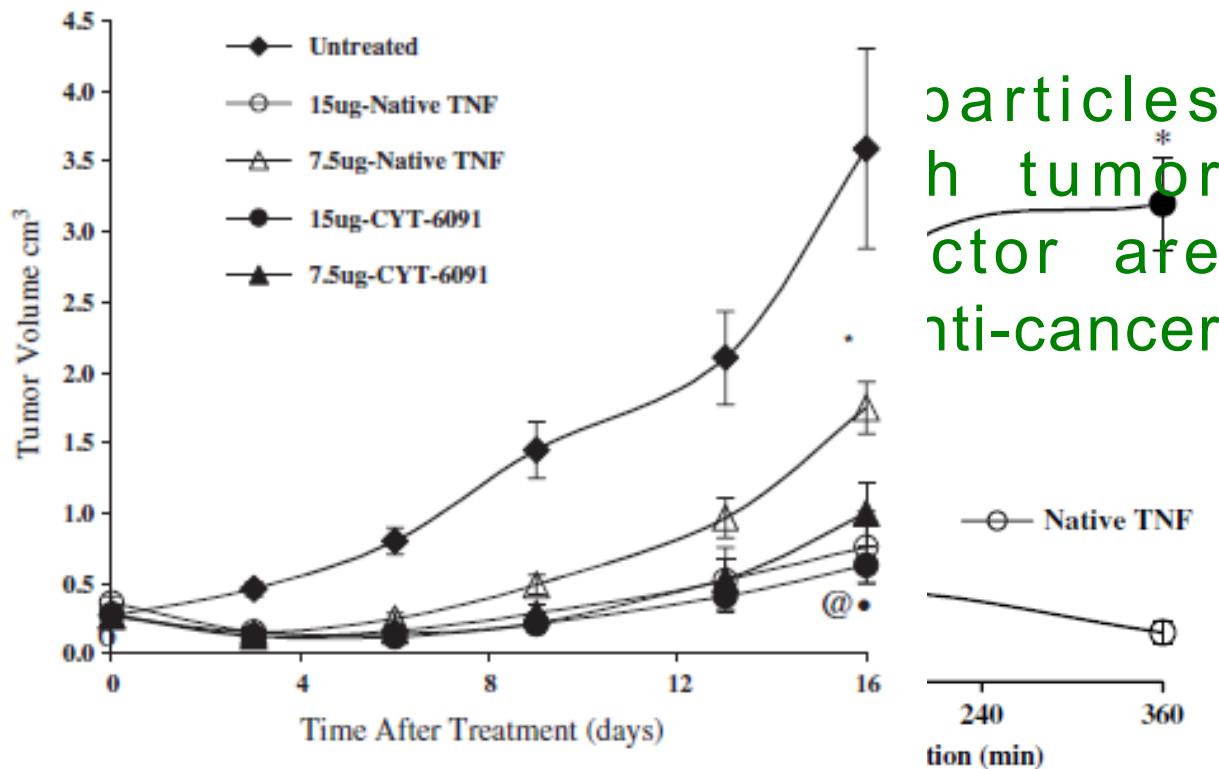
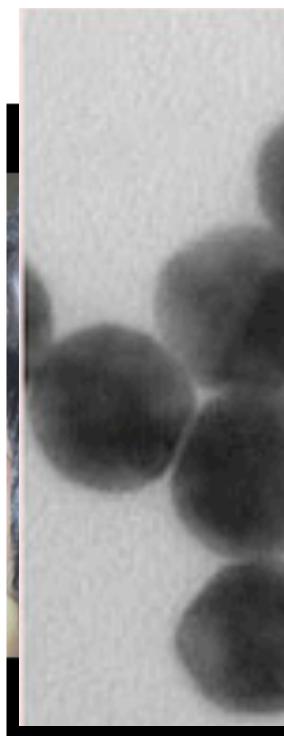


# Table of Contents

<u>Topic</u>	<u>pp.</u>
Photoelectric Effect	5
Properties of EM Radiation	7
Interactions of Light with Matter	12
Optical Resolution	15
Transmission	18
Refraction	21
Reflection	22
Molecular Orbital Theory	23
Atomic Absorption	51
Molecular Absorption	52
Molecular Potential Energy	53
Molecular Modes of Vibration	61
Rotations	64

# Nanomedicine and Instrumental Analysis

Nanomedicine is the use of nanometer-sized matter in the diagnosis and treatment of disease.



How could you quantify the biodistribution of gold in an animal?

# CH 6 Introduction to Spectrometric Methods

## CH 6 Homework

1. Calculate the frequency, energy in joules, and energy in eV of an X-ray photon with a wavelength of 6.24 Å.
2. When the D line of sodium light impinges an air-diamond interface at an angle of incidence of 30.0 degrees, the angle of refraction is 11.9 degrees. What is  $n_D$  for diamond?
3. Cs is used extensively in photocells and in television cameras because it has the lowest ionization energy of all the stable elements.

What is the maximum KE of a photoelectron ejected from Cs by 555 nm light? Note that if the wavelength of the light used to irradiate the Cs surface becomes longer than 660 nm, no photoelectrons are emitted.

4. Convert the following percent transmittance data into absorbance:

29.9, 86.1, 2.97

# CH 6 Introduction to Spectrometric Methods

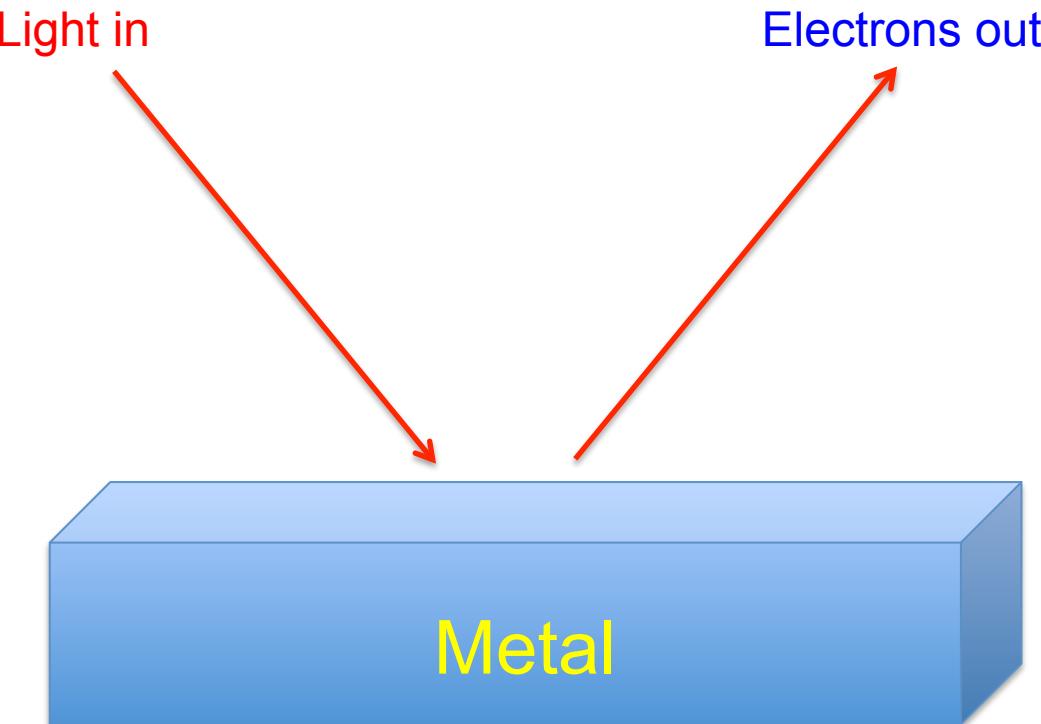
Spectroscopy: Involves the interactions between EM radiation and matter.

These interactions provide a number of ways to identify and quantify the presence of molecules in a sample.

# Properties of Electromagnetic Radiation

That mysterious property of light-The wave-particle duality

The Photoelectric Effect (Discovered by Tesla in 1901)

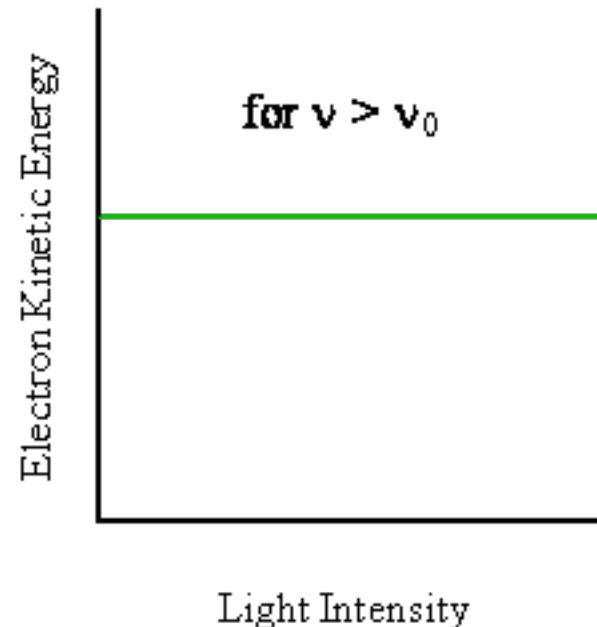
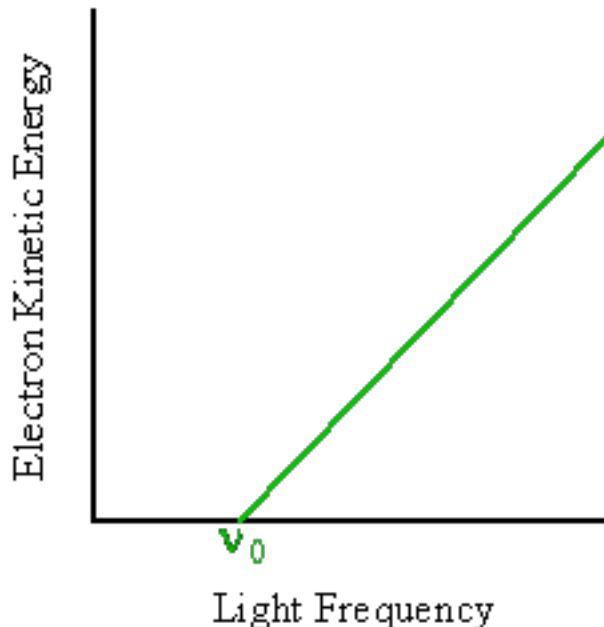


# Properties of Electromagnetic Radiation

## Concept Test

Increasing the intensity of the incident light:

- (A) Increases the KE of the electrons ejected.
- (B) Increases the # of electrons ejected but does not change their KE.
- (C) Has no effect at all.



E at  $\nu_0$  is called the work function of the metal.

# Properties of Electromagnetic Radiation

These relationships are not consistent with light behaving as a wave.

Instead they are consistent with light acting as a stream of particles now called photons, with each photon responsible for knocking a single electron out of the metal.

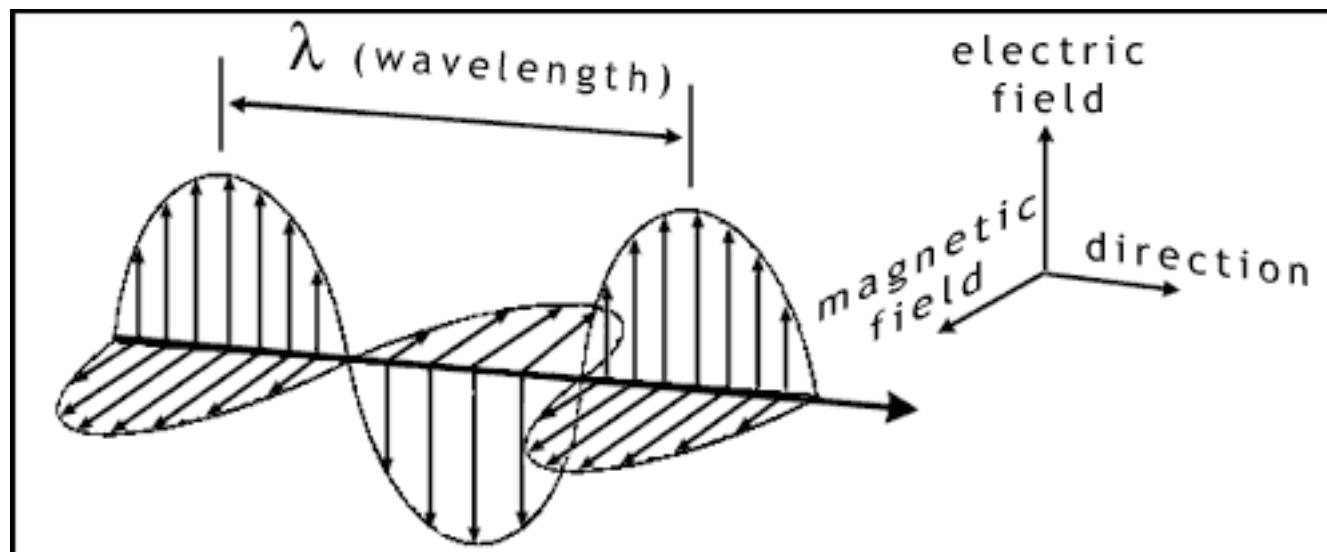
Increasing the intensity of the light only increases the # of photons impinging the surface. Unless these photons have enough energy, however, it doesn't matter how many are shot at the surface, no electrons will be ejected.

# Properties of Electromagnetic Radiation

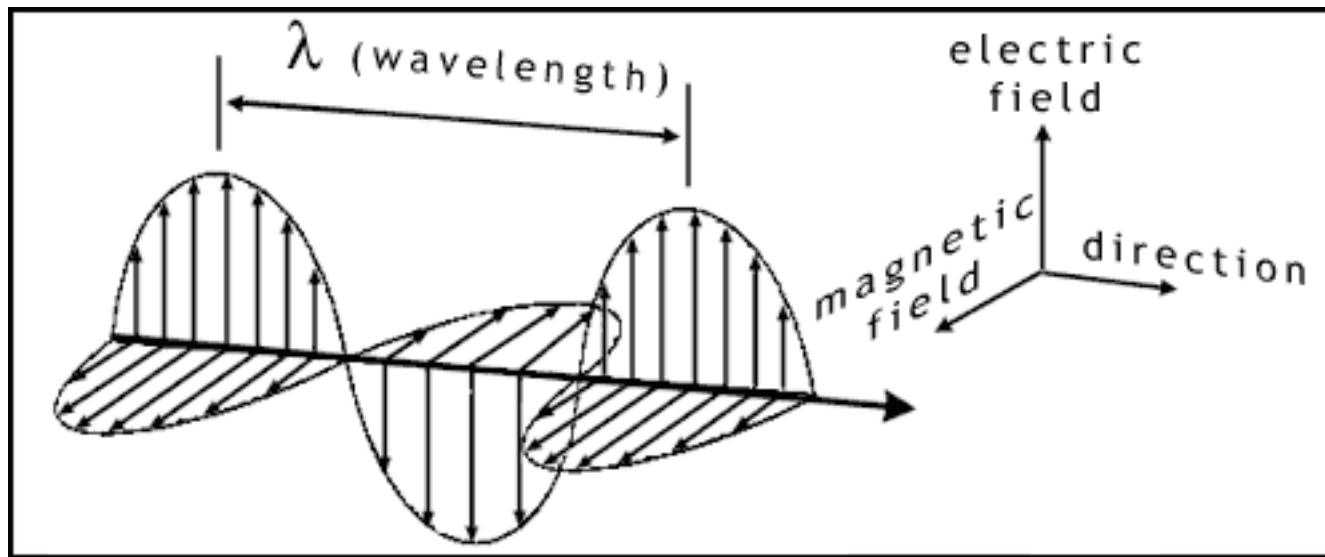


## Wave nature of light

A single plane of light with perpendicular electric and magnetic fields.



# Properties of Electromagnetic Radiation



$$\text{Velocity of propagation, } v_i = v\lambda_i$$

Frequency is determined by the source and is invariant.  
The velocity depends upon the medium through which it travels.

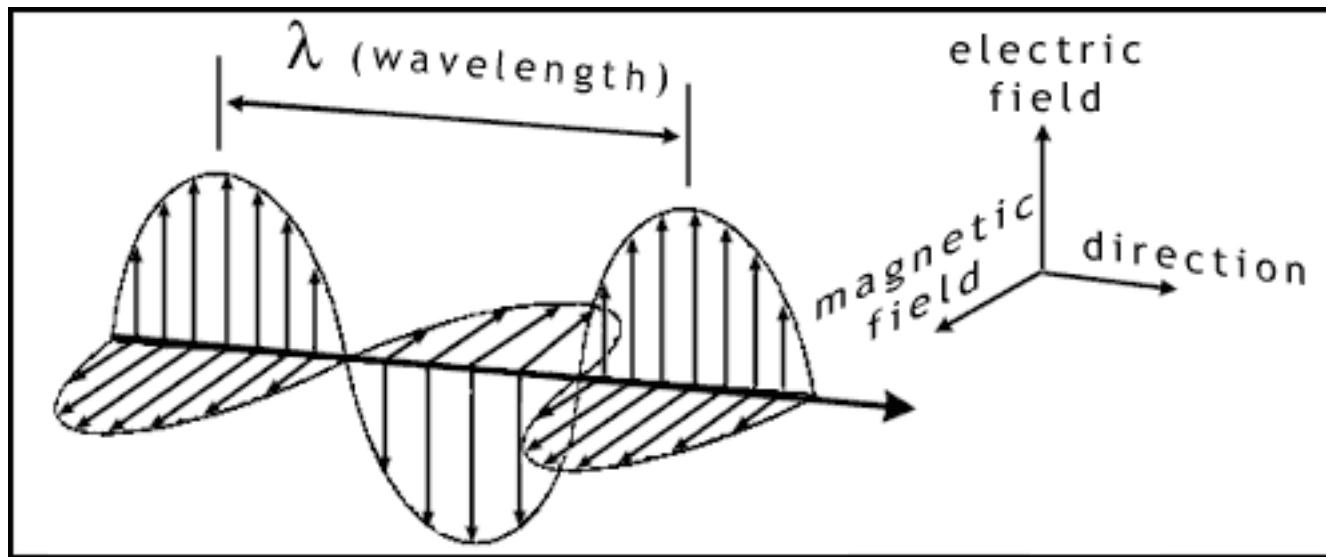
# Properties of Electromagnetic Radiation

## Concept Test

Which of the following changes when light passes from one medium to another?

- (A) Frequency
- (B) Wavelength
- (C) Speed
- (D) B and C

# Properties of Electromagnetic Radiation



$$\text{Wavenumber, } \bar{\nu} \text{ (cm}^{-1}\text{)} = 1/\lambda(\text{cm})$$

Used mostly in infrared spectroscopy

# Interactions of Light with Matter

Transmission

Refraction

Absorption

Scattering

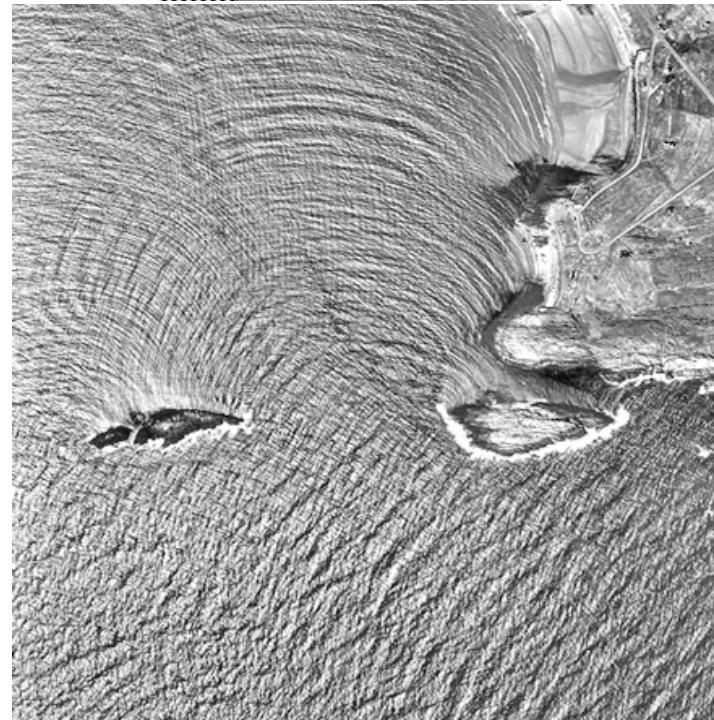
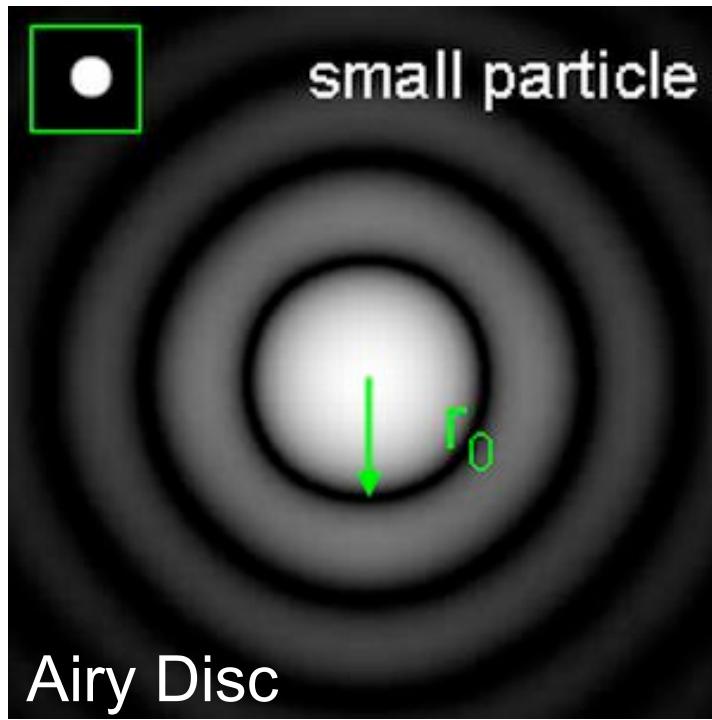
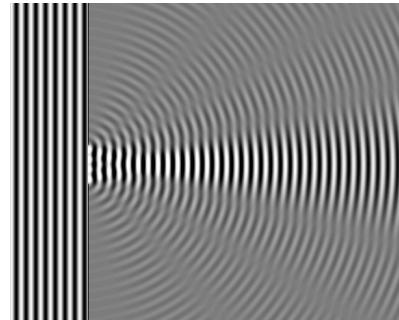
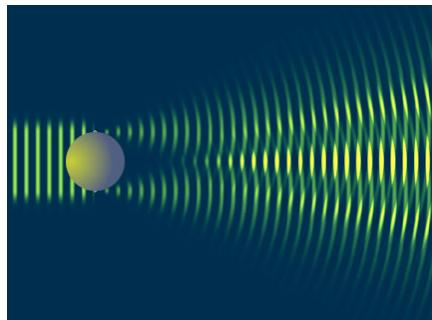
Diffraction

Reflection

# Interactions of Light with Matter

## Diffraction

Diffraction occurs any time light passes through a slit or by a barrier. Diffraction is the result of constructive and destructive interference of waves.

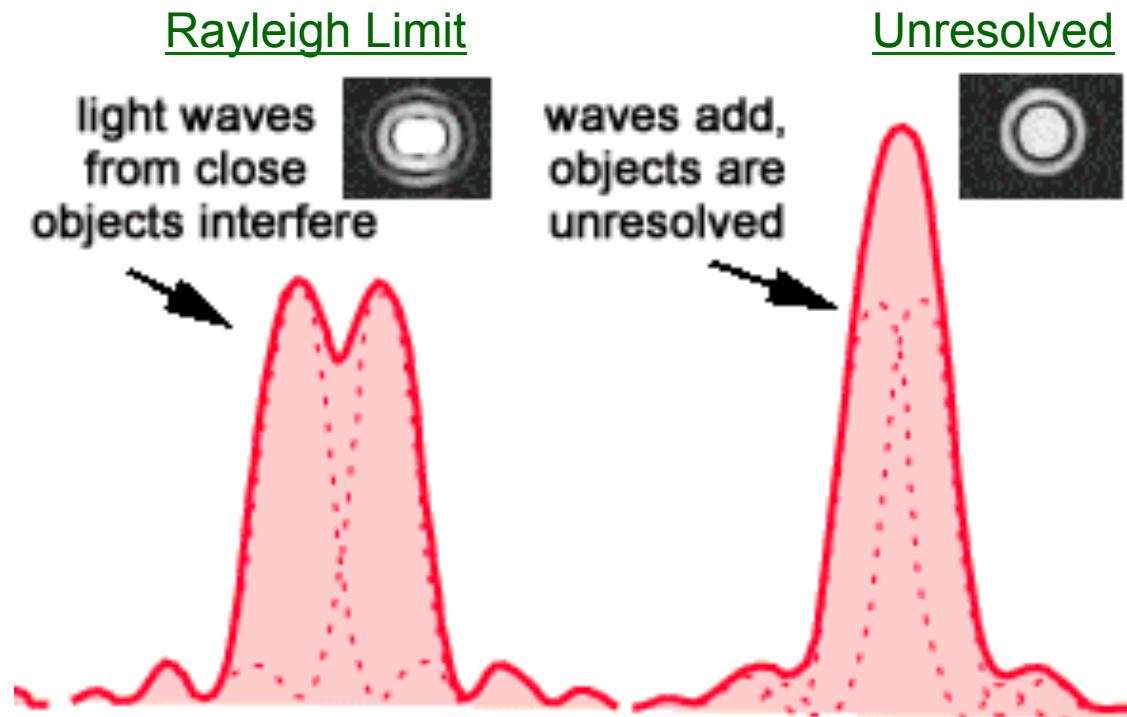


# Interactions of Light with Matter

*One example of the importance of diffraction: Optical resolution and the diffraction limit.*

Suppose we wish to image two objects with light. At what point can we tell there are two objects rather than one?

\*Key Concept: Diffraction limit occurs when the 1<sup>st</sup> minimum of the image of one object coincides with the maximum of another point source.



# Optical Resolution

Assume we have a microscope with a lens with a circular aperture of diameter D.

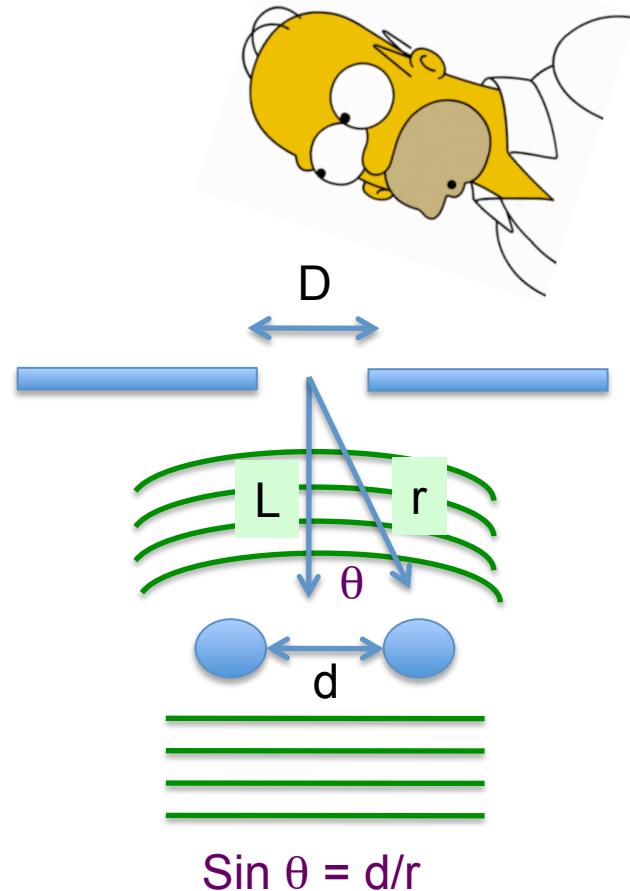
Diffraction limit is given by:

$$\sin \theta = 1.220 \frac{\lambda}{D}$$

Where  $\theta$  is the angle between objects.

For a single slit the equation is:

$$\sin \theta = \frac{\lambda}{D}$$



As a simplification: The resolution will be on the order of 1/2x to 1x the wavelength used to image depending upon the particular method used.

# Optical Resolution

## Sample Exercise

Two motorcycles, separated by 2.00 m are approaching an observer holding an infrared detector which is sensitive to radiation with a wavelength of 885 nm. What aperture diameter is required if the detector is to resolve the headlights at a distance of 10.0 km?

$$D = 1.22\lambda/\sin \theta$$

$$\sin \theta = d/r, \text{ but at long distances } r = L \text{ so } \sin \theta = d/L; d/L = 2 \times 10^{-4} \text{ m}$$

$$D = 1.22(885 \times 10^{-9} \text{ m})/2 \times 10^{-4} \text{ m}$$

$$D = 0.005 \text{ m} = 5 \text{ mm}$$

# Optical Resolution and the Human Eye

Normal vision is characterized as being 20/20, meaning that one can distinguish the letters on the 4<sup>th</sup> line up from the bottom at a distance of 20 ft.

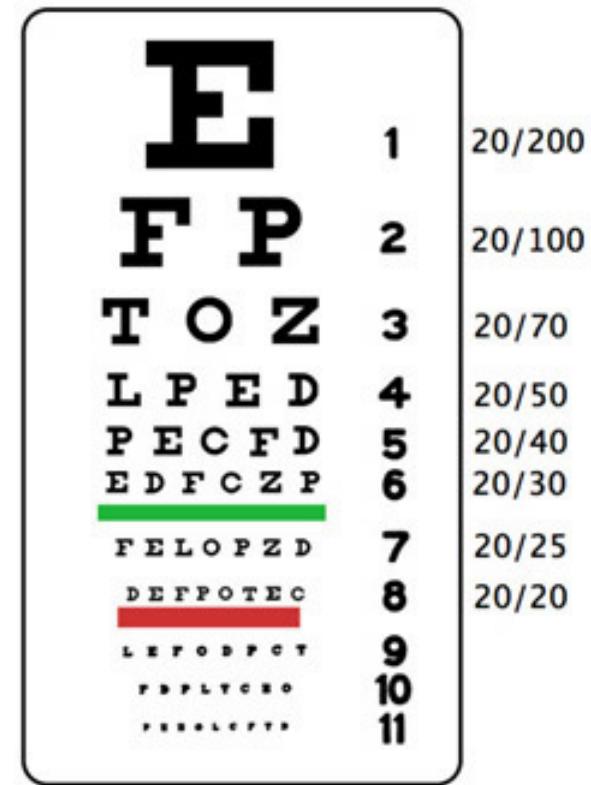
What does this mean in terms of the diffraction limit?

For a 5 mm iris and a  $\lambda$  of 500 nm, the Rayleigh criterion sets the resolution limit for a distance of 6 m at:

$$1.22 \lambda/D = d/L$$

$$d = 1.22 \times 6 \text{ m} \times 500 \times 10^{-9} \text{ m} / 5 \times 10^{-3} \text{ m}$$
$$= 0.7 \text{ mm}$$

The letters on the 20/20 vision line are 8.8 mm wide, so a 20/20 eye is within a factor of 12 of the diffraction limit. Some people have eyes that come within a factor of 2 of the diffraction limit!



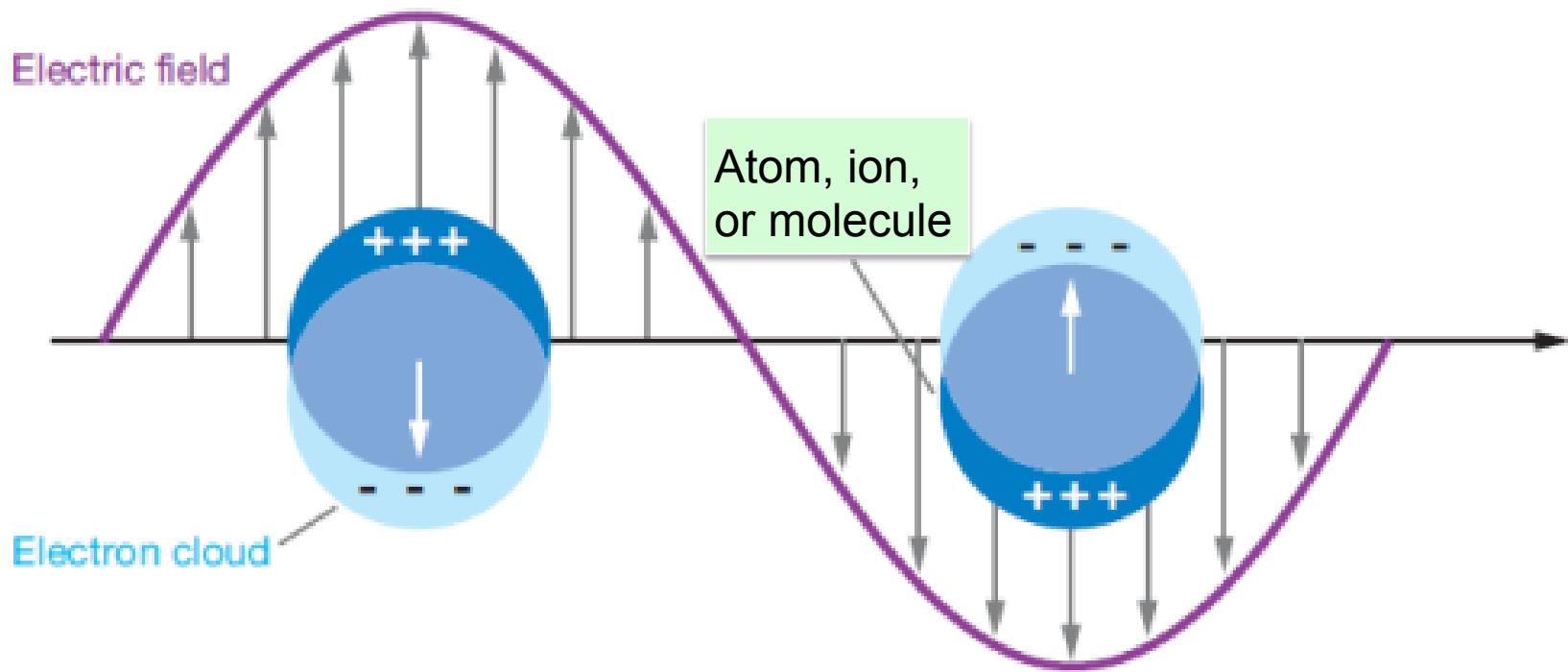
Snellen chart developed by Herman Snellen in 1862

# Transmission of Radiation



When light propagates through a medium filled with particles (ions, atoms, molecules) that are much smaller than its wavelength, the electric field of the light temporarily polarizes the particles.

# Transmission of Radiation

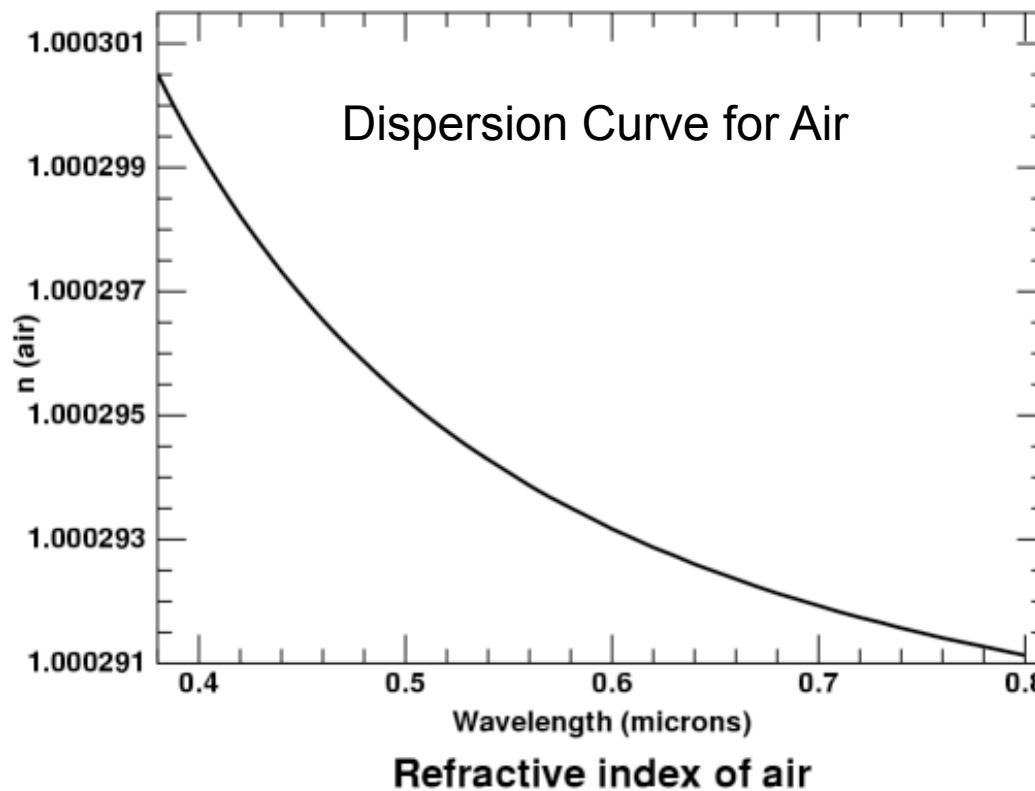


**\*Key concept:** The oscillating electron cloud of the particle re-emits light of the same energy (frequency). Thus, the light is not absorbed, but it is slowed down as it travels through the medium. In addition to being transmitted, part of the re-emitted light is also observed as reflected and scattered light.

# Transmission of Radiation

The ratio of the speed of light in a vacuum to the speed of light in a medium containing “particles” is the refractive index,  $n$ .

$$n_i = c/v_i; \text{ where } i \text{ indicates a certain frequency}$$

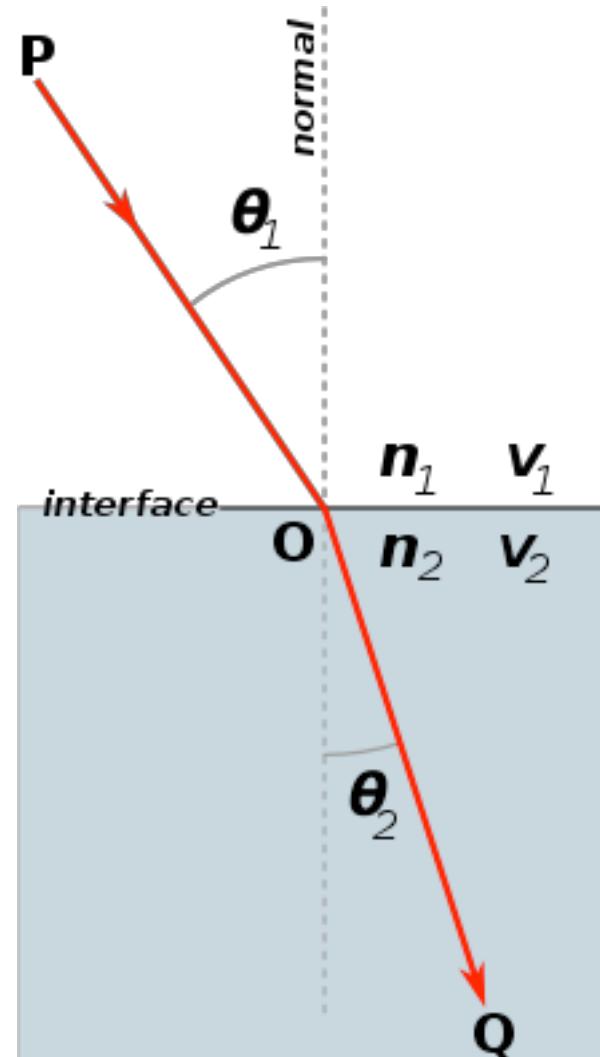


Note that  $n$  is wavelength dependent.

# Refraction of Radiation

Refractive index changes from one medium to another cause light to bend according to Snell's law.

$$\sin \theta_1 / \sin \theta_2 = n_2 / n_1 = v_1 / v_2$$



# Reflection of Radiation

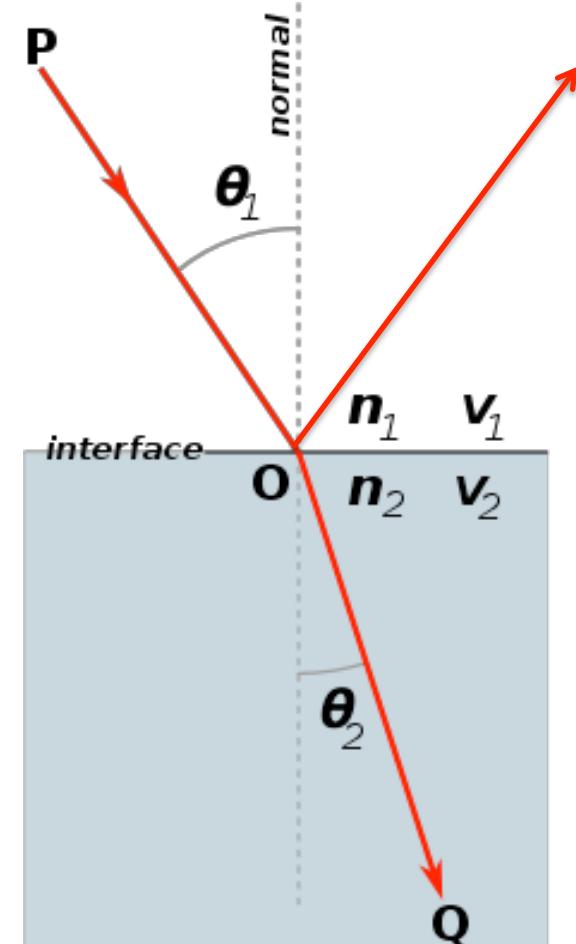
Reflection also always occurs at interfaces.

$$\frac{I_r}{I_o} = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2}$$

## Concept Test

To minimize reflected losses, one should try to:

- (A) Maximize the difference between  $n_1$  and  $n_2$
- (B) Match  $n_1$  and  $n_2$
- (C) Use materials with small  $n$  values



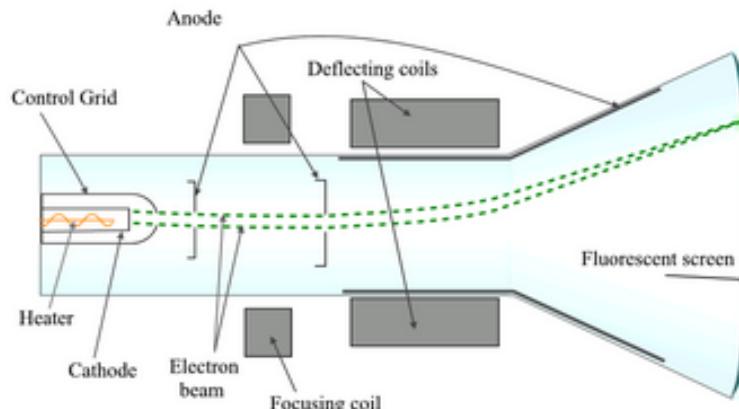
Much of optical spectroscopy exploits the behaviors of electrons in molecules.

Understanding how bonds are formed in molecules is critical to understanding optical spectroscopy.

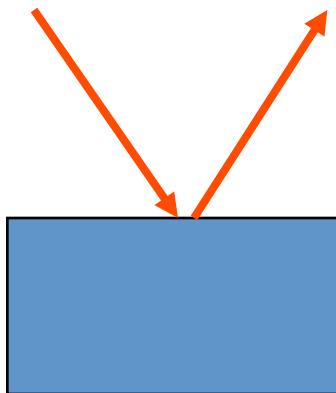
# To understand Molecular Orbitals, let's go back to the beginning (ca. 1900).

## Electrons as waves

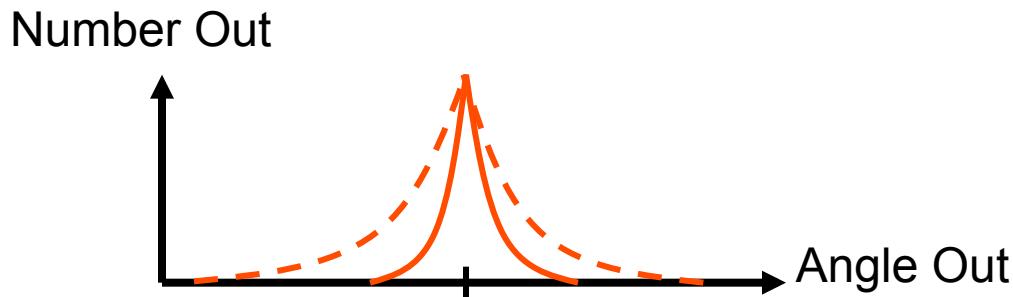
- Scientists came to this conclusion only *very* slowly and *very* painfully
- They HAD thought electrons were ~ little B-B's:
- In "Crooke's Tube" (early 1900 name for CRT) could form beams of electrons



- Behaved in electric fields just as they expected for little charged particles
- But then stumbled across many NEW situations where electrons acted as waves!
- One of these was when they bounced beam of electrons off a crystal of nickel:

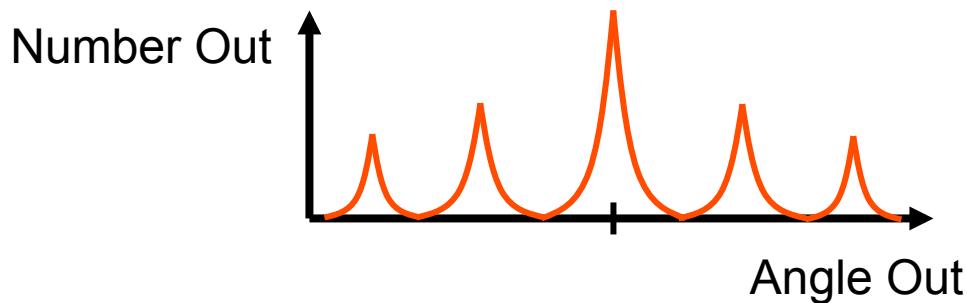


- Measured number bouncing off (with fixed incoming angle) vs. outgoing angle
- EXPECTED:



- Made SENSE: *All at outgoing angle = Incoming angle if smooth ( $\sim$  pool table)*  
*OR*  
*Scattered about Incoming angle if rough (on scale of electron size)*

- BUT WHAT THEY GOT WAS:

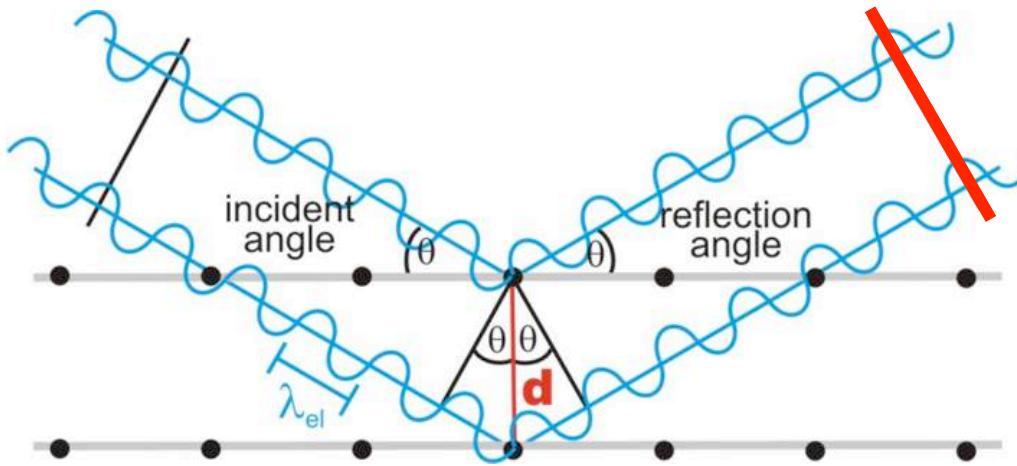


- Could ONLY explain IF:
- ELECTRONS were acting as waves
- Atomic planes in crystal acted as partially reflecting electron mirrors

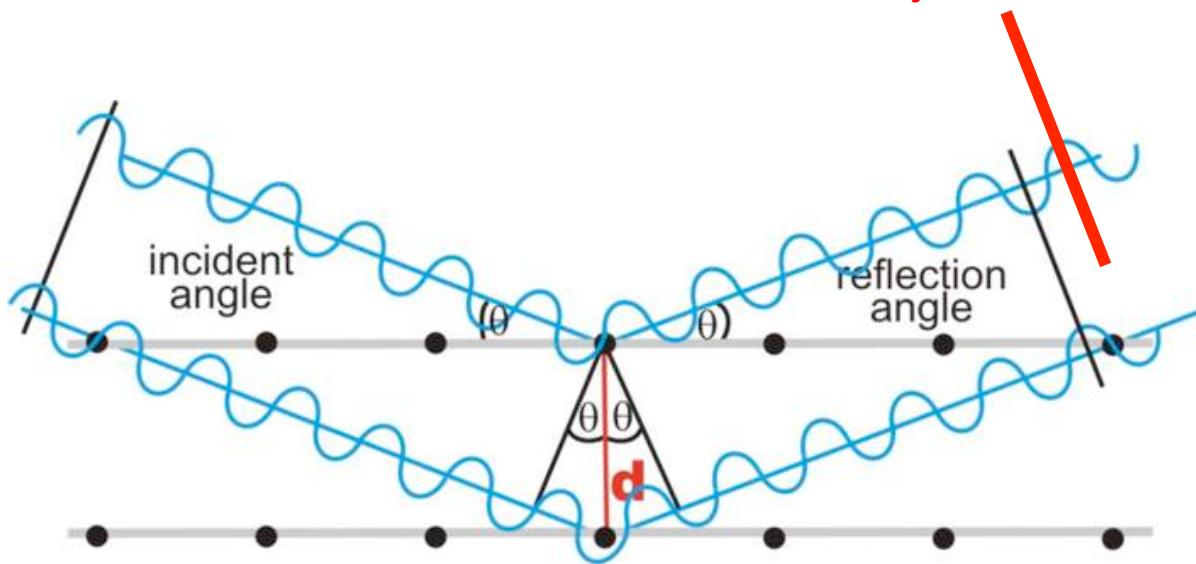
In certain directions sum of reflected WAVES added, in others cancelled.

# Bragg Diffraction

Some of the electrons bounce off and interfere constructively.



Some of the electrons bounce off and interfere destructively.



# Schrodinger: Wave Equations for Electrons

Niels Bohr, Erwin Schrodinger, and others suggested that electrons in atoms should be treated like waves and not particles.

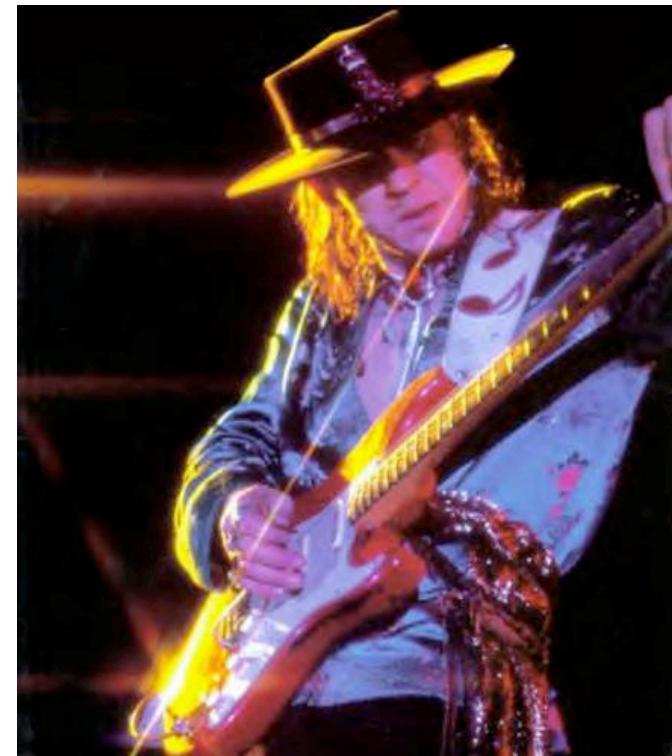
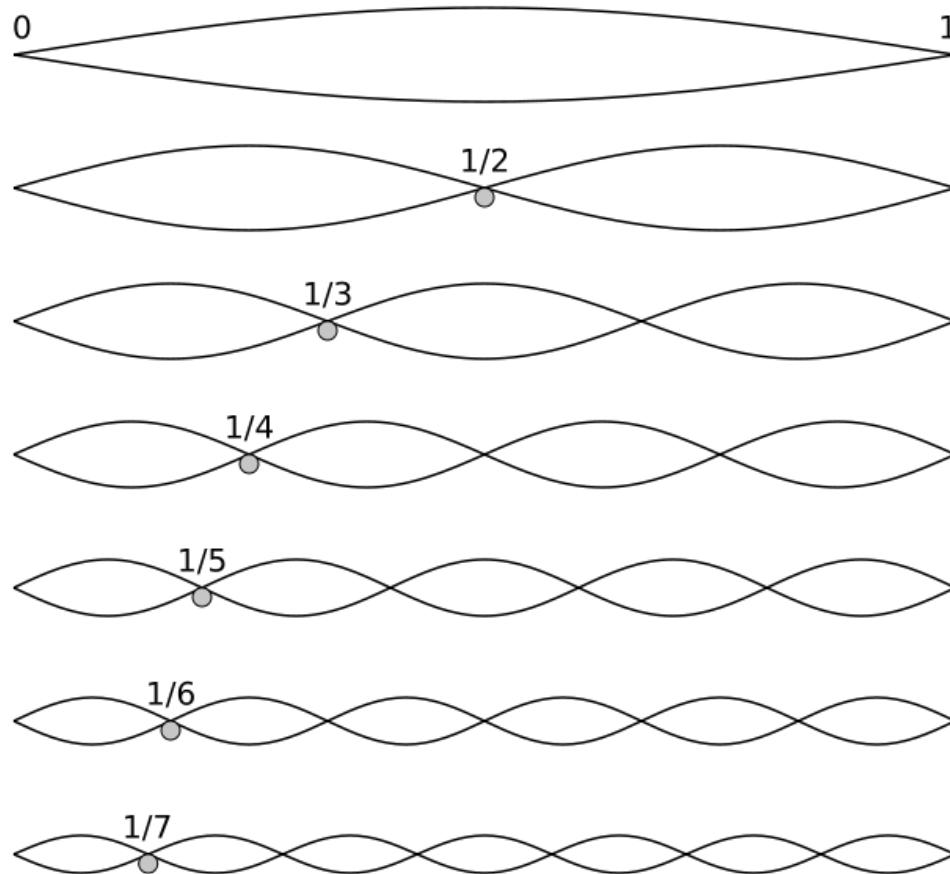
To describe electrons in atoms, they used equations that can solve for the energy and amplitude of a wave in time.



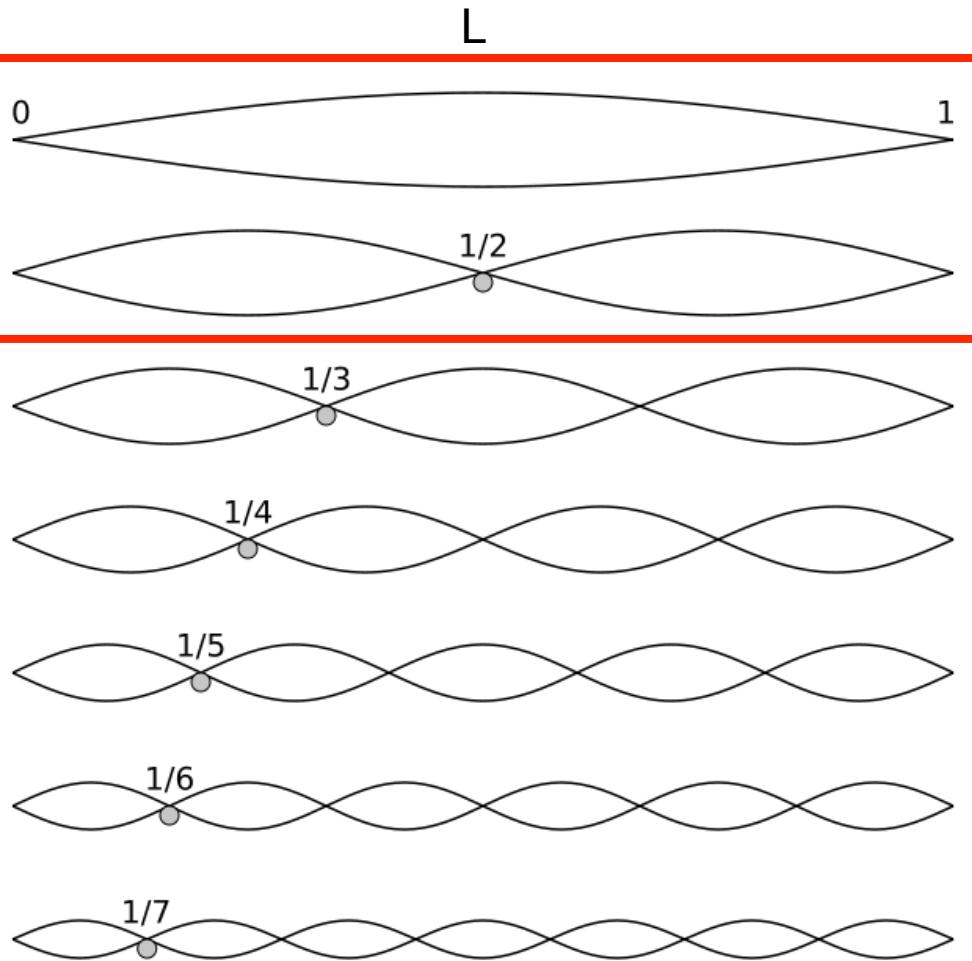
# Results of the Treatment of Electrons as Waves

The wave equations had been known for at least 200 years. You may be familiar with the results of the wave equation when applied to strings of length  $L$ :

Fundamental and 1<sup>st</sup> 6 overtones of a vibrating string form harmonics. The energies and amplitudes are quantized rather than continuous.



# Results of the Treatment of Electrons as Waves



Predictions from the Wave Equations

Nodes: Positions along  $L$  where the wave amplitude is 0.

$E$ : Increases as # of nodes increases.

Do these look like anything you have seen on an atom?

# Atomic Orbitals

AO wave equations: Waves around the nucleus (a 3D guitar string).  
Described mathematically by the wave function.

$\psi$  = radial function  $\times$  angular function

$\psi_{1s}$  = decreases exponentially as  $r$  increases  $\times$  constant

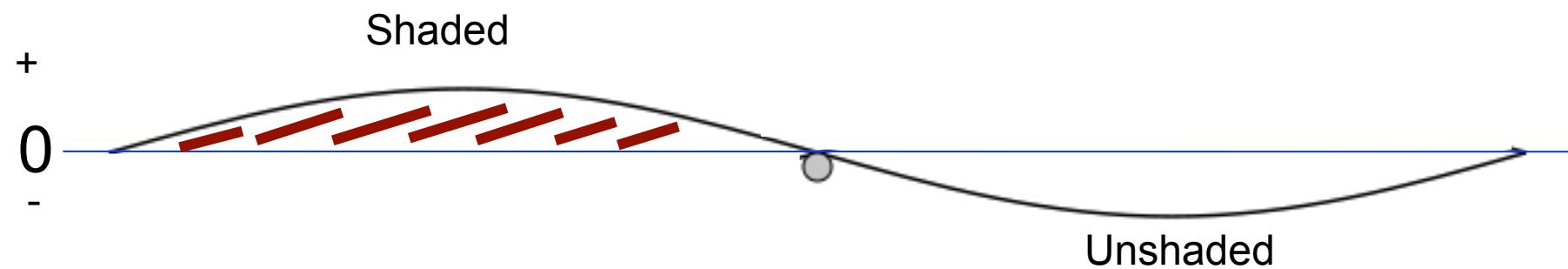
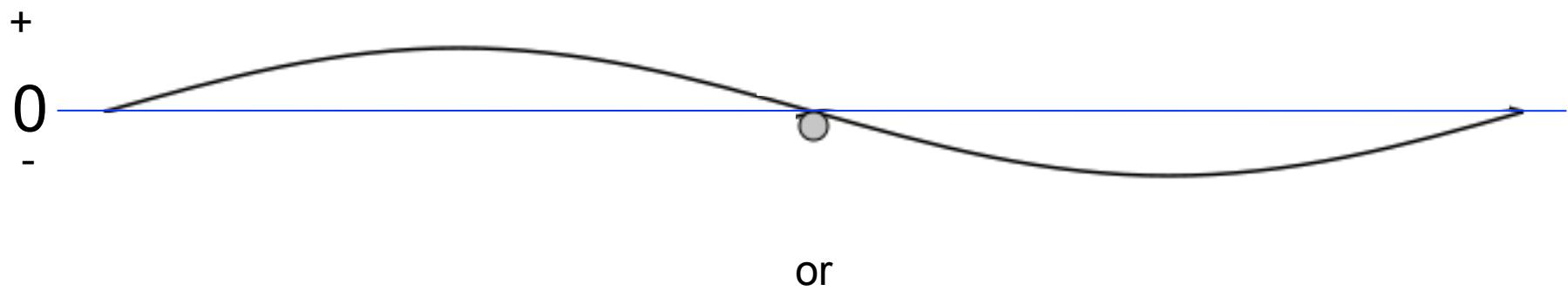
<http://winter.group.shef.ac.uk/orbitron/AOs/1s/wave-fn.html>

$\psi_{2p}$  = peaks on either side of the nucleus then decreases exponentially  
 $\times$  term dependent upon angle

<http://winter.group.shef.ac.uk/orbitron/AOs/2p/wave-fn.html>

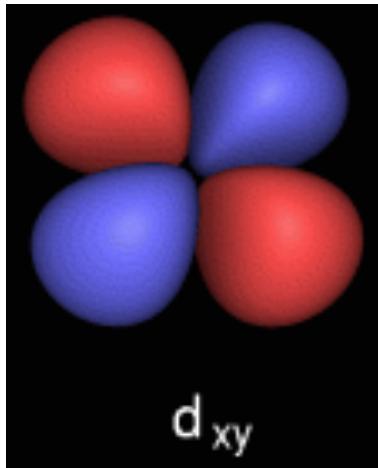
Notice that the sign of the equation describing the wave can change.

# Sign Conventions



# Atomic Orbitals

## Orbital Shading



The orbital shading represents a change in sign of the wave function.

This is a key concept in the use of atomic orbitals to construct molecular orbitals.

The figure shows a single d orbital (not 4 orbitals). An electron in this orbital may be described as a wave with a probability of having a non-zero amplitude in the regions colored blue and red.

# Molecular Orbitals

## MO Theory: Linear Combination of Atomic Orbitals

Basic Assumption: N atomic orbitals are summed to form N molecular orbitals (you saw this with hybridization).

Consider atoms A and B with atomic wave functions  $\psi_a$  and  $\psi_b$

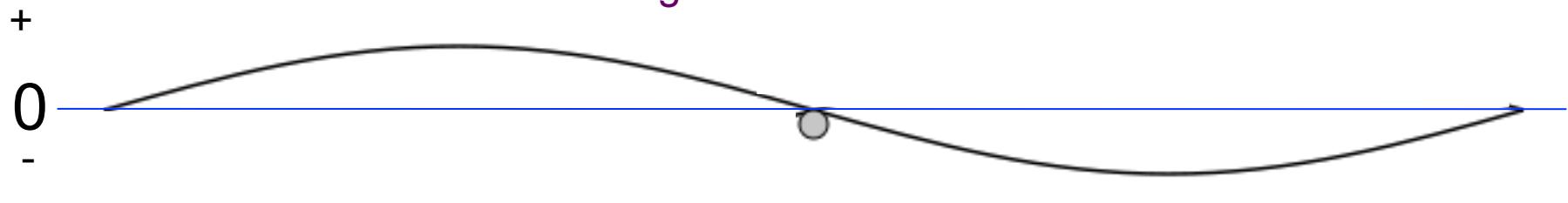
$$\psi_{ab} = \psi_a + \psi_b$$

$$\psi_{ab}^* = \psi_a - \psi_b$$

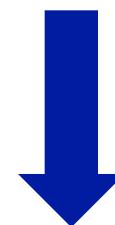
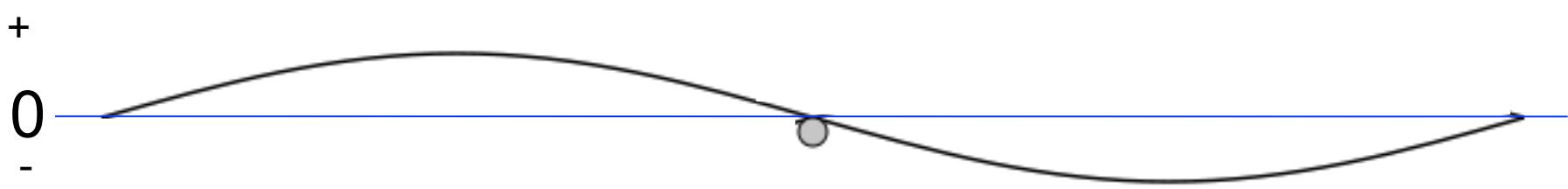
Two new molecular wavefunctions (orbitals) are obtained by taking the sum and difference of the atomic wavefunctions.

# Making Molecular Orbitals From Atomic Orbitals

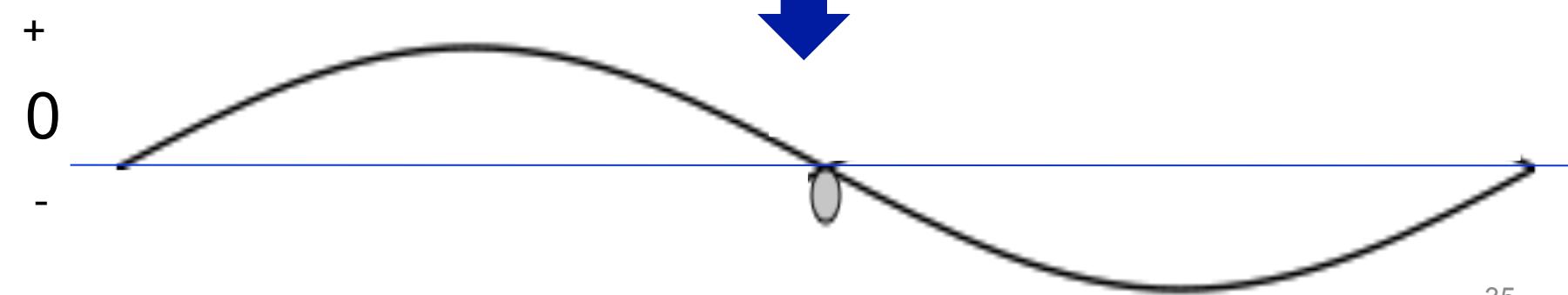
Adding Wavefunctions



+

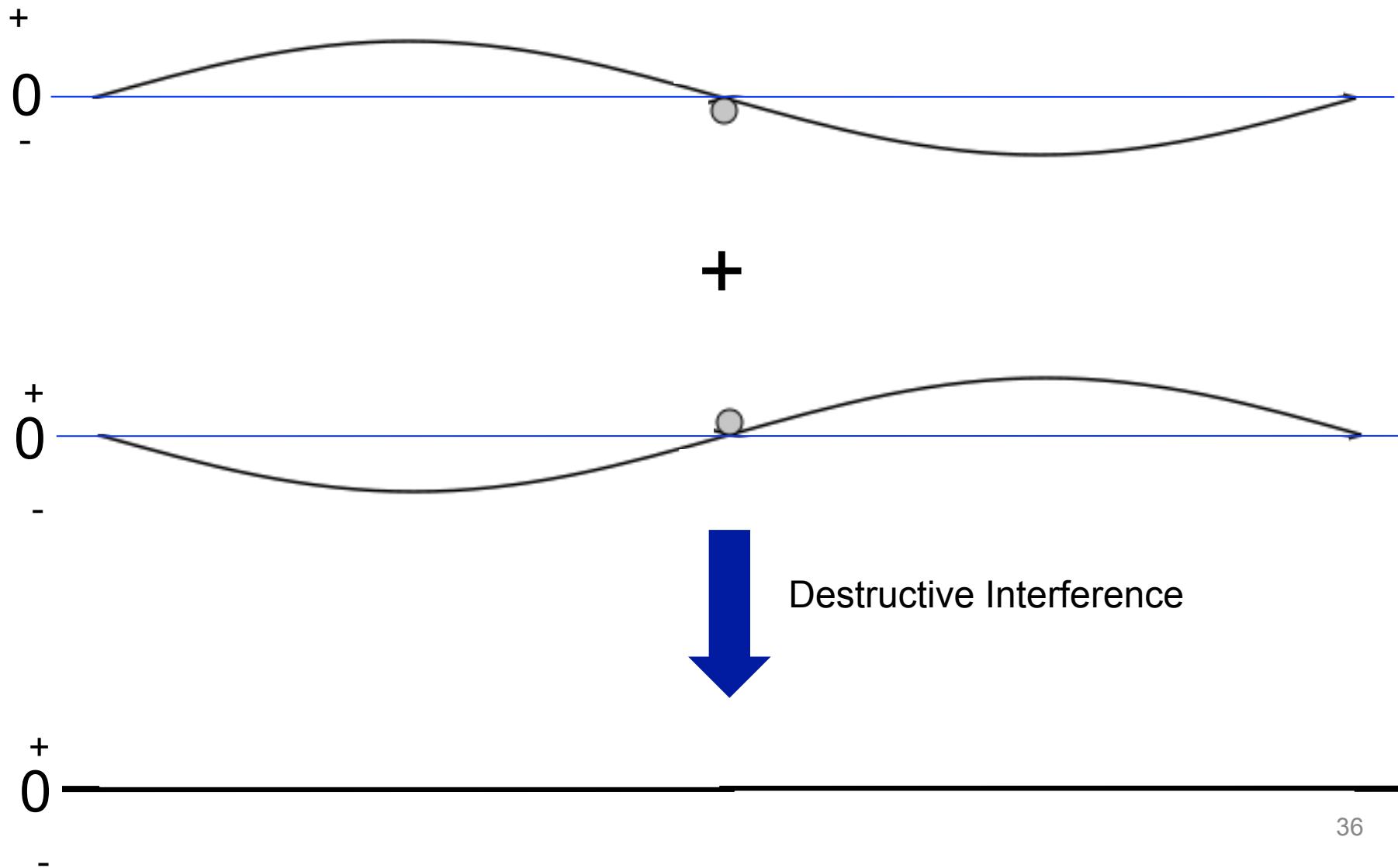


Constructive Interference



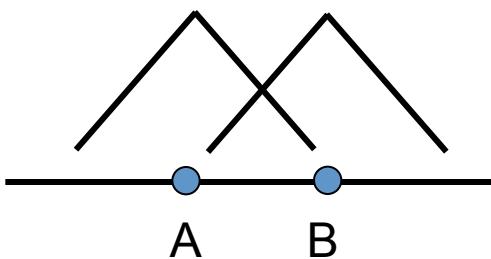
# Making Molecular Orbitals From Atomic Orbitals

Subtracting Wavefunctions: Changing the sign on one function and adding is equivalent to subtracting one from the other.

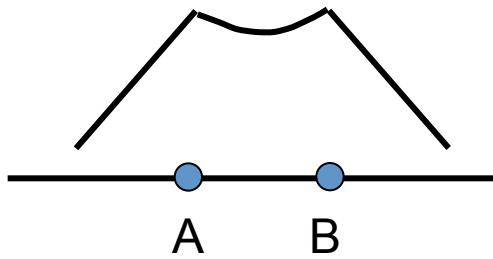


## Two s orbital wavefunctions

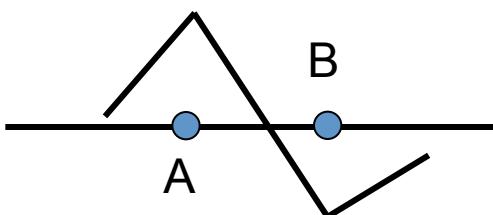
$\psi_a$  and  $\psi_b$



$$\psi = \psi_a + \psi_b$$

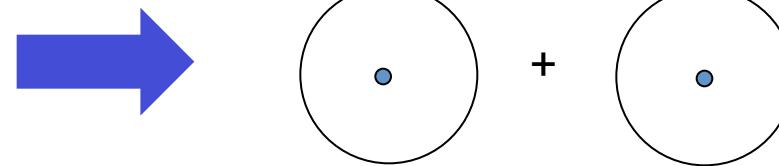


$$\psi^* = \psi_a - \psi_b$$



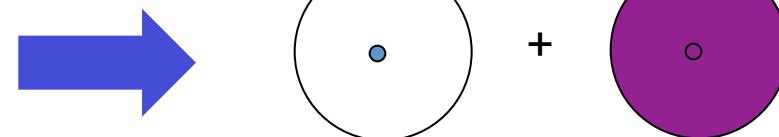
When taking the sum and difference, we are adding and subtracting waves to create a new wave.

AO's with Same Shading  
(Constructive Interference)



<http://winter.group.shef.ac.uk/orbitron/MOs/H2/1s1s-sigma/index.html>

AO's with Opposite Shading  
(Destructive Interference)



<http://winter.group.shef.ac.uk/orbitron/MOs/H2/1s1s-sigma-star/index.html>

# Electron Probability Functions

$\psi^2$  is taken to give the probability of finding the electron in a given position.

<http://winter.group.shef.ac.uk/orbitron/AOs/1s/radial-dist.html>

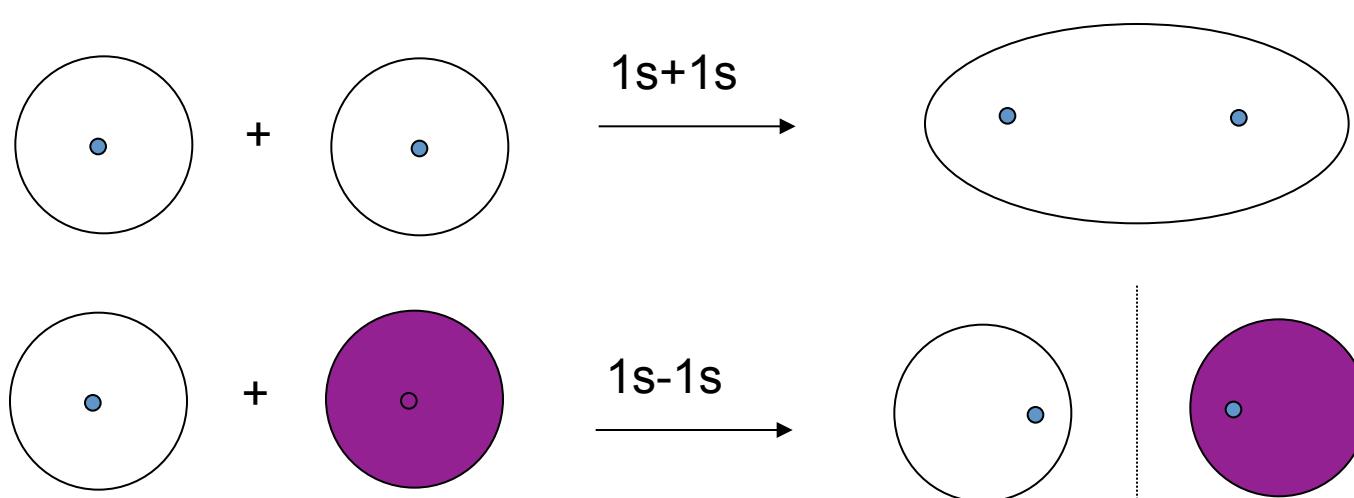
Notice that the probability of finding the electron in a 1s orbital at the nucleus is 0!

# In Molecules The Probability Function Leads to the Overlap Integral, S

$$\psi^2_{\text{bonding}} = \psi_a^2 + 2\psi_a\psi_b + \psi_b^2$$

$$\psi^2_{\text{antibonding}} = \psi_a^2 - 2\psi_a\psi_b + \psi_b^2$$

- $S > 0$ ; bonding orbital, created by overlapping regions with same shading
- $S < 0$ ; antibonding orbital, created by overlapping regions with opposite shading
- $S = 0$ ; nonbonding orbital



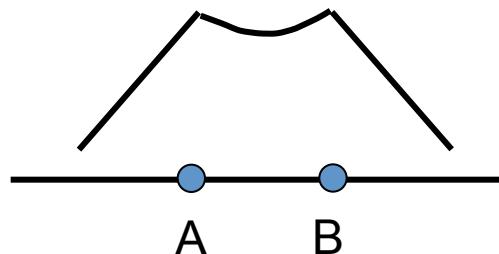
# Concept Review

Which of the following is not a true statement?

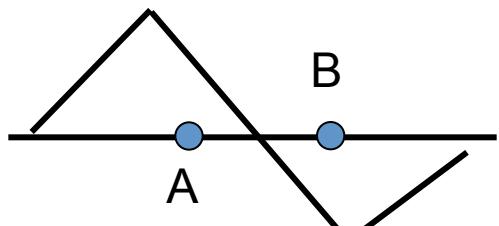
- (A) When making molecules from atoms, the # of atomic orbitals one starts with must equal the # of molecular orbitals one ends with.
- (B) Electrons in atoms are like satellites orbiting Earth.
- (C) Antibonding orbitals are never filled with electrons, that's why they're called ANTIbonding!
- (D) (B) and (C) are not true.

## Wavefunctions

$$\psi = \psi_a + \psi_b$$

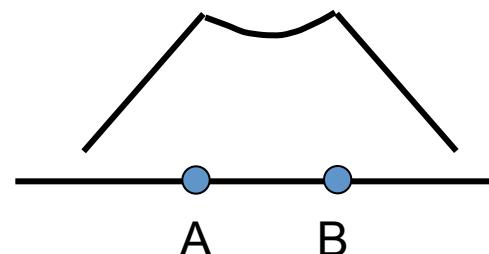


$$\psi^* = \psi_a - \psi_b$$

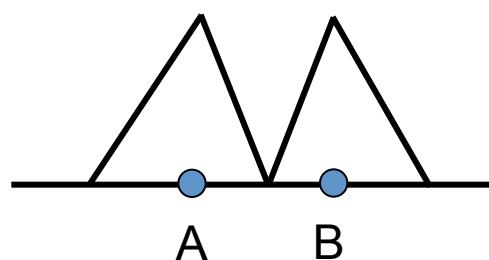


## Probability Functions

$$(\psi)^2 = \psi_a^2 + 2\psi_a\psi_b + \psi_b^2$$

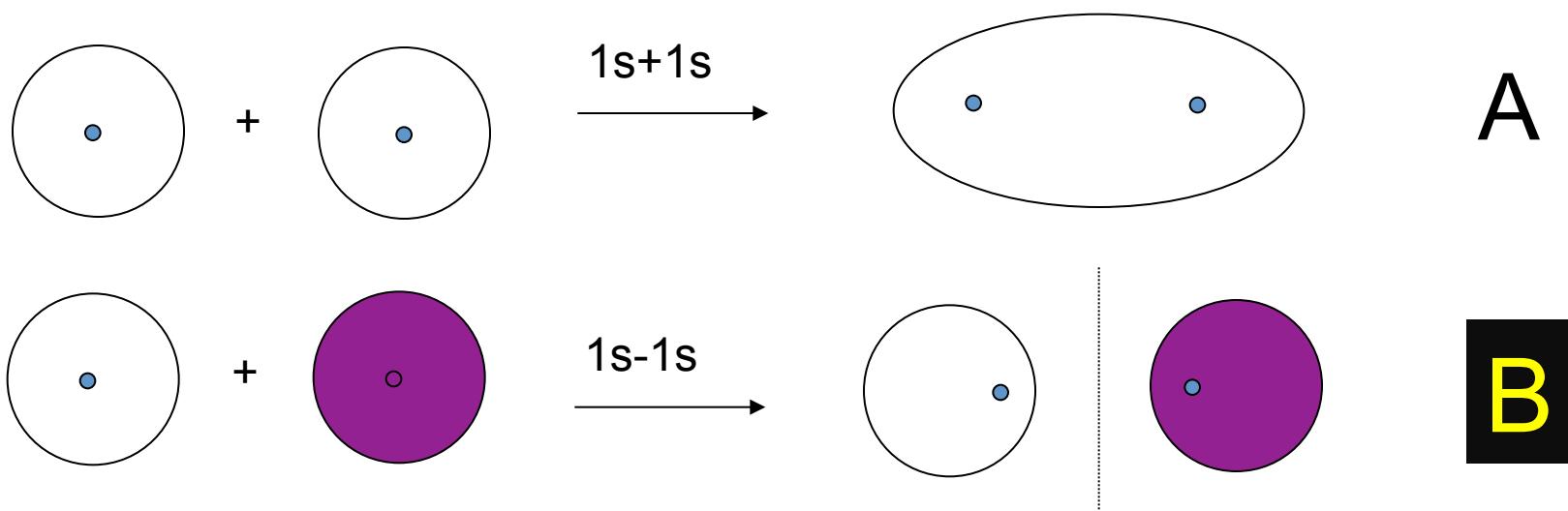


$$(\psi^*)^2 = \psi_a^2 - 2\psi_a\psi_b + \psi_b^2$$



# Concept Test

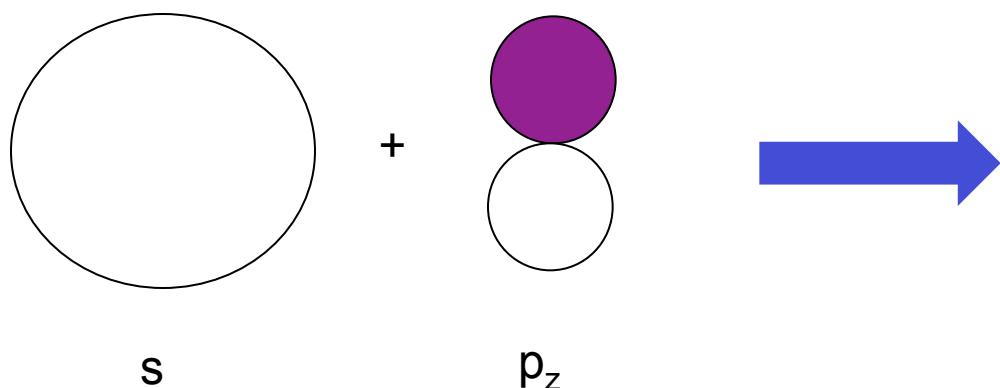
Imagine that the two 1s atomic orbitals below reside on two H atoms with the green circle representing the proton. When the two come together to form the bonding and antibonding molecular orbitals depicted at right, which MO would have a higher energy?



B contains a node; more nodes = higher Energy.

# Concept Test

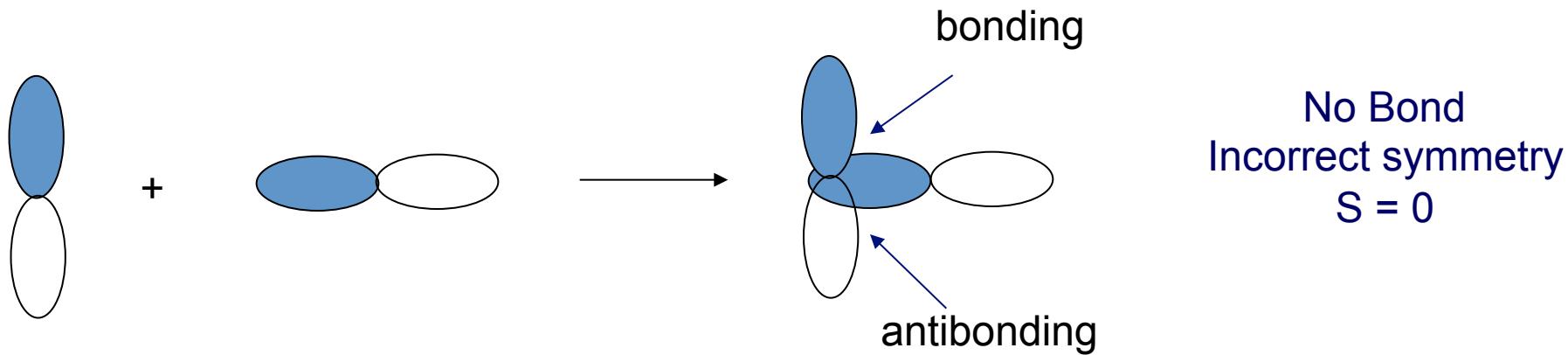
Imagine an s orbital on one atom attempts to form a bond with a  $p_z$  orbital on another atom as shown below. These AOs would form what type of MO?



- A) Bonding MO
- B) Antibonding MO
- C) No MO due to incorrect symmetry
- C) No MO due to incorrect symmetry

# Nonbonding Orbitals

Try overlapping 2 p orbitals that point in different directions:

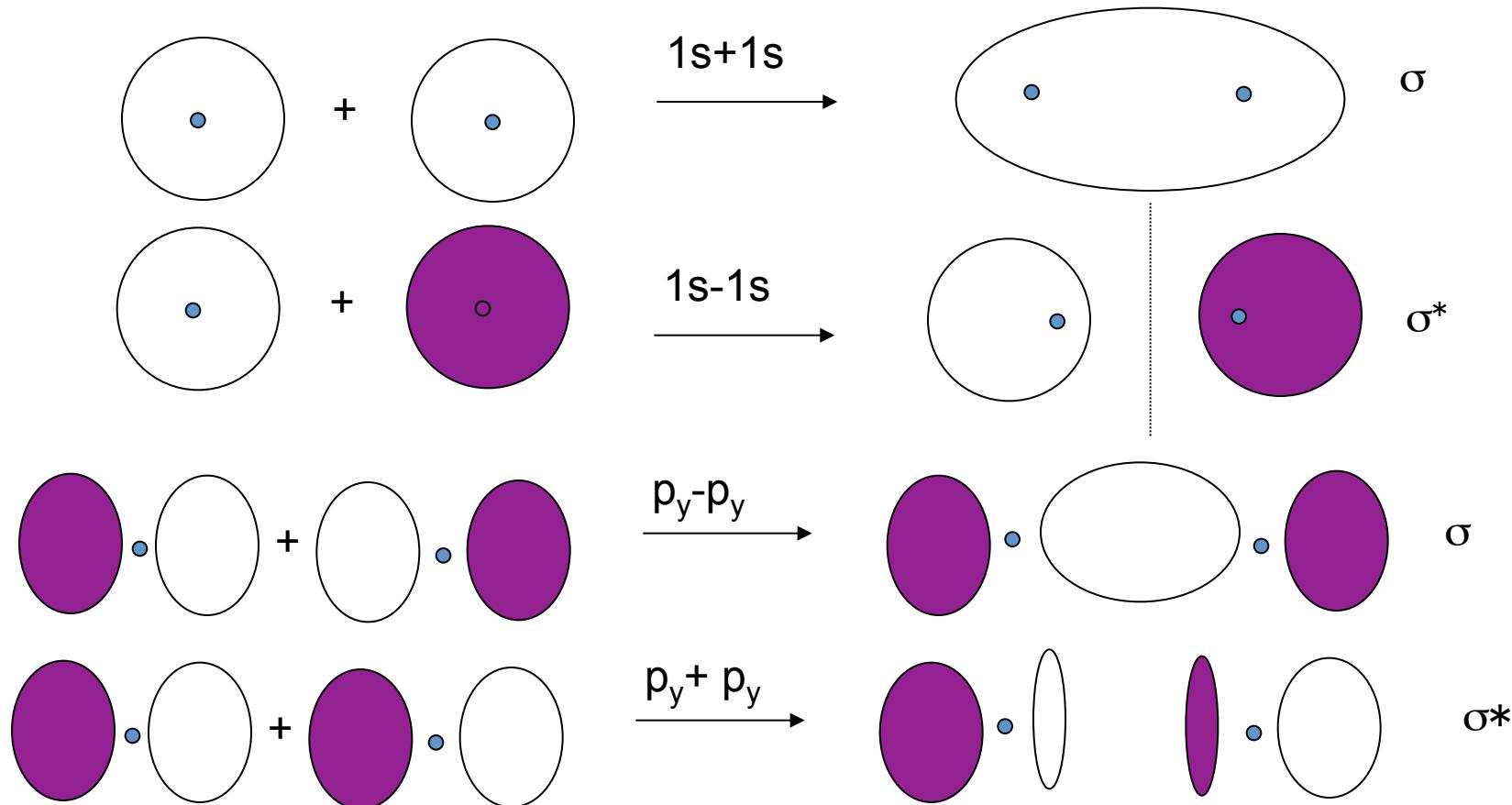


Symmetry Requirement: Atomic orbitals must point in the correct direction to form MOs.

# The General Guidelines of MO Theory

1. N atomic orbitals result in N molecular orbitals. If two atomic orbitals are combined to form a bond, two new MO orbitals result, a bonding MO and an antibonding MO.
2. Atomic orbital regions with the same shading will reinforce each other to create a “bonding orbital” while regions with opposite shading will destroy each other to form an “antibonding orbital”.
3. Bonding orbitals are lower in E than their antibonding counterparts.
4. Atomic orbitals can only “mix” to form bonding and antibonding molecular orbitals if they have relatively similar energies; the closer the atomic orbitals are in E, the stronger the interaction.
5. Only atomic orbitals with proper symmetry will mix to form bonding and antibonding MOs.
6. Atomic orbitals that do not mix are still there and must be accounted for, but they are called “non-bonding” orbitals.
7. The better the orbital overlap, the stronger the bond. In other words, the lower in energy the bonding orbital and the higher in energy the antibonding orbital.

# Examples of Bonding and Antibonding Orbitals



## Vocabulary

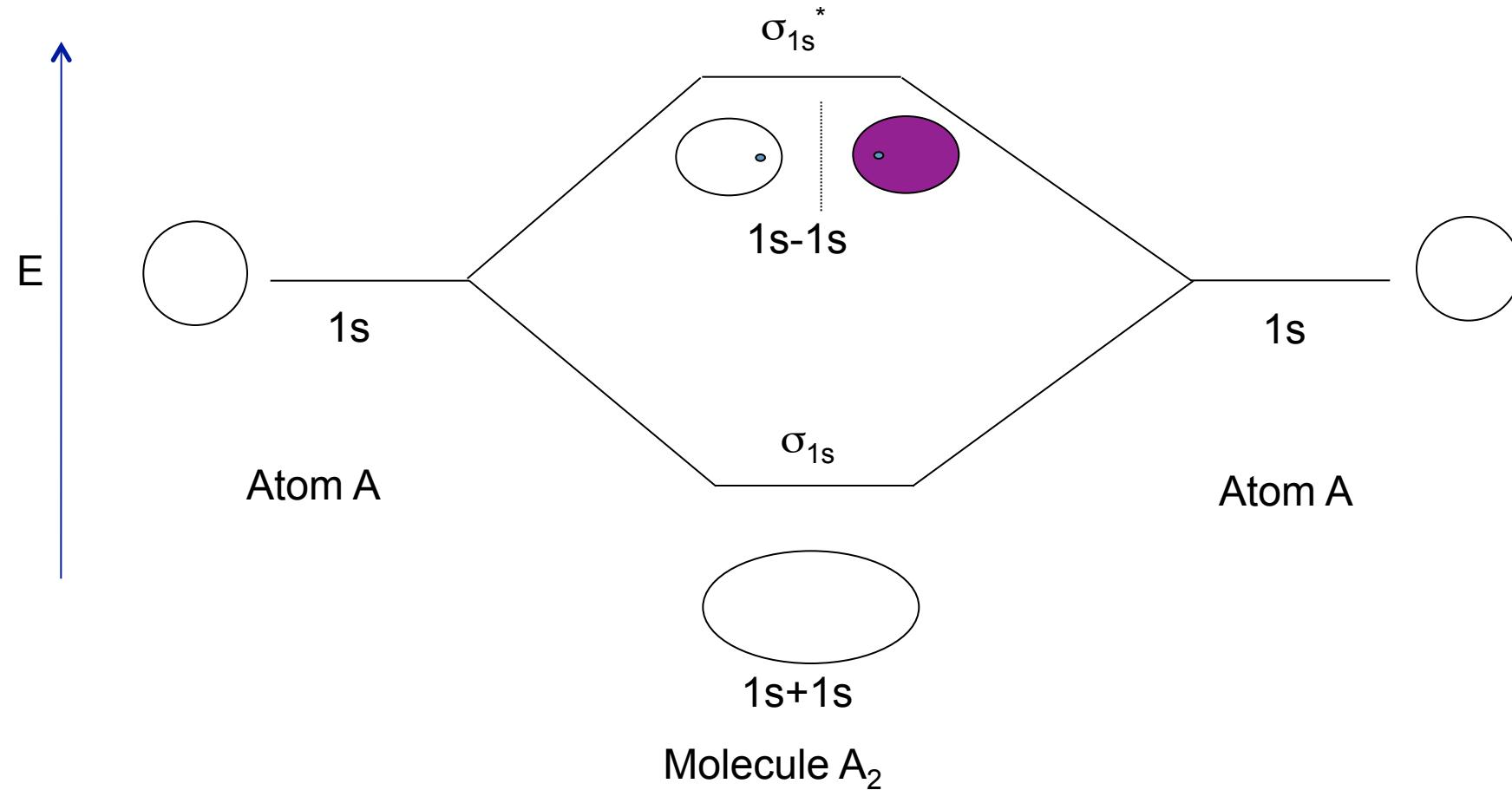
A “sigma” bond places the electrons between the plane of the nuclei.

A “pi” bond places the electrons above and below the plane of the nuclei.

Don’t be fooled, sigma bonds can be created from p orbitals.

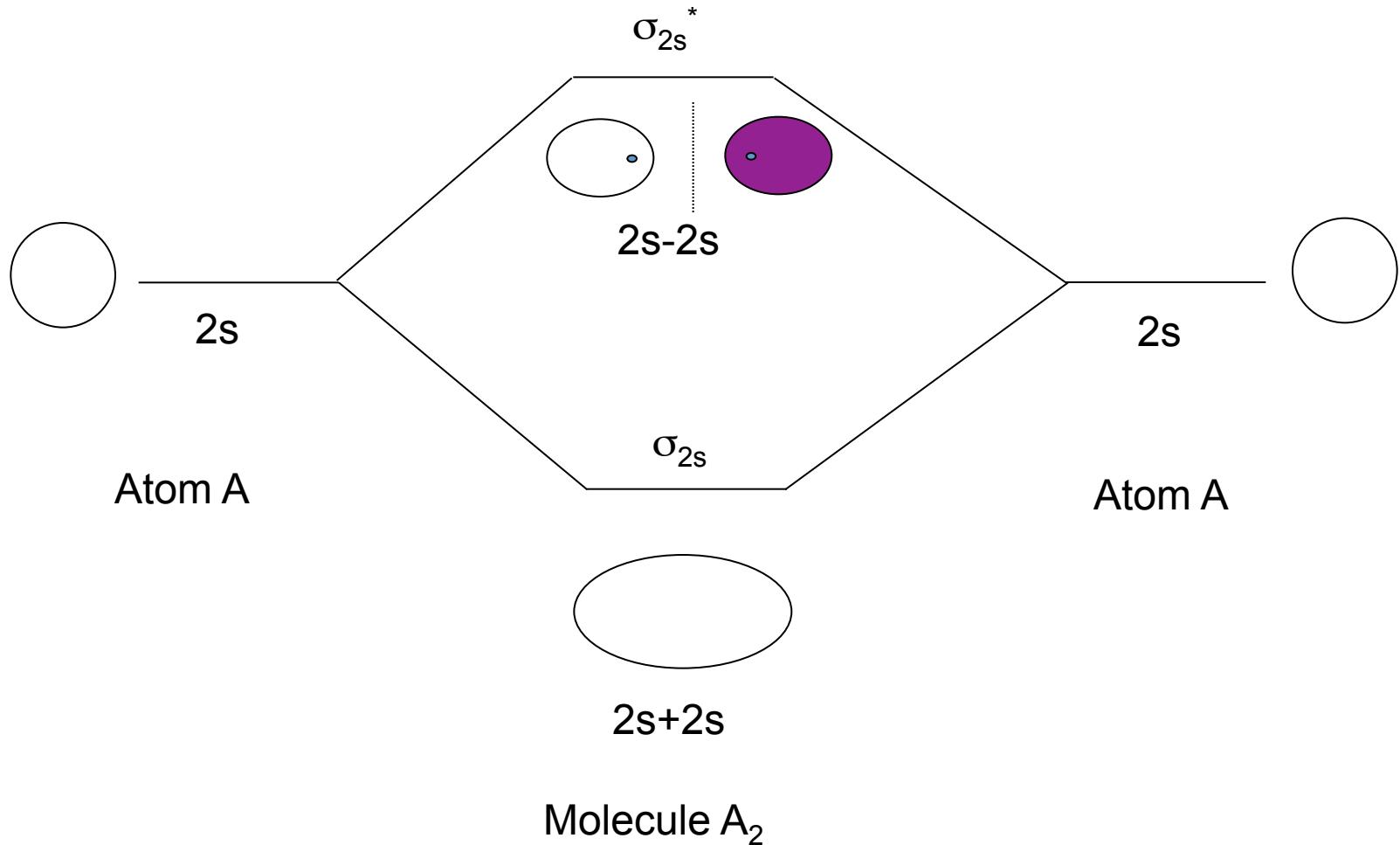
# Molecular Orbital Energy Level Diagrams

Consider the bonding that occurs between two identical atoms.

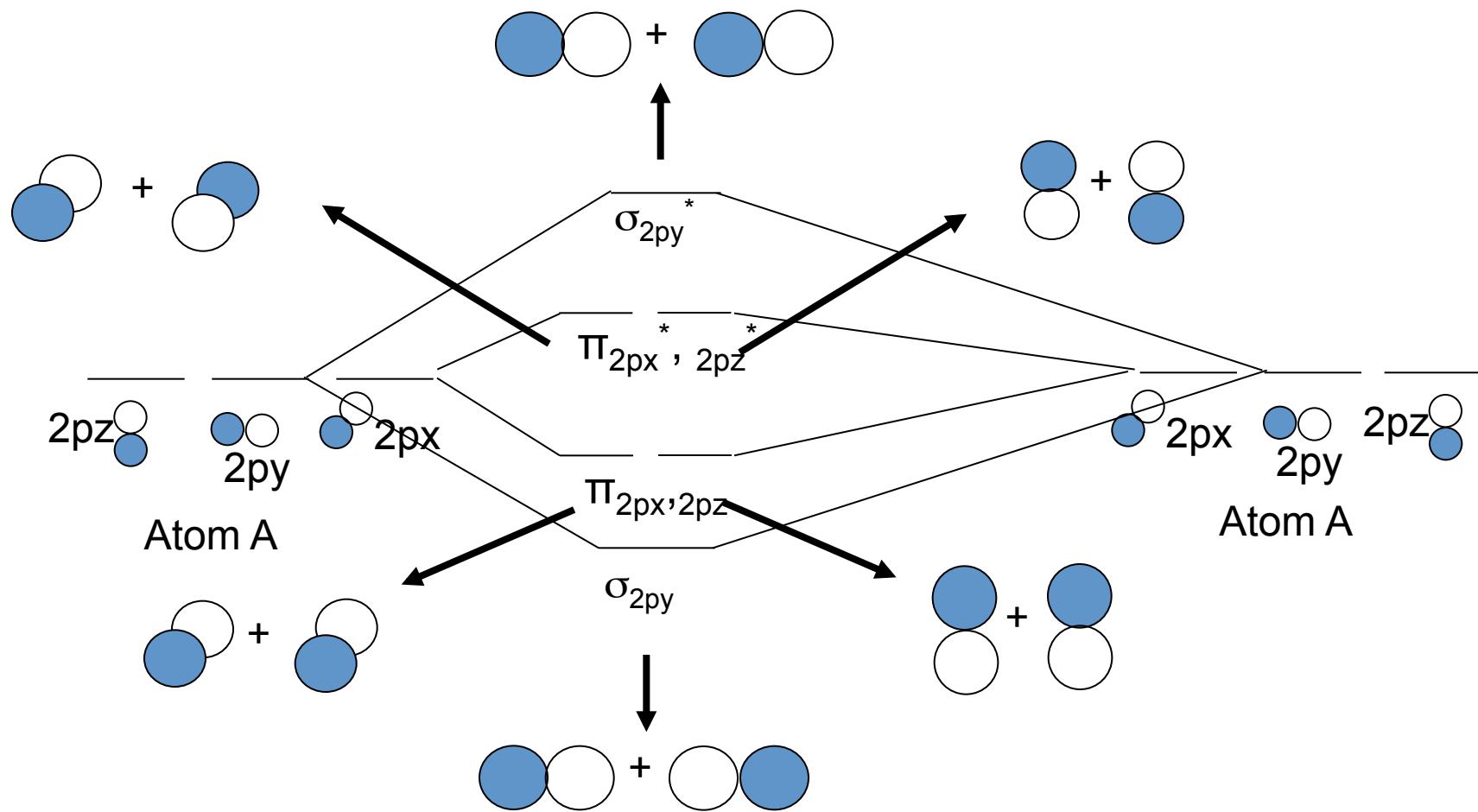


Notice that when we combine two AOs we must end up with two MOs. This is done by adding the two and then subtracting the two. Changing the shading on one of the orbitals and adding accomplishes the subtraction.

# Continuing:



## Molecular orbitals from atomic p orbitals:

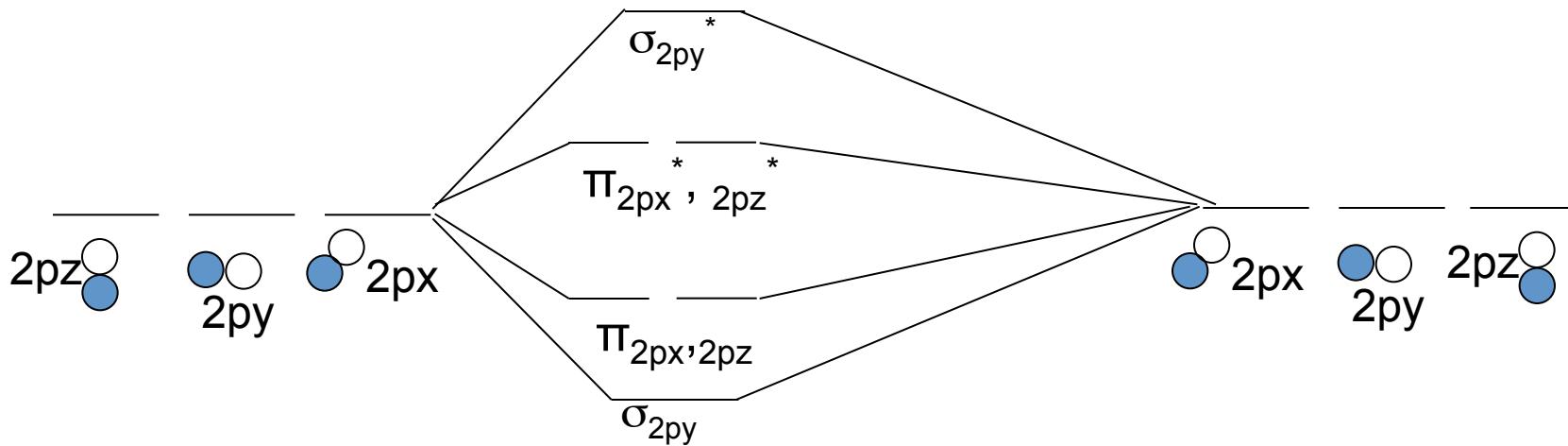


<http://winter.group.shef.ac.uk/orbitron/MOs/N2/2px2px-pi/index.html>

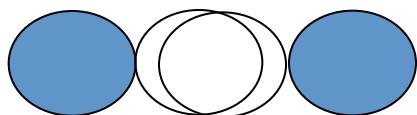
<http://winter.group.shef.ac.uk/orbitron/MOs/N2/2px2px-pi-star/index.html>

<http://winter.group.shef.ac.uk/orbitron/MOs/N2/2pz2pz-sigma/index.html>

# MO Diagrams for Simple Diatomics

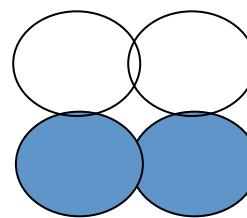


Why is it reasonable to predict that the sigma bond made from the 2p<sub>y</sub> orbitals at a lower energy than the pi bonds made from the other p orbitals?



Better Overlap = stronger bond!

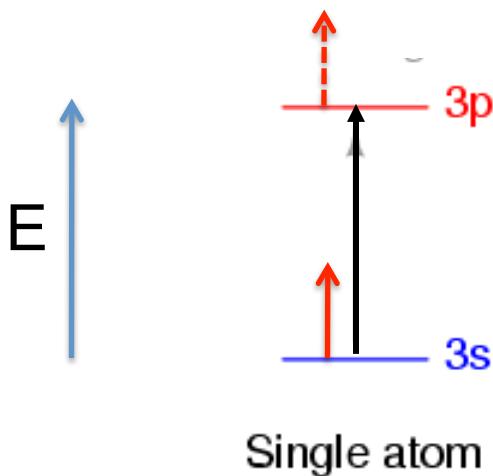
Stronger bond means lower the bonding combination and higher the antibonding combination



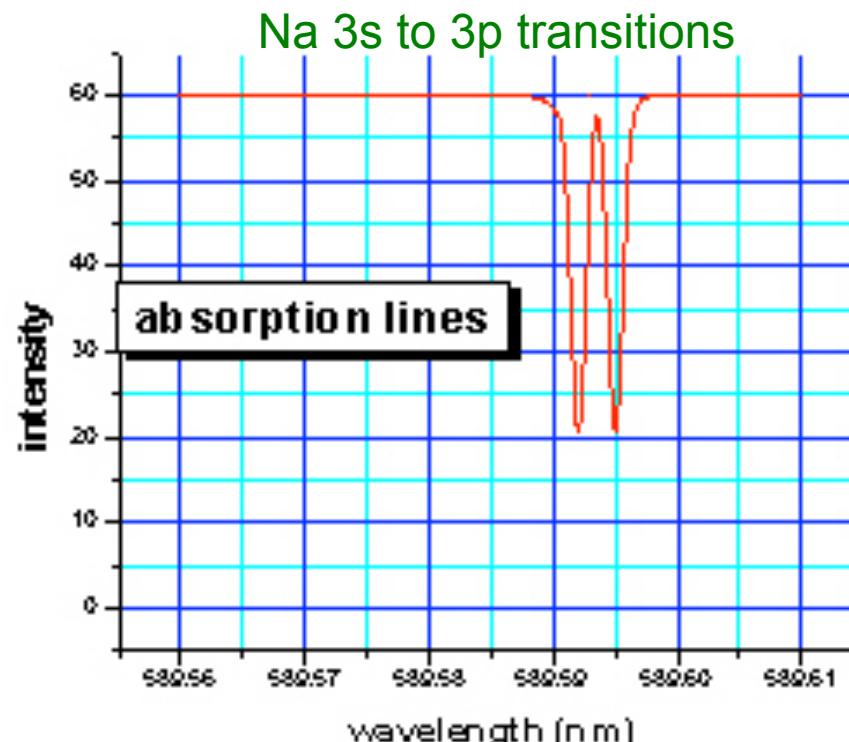
$\text{Sigma overlap} > \text{pi overlap}$

# Light Absorption and Emission

## Atomic Absorption



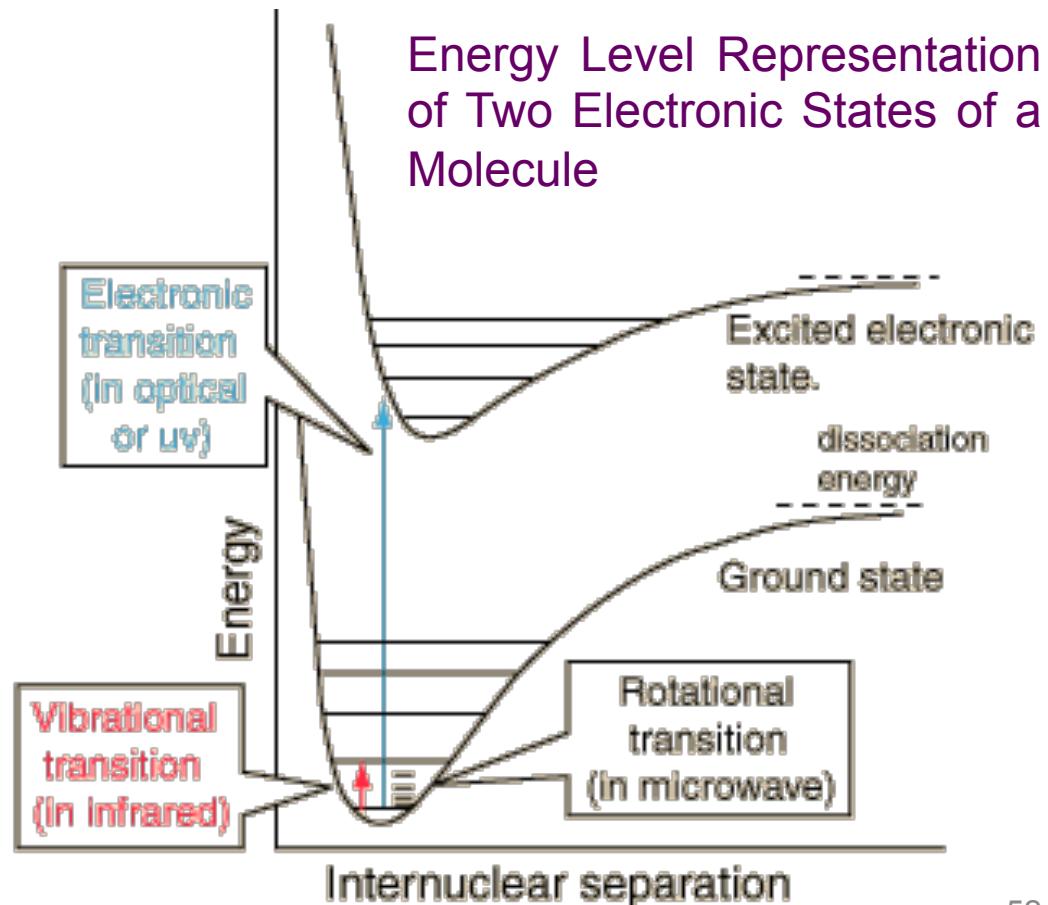
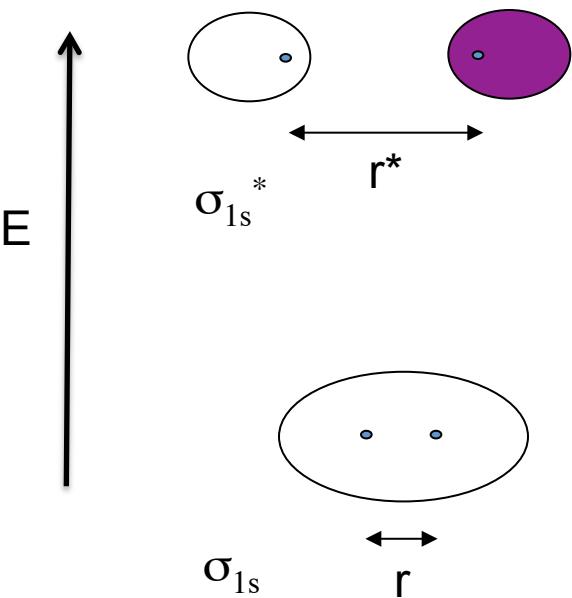
Light of the correct frequency promotes an electron from the ground state orbital to a higher-energy excited state orbital.



# Light Absorption by Molecules

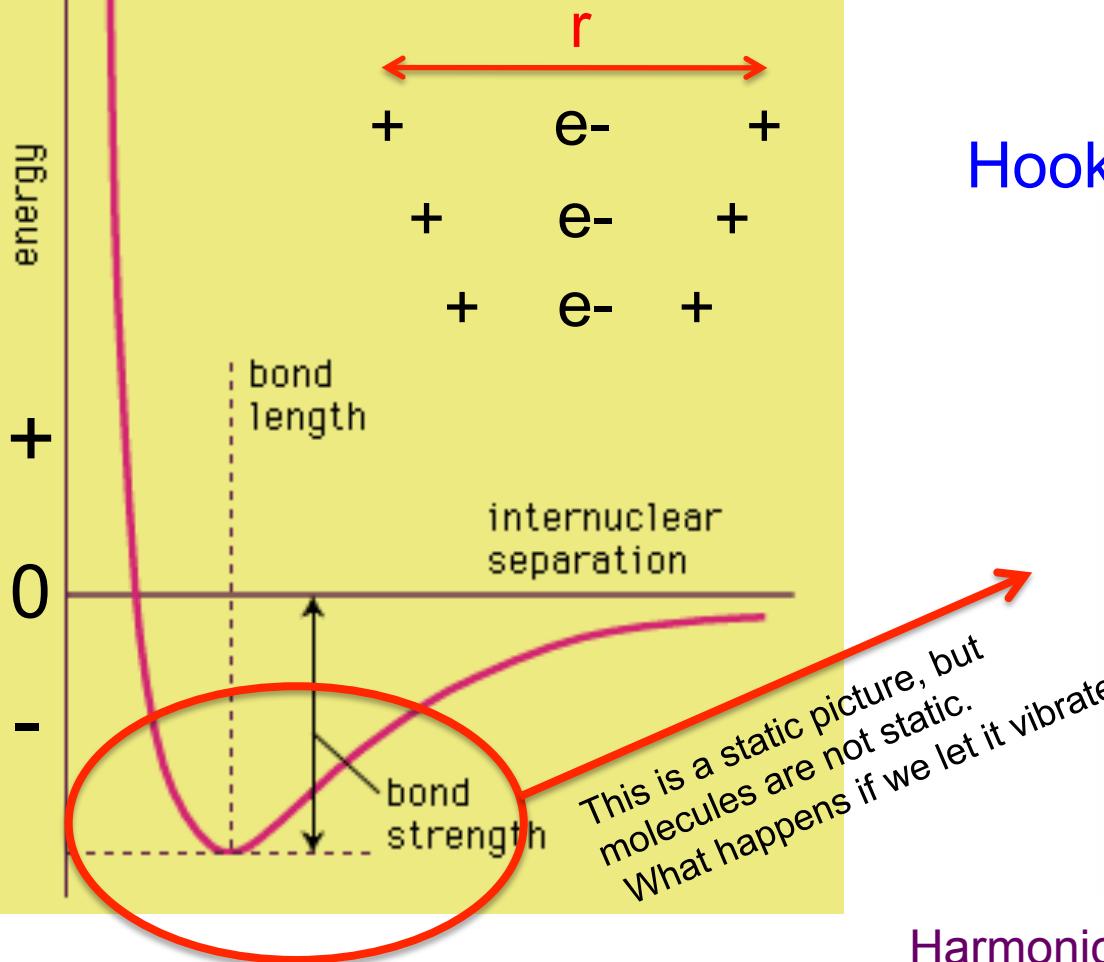
$$E_{\text{total}} = E_{\text{electronic}} + E_{\text{vibrational}} + E_{\text{rotational}}$$

Molecules have rotational, vibrational, and electronic energy states that are quantized. Light of the appropriate  $E$  can cause “transitions” between these states.

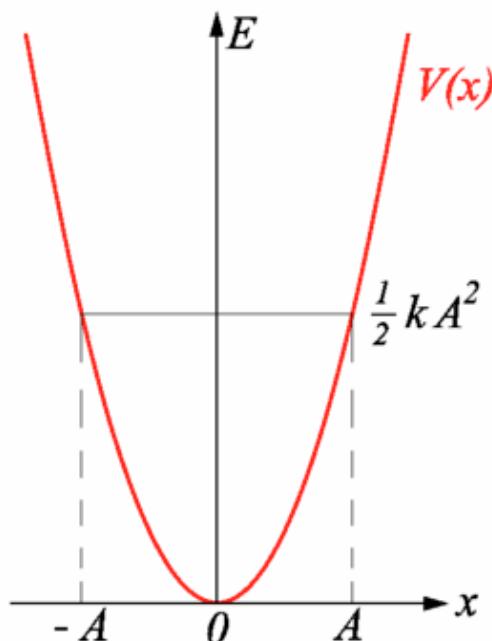


# Molecular Potential Energy

Energy of 1 electron and 2 protons separated by a distance  $r$  (H molecular ion).



$$\text{Hooke's Law: } \text{PE} = 1/2k(r - r_0)^2$$



Harmonic Oscillator Model: No other force except the restoring force of the spring<sup>53</sup>

# Molecular Potential Energy

The macroscopic (classical mechanical) version of Hooke's Law gives energies and vibrational frequencies of:

$$E = (1/2)kx^2$$

$$\nu_{\text{vib}} = (1/2\pi)(k/m)^{1/2}$$

where  $k$  is a spring constant that accounts for the stiffness of the spring and  $m$  is mass.

Notice that the frequency (or energy) of the vibration can take on any value.

# Molecular Potential Energy

But the vibrations of molecules are quantized!

The quantum mechanical solution to the energies of a vibrating molecule reflects this.

$$E_{\text{vib}} = (n + \frac{1}{2})(h/2\pi)(k/m)^{1/2}$$

$n = 0, 1, 2, \dots$

$h$  is Planck's constant

But this is for a particle attached to an immobile wall.

# Molecular Potential Energy

$$E_{\text{vib}} = (n + \frac{1}{2})(h/2\pi)(k/m)^{1/2}$$

$n = 0, 1, 2, \dots$

$h$  is Planck's constant

For two atoms connected by a spring  $m$  is replaced with the reduced mass:

$$\mu = \frac{m_1 m_2}{m_1 + m_2}$$

## Concept Test

At T = 0 K, a collection of molecules will all be in the n = 0 vibrational level. Thus, all vibrational motion will stop.

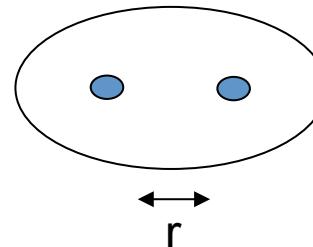
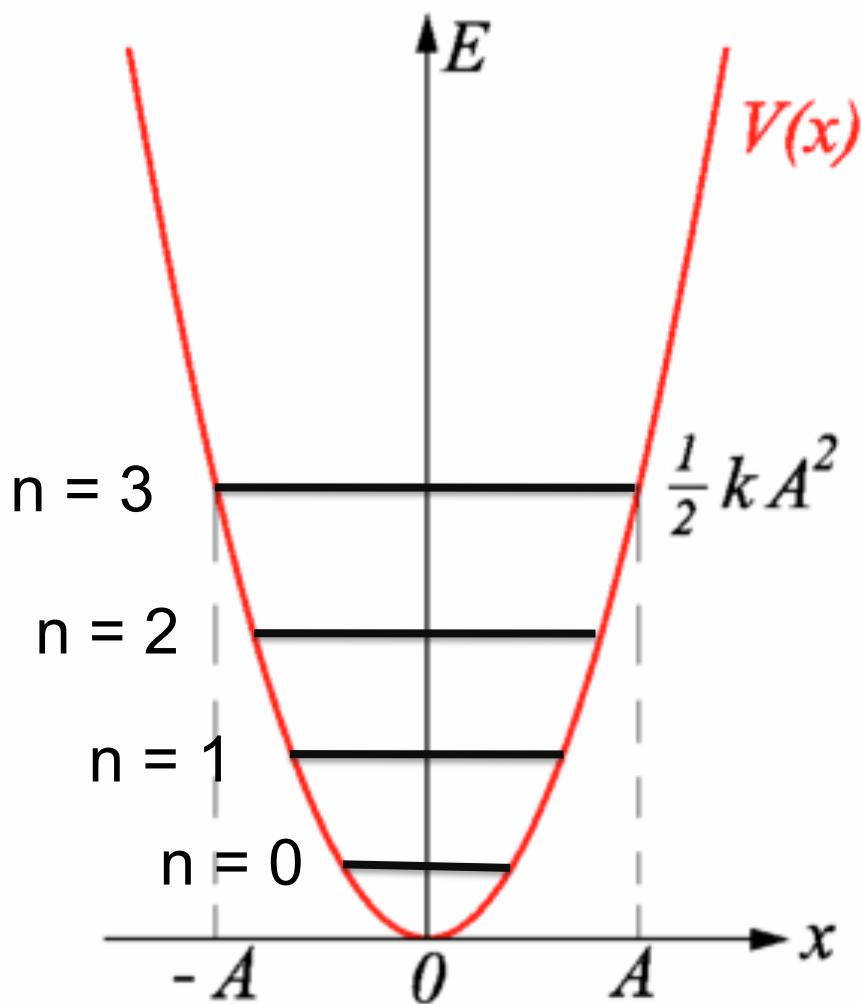
(A) True

(B) False

$$E_{\text{vib}} = (n + \frac{1}{2})(h/2\pi)(k/m)^{1/2}$$

This is called the zero-point energy.

# Molecular Potential Energy



So imagine a ground state bonding molecular orbital with an electron between two nuclei.

At some temperature  $T$ , assume that almost all of the molecules are in the  $n = 0$  vibrational state. (At some higher  $T$  the energy would be distributed between the  $n = 0$ ,  $n = 1$ .... levels.)

What happens if we irradiate the molecules with light equal in energy to the difference between the  $n = 0$  and  $1$  levels?

## Concept Test

What happens if we irradiate the molecules with light equal in energy to the difference between the  $n = 0$  and 1 vibrational levels?

- (A) The electron will move from the ground state orbital to an excited state orbital.
- (B) The molecule will vibrate with a different amplitude but the electron will remain in the same orbital.
- (C) A and B will happen.

If the light energy matches the difference in energy between vibrational energy levels the molecule will vibrate with a larger amplitude.

# Molecular Potential Energy

## Activity

For a group of three and build a diatomic molecule.

Illustrate the principle of molecular vibrations.

How many ways can your molecule vibrate?

Now form a triatomic molecule like water.

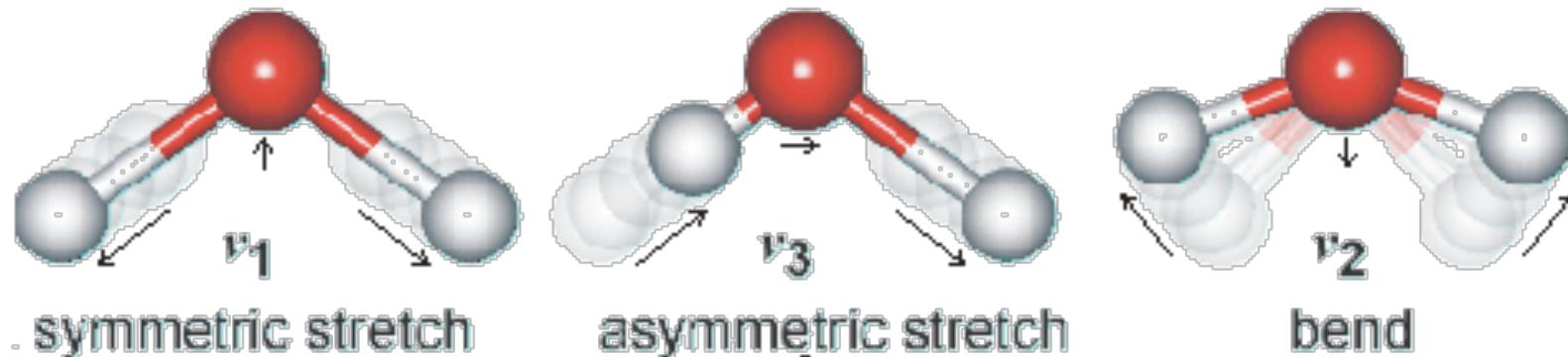
How many ways can your molecule vibrate?

Vibrational “degrees of freedom” =  $3N-6$  or  $3N-5$  for a linear molecule where  $N$  is the # of atoms.

Pick one vibration and show the Energy (amplitude) of the vibration is quantized.

# How Many Vibrations Did You Find?

$$3N - 6 = 3 \text{ modes of vibration}$$

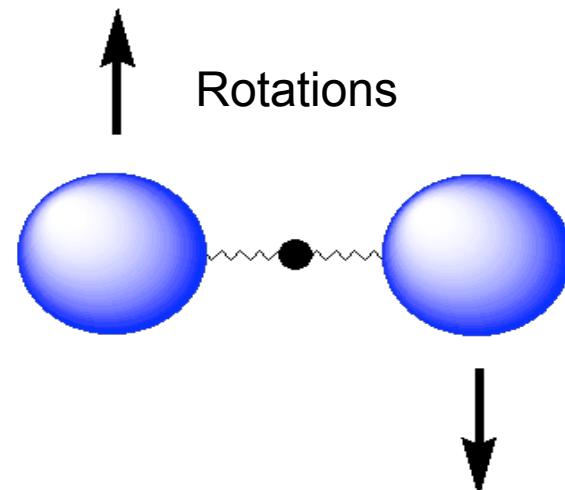


<http://www.chemtube3d.com/vibrationsH2O.htm>

# $3N - 6 = 3$ modes of vibration?

3 coordinates are required to describe the position of each atom in a molecule ( $3N$ ).

If we want to specify the positions of each atom in a molecule, we can give each atom an x, y, and z coordinate and worry about each one separately, or we can pick a center of mass with a single x, y, and z and denote angles around the center of mass through which the atoms will move. The entire molecule can move along x, y, and z (3 translations). Rotations and vibrations are movement of the atoms around a fixed center of mass.



1 atom can only translate, so it has 3 translational DOF.

2 atoms have 3 translations and 2 rotations, so there must be 1 vibration ( $3 \times 2 = 6$  total DOF).

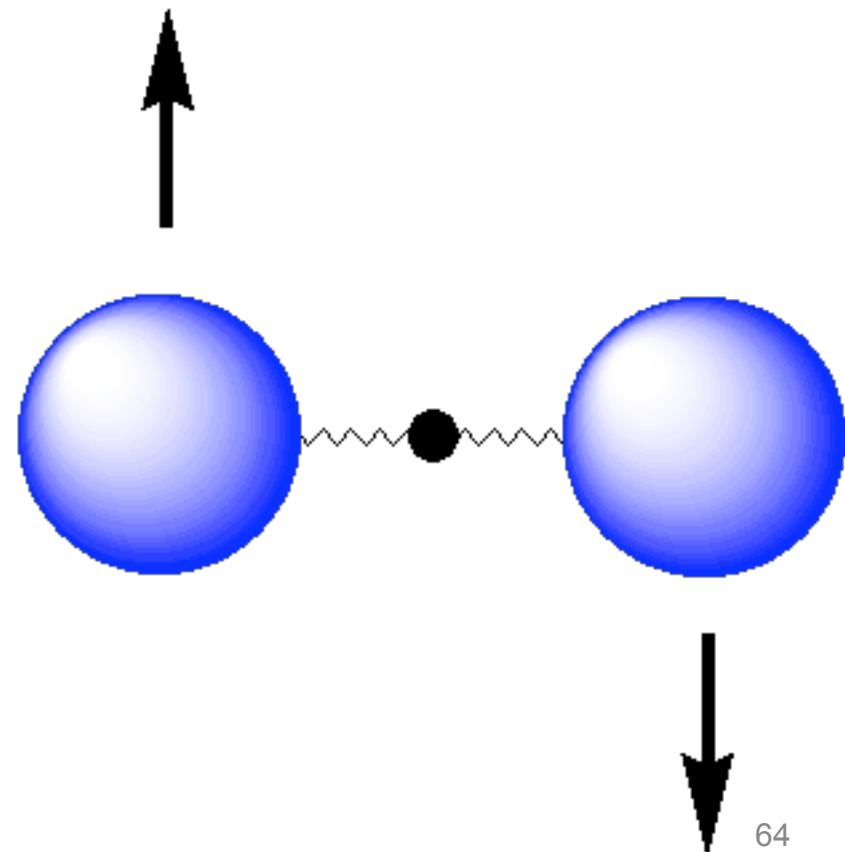
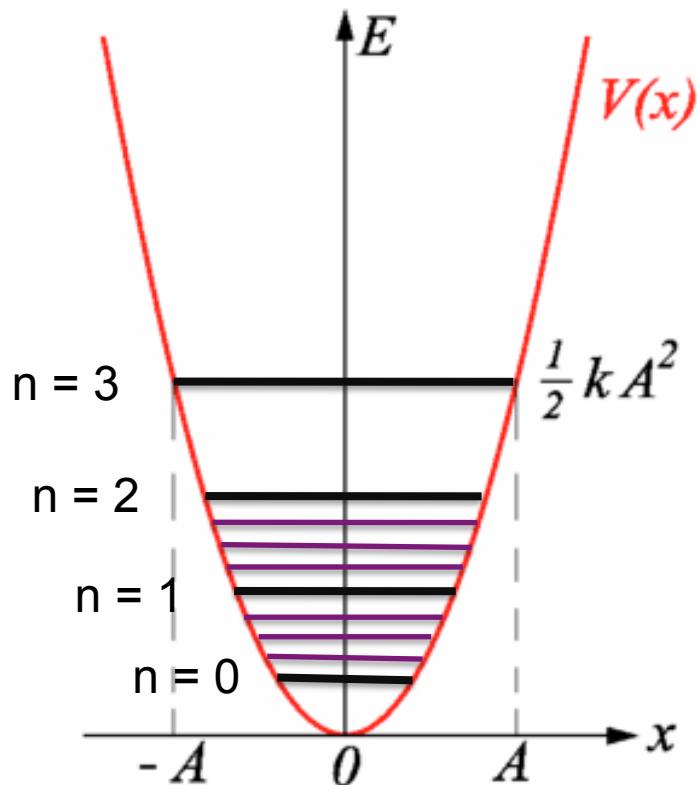
## Concept Test

Which transition requires more energy:

- (A) Electronic
- (B) Vibrational
- (C) Rotational
- (D) They all require about the same E

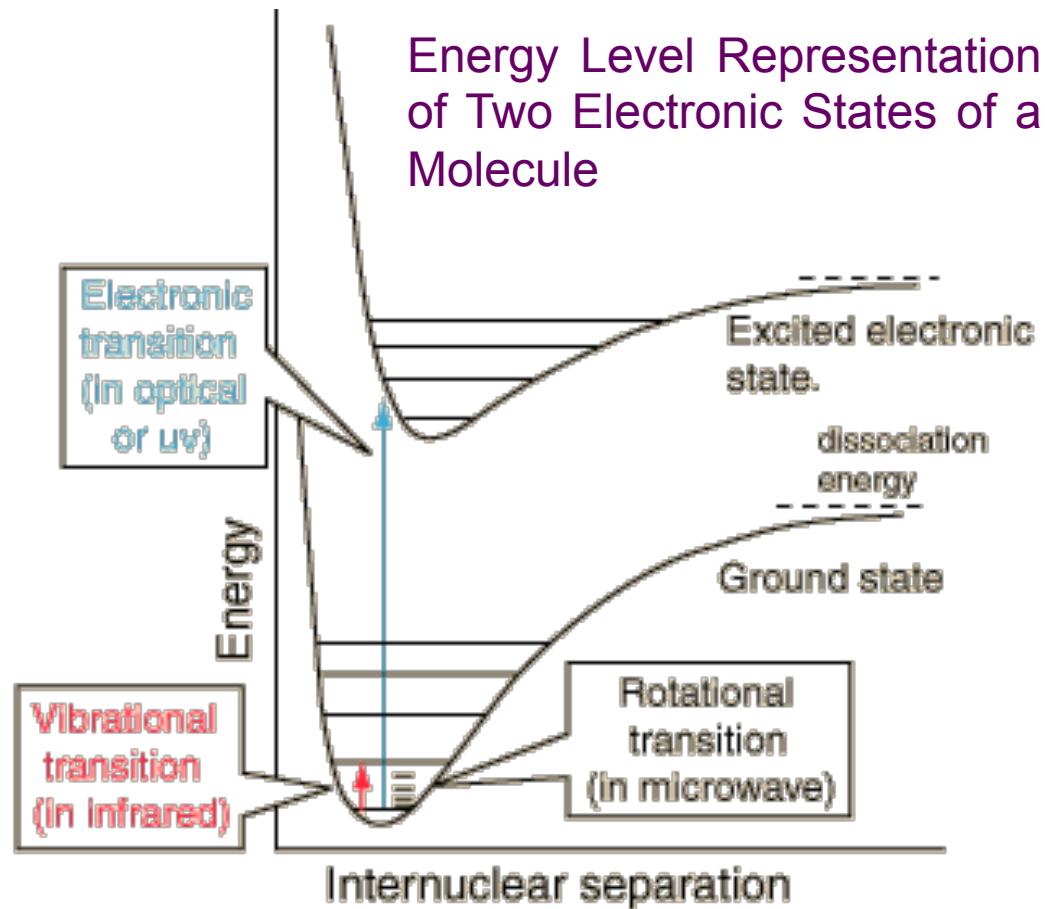
# Molecular Rotational Energy

Molecules also have energy because they can rotate, and these rotational energies are also quantized. The energy differences are very small (corresponding to microwaves), and appear as new levels within each of the vibrational levels.



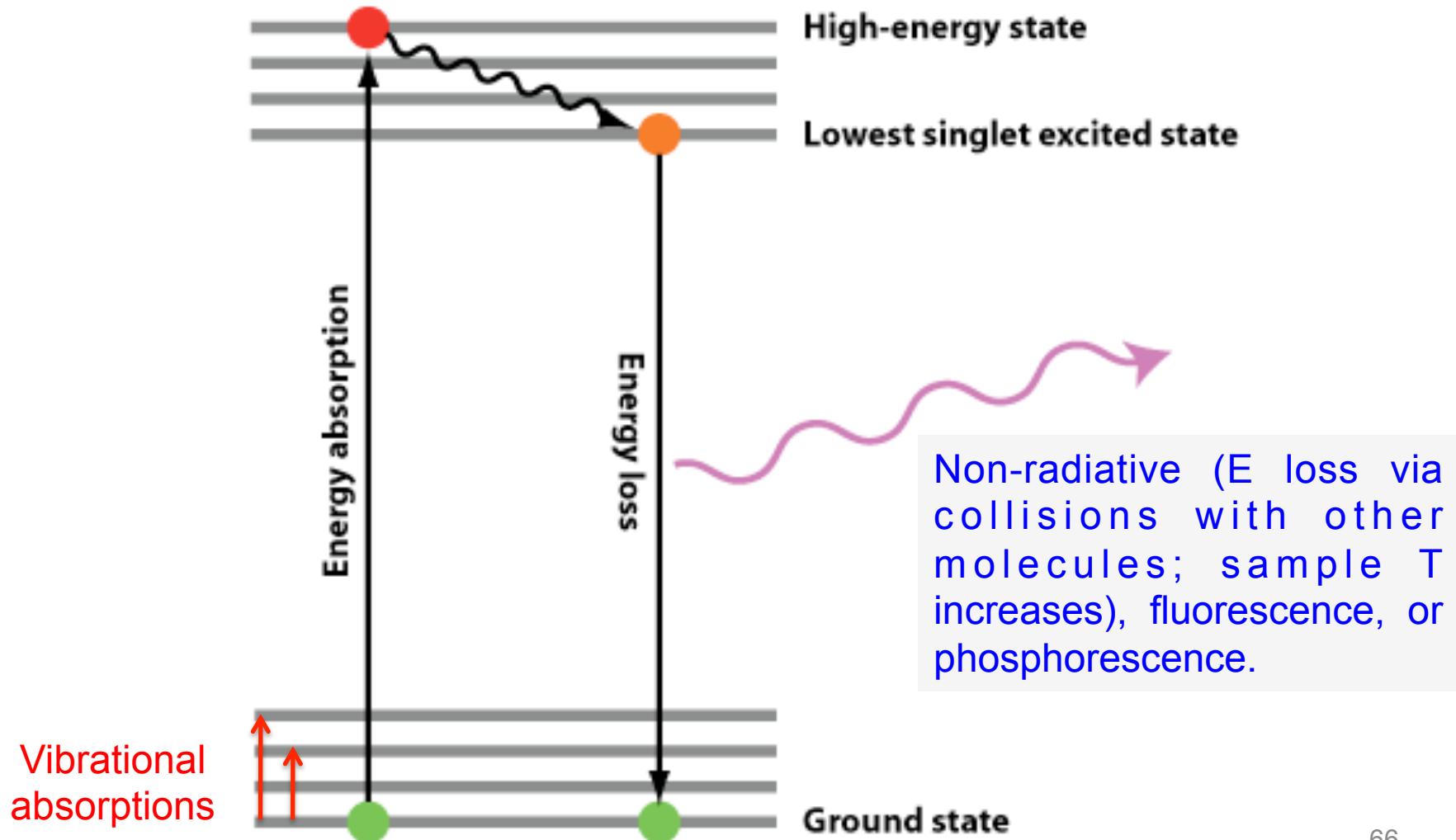
For each electronic energy state there can be many ways to vibrate and for each vibrational state there can be many ways to rotate.

Light can cause transitions between these rotational, vibrational, and electronic energy states. This provides a very useful tool for the identification and quantitation of atoms and molecules.



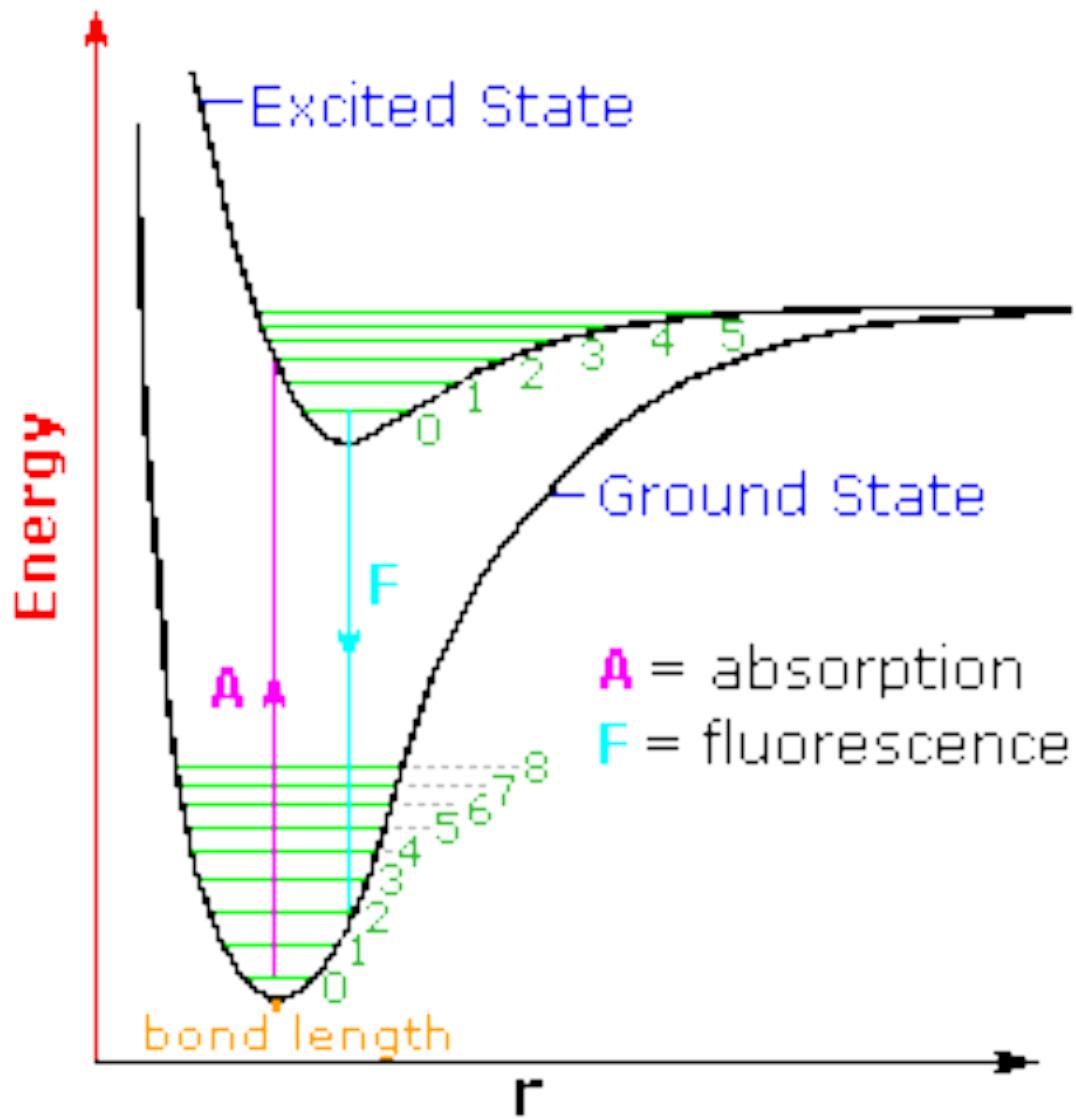
# Illustrations of Vibrational and Electronic Transitions

## A Joblonski Diagram



## Illustrations of Vibrational and Electronic Transitions

## Electronic Excitation of X-X

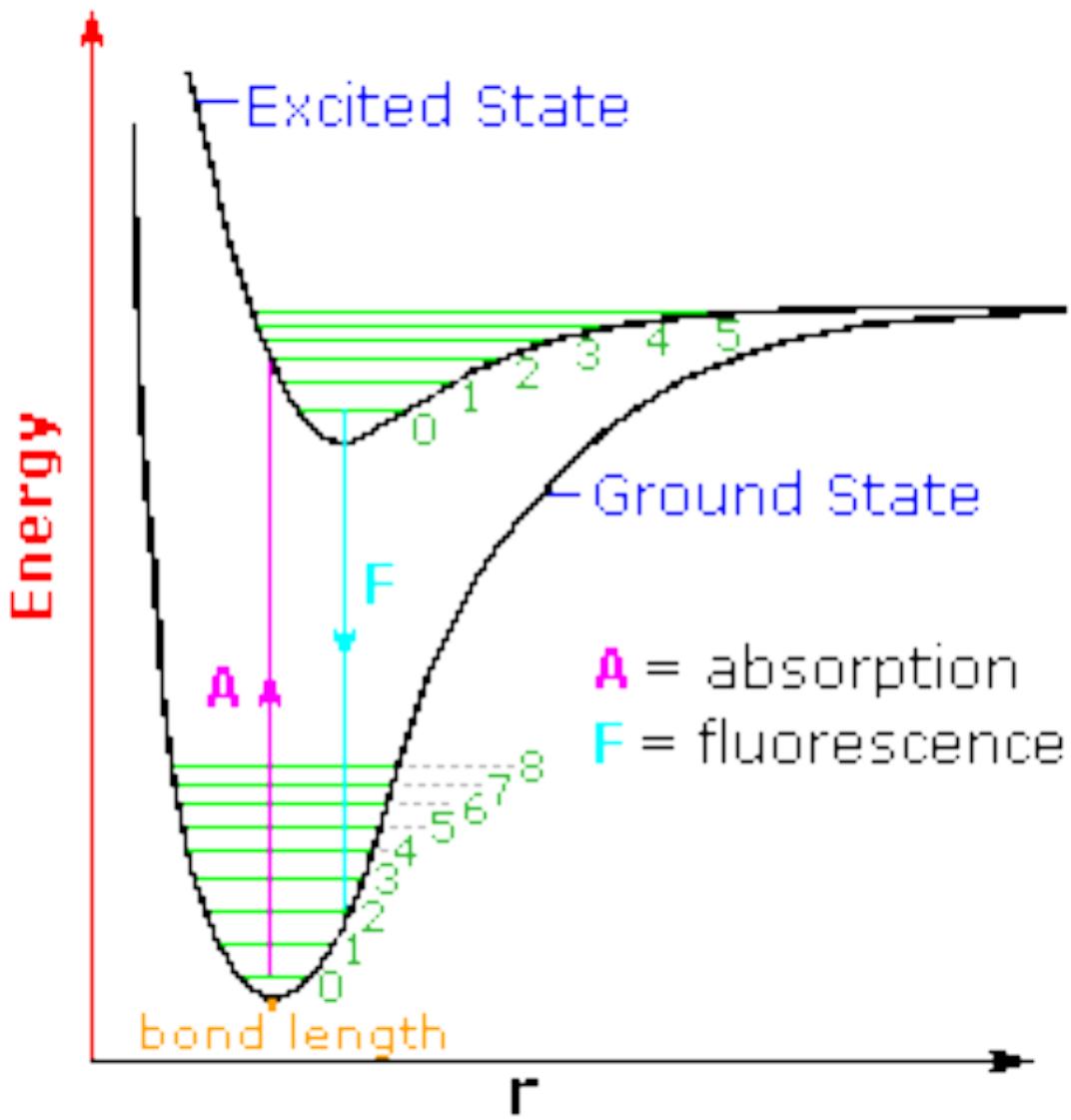


\* Key (and subtle) Concept:  
With rare exceptions electronic transitions are illustrated with vertical arrows.

The reason is because electronic transitions occur much faster than nuclear motion. Thus, the electron cannot start out at one  $r$  and immediately end up at another (as would be illustrated by a non-vertical arrow). The electron makes the transition and then the nuclei adjust by vibrating. This means that the energy emitted when fluorescence occurs happens from the  $n=0$  vibrational level of the excited electronic state.

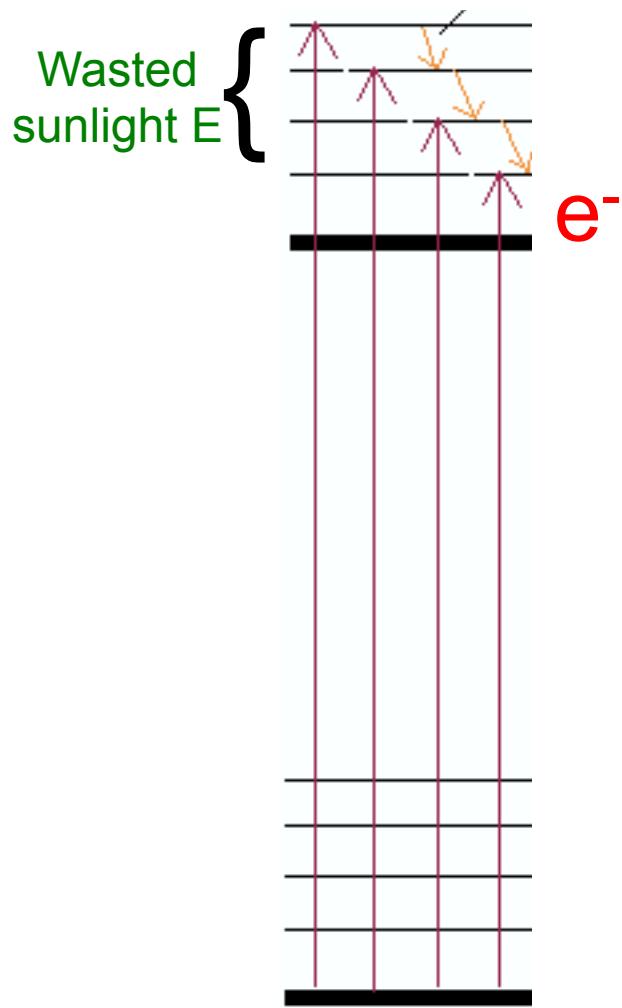
# Illustrations of Vibrational and Electronic Transitions

## Electronic Excitation of X—X



This also means that the emitted photons will have a lower energy than the absorbed photons. This is known as the Stokes shift.

# Solar Photovoltaics



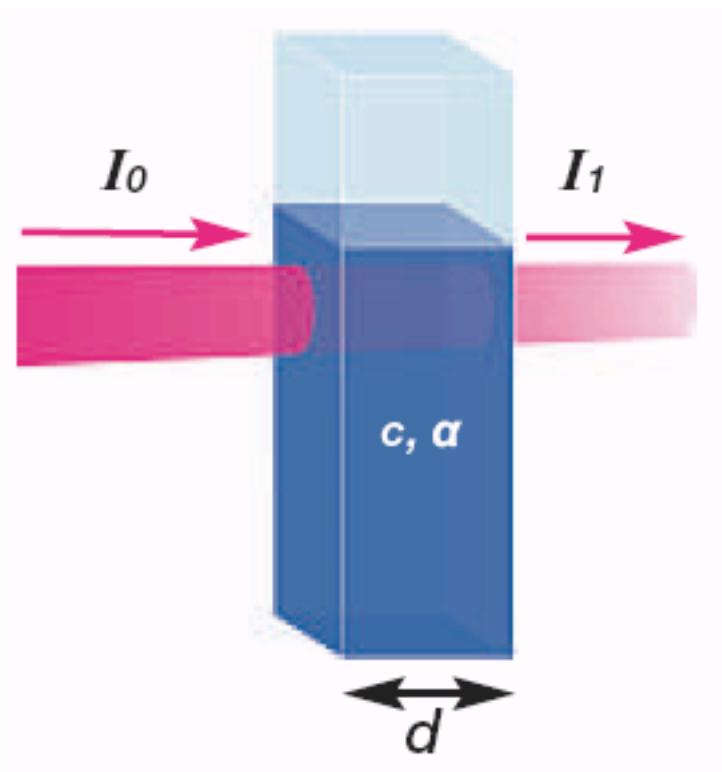
Light shines on a material, causing an electron to transition to an excited energy state. Before dropping back to the ground state, the excited electron is sent through a circuit where it can do work.

Much of the excited state energy we wish we could capture, however, is lost as heat when the excited-state electron relaxes to the  $n=0$  level of the excited state.



# Quantitative Aspects of Spectroscopy

## Absorbance and Transmittance



Interactions of a beam with input intensity  $I_0$  (or  $P_0$ ) and the sample causes attenuation of the beam such that the outgoing intensity is  $I_1$  (or  $P$ ).

The transmittance is defined as

$$T = I_1/I_0$$

$$\%T = I_1/I_0 \times 100$$

# Quantitative Aspects of Spectroscopy

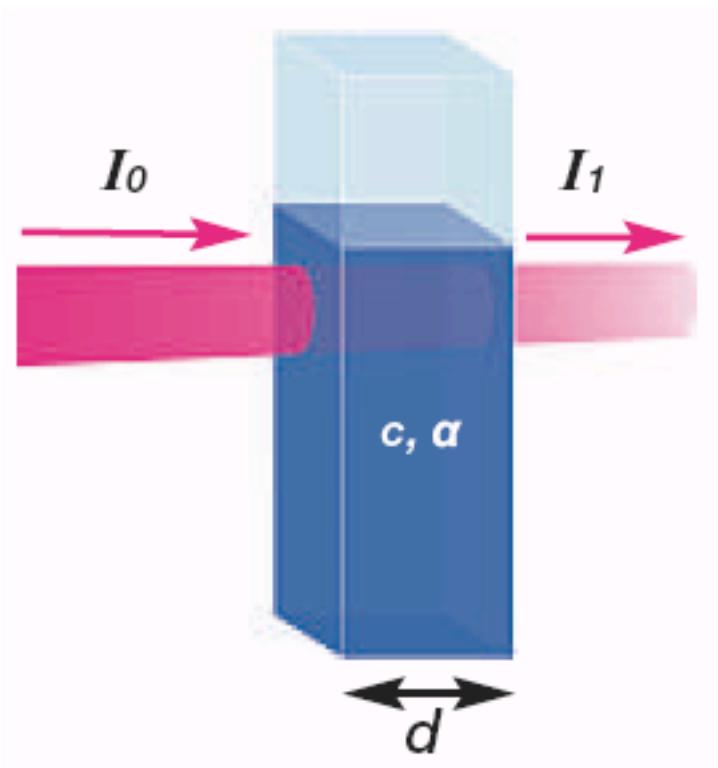
Absorbance is related to transmittance by

$$A = -\log T = \log(I_0/I_1)$$

Key Concept\*. The most important concept in absorbance spectroscopy is Beer's Law.

$$A = \epsilon b C$$

$\epsilon$  is the extinction coefficient of the chromophore (light absorber)  
 $b$  is pathlength  
 $C$  is concentration



# Quantitative Aspects of Spectroscopy

We will return to absorbance, fluorescence, and Beer's Law after we look at instrument technology.