Skills to Develop

- Give a very brief history on the development of chemistry as a science leading to the development of quantum theory.
- Explain these terms: electron, atomic nucleus, electromagnetic radiation, spectroscopy.

**Introduction to Quantum Theory**

Chemistry began as a discipline to document materials that restore health, as pharmacy is today. During the 16th to 18th centuries, we have learned that material consists of compounds that are combinations and variation of only about 90 chemical elements, each with a unique atomic weight. The variation of their macroscopic properties as a function of the atomic weight is very interesting. For example, lithium, sodium, potassium and cesium react with water vigorously, and their reactivity increases as their atomic weights increase. This discovery led to their arrangement in a periodic table in the 19th century.

During the 20th century, chemists have studied the structure of atoms. The discovery of electrons in 1897 by J.J. Thomson showed that there were more fundamental particles present in the atoms. Fourteen years later, Rutherford discovered that most of the mass of an atom resides in a tiny nucleus whose radius is 100,000 times smaller than that of an atom. In the meantime, Max Planck (1858-1947) theorized that light beams were made of photons that are equivalent to particles of wave motion. These discoveries created new concepts. When these concepts and discoveries are integrated, new ideas emerge. The result is a quantum theory, named perhaps from the discrete nature of energy levels in microscopic systems. This theory gives good interpretations of the phenomena of the atomic and subatomic world. In this microscopic world, distances are measured in nanometers (10^{-9} or 1e-9 meter) and fantometers (1e-15 meter, also called fermi, in honour of Fermi who built the first nuclear reactor).

The quantum theory has many mathematical approaches, but the philosophy is essentially the same. Quantum mechanics is the foundation of chemistry, because it deals with subatomic particles, as well as atoms, molecules, elements, compounds, and much larger systems.

At the sub-atomic scale, there is no boundary between particles and waves. In fact, both particles and wave properties must be considered simultaneously for a system. The study of quantum mechanics lead us to understand the material and the universe beyond the general perception of matter by our ordinary senses of tasting, seeing, hearing, feeling, and sensing.

Furthermore, when coupled with the theory of relativity developed by Einstein, there is no boundary between material
and energy. Energy and mass are equivalent, and they can convert into each other.

On this and some related pages that follow, you are introduced to the quantum theory for the treatment of the hydrogen atom. The quantum theory does much more than explaining the structure of the simplest atom, it rationalizes the existence of the chemical elements. The most widely used periodic table of chemical elements today is based on the results of quantum theory. What we tend not to appreciate today is the hard work and ingenuity that went into the development of the quantum theory we today take for granted.

A hydrogen atom is the simplest atom. It consists of a proton in the nucleus and an electron around it. This type of atom is also the most abundant atom in the solar system, as well as the universe. Closer to home, hydrogen is also very abundant on the surface of the planet of Earth. Most hydrogen atoms are combined with oxygen to form the water molecule. In organic substances, hydrogen atoms are mostly attached to carbon, nitrogen, and oxygen atoms. In terms of number, hydrogen is the most abundant atom in our body. (This is the atom which causes problems in our body with certain types of radiation -- Can you find why? -- This is a good topic to discuss with your professor after class)

To learn the theory, some basic concepts are required. Thus, we present several modules to explain quantum theory and the hydrogen atom.

Here is a preview of these modules

- Electromagnetic Radiation
  Transmission of energy through space via no medium is electromagnetic radiation. The visible region of the electromagnetic radiation is light, but that is a very small region. There is much more than light to meet the eye.

- Spectra
  Diagrams showing the distribution of intensity versus wavelengths are called spectra. Their study reveals the fundamentals of electromagnetic radiation as well as leading to useful applications. For example, the Hydrogen Spectra study led Bohr and others to develop the quantum theory to describe the atomic structures. For some cool spectrum demonstration, check out the IR Tutor created by Charles Abrams. Here is one of his animated pictures.

- Quantum numbers
  The states of electrons are represented by wavefunctions. Each wavefunction has a set of numbers, called quantum numbers. We often use quantum numbers to describe properties of electrons. This page gives a simplistic but important view of quantum numbers.

- Atomic orbitals
  Electronic states, represented by wavefunctions, in an atom are called atomic orbitals. Since we use quantum numbers to describe them, atomic orbitals are labelled by quantum numbers, such as 2s orbital. s represents quantum number \( l = 0 \); that implies \( m = 0 \). Each atomic orbital accommodates two electrons due to electron spin.

- Periodic table
  The beauty of quantum theory is its mathematical results not only explain the arrangement of the elements in the Periodic Table of chemical elements, but they seem to rationalize the existence of the elements. Its rationalization lies in the Electronic configuration of atoms with more than two electrons. Based on the electronic configurations, Atomic properties are nicely explained.

- Zests of elements - A delightful look at the chemical elements. Elements review - A review and quiz.

Here are some links to other Internet sites related to the quantum theory:
Confidence Building Questions

1. **Which element has the lightest atomic weight?**

   Hint: hydrogen

   **Skill** - Hydrogen consists of a proton and an electron.

2. **What led to the invention of a periodic table of chemical elements?**

   Hint: The study of properties of elements.

   **Skill** - Organization and analysis of information are scientific skills.

3. **What are cathode rays discovered by J.J. Thomson in 1897?**

   Hint: Electrons are the particles in the cathode rays.

   **Skill** - Explain how an experiment is done, and interpret the results.

4. **What is approximately the length of atomic radii?**

   Hint: Atomic radii are about 1 to 2 Angstrom (0.1 or 0.2 nanometer).

   **Examples** - Atomic radii in picometer ($10^{-12}$ m): $\text{\text{H}}$ 37, $\text{\text{He}}$ 50, $\text{\text{Li}}$ 152, $\text{\text{Cs}}$ 265, $\text{\text{Fe}}$ 124, $\text{\text{I}}$ 133 pm. 1 nm = 1000 pm.

5. **What is approximately the length of nuclear radii?**

   Hint: Nuclei are measured in fermi or femtometer.

   **Discussion** - A femtometer (fm) is $10^{-15}$ m. The radius of an atom is 100,000 times larger than that of its nucleus.

6. **Which is heavier, the proton or the electron?**

   Hint: The proton is almost 2000 times the mass of electrons.

   **Skill** - Know some properties of the subatomic particles.

7. **What theory is developed to interpret phenomena originated from the atom?**

   Hint: Quantum theory
Skill - The word quantum refers to a small bundle of energy.

8. Give some wave properties that particles do not have.

   Hint: Wavelength, frequency, and interference

Skill - Describe the duality of wave and particle for subatomic particles.

Contributors

- Chung (Peter) Chieh (Professor Emeritus, Chemistry @ University of Waterloo)