# Lesson 41: Quantum Model

Bohr's model of the atom was a great triumph, but it also had several problems that even Bohr was willing to admit. His model could not explain any of the following:

1. Why shouldn't electrons emit EMR when they are in their energy levels?
2. The formulas only work for hydrogen.
3. It was found that each emission line is actually made of two or more closely spaced lines, called the **fine structure**.
4. Some emission lines are brighter than others.

It must be remembered that in Bohr's model the electron was still considered to be a particle (like some infinitely small ball) spinning around the nucleus.

- Bohr hadn't totally realized how much his theory and quantum mechanics could be joined.
  - de Broglie had shown how particles have wavelike properties. Although everyday objects are too large to show much wavelike behavior, electrons definitely can and do.
  - It started to become clear that electrons can not be thought of as particles… maybe they are acting more like waves even in the model of the atom.

Assume that you figure out the de Broglie wavelength of an electron.

- For the electron to orbit the nucleus, its wavelength must be able to fit perfectly around the nucleus.
- You can't fit the electron's wavelength if the orbit is smaller or bigger than some multiple of the wavelength.

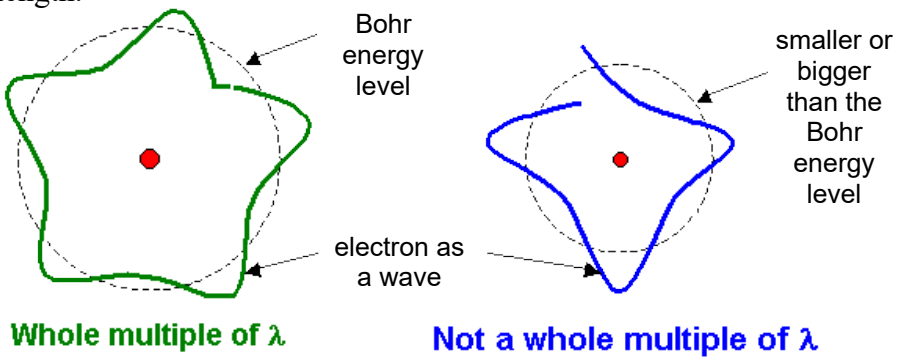


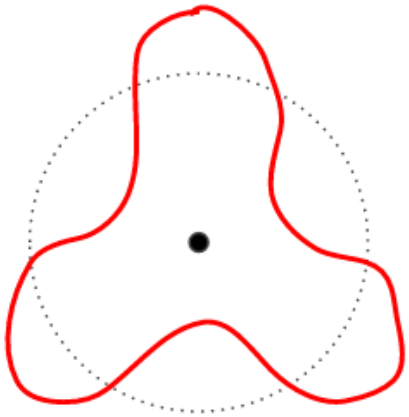

*Illustration 1: The electron as a wave will either fit or not fit as a whole number of wavelengths around the nucleus.*

Only some radii energy levels the correct radius to let the wavelengths wrap perfectly around.

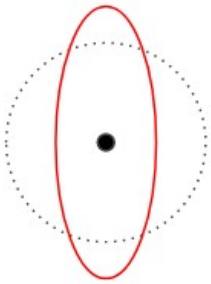
- If they're just a bit smaller or big, the wave would add destructively collapse.
- If it fits the radius, the electron (as a wave) is very stable.

If we know the circumference, we can calculate wavelength. Only a whole number of wavelengths, equal to the energy level number, will fit around the circumference.

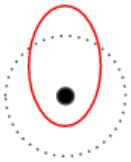
$$C = n\,\lambda$$



n = 3



n = 2



n = 1

**Example 1**: Assuming you have access to formulas and constants from the last section, **determine** the velocity of an electron in the fifth energy level of hydrogen.

First, we calculate the radius of the fifth energy level…

$$r_n = n^2 r_1$$
$$r_5 = 5^2 (5.29\text{e-}11)$$
$$r_5 = 1.3225\text{e-}9 \text{ m}$$

We will then calculate the circumference of the energy level…

$$C = 2\pi r$$
$$C = 2(3.14)(1.3225\text{e-}9)$$
$$C = 8.3053\text{e-}9 \text{ m}$$

Since there must be five wavelengths that fit in the fifth energy level, we will calculate how big a single wavelength is…

$$C = n\lambda$$
$$\lambda = C / n$$
$$\lambda = 8.3053\text{e-}9 / 5$$
$$\lambda = 1.66106\text{e-}9 \text{ m}$$

And, that electron has a wavelength because it is following the wave-particle duality set out by deBroglie…

$$p = mv \qquad p = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{mv}$$
$$v = \frac{h}{m\lambda}$$
$$v = \frac{6.63\text{e-}34}{9.11\text{e-}11(1.66106\text{e-}9)}$$
$$v = 438136.9002 = 4.38\text{e}5\, m/s$$

It explains why an electron does not emit EMR and spiral into the nucleus following Maxwell's theory of EMR.

- The electron exists as a standing wave, not as a regular particle.
  - Since it is not an accelerating charged particle, Maxwell's theory of EMR does not apply.

Remember that Bohr's model couldn't explain orbits in atoms beyond hydrogen. This new Quantum model can!

- If, for example, you add another proton to hydrogen you get helium.
  - The extra positive charge exerts a greater force on the electron and draws it into a smaller radius orbit.
  - The electron's velocity adjusts, so it now has a different wavelength. This means the radius must be different.
- The Quantum Model can explain all elements.

If you follow this theory, the electron stops being a particle orbiting the nucleus at a certain point.

- Instead, an electron's mass and charge can be thought of a "spread out" as a standing wave around the nucleus.
  - The electron is not really at any one position as a particle, it's everywhere as a wave.
- Even as a wave, the electron exists mostly right near the Bohr orbit.
- There is a probability associated with that wave and where you would "find" the electron at any moment.
  - This explains the fine structure of the emission spectra, since sometimes the electron is a little higher or lower when it falls.
- The electrons have become a "cloud" of electrons. Sometimes this model of the atom is called the **Electron Cloud Model**.

The Bohr model has evolved into a mathematical quantum model involving waves and probability.

- Using some fancy physics, the Quantum Model can even explain why some emission lines are brighter than others.
- The Quantum Model of the atom is the longest lasting model, and is essentially the model used today.

## *Homework*

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