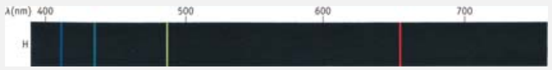
Lecture 31 CH101 A2 (MWF 11:15 am) Fall 2017

[TP] What electron cloud energies account for the 486 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

Response Counter

10

1

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Monday, November 27, 2017

For today ...

- Revisit: How light and matter exchange energy
- H atom energy diagrams: Balmer's formula
- H atom energy diagrams: Beyond Balmer's formula

Next lecture: H, He^{+}, Li^{2+}, etc., photon energies; Ionization (photoelectric effect); Review: Lewis structures, formal charge and oxidation number

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Revisit: How light and matter exchange energy

The CDF animation at http://goo.gl/Ac4HGM, illustrates that light and matter exchange energy smoothly and slowly.

We can now determine the frequency of the light at resonance in the animation.

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Revisit: How light and matter exchange energy

Sketch the electron cloud at the start of the animation.

What electron cloud is it?

Sketch the electron cloud at the end of the animation.

What electron cloud is it?

Start	End

5

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Revisit: How light and matter exchange energy

Write an expression for the frequency of the light at resonance in the animation.

$$\nu = \frac{|E_f - E_i|}{h} = \frac{\mathrm{Ry}|-1/4-(-1)|}{h} = \frac{3\mathrm{Ry}}{4h} = 2.47 \times 10^{15}\,\mathrm{J}$$

So, in the UV region of the spectrum.

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Revisit: How light and matter exchange energy

Let's now use this approach to understand the effect of light in the visible region of the spectrum.

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H atom photon energies: Balmer's formula

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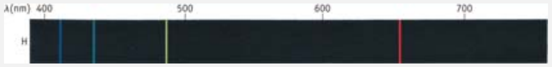
H atom photon energies



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

$$\Delta E_{\mathrm{light}} = E_{\mathrm{photon}} = \frac{hc}{\lambda_{\mathrm{red}}} = \frac{hc}{656\ \mathrm{nm}} = 3.03 \times 10^{-19}\,\mathrm{J}$$

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

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

in terms of terms of the Rydberg unit of energy

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

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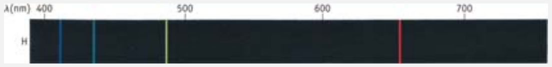
H atom photon energies



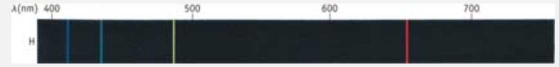
What is remarkable is that by changing one of the integers, Balmer was able to reproduce the photon energies of the other three lines,

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

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

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

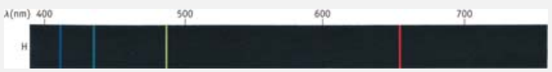
H atom photon energies



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

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

H atom photon energies



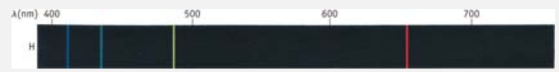
Then, since $\Delta E_{\text{light}} = -\Delta E_{\text{atom}}$, we can interpret Balmer's results in term of differences of electron cloud energies

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

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

$$\Delta E_{\text{atom}} = E_f - E_i = E_2 - E_3 = -\text{Ry}\,(\frac{1}{2^2} - \frac{1}{3^2}) = -\Delta E_{\text{light}}$$

H atom photon energies

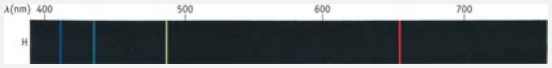


Now, long after Balmer's discovery, it was understood that the integers 2, 3, 4, … etc., that appear Balmer's formulas are …

the number of loops in the electron wave, and that

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

H atom photon energies



Further, since the energy change involves two different numbers of loops, in an atom it must be that it is …

the mixture of electron waves that moves

in resonance with the electric field of light.

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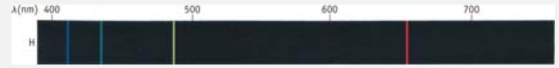
H atom photon energies



For example, the red line in H atom,

$$E_{\text{photon}} = \frac{hc}{656\text{ nm}} = |E_f - E_i| = \left|-\frac{\text{Ry}}{2^2} + \frac{\text{Ry}}{3^2}\right| = \text{Ry}\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = 1.89\text{ eV}$$

is due to resonant motion of the electron cloud made from the mixture of …

the 2-loop ($n = 2$) and 3-loop ($n = 3$) electron waves.

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[TP] What electron cloud energies account for the 486 nm line in the gas discharge spectrum (Balmer series) of H atoms?

0% 1. Only the $n = 3$ cloud energy
0% 2. Only the $n = 4$ cloud energy
0% 3. Only the $n = 5$ cloud energy
0% 4. The $n = 2$ and $n = 4$ cloud energies
0% 5. The $n = 2$ and $n = 5$ cloud energies
0% 6. None of these

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

0% 1. Only the $n = 3$ cloud energy
0% 2. Only the $n = 4$ cloud energy
0% 3. Only the $n = 5$ cloud energy
0% 4. The $n = 2$ and $n = 4$ cloud energies
0% 5. The $n = 2$ and $n = 5$ cloud energies
0% 6. None of these

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What about clouds made from a single *n*?

It turns out that clouds made from a single electron wave do not move.

That they do not move is why the electrons in an atom do not collapse into the nucleus, and so why atoms exist!

It is only clouds resulting for the mixture of different electron waves that move.

And it is interaction with light that creates such mixtures.

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Light-matter resonance questions

Question: We have said electrons in an atom are a non-moving cloud. Then, how can there be "jiggling" at the light frequency?

Answer: Clouds for electron energy states indeed do not "jiggle".

Rather, when light interacts with matter, it produces a mixture of electrons states of energy E_i and E_f.

It is these mixtures whose clouds "jiggle" at the frequencies

$$\nu_{\text{light}} = \nu_{\text{cloud}} = \frac{|E_f - E_i|}{h}$$

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H atom photon energies: Beyond Balmer's formula

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H atom photon energies: Beyond Balmer

Balmer's formula always involves $E_2 = -\frac{\text{Ry}}{2^2}$.

What about extending the formula in terms of $E_1 = -\frac{\text{Ry}}{1^2}$, as

$$\Delta E_{\text{light}} = E_{\text{photon}} = \frac{hc}{\lambda} = \left| -\frac{\text{Ry}}{1^2} + \frac{\text{Ry}}{n^2} \right| = \text{Ry}\left(\frac{1}{1^2} - \frac{1}{n^2}\right),\ n = 2, 3, 4, 5, \ldots, \infty\ ?$$

Where in the spectrum would lines given by this formula occur?

