Topic 19: Quantum Mechanics

Source: Hewitt's *Conceptual Physics* textbook

Types of Material: Hewitt's textbook and other high school textbooks or non-calculus college textbooks treating quantum mechanics

Building on: The behavior of matter on a macro (large) scale is studied early in physics. The mathematical study of the behavior of matter on the micro (small) scale needs high level mathematics, however, some of the statistical results can be explored without the math if you discuss particles like e's traveling in a wavelike motion with a chance of being here or there. If you pin down a particle's location, then its mass and momentum are not so certain and vice versa.

Leading to: Although QM is often viewed as an esoteric subject and only of interest to theoretical physicists, it is the theory that permits us to understand many of the properties of matter that we observe every day such as why glass is transparent and why copper conducts electricity and Styrofoam doesn't. Quantum mechanics is today's technology and for the future for devices such as lasers, medical imaging devices like the MRI and PET. Atomic clocks make GPS possible and are dependent on QM. (Reference: A New Model Course in Quantum Mechanics for Scientists and Engineers from the University of Maryland Physics Education Research Group. http//www.physics.umd.edu/rgroups/ripe/perg/qm/)

Links to Physics: As mentioned in "leading to," engineers can build lasers, MRI and PET machines. Theoretical physicists use QM to probe atoms for particles and force laws at high-energy physics accelerator facilities like Fermilab in Batavia, Illinois.

Links to Chemistry: QM details are left for the advanced chemistry student. Applications are shown in Pauling's book on QM for chemical bonds, resonance energy, electronegativity, crystal structure of molecules and hydrogen bonds. Also shown are bonds in molecules. http://www.amazon.com/introduction-mechanics-applications-chemistry/dp/B0007HQ8FZ

Links to Biology: Quantum biology uses high-performance computers to precisely model complex biological processes. Protein behavior is being studied and understood using QM with the use of these supercomputers on atoms versus large groups of atoms. Rensselaer University: http://news.rpi.edu:80/campusnews/update/do
Paul A. M. Dirac extended Erwin Schrödinger's quantum mechanics work when Dirac developed his famous wave equation. Also predicted by Dirac was pair production where matter and antimatter annihilated each other to

produce radiation. Positrons are used everyday in medicine in the PET (positron emission tomography) scanners that pinpoint interesting places in the brain when the radiation detected originates at the site where the positron and ordinary nearby electrons annihilate each other.

Materials:

(a) Hewitt*

(b) Hsu*

(c) My Lab*

(d) Worksheet*

(e) Demonstration: See website (f).

(f) Websites and Videos
www.upscale.Utoronto.ca/GeneralInterest/Harrison/Flash/
(Quantum Mechanics Demonstrations – Physics Flash Animations)

(g) Good Stories
Three Men Who Created Quantum Mechanics: Werner Heisenberg, Erwin Schrödinger, and Paul Dirac

Three Men Who Created Quantum Mechanics:
Werner Heisenberg, Erwin Schrödinger, and Paul Dirac

Before the creation of quantum mechanics, Neils Bohr used classical mechanics to create the Bohr model of the atom that nicely explained the workings of the hydrogen atom. This model had electrons orbiting the nucleus in different energy levels and at different orbital radius in the hydrogen atom. Photon emission occurred when electrons dropped to lower energies and electrons are bumped upward after capturing a photon if the energy was of sufficient value. Even though Bohr developed this model, he supported the development of the quantum mechanical model and worked with Heisenberg on the QM model. Albert Einstein, living at the same time, was very uncomfortable with QM and the uncertainty that is a fundamental part of the model. Einstein is reported to have said, “God doesn’t play dice with the universe.”

Werner Heisenberg (Nobel Prize in Physics, 1932):

World War 1 interrupted Werner Heisenberg’s high school years, when he had to leave school to help harvest crops in Bavaria. After the war he was involved in youth groups to rebuild German society.

In 1920, Werner entered the University of Munich to pursue a degree in math. The math professor wouldn’t allow him into an advanced seminar, so he quit. He transferred to physics. He immediately took an interest in theoretical physics. At age 22, he left Bavaria for the island of Heligoland due to severe seasonal allergies. There he applied a mathematical system to atomic physics, called matrix mechanics. Many physicists didn’t like this atomic model because it had no physical model to relate to. Erwin came up with wave mechanics about a year later and many physicists jumped to this new model. Schrödinger, however, then proved the two models were identical.

In the 1930's, many German scientists fled German fearing for their safety from Hitler's war. Werner did stay to continue work on an atomic bomb, but tried to resist Hitler's efforts to "purify" science and academics. Werner was captured by American troops and imprisoned in England for six months. He was released and returned to Germany to continue his work and developed the Heisenberg Uncertainty Principle. This principle determines the position and momentum of a moving particle and is equal to or greater than the quantum constant, h, when multiplied together and must be considered when studying the atom. www.pbs.org

Erwin Schrödinger (Nobel Prize in Physics, 1933):

Erwin Schrödinger had an extensive education and wide interests in chemistry, Italian paintings, botany, ancient grammar, German poetry, and theoretical physics.

Erwin felt that Neils Bohr's orbit theory and the atomic Spectra needed to be explained mathematically using eigenvalue problems. This lead to his shared Nobel Prize with Paul Dirac in 1933. Erwin continued to pursue his wave mechanics since he wasn't comfortable with the dual description of particle motion of waves and particles. www.nobelprize.org

Paul A. M. Dirac (Nobel Prize in Physics, 1933):

Dirac produced an independent mathematical equivalent to Heisenberg's 1928 new quantum mechanics for calculating atomic properties. Also in 1928, Dirac wrote a series of papers on relativistic theory of the electron and the theory of holes in 1930. Paul Dirac's famous wave equation introduced special relativity into Schrödinger's equations by taking into account that, mathematically speaking, relativity theory and quantum theory seem to oppose each other but Dirac's work could be considered a reconciliation between the two theories.

Due to Dirac's engineering early training, he recognized that mathematical solutions to equations were only approximations in the actual world. When asked, "How did you find the Dirac equation?" he said to have replied: "I found it beautiful."

In several writings of Dirac, the list of quantum mechanics breakthroughs is vast and insightful. Little mention of external hobbies was listed. Paul did marry Margit Wigner of Budapest in 1937. From what was found in print, Dirac seemed to be consumed with his scientific advances. Neils Bohr said of Dirac, "Paul Dirac was the purest soul in physics."

www.nobelprize.org