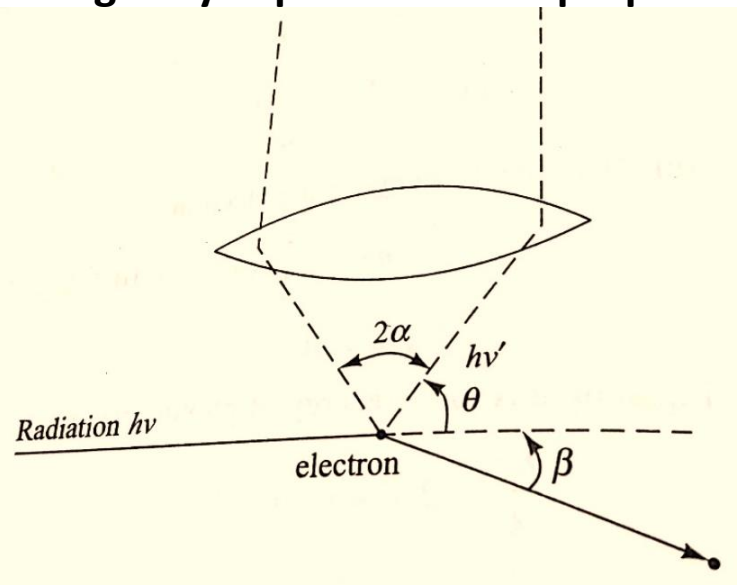
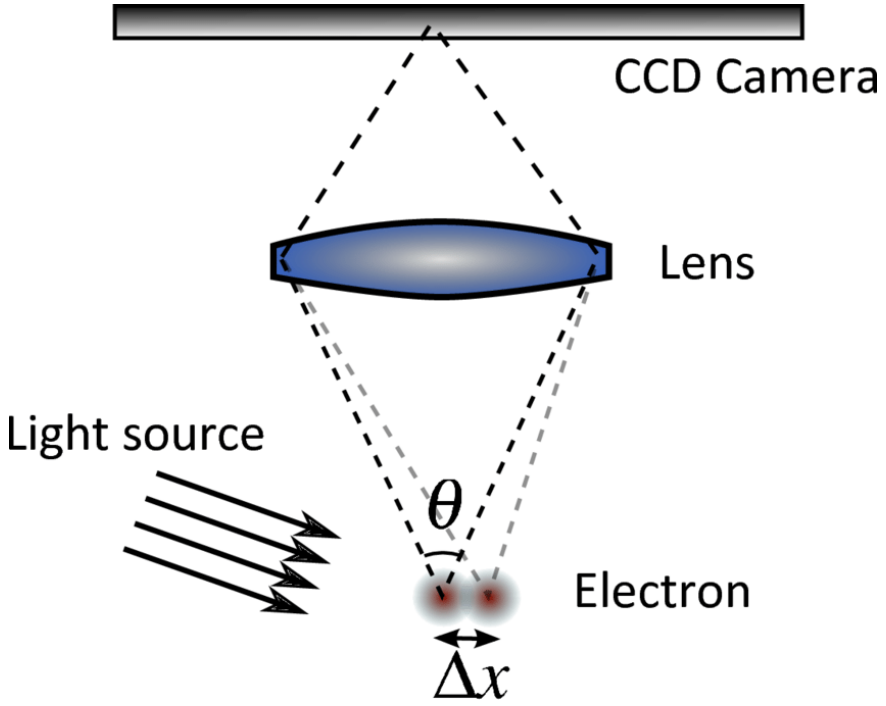
…… *to see an electron using microscope*

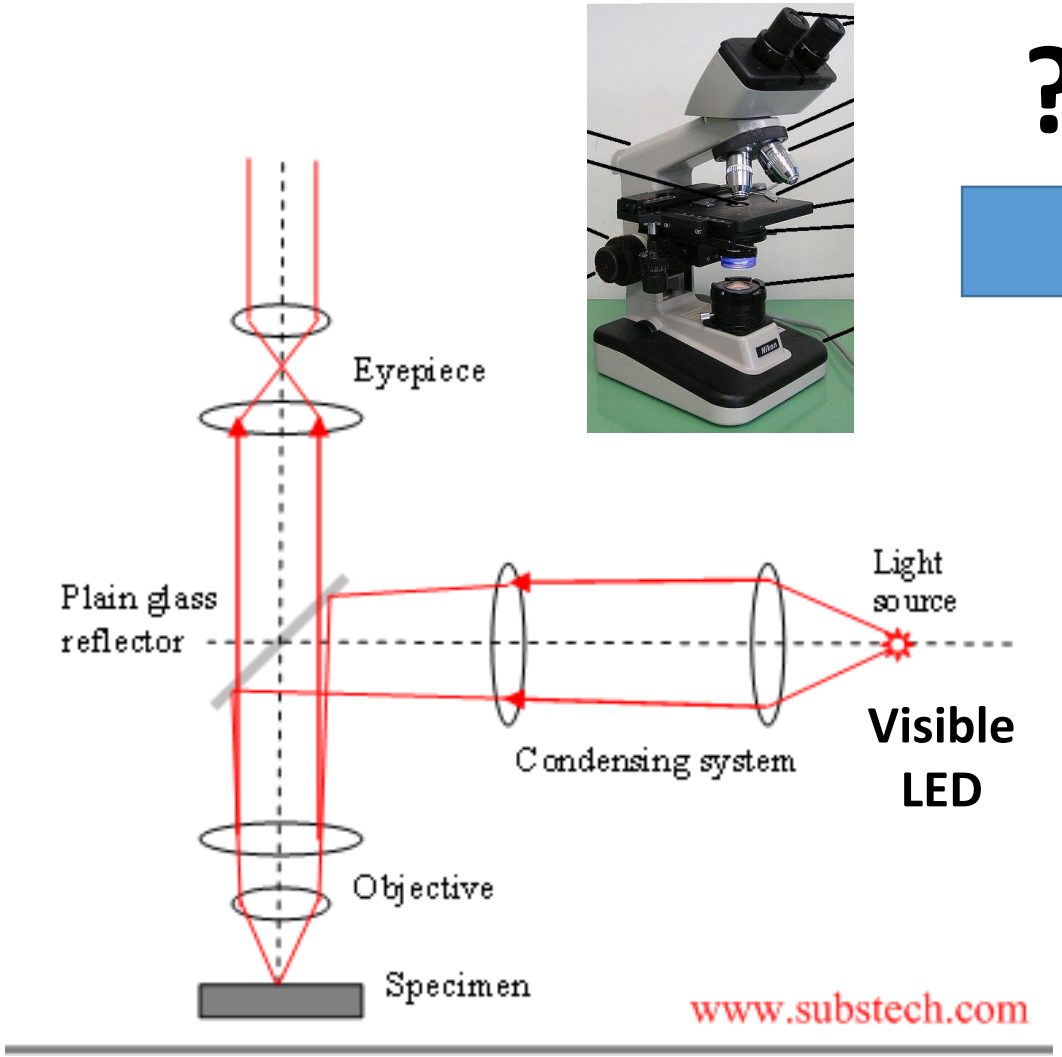


An imaginary experiment was proposed!



Heisenberg's Microscope
(No Real Existence)





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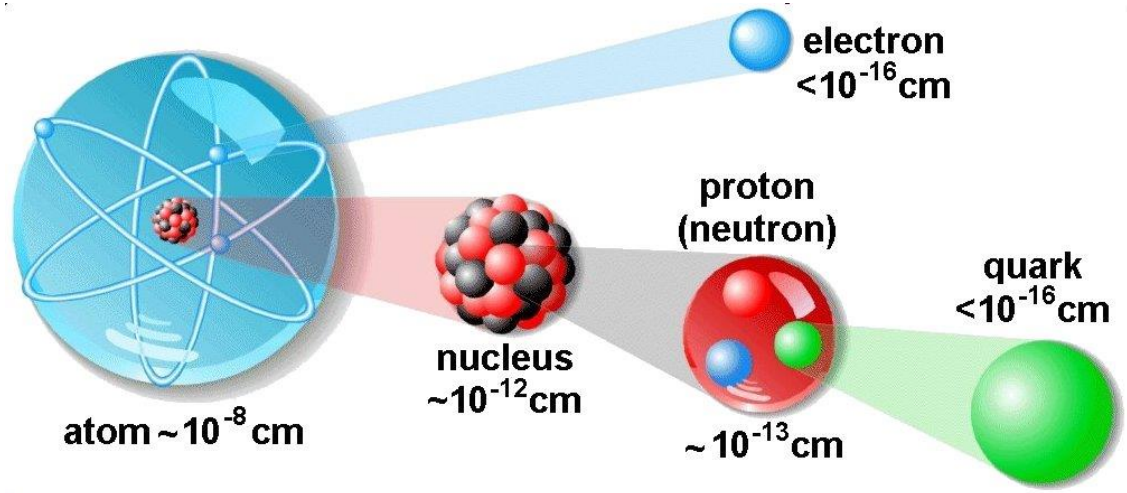

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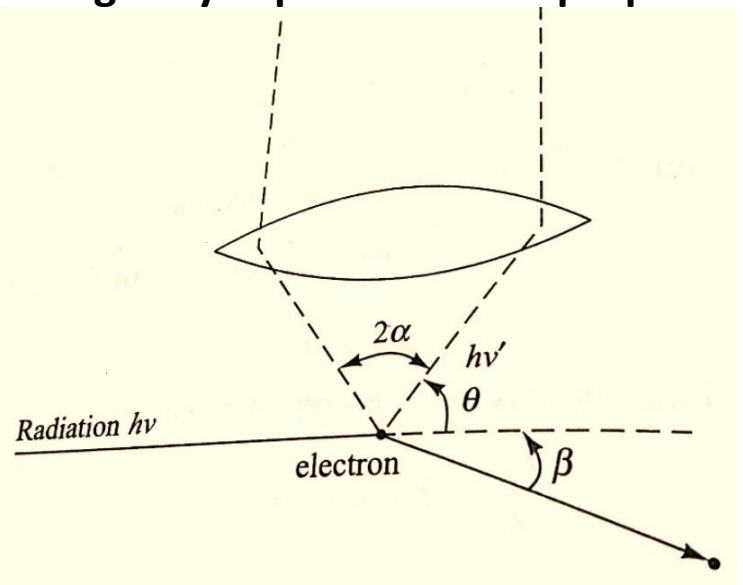
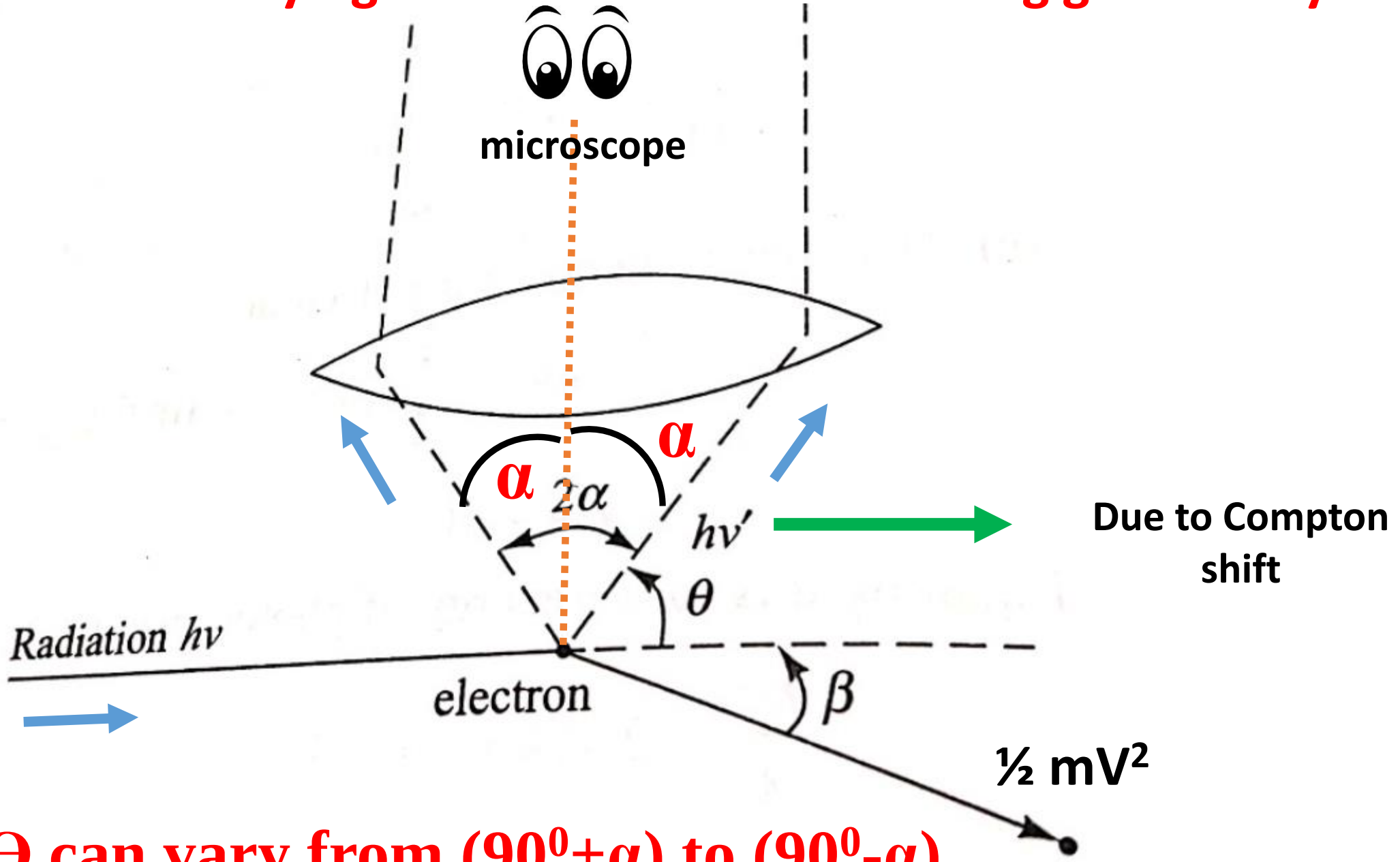


We are trying to locate the electron using gamma ray



Θ can vary from $(90^0+\alpha)$ to $(90^0-\alpha)$

Frequency of scattered photon will undergo a Compton shift.

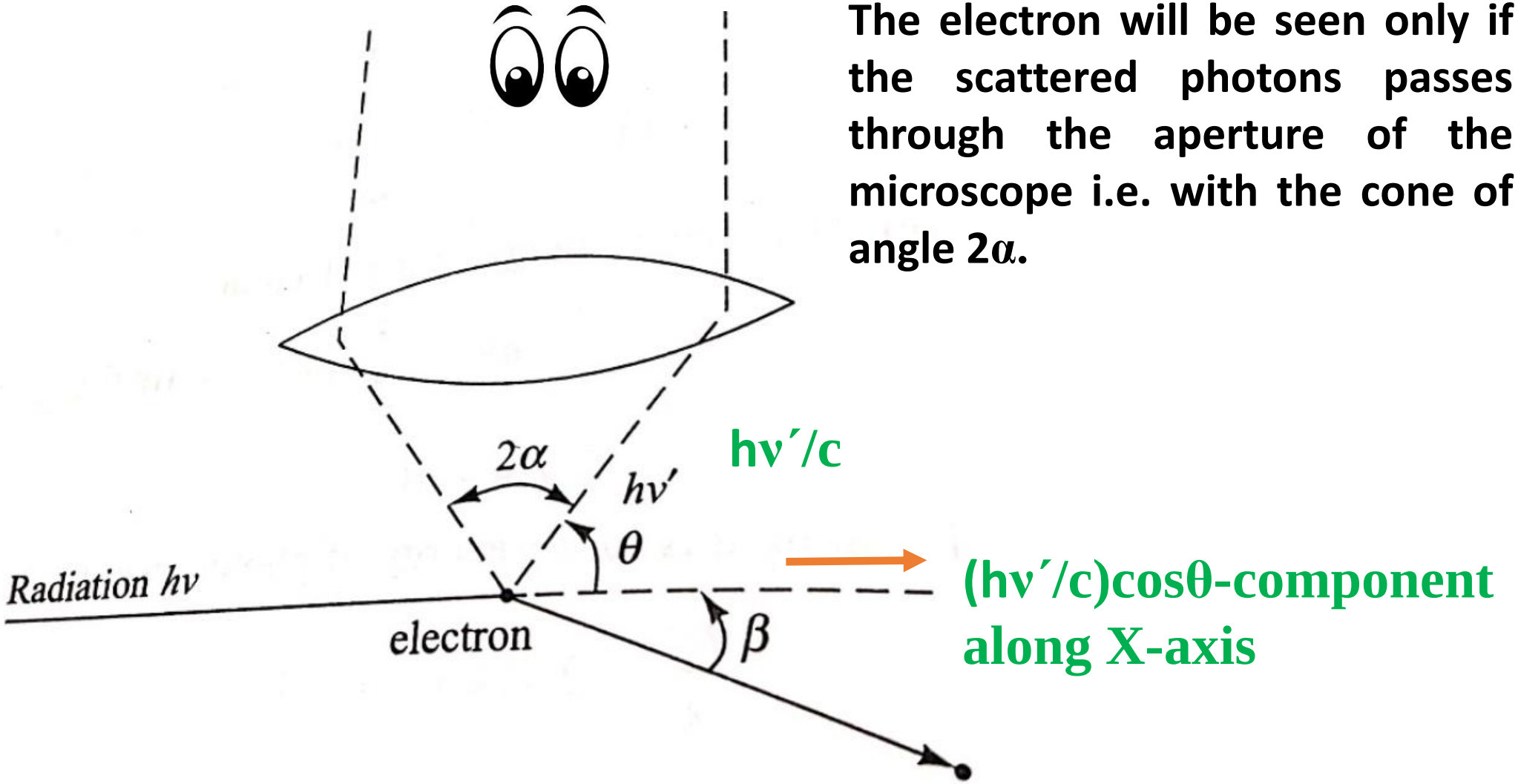
The electron will acquire a photon and will move in a direction making an angle ‘β’ with the x-axis, after stroked by the gamma-ray photons. The photon will transfer some momentum to the electron after collision and will generate the uncertainty in momentum of electron.

1) Momentum (P) of the photon before collision:

$P = h/\lambda = h\nu/c$ [Remember $\lambda = h/P$]

2) Momentum (P) of the photon after collision:

$P' = h/\lambda' = h\nu'/c$



The electron will be seen only if the scattered photons passes through the aperture of the microscope i.e. with the cone of angle 2α.

The gain in momentum by electron along X-axis = hν/c - (hν′/c)cosθ

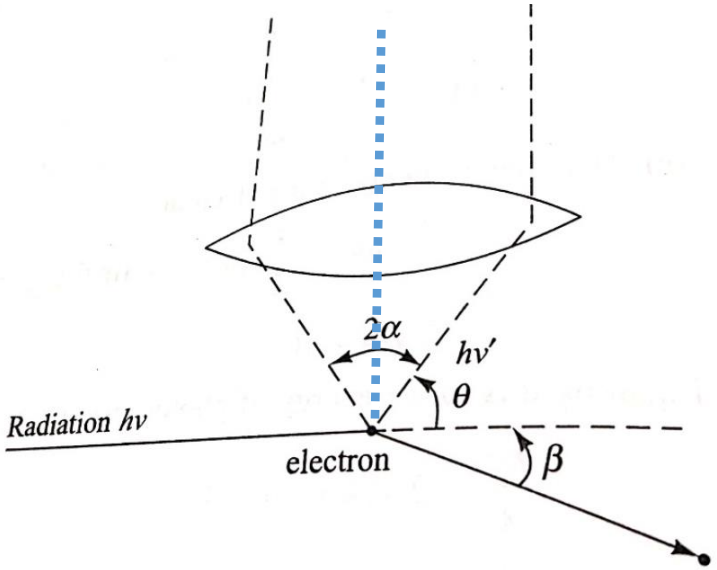
(This is nothing but the loss in momentum by the photon)

Loss of momentum by the photon=gain in momentum by the electron

The gain in momentum by the electron = hν/c - (hν′/c)cosθ
Assuming that: ν′ = ν (frequency did not change significantly)

The gain in momentum: hν/c[1 – cosθ]
Range of θ = (90^0-α) to (90^0+α)

Since the photon can be deflected at any value of θ between (90^0 ± α)



The momentum can have any value between $h\nu/c \times [1 - \cos(90^0 \pm \alpha)]$ depending on the scattering angle of photon

Thus the uncertainty in momentum under the limiting value: $(90^0+\alpha)$ to $(90^0-\alpha)$ can be given by: $\Delta P=P-P'$

$$\Delta P=h\nu/c[1 - \cos(90^0+\alpha)-1+\cos(90^0-\alpha)]$$
$$=h\nu/c[2\sin\alpha]$$

Now the aperture of the lens = α, the accuracy with which an object can be located by a microscope is defined by Rayleigh equation for the resolving power:

$$\Delta X=\lambda/2\sin\alpha$$

Thus, $\Delta P \times \Delta X=(h\nu/c)\ [2\sin\alpha] \times (\lambda/2\sin\alpha) = h$

Uncertainty in momentum will depend on 'α'. If we make 'α' small then ΔP will be smaller; but will create increase in the uncertainty in ΔX.

$$\downarrow \Delta P=(h\nu/c)\times[2\sin\alpha] \downarrow$$

$$\uparrow \Delta X=\lambda/2\sin\alpha \downarrow$$

Similarly, if we employ energy of high frequency- 'ν' (lower wavelength); the uncertainty in position ΔX will be low but uncertainty in ΔP will be very high.

$$\Delta X=\lambda/(2\sin\alpha)= c/(2\nu\sin\alpha)$$

"One of the direct consequences of the uncertainty principle is that sub atomic particles (electrons/protons) can't have precise values of velocity, momentum"

1. Calculate the uncertainty in velocity (ΔV) of an electron with uncertainty of position (ΔX) from the nucleus of 5 pm.
Ans: $N \times 10^{7}$ m s^{-1} **[Huge]**

2. Calculate the uncertainty in velocity (ΔV) of a cricket ball of mass 200 gm with uncertainty of position (ΔX) of 5 pm.
Ans: $N_2 \times 10^{-23}$ m s^{-1} **[negligible-beyond our limit of detection with available technique!]**

de Broglie's wavelength is associated with any particles in the subatomic world. ***(No significance in the daily life!)***

Quantum Particle: A quantum particle can be defined as a particle for which the corresponding de Broglie's wavelength is within the limit of measurement.

In subatomic systems, whenever we will try to measure position accurately, we won't be able to precisely measure its momentum.

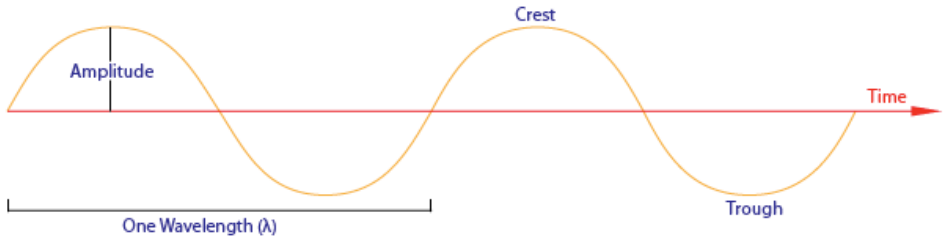
What is Chemical Bonding?

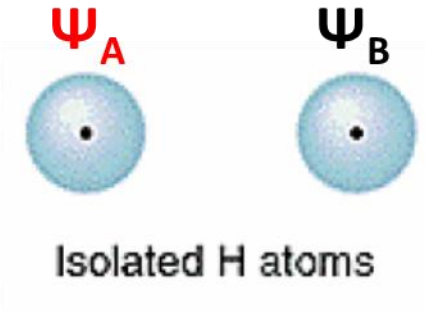
- **It's a force of attraction.**

Or,

- **Bonding is a process for decreasing the repulsion between two nucleus.**

Considering Electrons as Wave

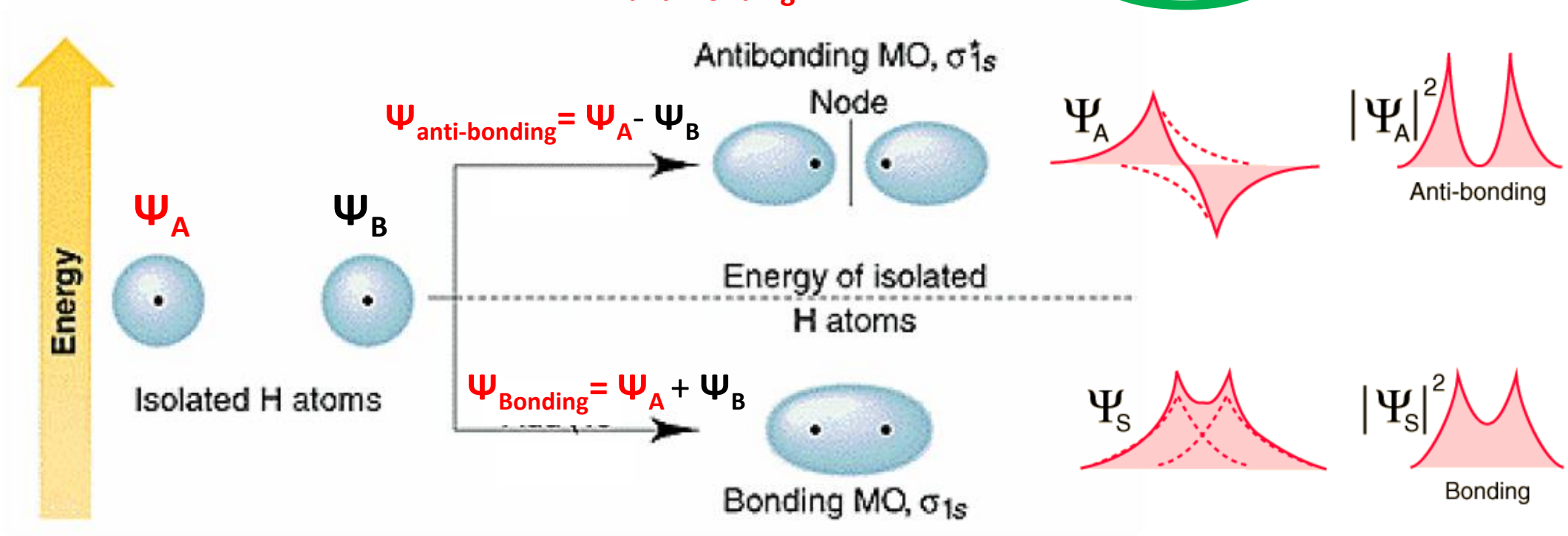




- **We can represent electron wave-function as Ψ_A /Ψ_B (which are the amplitude function)**
- **In case of light, intensity of light or energy of electromagnetic field is proportional to the square of the amplitude of the wave at any point.**
- **Ψ_A^2 or Ψ_B^2 gives the probability density of electrons when present over individual hydrogen atom.**

Anti-Bonding (destructive interference): ($\Psi_A - \Psi_B$)

Probability density: $\Psi_{anti\text{-}Bonding}$ $(\Psi_A - \Psi_B)^2 = \Psi_A^2 - 2\Psi_A\Psi_B + \Psi_B^2$



Bonding (constructive interference): ($\Psi_{Bonding} = \Psi_A + \Psi_B$)

Probability density: $(\Psi_A + \Psi_B)^2 = \Psi_A^2 + 2\Psi_A\Psi_B + \Psi_B^2$

http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/emwavecon.html