[TP] A student asked, "I understand the transfer of a photon of energy takes about 100,000 oscillations of the electric field. But won't the photon have moved away from the atom in that time." A good answer to this question is …

20% 1. The photon is attracted to the atom and so stays close by.

20% 2. The atom moves back and forth the with the photon.

20% 3. It is the tugs of the electric field that transfer the energy.

20% 4. The photon disappears after the first electric field oscillation, but its energy doesn't appear in the atom until all of the field oscillations are complete.

20% 5. Some other answer.

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Lecture 30 CH101 A1 (MWF 9 am)

Friday, November 18, 2016

- Review: Resonant tugs by light on an electron cloud http://goo.gl/Ac4HGM
- Electron waves and quantization
- H atom photon energies

Next lecture: He^+ , Li^{2+} , etc., photon energies; Photoionization (photoelectric effect); Hydrogen atom electron waves http://goo.gl/XPkcxv

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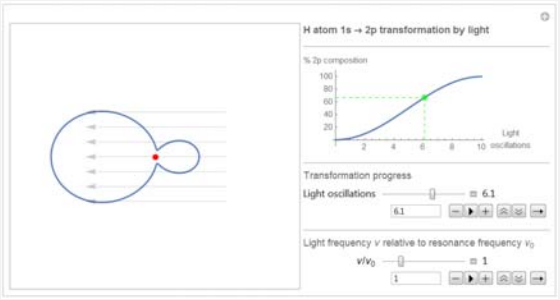
Resonant tugs by light on an electron cloud

http://goo.gl/Ac4HGM



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Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is

Recipe to make the energy diagram that accounts for this spectrum.

1. Lines at 656.3 nm, 486.1 nm, 434.1 nm, and 410.2 nm

2. Express energies in eV: 1.889 eV, 2.551 eV, 2.856 eV, 3.023 eV

3. Emission means energy given off by atom, so downward arrows.

4. Assume all arrow end at the same place.

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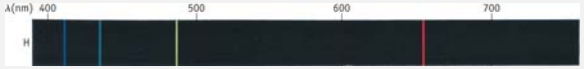
Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is



Recipe to make the energy diagram that accounts for this spectrum.

Carry out this recipe at home, making diagram to scale, in your notes.

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20% 5. Some other answer.

Electron clouds are built from waves

By analogy to the energy-frequency relation for light,

$E_{photon} = h \nu_{light}$

De Broglie guessed that electron clouds are built from waves with wavelength

$\lambda_{electron} = h / p_{electron}$

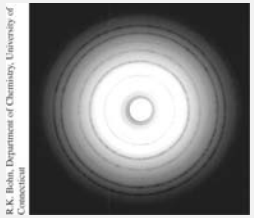
inversely proportional to electron momentum

$p_{electron} = m u$

Units are OK:

$h / m u = \text{J s} / (\text{kg m/s})$

$= \text{kg m}^2/\text{s}^2 \text{ s} / (\text{kg m/s}) = \text{m}$



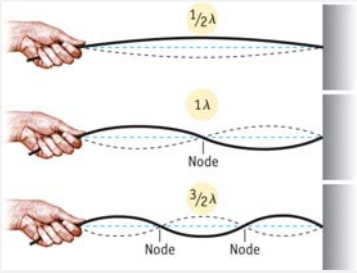
Electron "waves"

Big idea 1:

Integer number of *loops*, $\lambda / 2$, must "fit" in the atom

Integer number of loops fit in the atom

- 1 loop
- 2 loops
- 3 loops



Electron "waves"

Big idea 2:

More loops, …

more energy

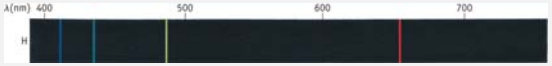
Let's see:

Integer number of loops

More loops, more energy

H atom photon energies

H atom photon energies



We can calculate that the photon energy of the red line, $\lambda_{red} = 656$ nm, is

$\Delta E_{light} = E_{photon} = h\,c\,/\,\lambda_{red} = 3.03 \times 10^{-19}$ J

Balmer discovered by trial and error that this photon energy is also given by the formula

$\text{Ry}\,(\frac{1}{2^2} - \frac{1}{3^2}) = 3.03 \times 10^{-19}$ J $= 1.89$ eV

In terms of terms of the Rydberg unit of energy

Ry $= 2.17987 \times 10^{-18}$ J $= 13.6$ eV

1 eV = energy of electron in a field of 1 V = 1 J/C

energy = "charge" × "voltage"

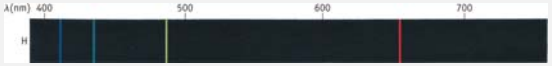
"charge" = electron charge $e = 1.6021766 \times 10^{-19}$ C

"voltage" = 1 V = 1 J/C

eV $= e \times 1$ J/C $= 1.6021766 \times 10^{-19}$ J

$\text{Ry} = 2.17987 \times 10^{-18}\ \text{J} \times \frac{1\ \text{eV}}{1.6021766 \times 10^{-19}\ \text{J}} = 13.6$ eV

H atom photon energies



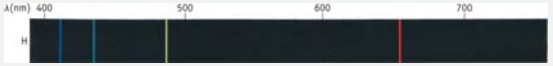
What is remarkable is that by changing one of the integers, Balmer was able to reproduce the photon energies of the other three lines,

$h\,c\,/\,(486\ \text{nm}) = 4.09 \times 10^{-19}$ J $= \text{Ry}\,(\frac{1}{2^2} - \frac{1}{4^2}) = 2.55$ eV

$h\,c\,/\,(434\ \text{nm}) = 4.58 \times 10^{-19}$ J $= \text{Ry}\,(\frac{1}{2^2} - \frac{1}{5^2}) = 2.86$ eV

$h\,c\,/\,(410\ \text{nm}) = 4.83 \times 10^{-19}$ J $= \text{Ry}\,(\frac{1}{2^2} - \frac{1}{6^2}) = 3.02$ eV

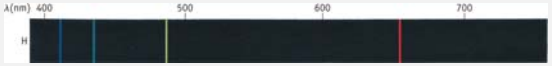
H atom photon energies



We can combine Balmer's results for the different lines as

$\Delta E_{light} = E_{photon}\ h\,c\,/\,\lambda = \text{Ry}\,(\frac{1}{2^2} - \frac{1}{n^2})$, $n = 3, 4, 5, 6, \ldots, \infty$

H atom photon energies



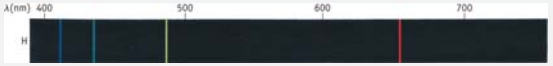
We can combine Balmer's results for the different lines as

$\Delta E_{\text{light}} = E_{\text{photon}}\ h\,c\,/\,\lambda = \text{Ry}\,(\frac{1}{2^2} - \frac{1}{n^2})$, $n = 3, 4, 5, 6, \ldots, \infty$

Since $\Delta E_{\text{light}} = -\Delta E_{\text{atom}}$, we can interpret Balmer's results in term of electron cloud energies

$E_2 = -\frac{\text{Ry}}{2^2}$, $E_3 = -\frac{\text{Ry}}{3^2}$, $E_4 = -\frac{\text{Ry}}{4^2}$, etc.

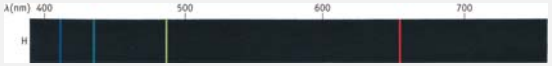
H atom photon energies



For example, the atom energy change due to the red lines is

$\Delta E_{\text{atom}} = E_{\text{f}} - E_{\text{i}} = E_2 - E_3 = -\,\text{Ry}\,(1/2^2 - 1/3^2) = -\Delta E_{\text{light}}$

H atom photon energies



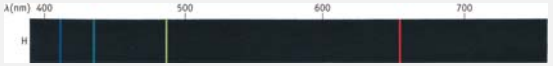
Now, long after Balmer's discovery, it was discovered that the integers 2, 3, 4, … etc., that appear Balmer's formulas are

the number of loops in the electron wave,

and that

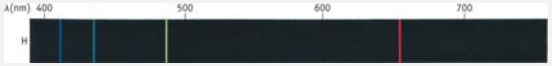
the energy of the electron wave with n loops is $E_{\text{n}} = -\frac{\text{Ry}}{\text{n}^2}$.

H atom photon energies



Further, since the energy change involves two different numbers of loops, it must be the mixture of electron waves that moves in resonance with the electric field of light, in an atom

H atom photon energies

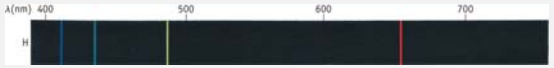


For example, the red line in H atom,

$$E_{\text{photon}} = h\,c\,/\,\lambda = |E_f - E_i| = |-\frac{\text{Ry}}{2^2} + \frac{\text{Ry}}{3^2}| = \text{Ry}(\frac{1}{2^2} - \frac{1}{3^2}) = 1.89 \text{ eV}$$

is due to a cloud made from a mixture of the 2-loop ($n = 2$) and 3-loop ($n = 3$) electron waves.

[Group quiz] What electron cloud energies account for the 434 nm line in the gas discharge spectrum (Balmer series) of H atoms?



17% 1. Only the $n = 3$ cloud energy
17% 2. Only the $n = 4$ cloud energy
17% 3. Only the $n = 5$ cloud energy
17% 4. The $n = 2$ and $n = 4$ cloud energies
17% 5. The $n = 2$ and $n = 5$ cloud energies
17% 6. None of these