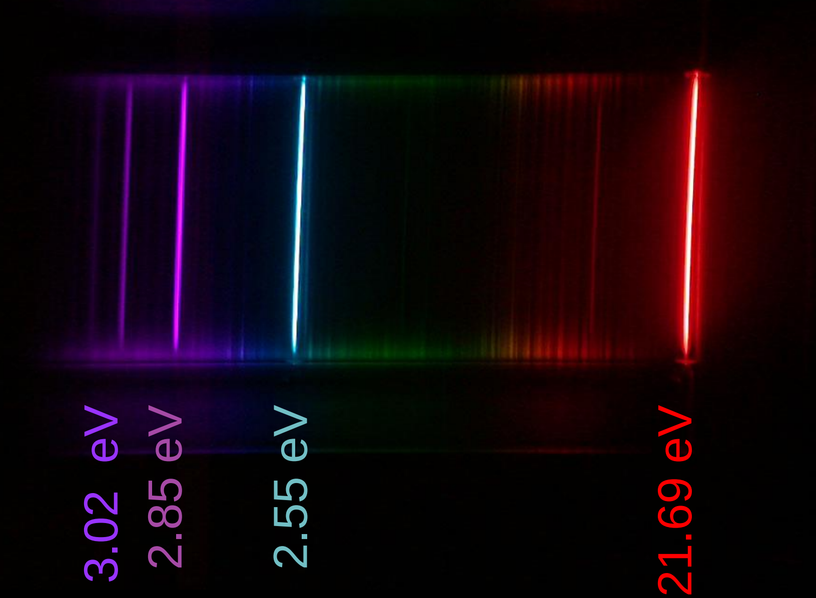
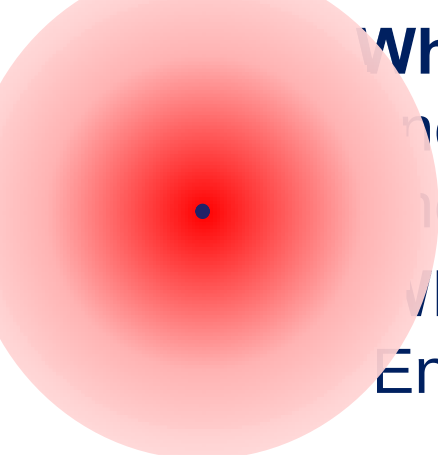
Fri.	8.4-.7 More Energy Quantization	RE 8.b
Mon. Tues. Wed. Lab Fri.	9.1-.2, (.8) P and En Multi-particle Systems 9.3 Rotational Energy Quiz 8 Review Exam 2 (Ch 5-8) Exam 2 (Ch 5-8)	RE 9.a HW8: Ch 8 Pr's 21, 23, 27(a-c) RE 9.b Practice Exam 2 (bring to class)

Shedding light on atomic energy levels
(segment of Hydrogen spectrum)

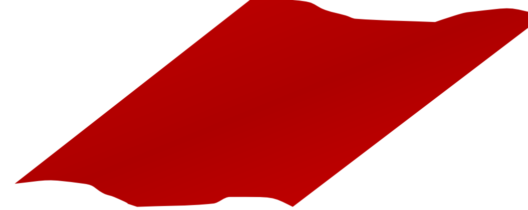




Where we've been:

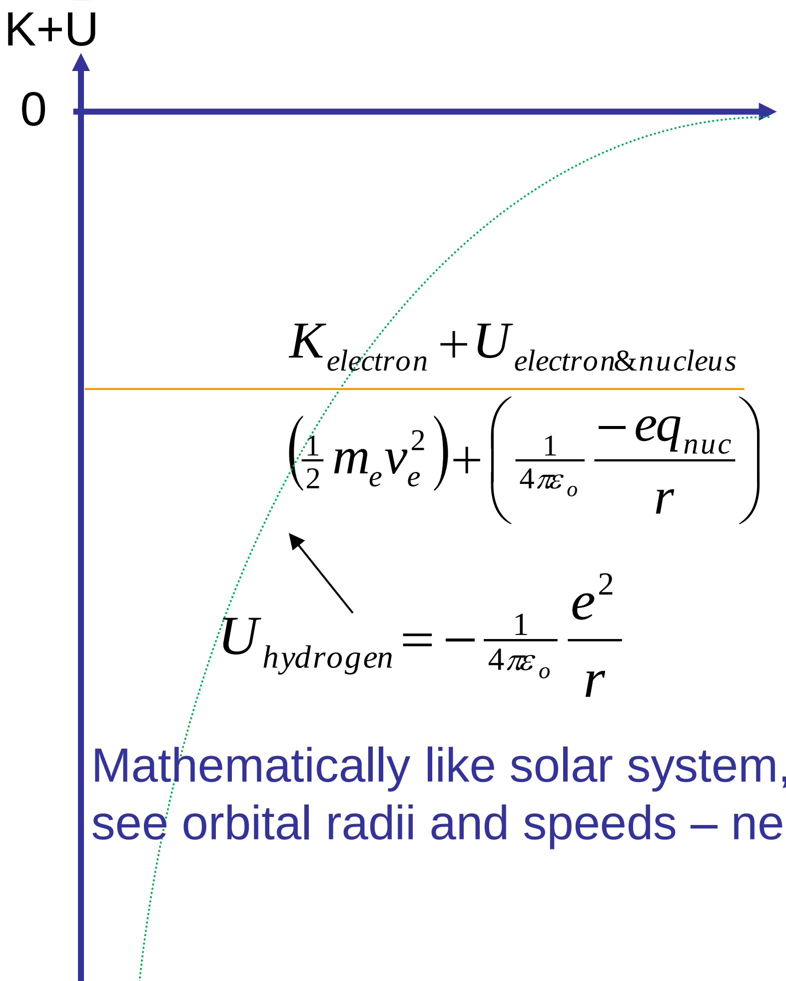
Energy on the macroscopic scale

Energy on the atomic scale



Where we're going:

Energy on the electronic scale



$$K_{electron} + U_{electron\&nucleus}$$

$$\left(\tfrac{1}{2} m_e v_e^2\right) + \left(\frac{1}{4\pi\varepsilon_o} \frac{-eq_{nuc}}{r}\right)$$

$$U_{hydrogen} = -\frac{1}{4\pi\varepsilon_o} \frac{e^2}{r}$$

Mathematically like solar system, but much too small and delicate to directly see orbital radii and speeds – need another way to deduce

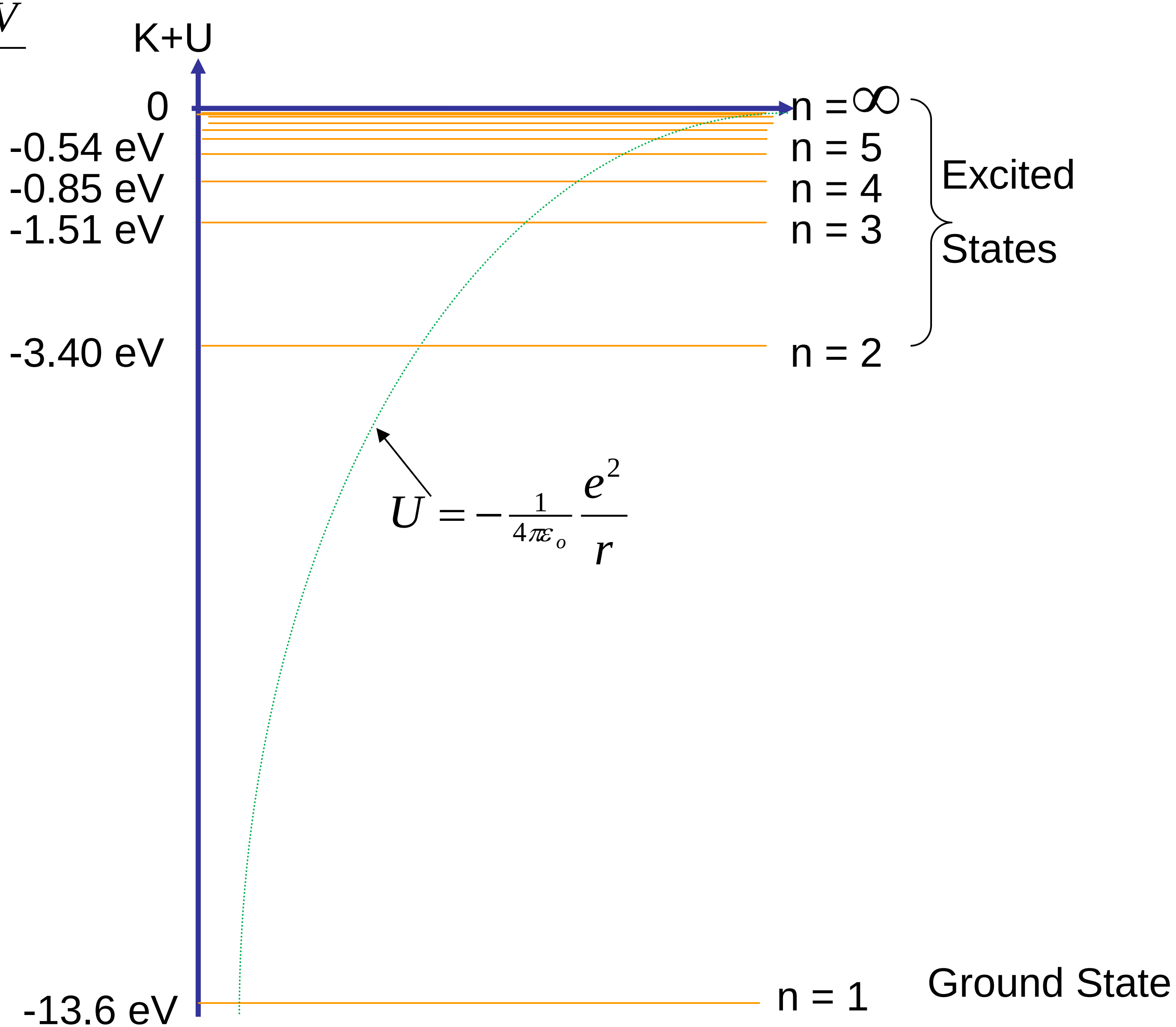
Hydrogen Energy Levels

$$(K+U)_n = -\frac{13.6eV}{n^2}$$

etc.

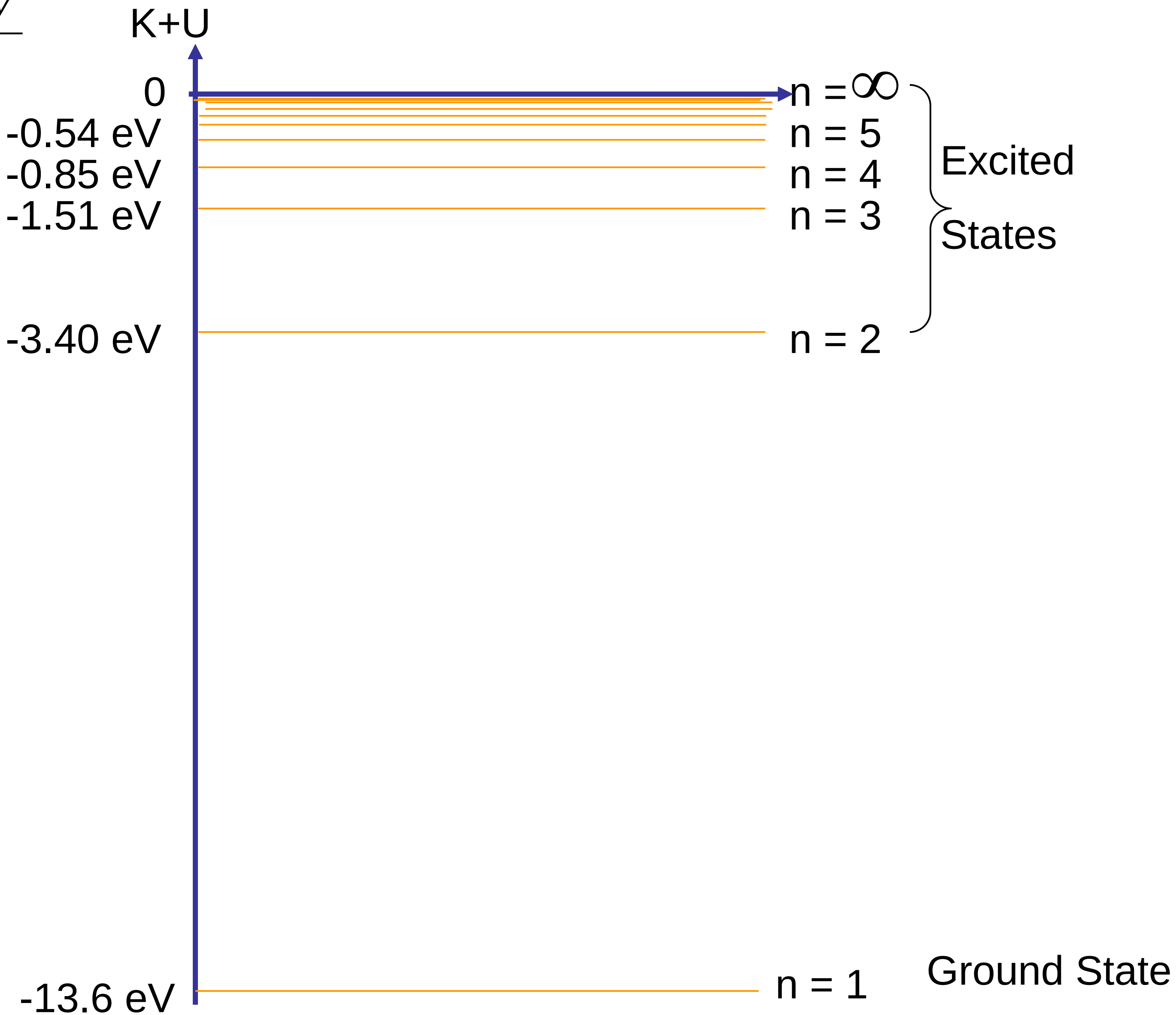
$$(K+U)_2 = -\frac{13.6eV}{2^2}$$

$$(K+U)_1 = -\frac{13.6eV}{1^2}$$



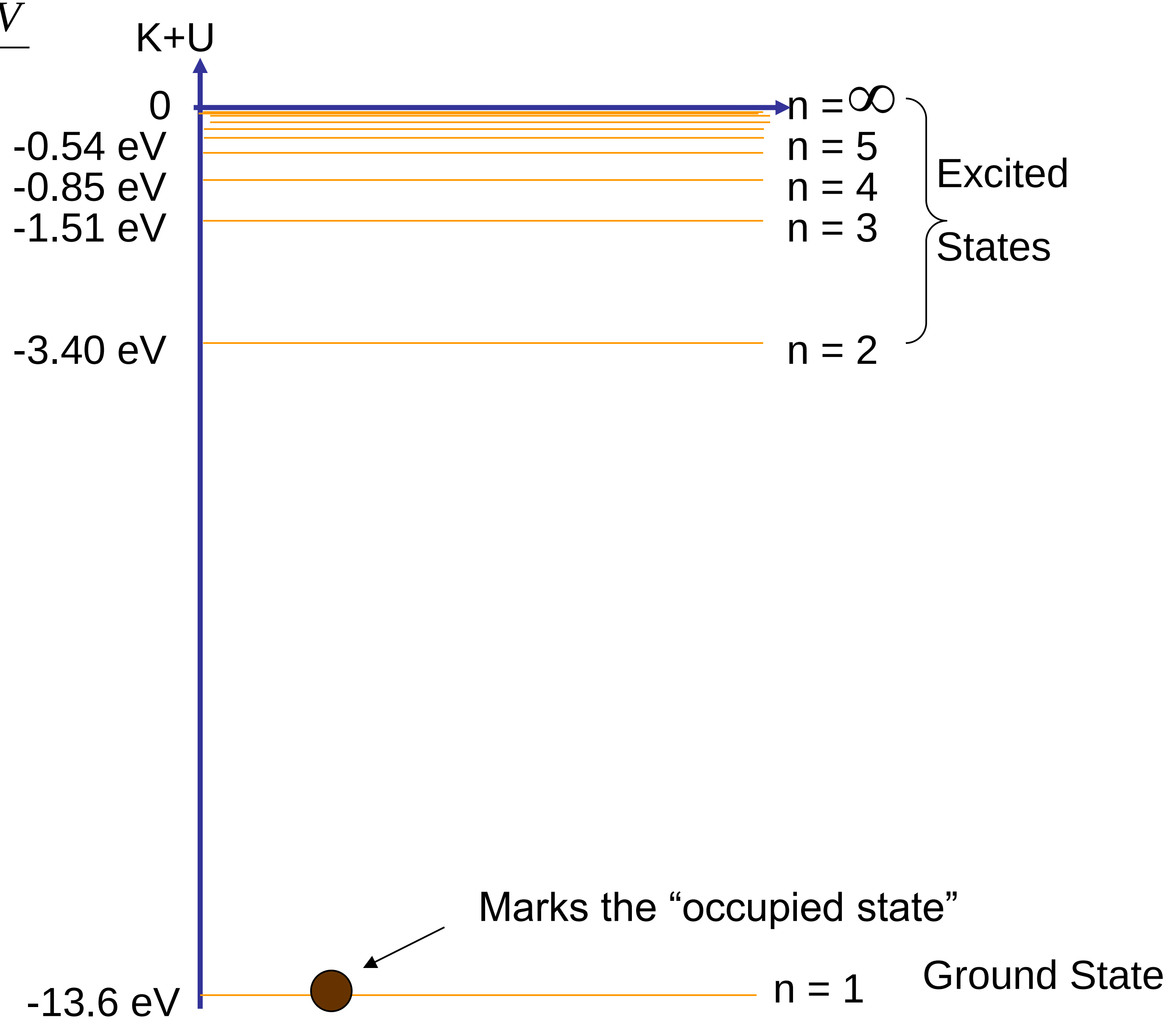
Hydrogen Energy Levels: Excitation

$$(K+U)_n = -\frac{13.6eV}{n^2}$$



Hydrogen Excitation: 1st in ground state

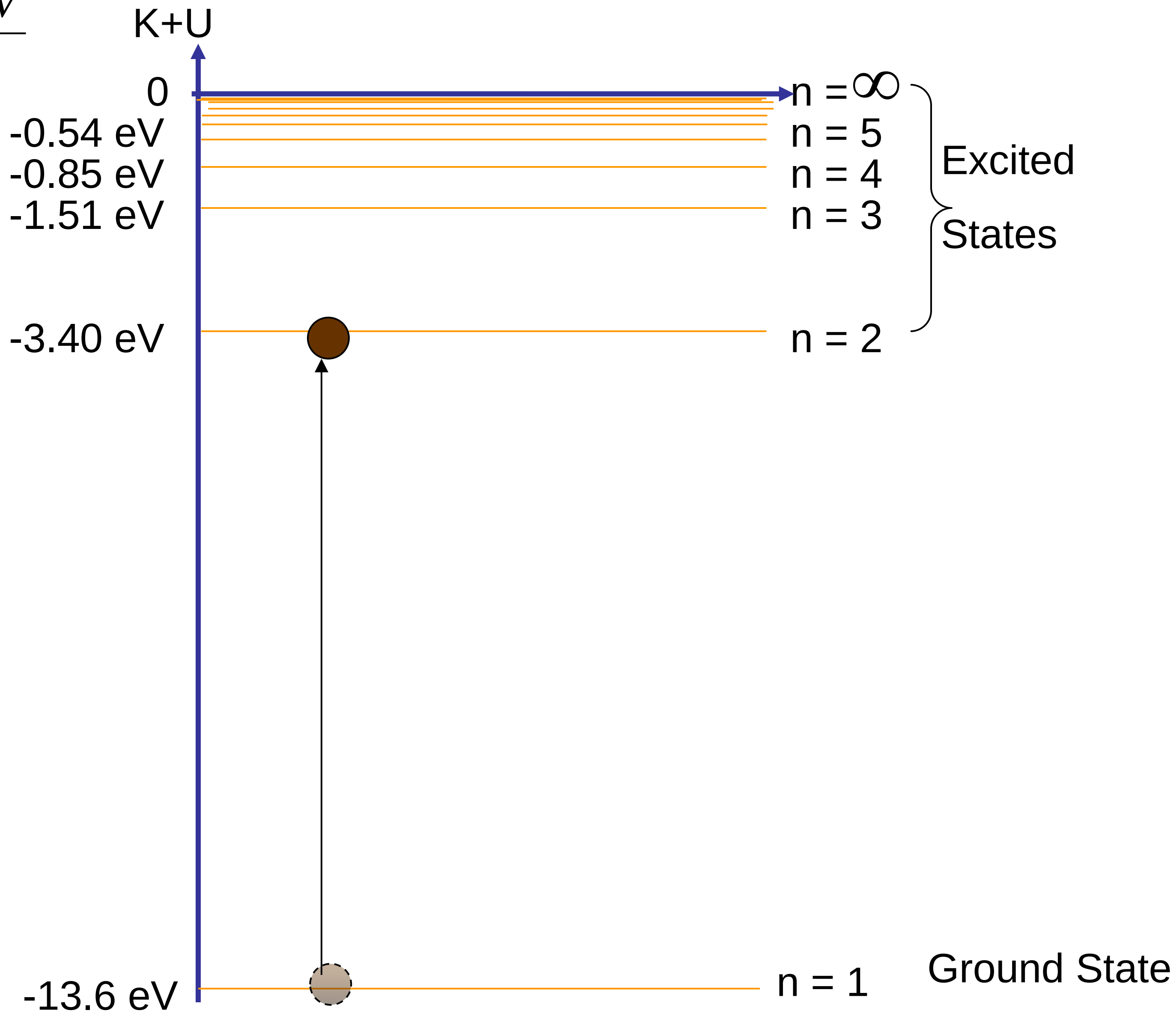
$$(K+U)_n = -\frac{13.6eV}{n^2}$$



Hydrogen Excitation: 2nd Adsorbs energy from Collision

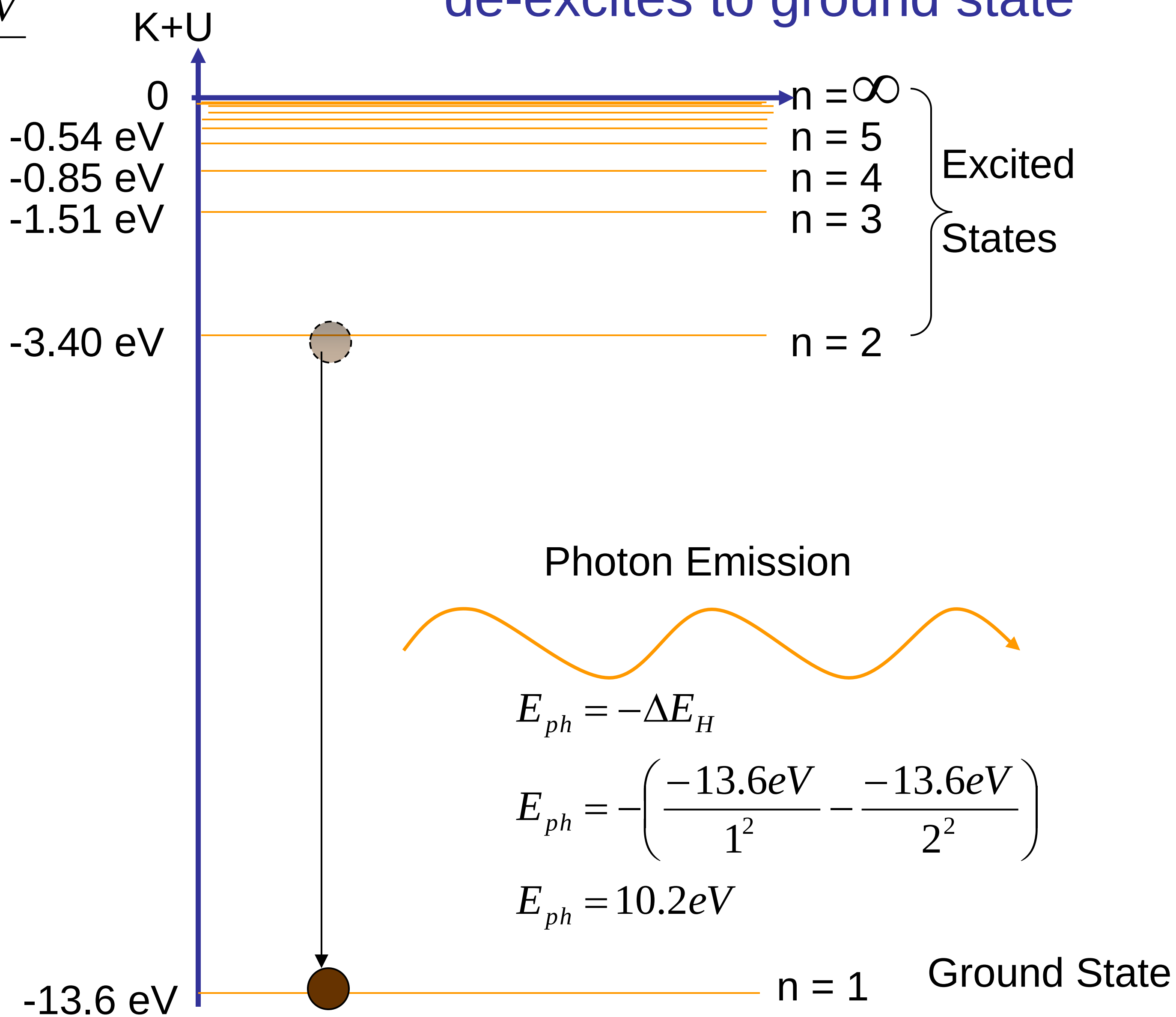
excites to 2nd state

$$\left(K+U\right)_n = -\frac{13.6eV}{n^2}$$



Hydrogen Excitation: 3rd Looses Energy by photon emission, de-excites to ground state

$$(K+U)_n = -\frac{13.6eV}{n^2}$$

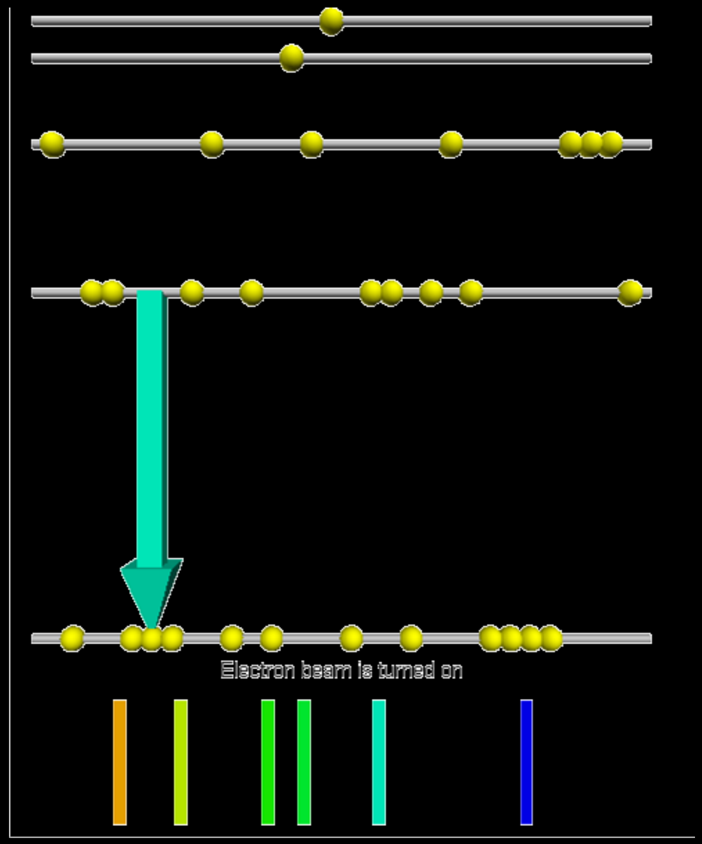


$$E_{ph} = -\Delta E_H$$

$$E_{ph} = -\left(\frac{-13.6eV}{1^2} - \frac{-13.6eV}{2^2}\right)$$

$$E_{ph} = 10.2eV$$

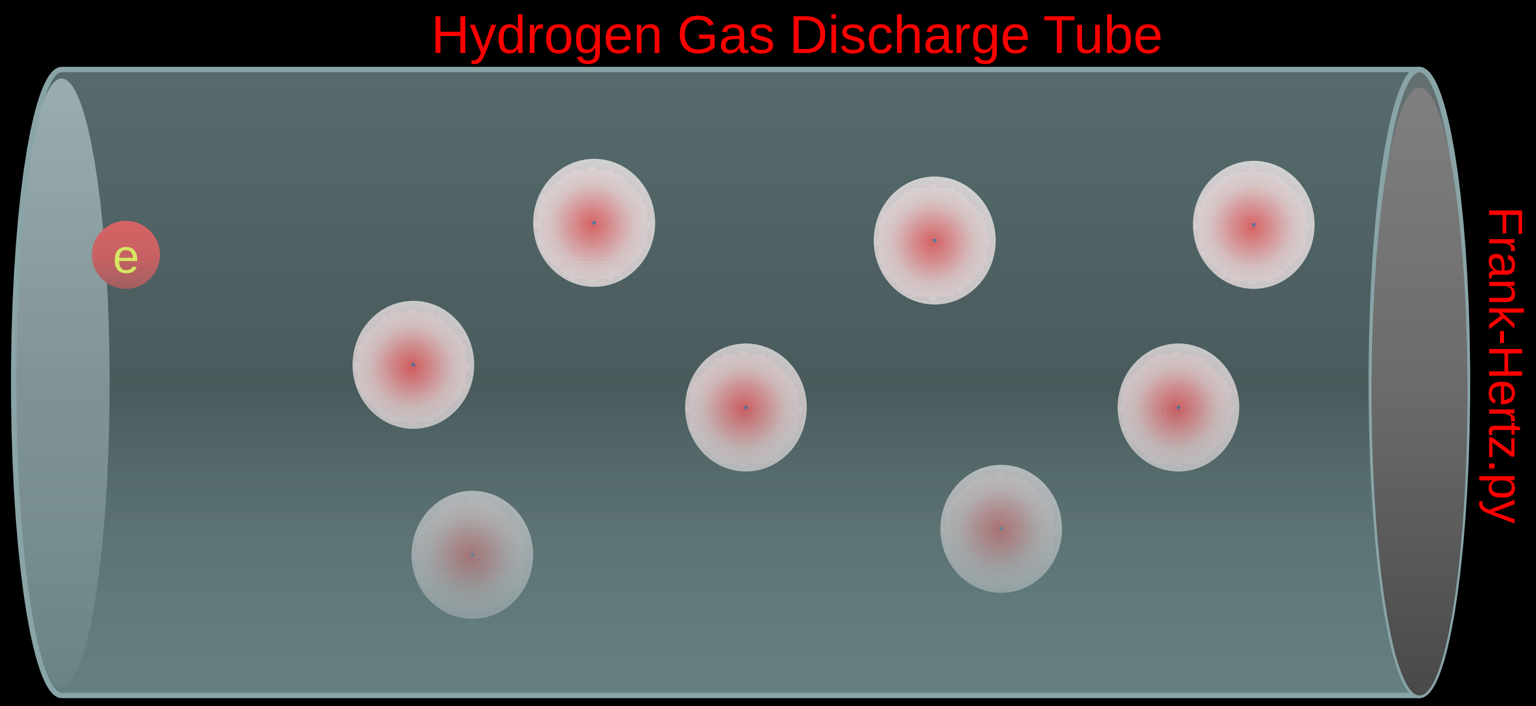
Example Atoms in Gas-Discharge Tube

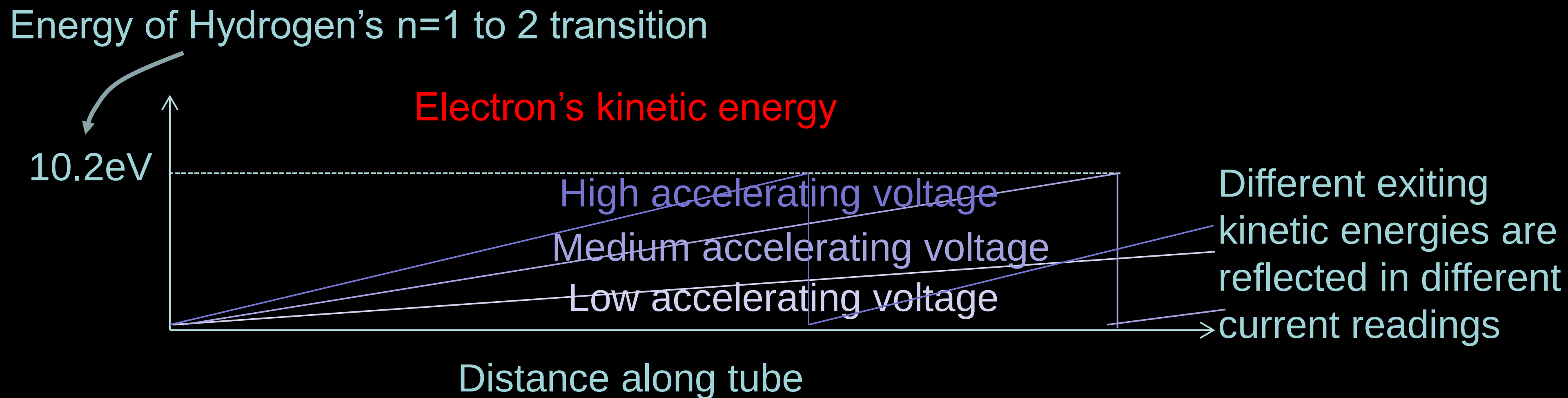


06_Adsorb_emit.py.

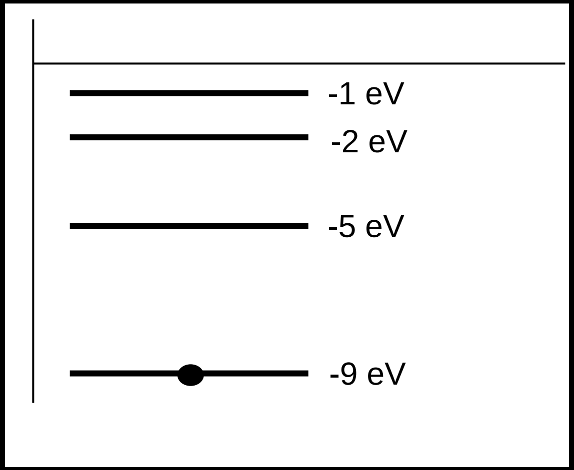
Frank-Hertz Experiment

Monitoring electron beam's *loss* of energy to the atoms



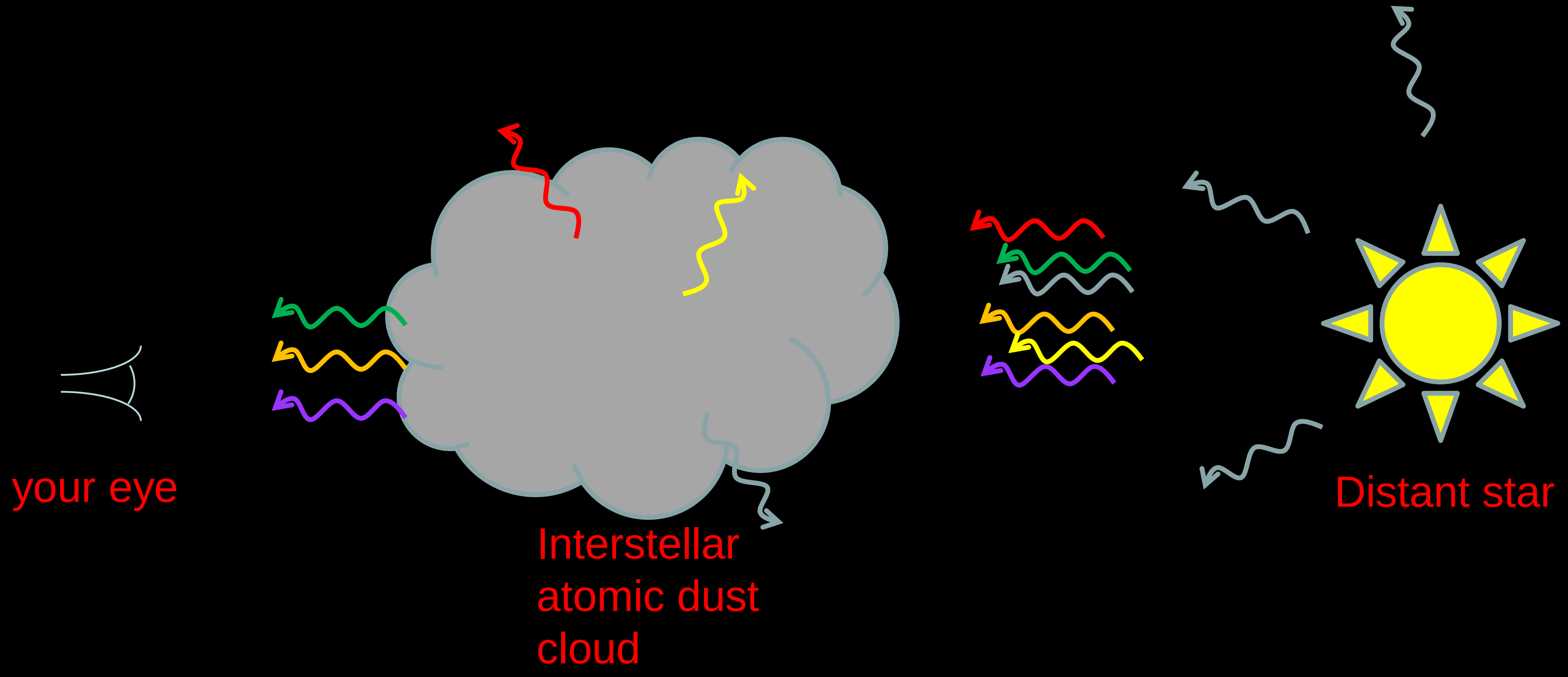


Here are the quantized energy levels (K+U) for an atomic or molecular object, and the object is in the "ground state" (marked by a dot). An electron with kinetic energy 6 eV is fired at the object and excites the object to the –5 eV energy state. What is the remaining kinetic energy of this electron?



a) 9 eV
b) 6 eV
c) 4 eV
d) 3 eV
e) 2 eV

Absorption Spectrum

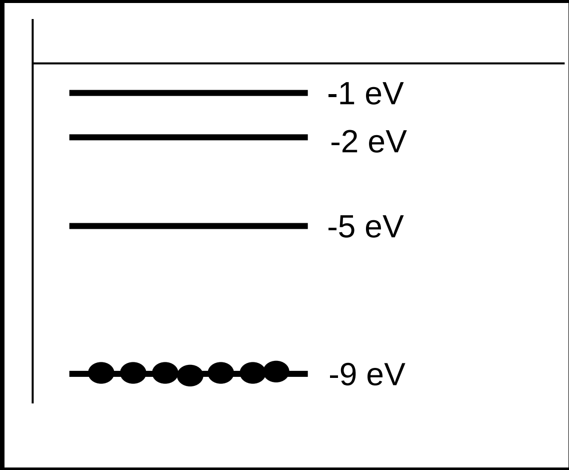


Colors / energies of light from the star that interact with cloud's atoms scatter;
it's depleted from the star light you see.

06_spectrum.py.

A collection of some atoms objects is kept **very cold**, so that all the objects are in the ground state. Light consisting of photons with a range of energies from 1 to 7.5 eV passes through this collection of objects. What photon energies will be depleted from the light beam ("dark lines")?

Note: assume the atoms don't stay in excited states long enough to get further excited another step up from them.



a) 2 eV, 5 eV, 9 eV

b) 3 eV, 4 eV

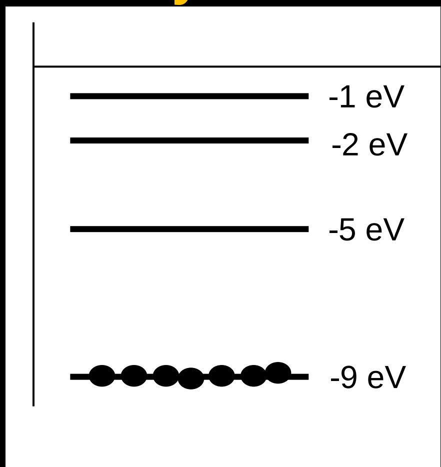
c) 0.5 eV, 3 eV, 4 eV

d) 4 eV, 7 eV

e) 3 eV, 4 eV, 7 eV

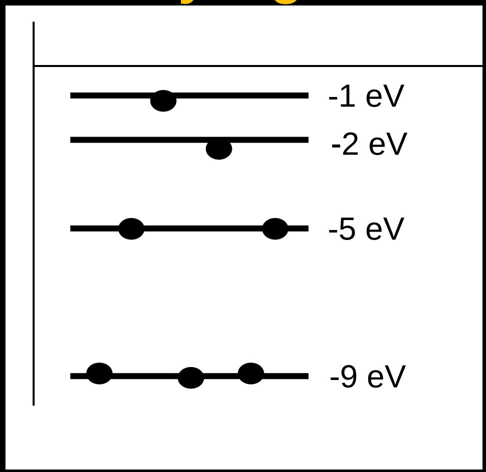
Temperature Effects on Absorption Spectrum

T very low



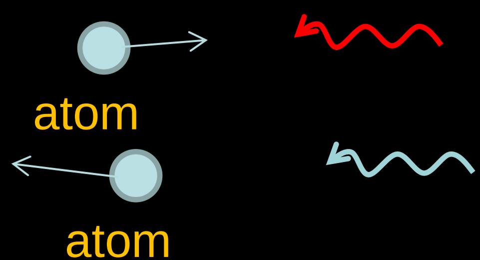
All atoms initially in ground state; only absorption lines for transitions from it

T very high



Many states have some atoms; you see absorption lines between many states

T medium



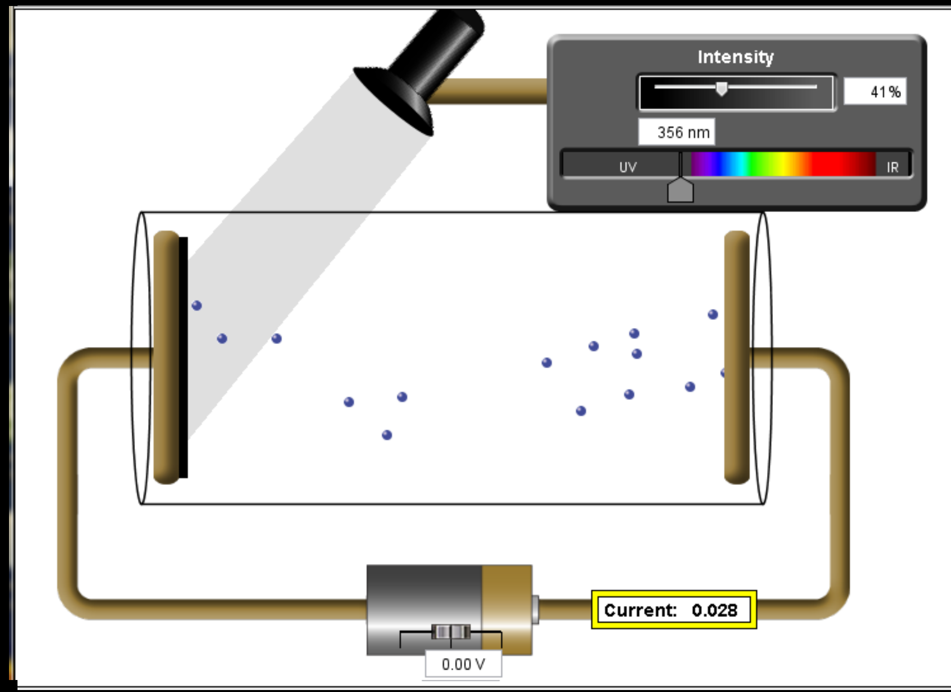
More energetic collision; lower-energy (redder) light excites transition

Less energetic collision; higher (bluer) light excites transition

Thermally broadened Spectral lines

Quantitatively Relating Light's Energy and Frequency

The Photo-electric Effect



Phet Phot-Electric

"Ionizing" metal plate

Shine mono-chromatic (single color) light on metal

With low frequency light, no matter how bright, no electrons are freed, no current measured

Turn up frequency; at and above some threshold frequency, f, electrons *are* freed, current

Threshold frequency relates to metal plate's "ionization energy" (work function) by $E = hf$

Deduce: light falls like rain with packets of energy related to its frequency $\boldsymbol{E = hf}$

$h = 6.6\times10^{-34}$Js $= 4.1\times10^{-15}$eVs

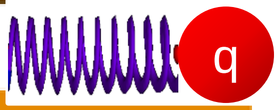
Example: He-Ne laser.

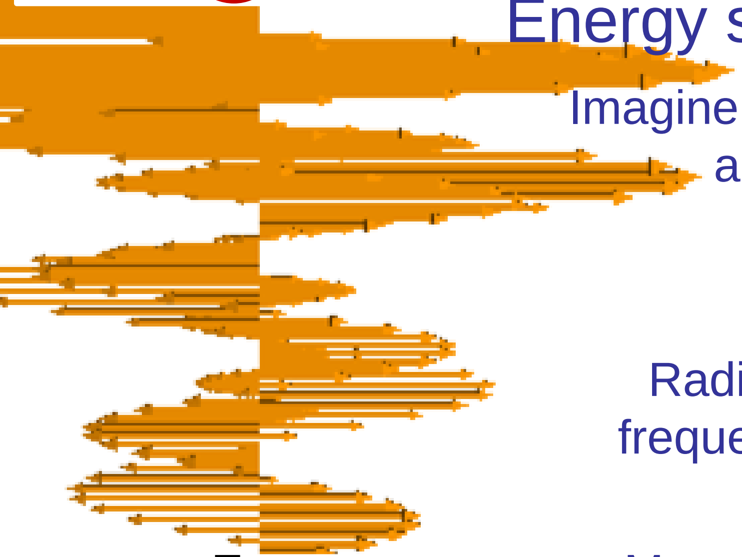
Gas discharge tube filled with He and Ne. They have a rich emission spectrum but the tube's length, like the string of a piano is right to help light resonate at just one frequency, 4.36×10^{14}Hz, a rich red. How much energy does one red photon of from the He-Ne have?

This is a 0.95mW = 0.00095 J/s laser; that's the rate at which the beam of photons carry away energy. How many photons are emitted per second?

Simple Harmonic Oscillator

Energy spectrum & Structure





Imagine a charged particle riding a mass on a spring

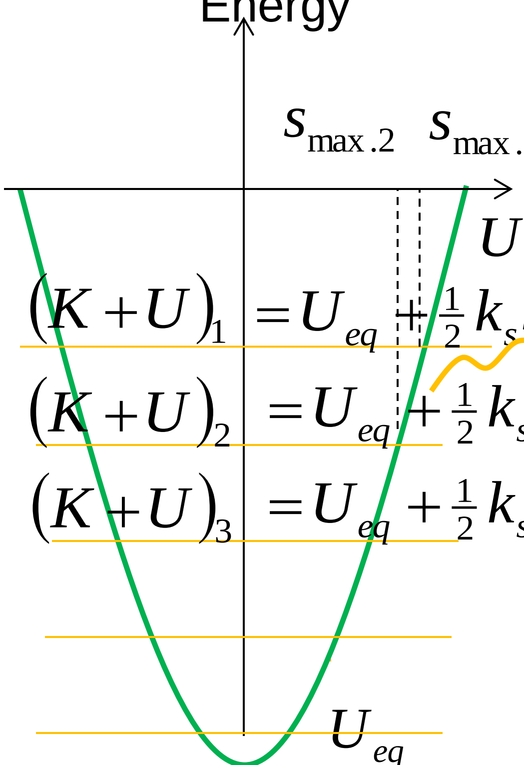
$$f = \tfrac{1}{2\pi}\sqrt{\frac{k_s}{m}}$$

Radiates light with the same frequency as its own oscillation

$$E_{light} = hf$$

Mass-on-spring must *loose* this much energy

ΔE_{system} = E_{light} = *hf*



$$U = -|U_{eq}| + \tfrac{1}{2} k_s s^2$$

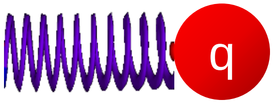
$$(K+U)_1 = U_{eq} + \tfrac{1}{2} k_s s^2_{\max .1}$$

$$(K+U)_2 = U_{eq} + \tfrac{1}{2} k_s s^2_{\max .2}$$

$$(K+U)_3 = U_{eq} + \tfrac{1}{2} k_s s^2_{\max .3}$$

Still oscillating at same *f* again radiates light of frequency *f*.

Etc.



Simple Harmonic Oscillator

Energy spectrum & Structure

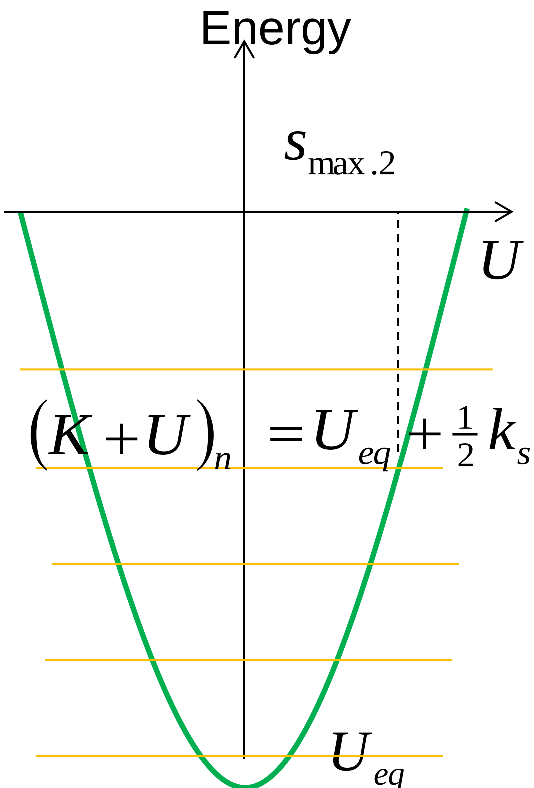
Imagine a charged particle riding
a mass on a spring

$$f = \tfrac{1}{2\pi}\sqrt{\frac{k_s}{m}}$$

We've deduced

$$(K+U)_n = U_{eq} + \tfrac{1}{2}k_s s_{\max.n}^2 = E_{\min} + nhf$$ where n = 1,2,3,…

Takes real Quantum Mechanics to
nail down E_{min}: $E_{\min} = U_{eq} + \tfrac{1}{2}hf$

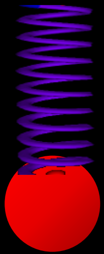


$$U = -\left|U_{eq}\right| + \tfrac{1}{2}k_s s^2$$

$$(K+U)_n = U_{eq} + \tfrac{1}{2}k_s s_{\max.n}^2$$

$$(K+U)_n = U_{eq} + hf\left(n+\tfrac{1}{2}\right) = U_{eq} + \hbar\omega\left(n+\tfrac{1}{2}\right)$$

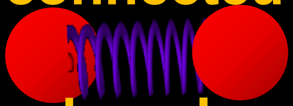
Example: Macro-scopic mass on spring

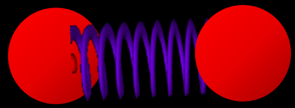


We certainly don't *notice* that a mass on a spring has only specific allowed energies, it *seems* to be able to oscillate with *any* energy / amplitude (until it breaks). Given an 0.01 kg mass on our 3 N/m spring, initially displaced 0.1m, how much energy has it got, and how big is the step to the next energy level lower?

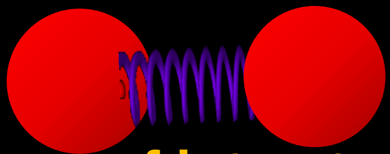
How about a H_2 molecule, what's the energy step size for its vibrations? Roughly 10^{-27} kg mass protons and 100 N/m spring constant.

Molecular Bonds

Two atoms joined by a chemical bond can be modeled as two masses connected by a spring.  In one such molecule, it takes 0.05 eV to raise the molecule from its vibrational ground state to the first excited vibrational energy state.	How much energy is required to raise the molecule from its first excited state to the second excited vibrational state? 1) 0.0125 eV 2) 0.025 eV 3) 0.05 eV 4) 0.10 eV 5) 0.20 eV

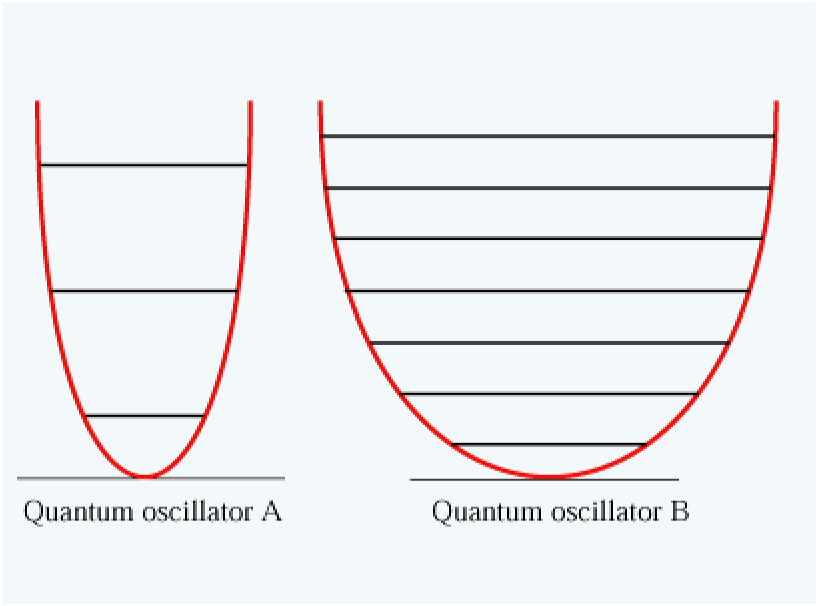


Molecular Bonds

Molecule A: 2 atoms of mass M_A Molecule B: 2 atoms of mass $4{*}M_A$  Stiffness of interatomic bond is approximately the same for both.	Which molecule has vibrational energy levels spaced closer together? 1) A 2) B 3) the spacing is the same

Suppose the atoms in diatomic molecules C and D had approximately the same masses, but Stiffness of bond in C is 3 times as large as stiffness of bond in D.	Which molecule has vibrational energy levels spaced closer together? 1) C 2) D 3) the spacing is the same

Molecular Bonds

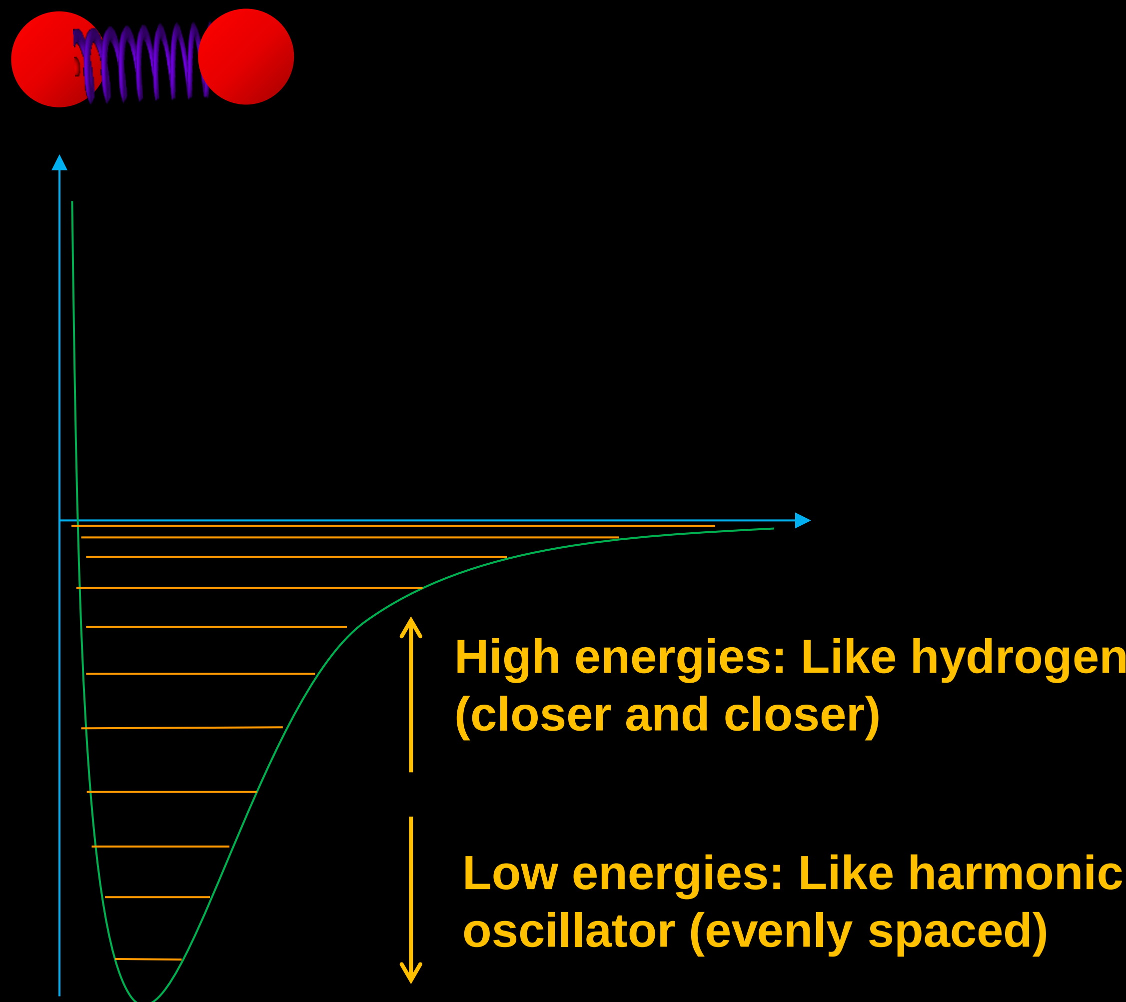


Pb: k_s ~ 5 N/m   Al: k_s ~ 16 N/m

Which vibrational energy level diagram represents Pb, and which is Al?

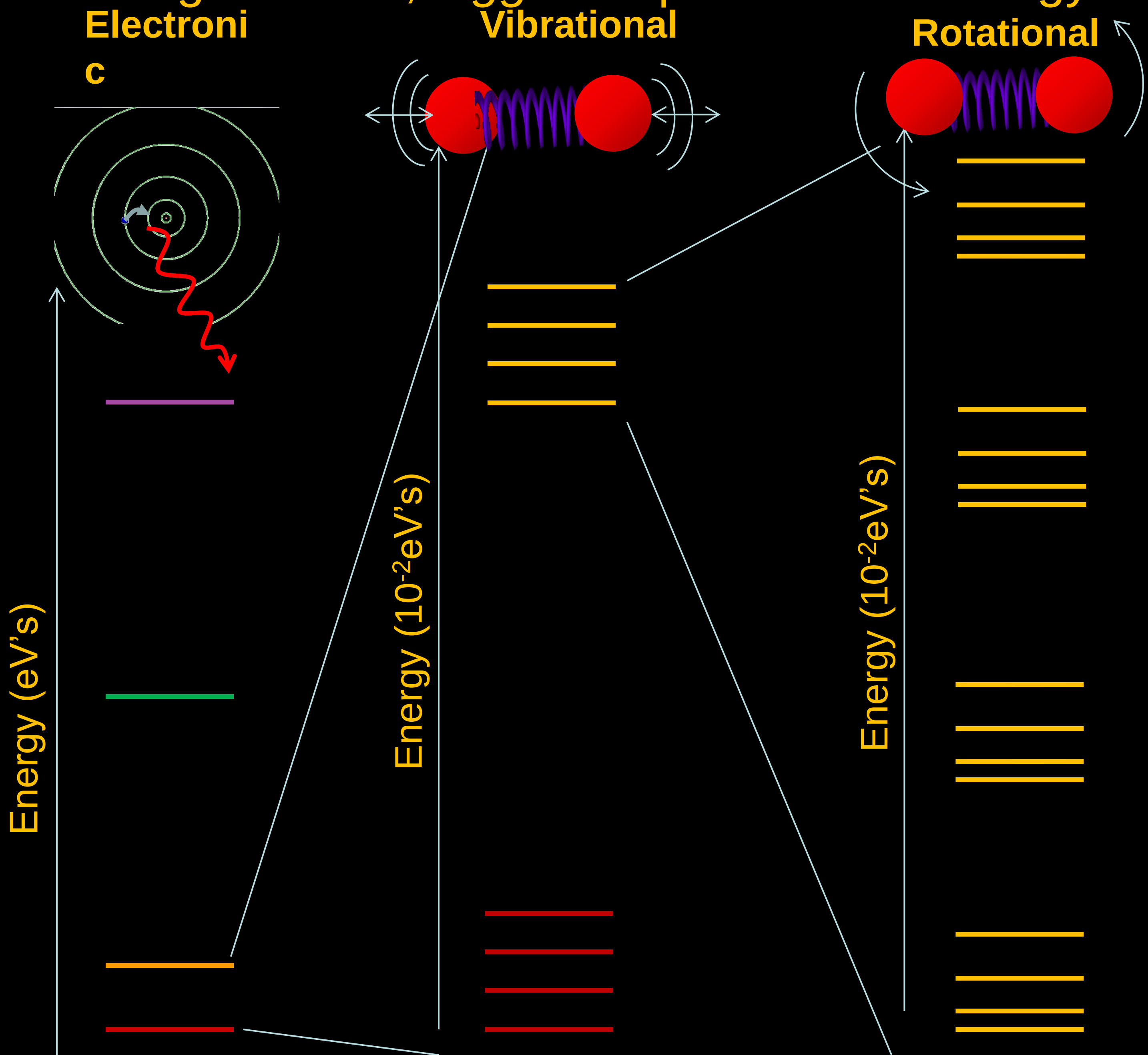
1) A is Pb and B is Al
2) A is Al and B is Pb
3) A is both Pb and Al
4) B is both Pb and Al

Molecular Bonds
(zoomed out)



Spectra & Energy Step Sizes

Stiffer / stronger bonds, *bigger* steps between energy levels



Stiffer / stronger bonds, *bigger* steps between energy levels

Type of State Scale	**Energy**
Hadronic (quark composites)	10^{8}eV
Nuclear (nucleon composites)	10^{6}eV
Electronic (atoms & molecules)	1 eV
Vibrational (molecules)	10^{-2}eV
Rotational (molecules)	10^{-4}eV