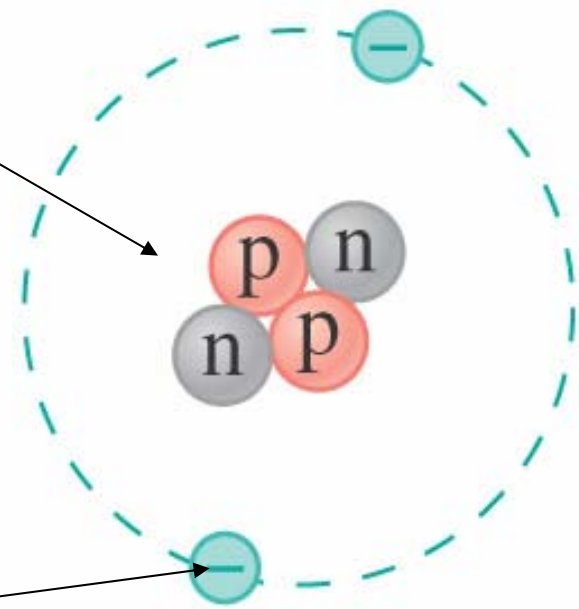
quantization

part 2 –particles as waves

ch 37

The world – a) matter - atoms

nucleus of tightly packed protons and neutrons.
Protons-positive charge



electrons orbiting negative charge

^{4}He

$Z = 2 \qquad N = 2$

$A = 4$

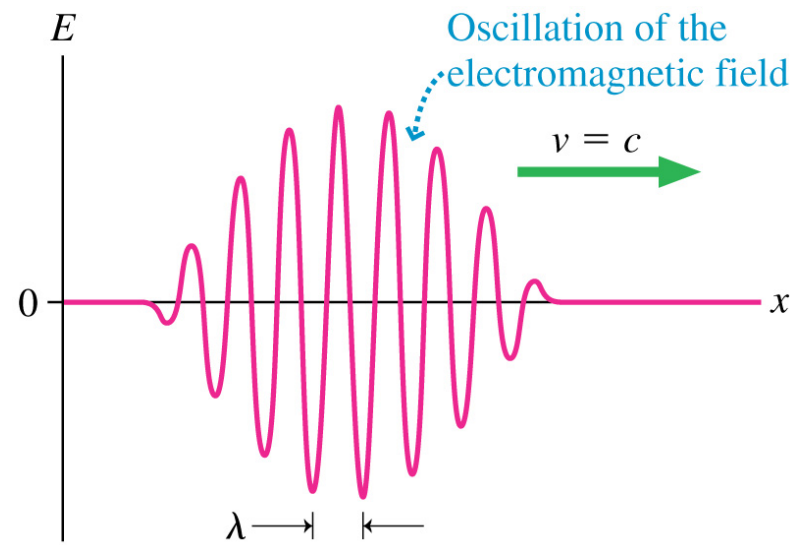
99.9999% abundance

charges come in bits
$e=1.602 \times 10^{-19}C$
"quantized"

The World: Light
We have a crazy new idea

- LIGHT IS A PARTICLE ….
  - These things are called photons

$$E = hf$$



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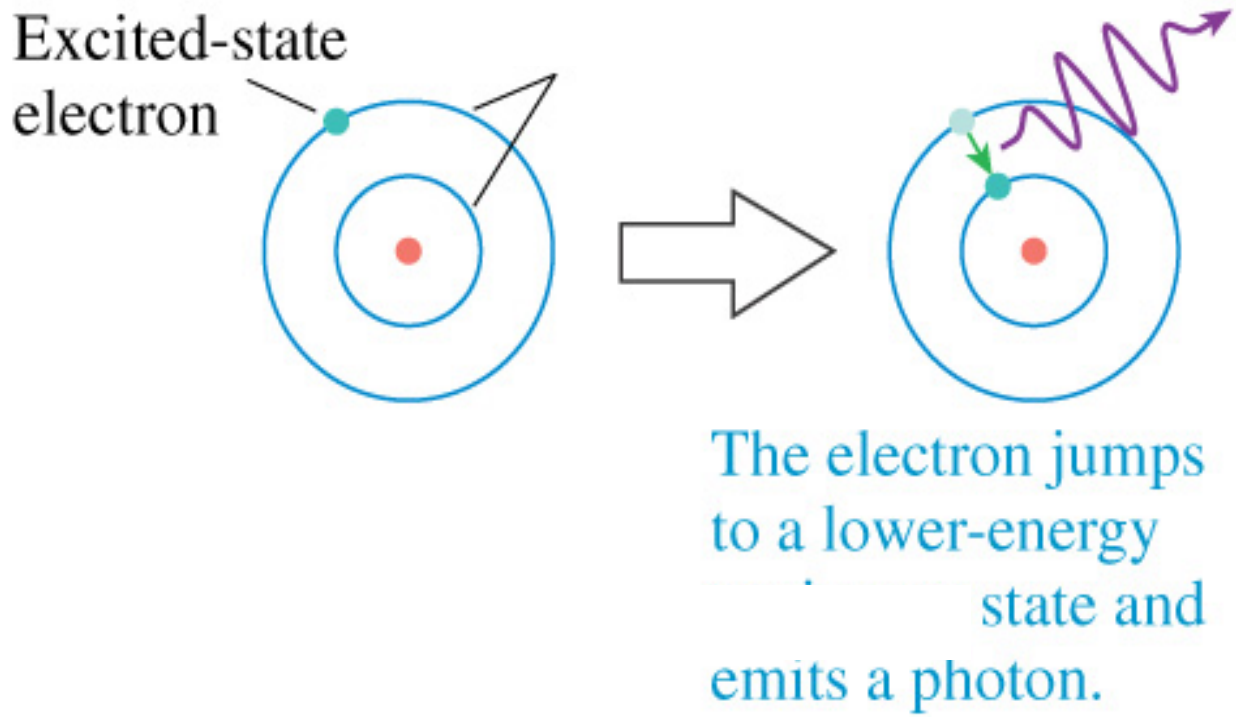
h a constant – Plank's constant

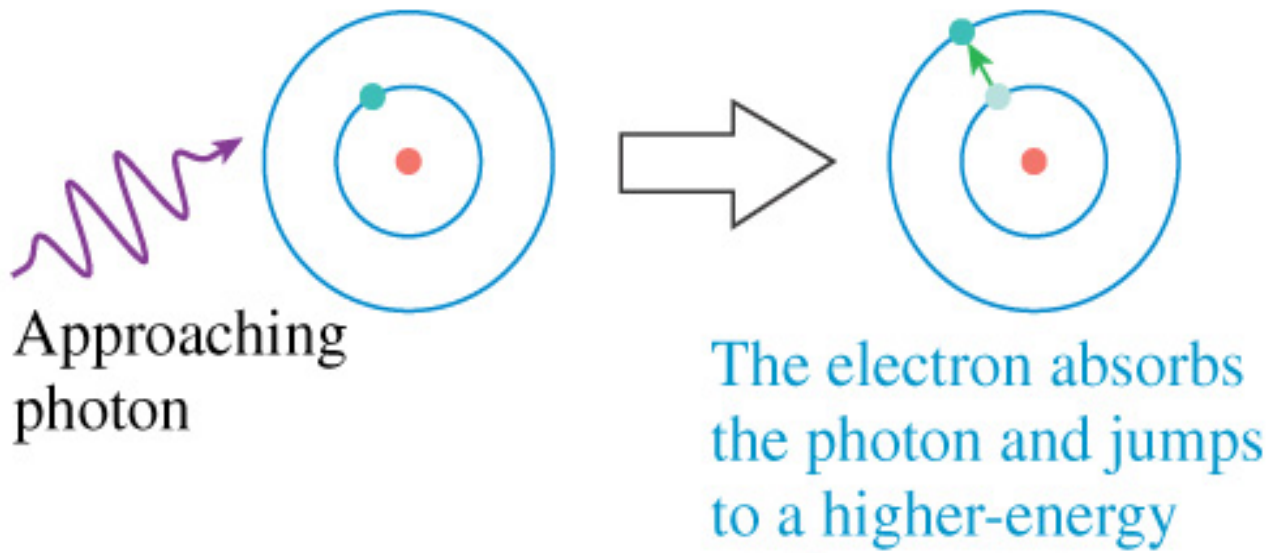
h=6.625 x 10-34 J-s
1eV=1.602 x 10^{-19}J

How is light made?

absorbed?

idea!

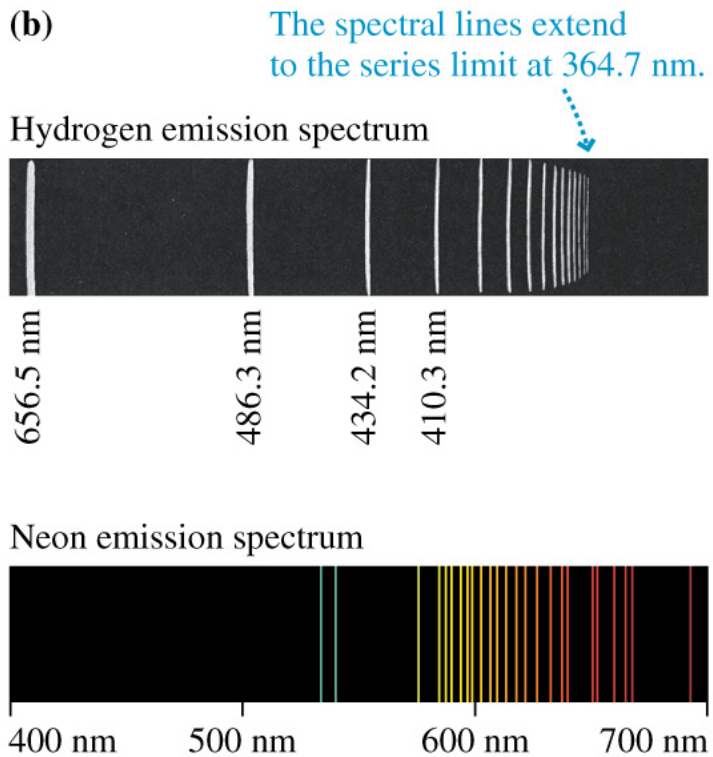




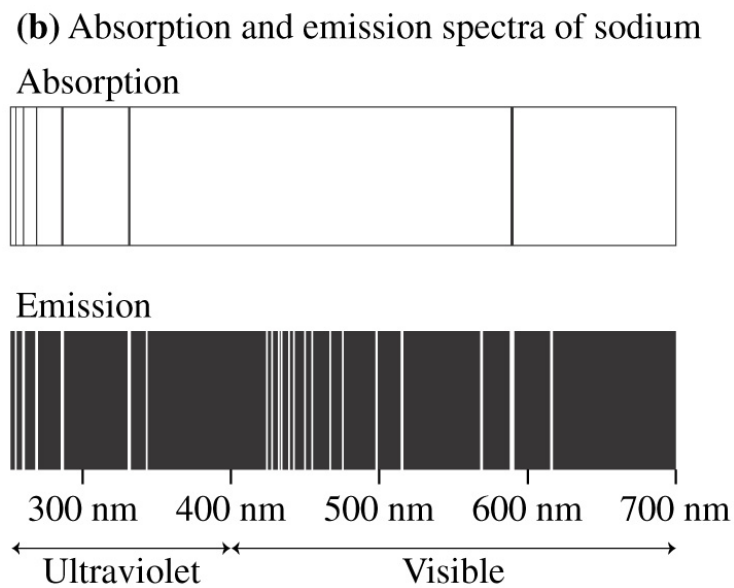
Trouble: Why discreet??

$$\lambda \sim \frac{1}{\frac{1}{m^2} - \frac{1}{n^2}}$$

Emission spectrum

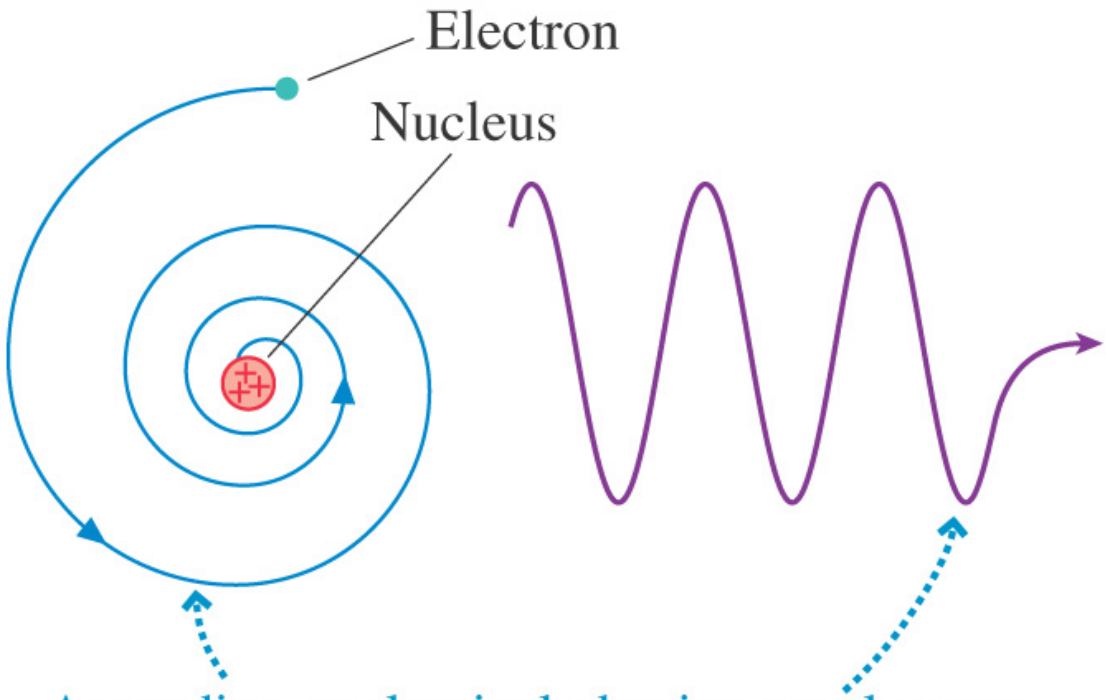


Absorption spectrum



Like a Merry go round that can only go 1mph, 3mph, 5mph and NOTHING IN BETWEEN

Why do we exist at all????

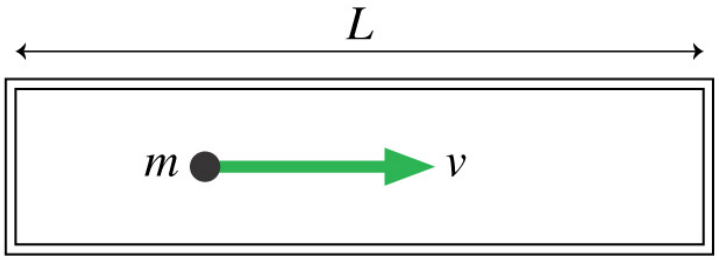


According to classical physics, an electron would spiral into the nucleus while radiating energy as an electromagnetic wave.

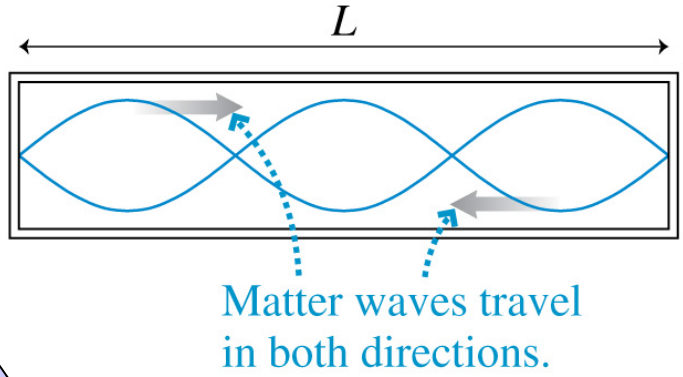
Crazy possibility #2 – Bohr: **electrons are waves**

here is what the book says (It doesn't help me much) Think of a bugle

(a) A classical particle of mass m bounces back and forth between the ends.

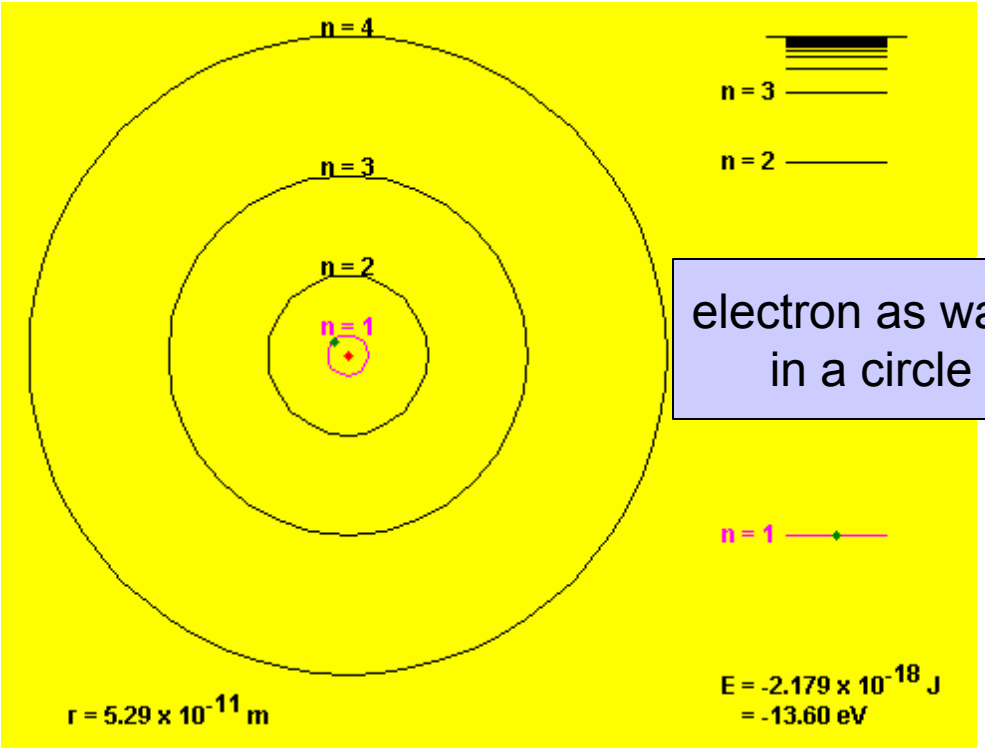


(b) Matter waves moving in opposite directions create standing waves.

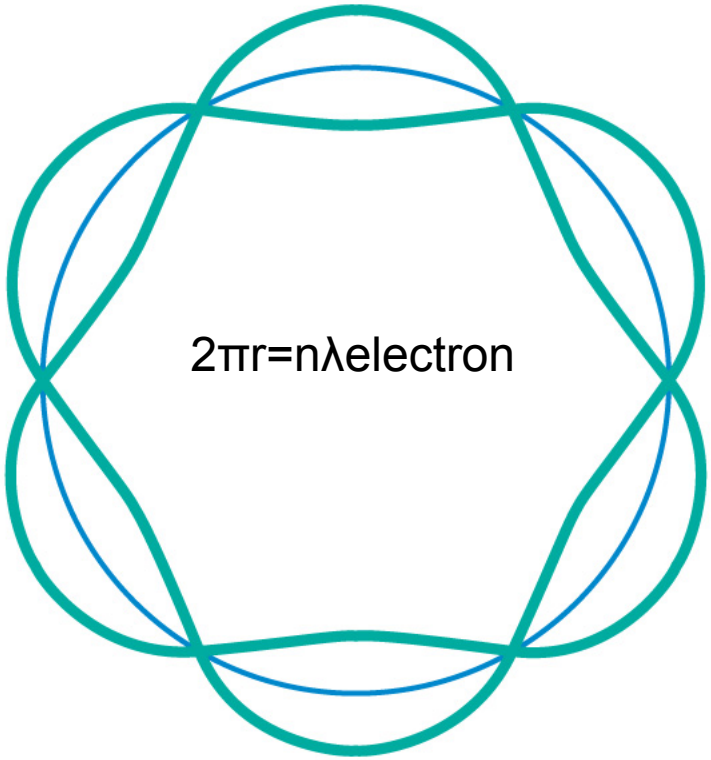


now take this
in a circle

Bohr 1

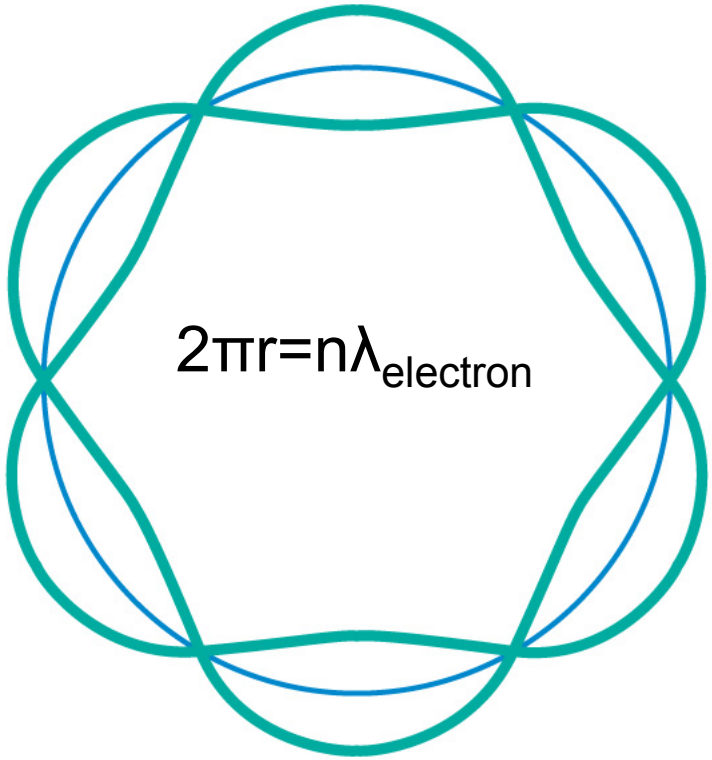


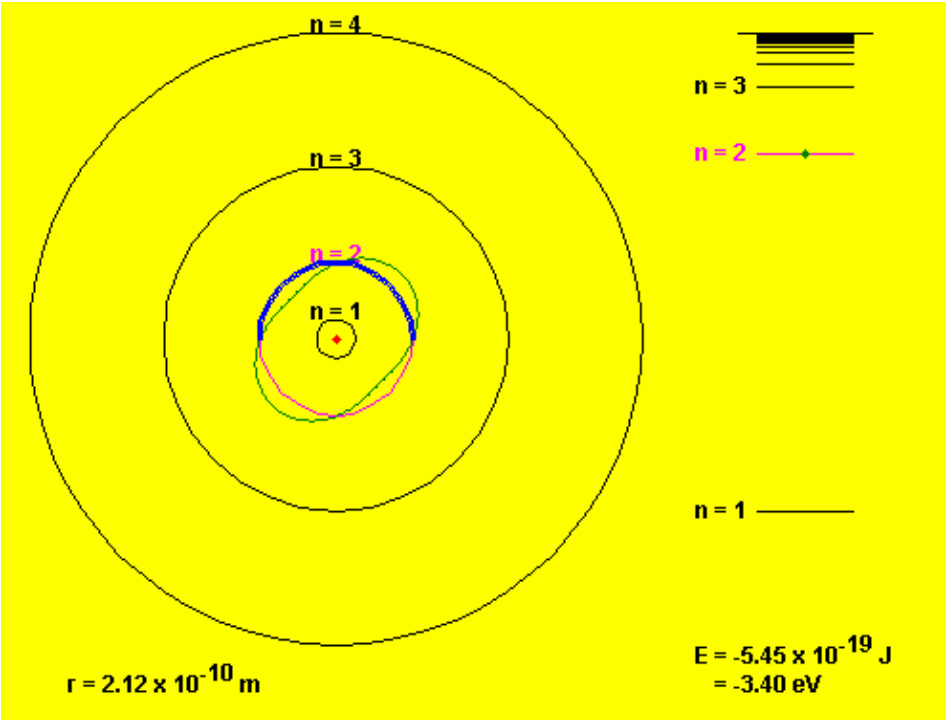
electron as wave in a circle

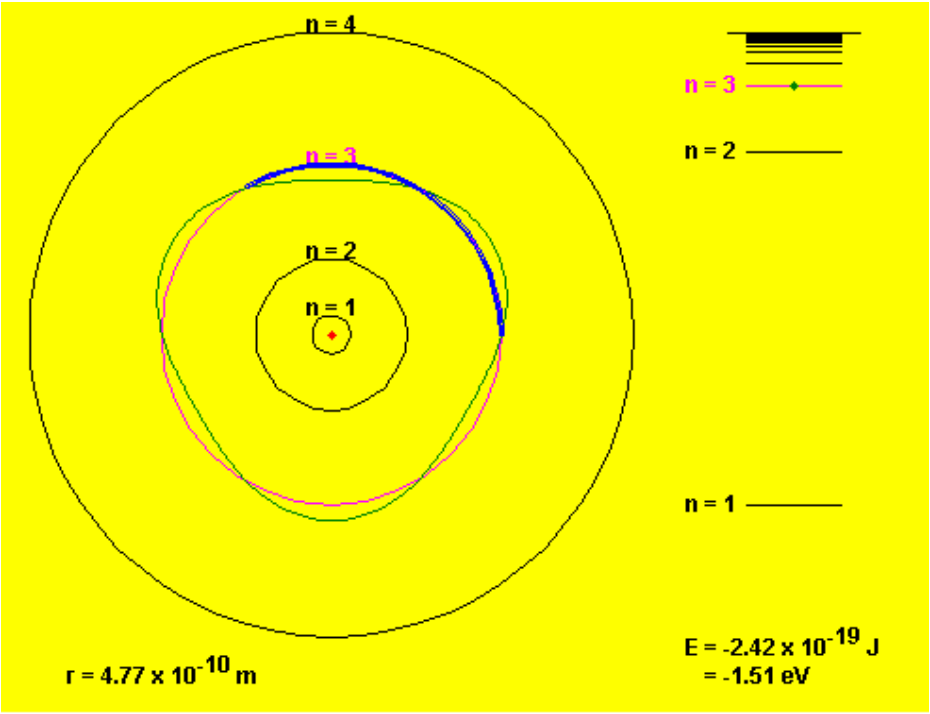


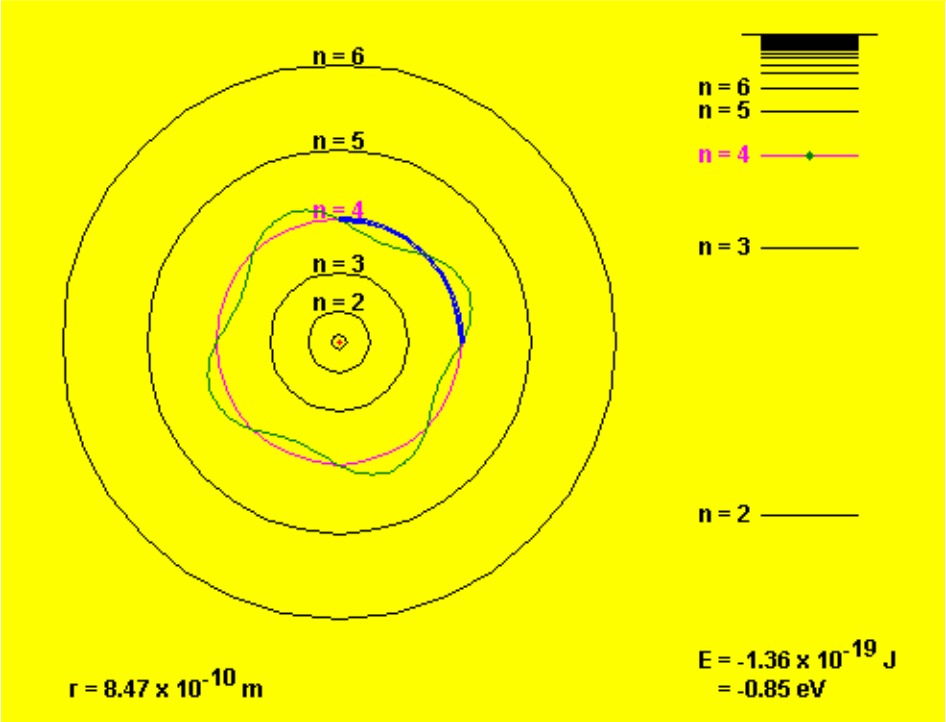
Quantization of orbitals

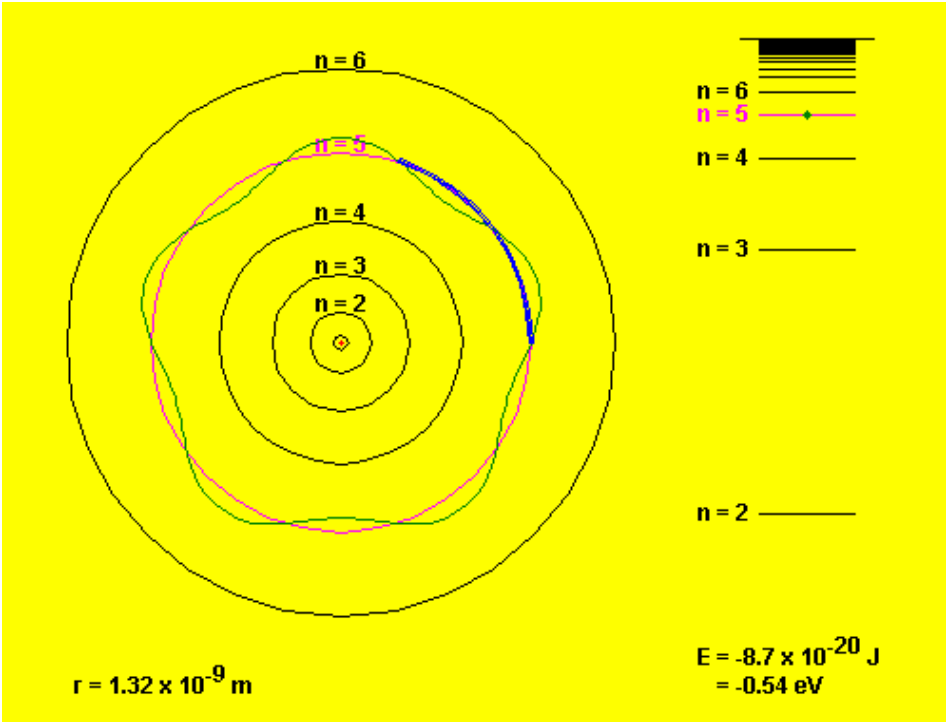
- So only certain orbitals are OK, and NOTHING in between.
  - We require $2\pi r = n\lambda_{electron}$ (whatever $\lambda_{electron}$ is…)
  - States are stationary
  - For orbitals in between, the electron goes around and interferes destructively with itself.




n = 4
n = 3
n = 2
n = 1
n = 3
n = 2
n = 1
r = 2.12 x 10^-10 m
E = -5.45 x 10^-19 J
= -3.40 eV


n = 4
n = 3
n = 2
n = 1
n = 3
n = 2
n = 1
r = 4.77 x 10^-10 m
E = -2.42 x 10^-19 J
= -1.51 eV


n = 6
n = 5
n = 4
n = 3
n = 2
n = 6
n = 5
n = 4
n = 3
n = 2
r = 8.47 x 10^-10 m
E = -1.36 x 10^-19 J
= -0.85 eV


n = 6
n = 5
n = 4
n = 3
n = 2
n = 6
n = 5
n = 4
n = 3
n = 2
r = 1.32 x 10^-9 m
E = -8.7 x 10^-20 J
= -0.54 eV

Now lets see if we can figure out the energies of these orbitals

- Starting Stuff
  - Relativity

$$E = \sqrt{p^2c^2 + m^2c^4}$$

  - Einstein
    - E=hf
- Waves c=fλ
- Mechanics
  - F=ma
  - circular motion
    - $$a = \frac{mv^2}{r}$$
- E&M $$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

$2\pi r = n\lambda_{electron}$

But what is $\lambda_{electron}$???

- back to light as particle
  - Relativity $E = \sqrt{p^2c^2 + m^2c^4}$
  - mass of light?? mass of photon?? =0
  - E=pc=hf=hc/λ SO **p=h/λ** or **λ=h/p**
- Now to electron as wave
  - $\lambda_{electron} = h/p_{electron}$

Now lets see if we can figure out the energies of these orbitals (Hydrogen)

- F=ma

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}=\frac{mv^2}{r}$$

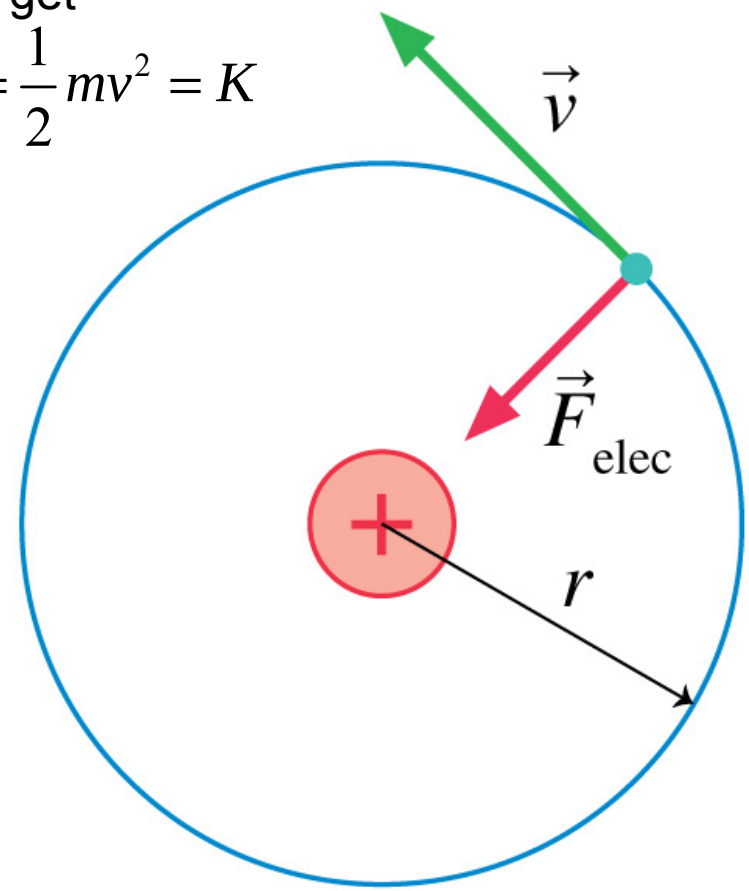
here we get

$$\frac{1}{8\pi\varepsilon_0}\frac{e^2}{r}=\frac{1}{2}mv^2=K$$

- $2\pi r=n\lambda_e$

$$r=\frac{n}{2\pi}\lambda_e=\frac{n}{2\pi}\frac{h}{p_e}=\frac{n\hbar}{m_e v}$$

$$where \quad \hbar=\frac{h}{2\pi}$$



from here we get L=mvr=nh/2π the quantization of angular momentum

quantization of the energy levels

- We get $r = 4\pi\varepsilon_0 \dfrac{n^2\hbar^2}{m_e e^2}$

$$E = K + U = \frac{1}{2} m_e v^2 - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = \frac{1}{8\pi\varepsilon_0}\frac{e^2}{r} - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} =$$

$$-\frac{1}{8\pi\varepsilon_0}\frac{e^2}{r} = -\frac{1}{8\pi\varepsilon_0}\frac{e^2}{\left(4\pi\varepsilon_0 \dfrac{n^2\hbar^2}{m_e e^2}\right)} = -\frac{1}{32\pi^2\varepsilon_0{}^2}\frac{m_e e^4}{n^2\hbar^2}$$

$$\text{Rydberg's Constant} = \frac{1}{32\pi^2\varepsilon_0{}^2}\frac{m_e e^4}{\hbar^2} = 13.6eV$$

$$E = -\frac{13.6eV}{n^2}$$

The Rydberg constant and Bohr radius

$$\frac{1}{4\pi\epsilon_0} = 9\,\text{x}10^9\ \frac{\text{Nm}^2}{C^2} \qquad m = 9.11\,\text{x}10^{-31}\ \text{kg}$$

$$\hbar = 1.05\,\text{x}10^{-34}\ \text{Js} \qquad e = 1.602\,\text{x}10^{-19}\ C$$

$$\mathcal{R} = \frac{1}{2}\left(\frac{1}{4\pi\epsilon_0}\right)^2 \frac{\text{me}^4}{\hbar^2} = \frac{1}{2}\left(9\,\text{x}10^9\ \frac{\text{Nm}^2}{C^2}\right)^2 \frac{9.11\,\text{x}10^{-31}\ \text{kg}\left(1.602\,\text{x}10^{-19}\ C\right)^4}{\left(1.05\,\text{x}10^{-34}\ \text{Js}\right)^2} =$$

2.2x10-18J=13.6 eV

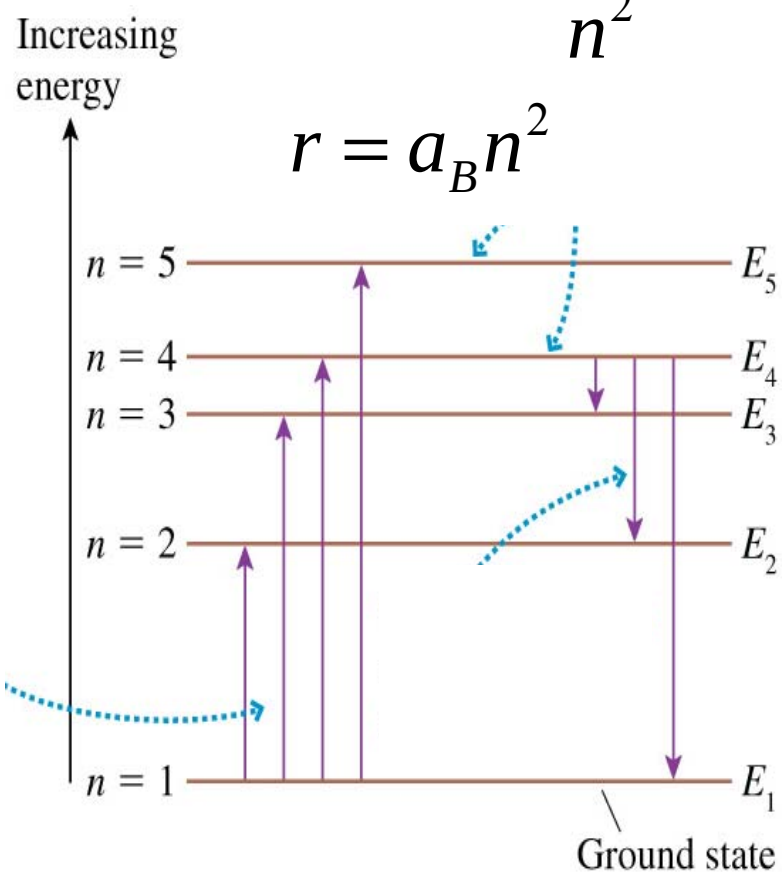
$$r = 4\pi\epsilon_0\ \frac{\hbar^2}{\text{me}^2}\ n^2 = a_B\, n^2 \qquad a_B = 4\pi\epsilon_0\ \frac{\hbar^2}{\text{me}^2} = 5.3\,\text{x}10^{-11}\ m$$

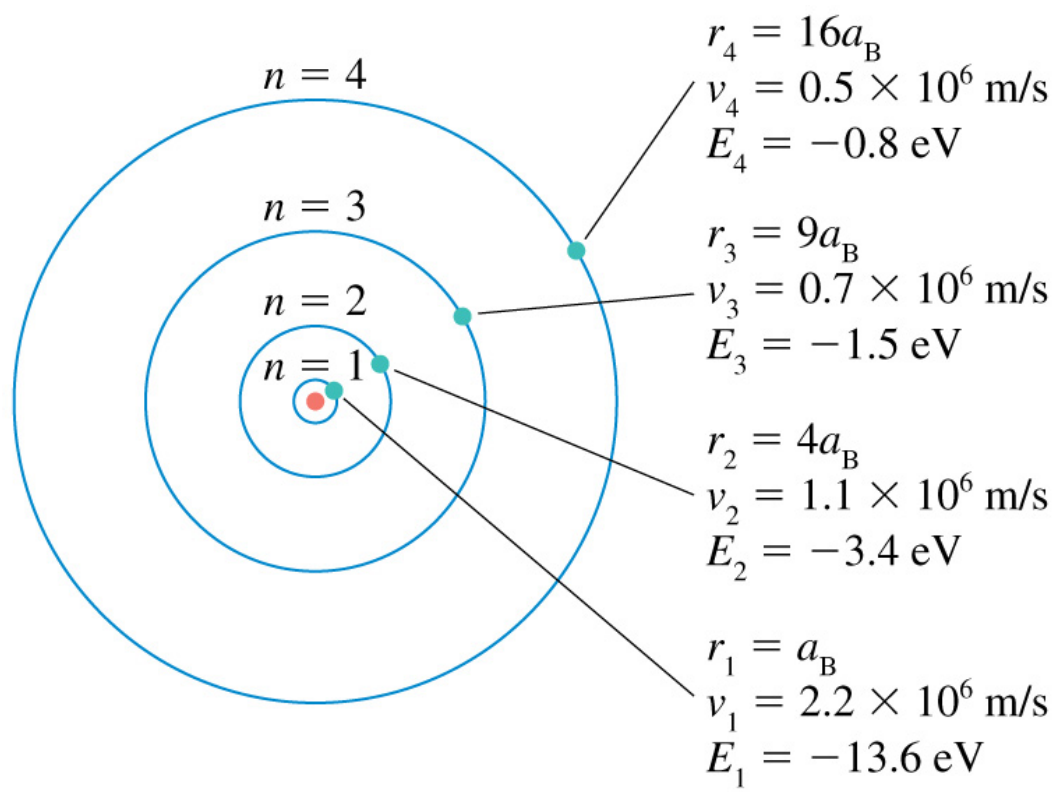
a_B~ size of atom ~10^{-10}m

quantized energy, radius, velocity

$$E = -\frac{13.6eV}{n^2}$$

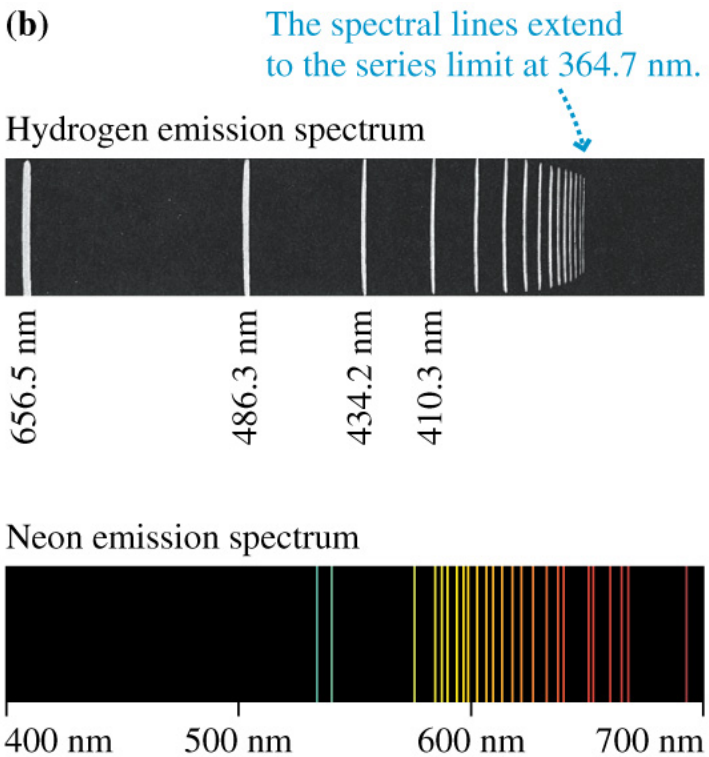
$$r = a_B n^2$$

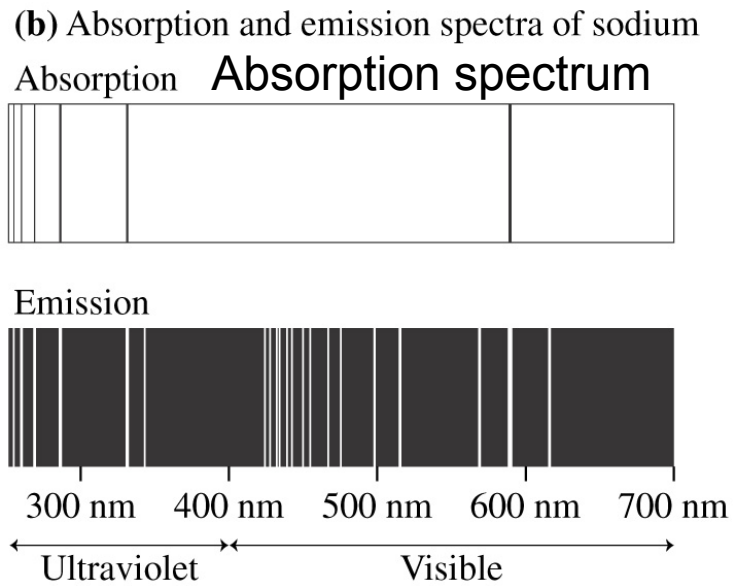




What about the spectral lines?

Emission spectrum

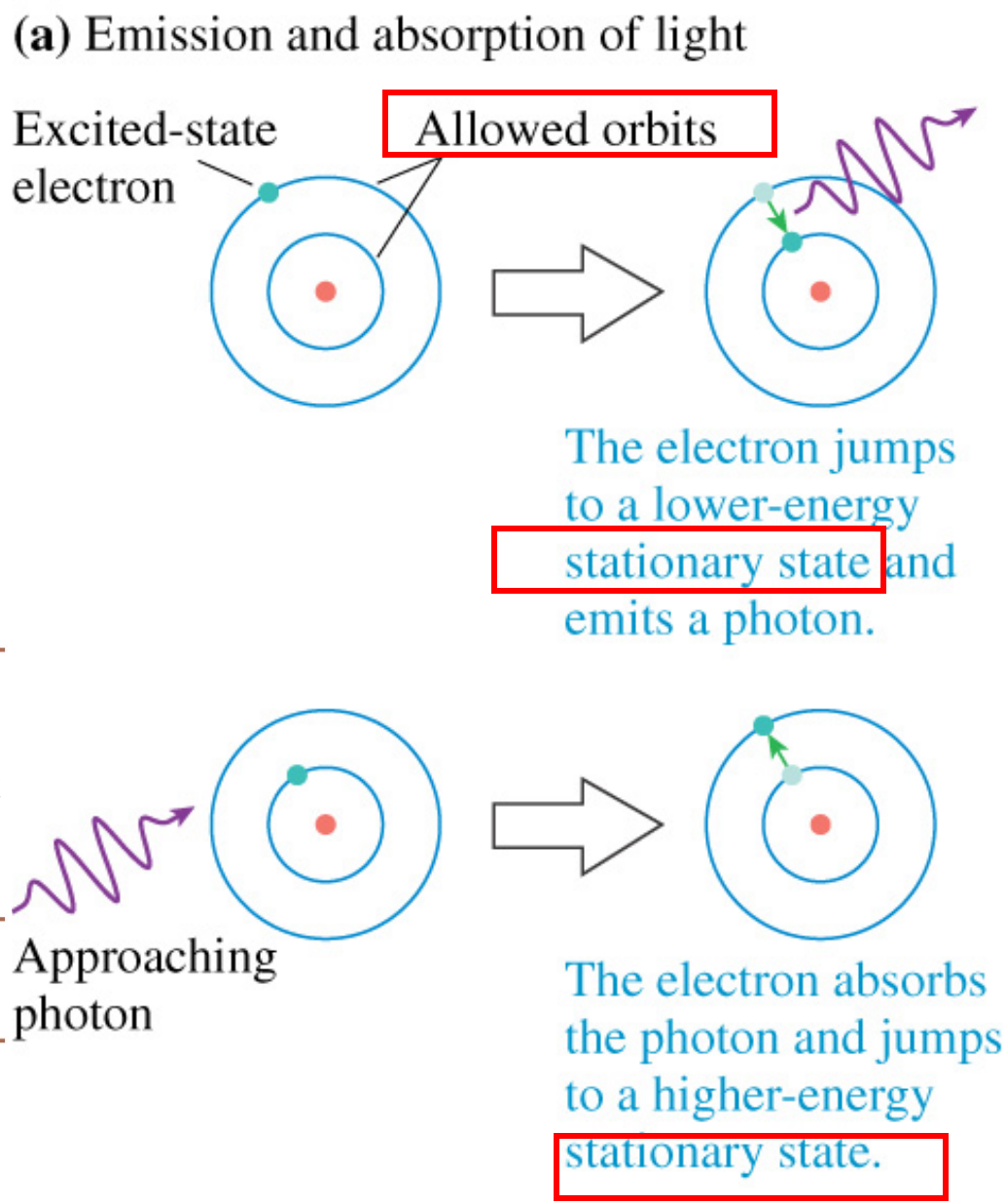


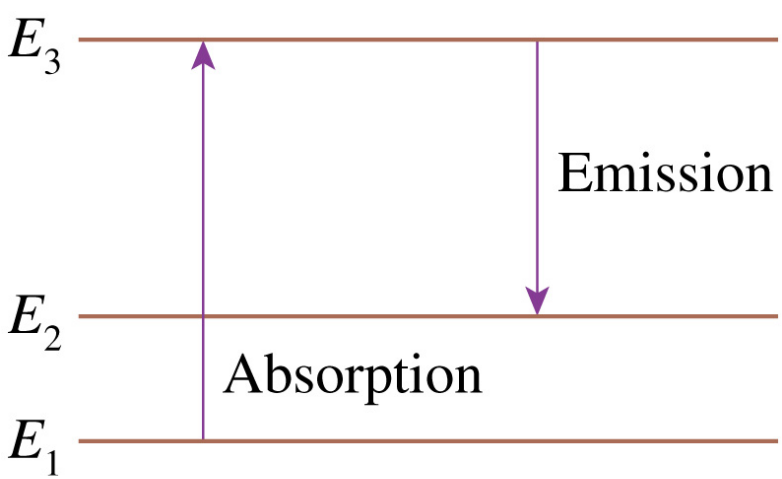


$$\lambda \sim \frac{1}{\frac{1}{m^2} - \frac{1}{n^2}}$$

Balmer forumla

- Only photons with certain energies allowed!





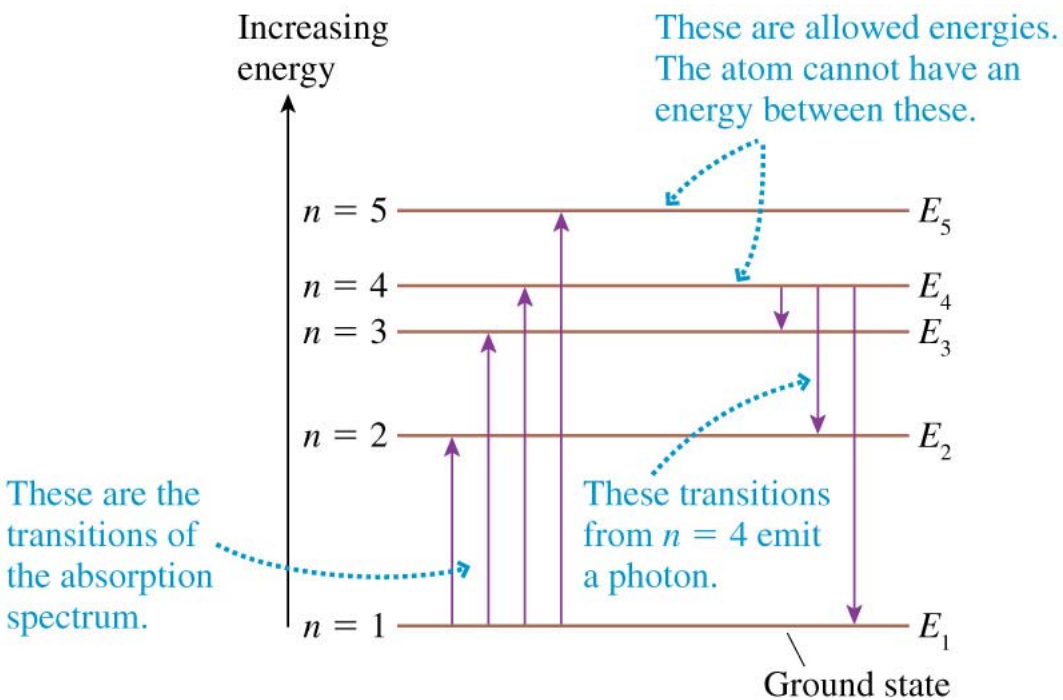
bohr photons

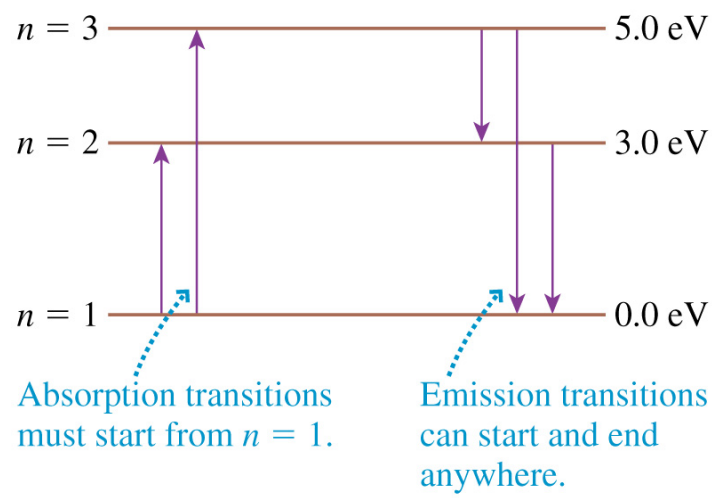
Energy of the photons the Balmer formula

$$E_{photon} = E_n - E_m = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right) = \frac{hc}{\lambda}$$

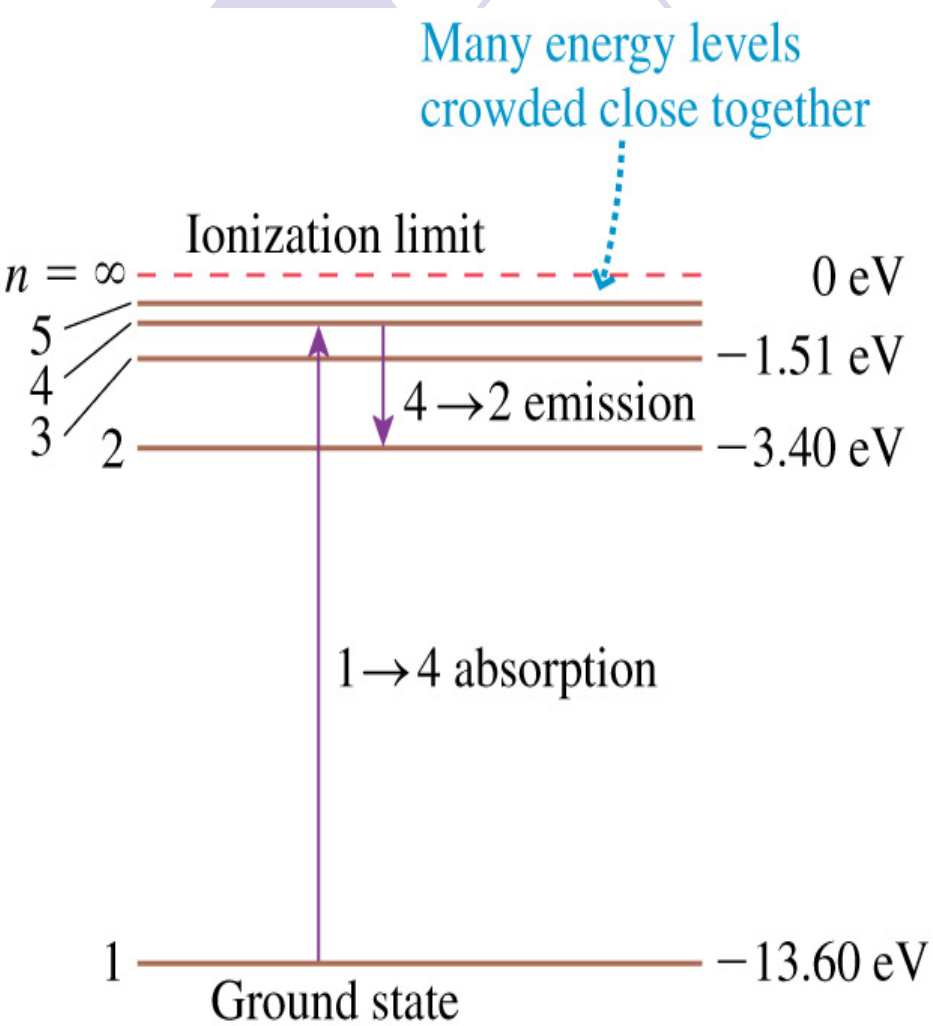
So we get the Balmer formula!!!

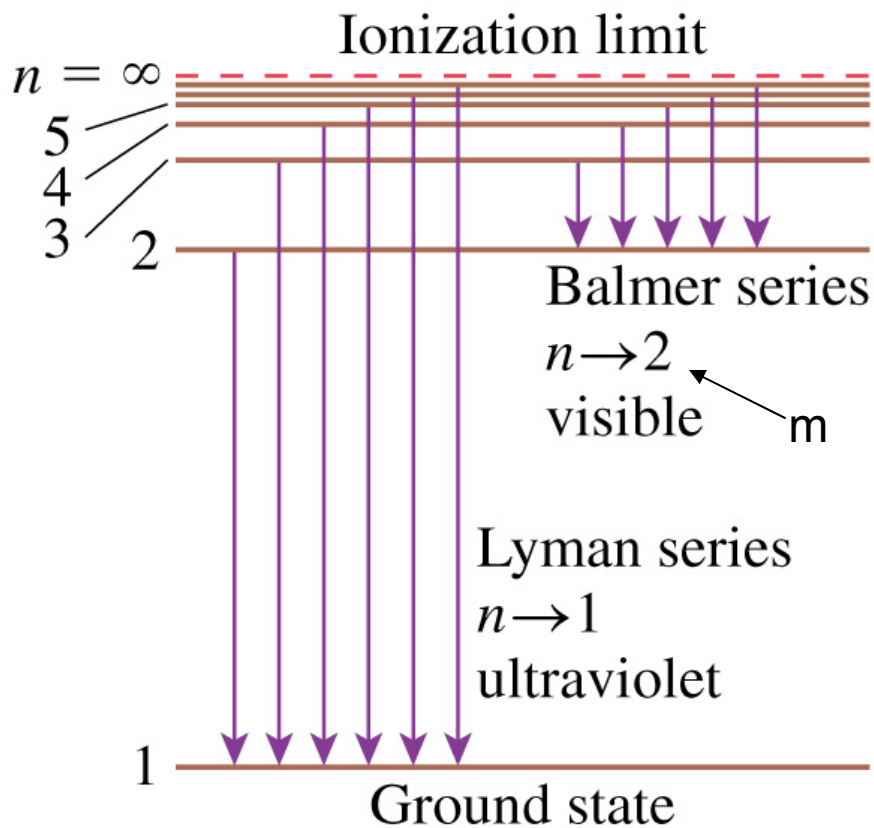
$$\lambda = \frac{hc}{R\left(\frac{1}{m^2} - \frac{1}{n^2}\right)}$$





Some names for hydrogen



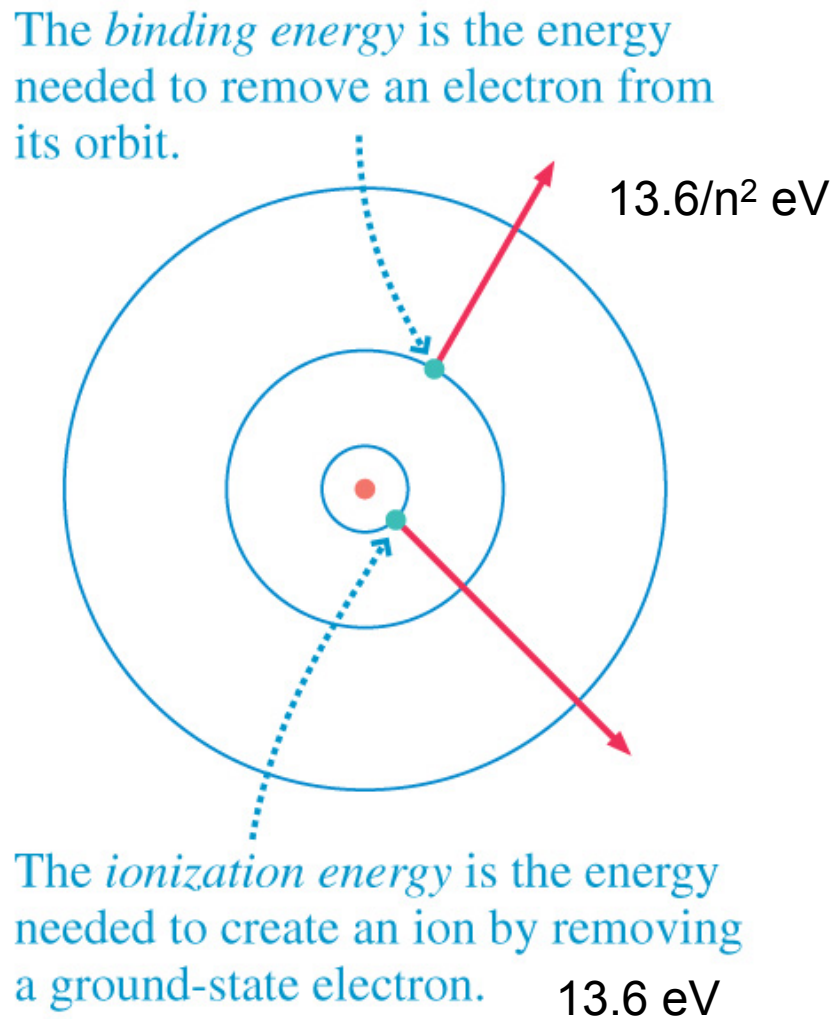


$$E_{photon} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right) = \frac{hc}{\lambda}$$

Binding energy, ionization energy

$$E_n = -\frac{Z\,13.6eV}{n^2}$$

$$|E_n| = Binding\ energy$$



The Davison Germer Experiment

- If electrons are really waves, they should diffract.
- The Davison Germer Experiment