The Quantum-Mechanical Model of the Atom

Unit: Electronic Structure

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS1-1

Mastery Objective(s): (Students will be able to…)

- Describe & explain the quantum mechanical model of the atom.

Success Criteria:

- Descriptions successfully communicate accurate information about the quantum mechanical model of the atom and how it describes the behavior of atoms.

Tier 2 Vocabulary: mechanical

Language Objectives:

- Explain scientific information about the quantum mechanical model of the atom.

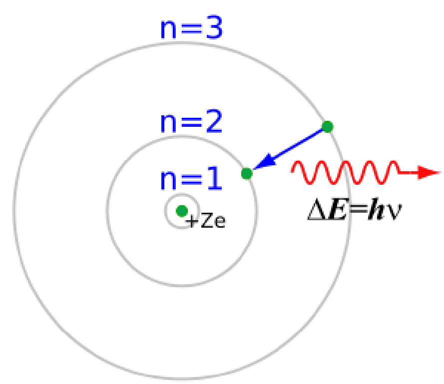
Notes:

quantum: a discrete increment (plural: *quanta*) If a quantity is *quantized*, it means that only certain values for that quantity are possible.

Because an electron behaves like a wave, it can only absorb energy in quanta that correspond to exact multiples of its wavelength.

Neils Bohr was the first to realize that because atomic spectral emissions are quantized, electron energy levels must also be quantized. (See the "Historical Development of Atomic Theory" section on page 141 for more details.)

Recall that in the Bohr model of the atom, an electron's (quantum) energy level determined its distance from the nucleus.



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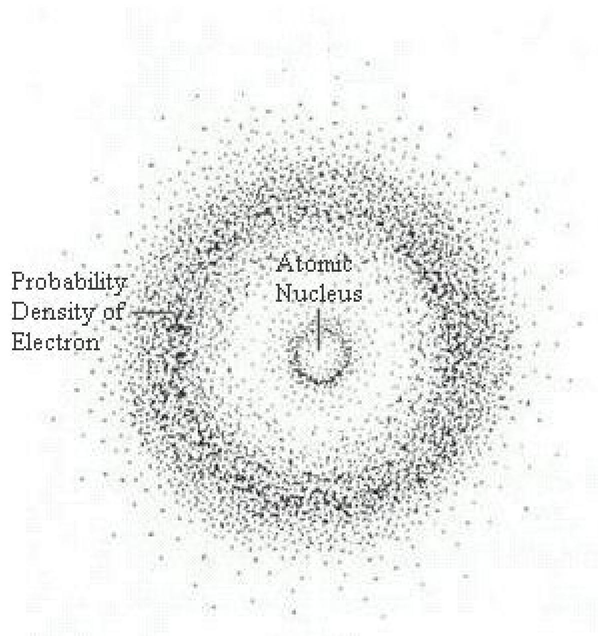
What actually happens is not that simple. If an electron is in a particular energy level, the Bohr model may predict its *average* distance from the nucleus, but the electron is also a particle, so it has some freedom to move closer or farther.

In 1925, Austrian physicist Erwin Schrödinger found that by treating each electron as a unique wave function, the energies of the electrons could be predicted by the mathematical solutions to a wave equation. The use of Schrödinger's wave equation to construct a probability map for where the electrons can be found in an atom is the basis for the modern quantum-mechanical model of the atom.

To understand the probability map, it is important to realize that because the electron acts as a wave, it is detectable when the amplitude of the wave is nonzero, but not detectable when the amplitude is zero. This makes it appear as if the electron is teleporting from place to place around the atom. If you were somehow able to take a time-lapse picture of an electron as it moves around the nucleus, the picture might look something like the diagram to the right, where each dot is the location of the electron at an instant in time.



Notice that there is a region close to the nucleus where the electron is unlikely to be found, and a ring a little farther out where there is a much higher probability of finding the electron. As you get farther and farther from the nucleus, Schrödinger's equation predicts different shapes for these probability distributions. These regions of high probability are called "orbitals," because of their relation to the orbits originally suggested by the planetary model.

The quantum mechanical model of the atom is based on this combination of quantized energy levels and probabilities.

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The claims of the quantum mechanical model of the atom are:

- The electrons orbiting an atom behave like waves as well as particles, and their behavior can be described by Schrödinger's wave equation, which has integer solutions called quantum numbers.
- The energies and therefore locations of electrons within an atom cannot be determined exactly, but there are regions with a high probability of finding an electron (called "orbitals"), and other regions with a low probability of finding an electron.
- The energy of each electron (and therefore its probable location) can be described by a unique set of quantum numbers. No two electrons can have the same energies, which are described by the electron's unique set of quantum numbers, which means no two electrons can have the exact same set of quantum numbers. This is called the *Pauli exclusion principle*, named after the Swiss-American physicist Wolfgang Pauli.
- Electrons move within their orbitals at speeds near the speed of light.
- An electron is constrained to stay within its orbital because of its energy. If the electron absorbs energy, it can move to a higher-energy orbital. If an unoccupied lower-energy orbital is available, the electron can release energy (in the form of a photon, which can be observed as light) and move to the lower-energy orbital.
- The shape of any given orbital (the region where there is high probability of finding an electron) depends on all of the forces that affect that electron. Some of these forces relate to the energy characteristics of the specific orbital, but other forces can include electrostatic repulsion of other electrons within the atom, electrostatic repulsion of the electrons in ionically-bonded atoms, or the sharing of electrons in a covalently-bonded atom. In real atoms, the shapes of orbitals are continuously changing as all of the electrons within the atom repel one another as they move at near-light speed.

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