Part III

Origins of Quantum Mechanics

Chapter 6

Introduction to Quantum Mechanics

Just as the rules of classical physics break down when objects move at speeds comparable to the speed of light. The laws of classical physics break down when they are applied to microscopic systems.

This has lead to the Theory of Quantum Mechanics, which is the only extant theory that adequately describes such phenomena.

Quantum mechanics was primarily hashed out between (1881-1932). The origin of quantum mechanics are in thermodynamics.

Some Important Dates(from tipler)

- 1895 Röngen discovers x-rays
- 1896 Becquerl discovers nuclear radiation
- 1897 J.J. Thompson discovers the electron and measures e/m, shows the electron is part of an atom
- 1900 Plank explains blackbody radiation through energy quantization and a new constant h
- 1905 Einstein explains the photoelectric effect
- 1907 Einstein applies energy quantization to temperature dependence of heat capacities
- 1908 Rydberg and Ritz generalize Balmer's formulas
- 1909 Millikin's oil drop experiment
- 1911 Rutherford's discovery of the nucleus
- 1913 Bohr Model of Hydrogen atom

- 1914 Mosely Analyzes x-ray spectra using Bohr model
- 1914 Frank and Hertz Demonstrate atomic energy quantization
- 1916 Millikin verifies Einstein's photoelectric equations
- 1923 Compton explains x-ray scattering
- 1924 de Broglie proposes electron waves of $\lambda = h/p$
- 1925 Shrödinger develops mathematics of electron wave mechanics
- 1925 Heisenberg invents matrix mechanics
- 1925 Pauli exclusion principle
- 1927 Heisenbure uncertainty principle
- 1928 Gamow and Condon and Gurney Apply Quantum Mechanics to explain alpha-decay lifetimes
- 1928 Dirac invents relativistic quantum mechanics and predicts the positron
- 1932 Chadwick discovers the neutron
- 1932 Anderson discovers the positron

Chapter 7

Quantum mechanics I: The Electron

7.1 The Electron (Cathode Rays) J.J. Thompson

Here we outline the J.J. Thompson's paper on cathode rays. Thompson gives two posibilities for the make up of cathode rays.

1. Cathode rays: are "due to some process in the aether" ie a wave.

2. Cathode rays: are electrified particles: rays are material, and the ray is the path of some charged particle

Thompson discusses 5 experiments: 4 performed by him and 1 that was previous to the paper.

7.1.1 Perrin's Experiment

Two cocintric cylinders seperated by an insilator are placed infront of a cathode ray. There is a hole in each cylinder so that the cathode rays can reach the inner cylinder.

- when the ray is not deflected by a magnetic field, the inner cylinder picks up a negative charge.

- when he ray is deflected there is no charging on the inner cylinder.

"This experiments proves that something charged with negative electricity is shot off of the cathode, ...and that this something is deflected by a magnet; it is open, however, to the objection that it does not prove that the cause of the electrification in the electroscope has anything to do with the cathode rays."

7.1.2 Thompson 1: Perrin Thompson's way

Now the apparatus has the same concentric cylinders but the are arranged such that the inner cylinder is only charged if the cathode ray is deflected such that it strikes the holes. Without deflection the ray does not hit the cylinders.

- When the cathode rays do not fall on the slit, there is no charging.
- When the rays hit the hole the charge changes

The conclusion is that the negative electrification follows the path of the cathode rays.

7.1.3 Thompson 2: Deflection by electric field

There is (was) an objection to the idea that cathode rays are a charged particle, in that under small electric fields there was no deflection of the cathode ray.

Thompson repeated the experiment showing the same result, but he doesn't stop there. He continues to examine this in more detail, proving that the abscence of delfection is due to the conductivity passed to the gas by the cathode rays.

Observations

1. When the experiment is performed under a vaccum there is a deflection (after a time the deflection goes away due to the small amount of gas still present being turned into a conductor)
2. under low pressure and high potential, the cathode ray is deflected. when the medium breaks down(electric discharge), the ray jumps back to its undeflected position.
3. When the rays are deflected by an electostatic field the phosphorescent band breaks into several bright bands separated by dark spaces. This is analogus to Birkland's magnetic spectra.

7.1.4 Thompson 3

This experiment uses the same apparatus as the previous, but it is used to examine the conductivity of the gas inclosed in the cathode tube. Then charge flow and deflection can be measured to determine some properties of the gas enclosed in the tube.

7.1.5 Thompson 4: magnetic deflection of the cathode rays in different gases

Thompson places a cathode tube between two helmholtz coils this allows him to measure the radius ρ, of curvature on the cathode ray as related to the magnetic field

H. we can related the momentum of the charged particle to the field and the radius of curvature as,

$$\frac{mv}{e} = H\rho = I \tag{7.1}$$

The total charge that is transferred is,

$$Ne = Q \tag{7.2}$$

While the work done on the cathode is

$$W = \frac{1}{2}Nmv^2 \tag{7.3}$$

now we can write,

$$\frac{1}{2}\frac{m}{e}v^2 = \frac{W}{Q} \tag{7.4}$$

and,

$$\frac{m}{e} = \frac{I^2Q}{2W} \tag{7.5}$$

W can be measured from the deflection of a galvanometer if the ray strikes a metal of known specific heat. This allowed Thompson measured $m/e \approx 0.5 \times 10^{-7}$.

Actual $m/e = 0.569 \times 10^{-7} emu/gram = 5.68 \times 10^{-12} kg/C$

7.1.6 Thompson 5: m/e with E and B fields

$$\begin{aligned}
\frac{Fe}{m} &= \frac{l}{v} && (7.6)\\
\theta &= \frac{Fe}{m}\frac{l}{v^2} && (7.7)\\
\frac{Hev}{m} &= \frac{l}{v} && (7.8)\\
\phi &= \frac{He}{m}\frac{l}{v} && (7.9)\\
v &= \frac{\phi}{\theta}\frac{F}{H} && (7.10)\\
\frac{m}{e} &= \frac{H^2\theta l}{F\phi^2} && (7.11)
\end{aligned}$$

If H is adjusted so that $\theta = \phi$ then,

$$\begin{aligned}
v &= \frac{F}{H} && (7.12)\\
\frac{m}{e} &= \frac{H^2 l}{F\theta} && (7.13)
\end{aligned}$$

7.1.7 Thompson's Conclusions

1. The charge carriers are the same for all gases
2. The mean free path of the charge carriers depend on the density of the gas.
3. Atoms are different aggregates of the same particles of which the electron is one
4. An Electric field is sufficient to remove the negatively charged particles from an atom.
5. Atoms are made of smaller particles
6. Calculating the stability of atoms is difficult because of the large number of particles involved.
7. velocity of cathode rays is proportional to the potential difference between the cathode and anode.
8. The material of which the cathode is manufactured is unimportant to the process.

7.2 Fundamental Charge: Robert Millikin

(notes from Modern Physics: for scientists and engineers by Taylor, Zafiratos and Dubson)

Thompson could measure the ratio of m/e but not m or e, he measured the ratio from the charges interation with magenetic and electric fields

$$m\vec{a} = -e(\vec{E} + \vec{v} \times \vec{B}) \tag{7.14}$$

Robert Millikin was able to take the for which the mass M was known and measure M/e thereby measure the charge e.

Experimental method

1. Spray a fine mist into the reqion between 2 charged plates. The drops fall reaching terminal speed with the weight of the drop balanced by the viscous drag of air.
2. Switch on the electric field, some drops move down more rapidly, some drops move upward.

The conclustion is some oil drops have aquired positive or negative charges.

7.2.1 Measureing M by terminal speed

It is well known that the terminal velocity may be calculated from,

$$v = \frac{F}{6\pi r\eta} \tag{7.15}$$

where, r =radius of sphere, η= viscosity of gas, $F = Mg = 4/3\pi r^3 \rho g$= weight of oil drop. Now we write,

$$v = \frac{2r^2\rho g}{9\eta} \tag{7.16}$$

Since ρ, g, η are known a measurement of the velocity gives the radius and the radius gives us the mass M.

Millikin also noticed that occasionally a drop would suddenly move up or down indicationg a change in charge. Millikin theorized that this was due to gaining electrons from the ionized air in the chamber. In order to test this he ionized the air by exposure to x-rays. In this way he studied the change in charge.

Subsequently, he measured that all changes in charge were integer multiples of $e = 1.6 \times 10^{-19} C$. This is the basic unit of charge. The charge of an electron.

Millikin also noticed when there was a near vaccuum in the container x-rays changed that charge but only to the positive, Leading MIllikin to correctly conclude that the x-rays are knocking electrons out of the oil drops.

2 important results,

1. The charge of one electron is $q = -e$, this leads to the mass of an electron being 1/2000 Hydrogen
2. All charge come in multitudes of e.

We know from experience that an object that is heated gives off radiation. This is known as thermal radiation. Usually this radiation is in the IR range.

- $1000K \sim$ Red hot
- $2000K \sim$ Yellowish-white

The actual light is a collection of the wavelength's given off, a contiuous spectrum with a dominate wavelength.

[INSERT PICTURE]

We can simulate this with the use of a Blackbody, as we recall a blackbody is an ideal absorber/emitter of radiation. We can think of a black body a cavity with a small hole, ratiation that falls on the hole enters the cavity, but does not leave.

As the temperature increases the dominate wavelength sifts, this is known as wein's displacement law,

$$\lambda_{max} T = 2.90 \times 10^{-3} mK \tag{7.17}$$