Quanta 1

Disclaimer: These lecture notes are not meant to replace the course textbook. The content may be incomplete. Some topics may be unclear. These notes are only meant to be a study aid and a supplement to your own notes. Please report any inaccuracies to the professor.

The Discovery of Quanta

We have learned about Einstein's theories of Relativity as one cornerstone of 20th century physics. The other major accomplishment is Quantum Mechanics, which concerns itself with physics at the atomic scale. In fact, one might classify the 20th century, and a few years before, as the age of the atom. Unlike Relativity, the development of quantum mechanics included contributions from many great physicists.

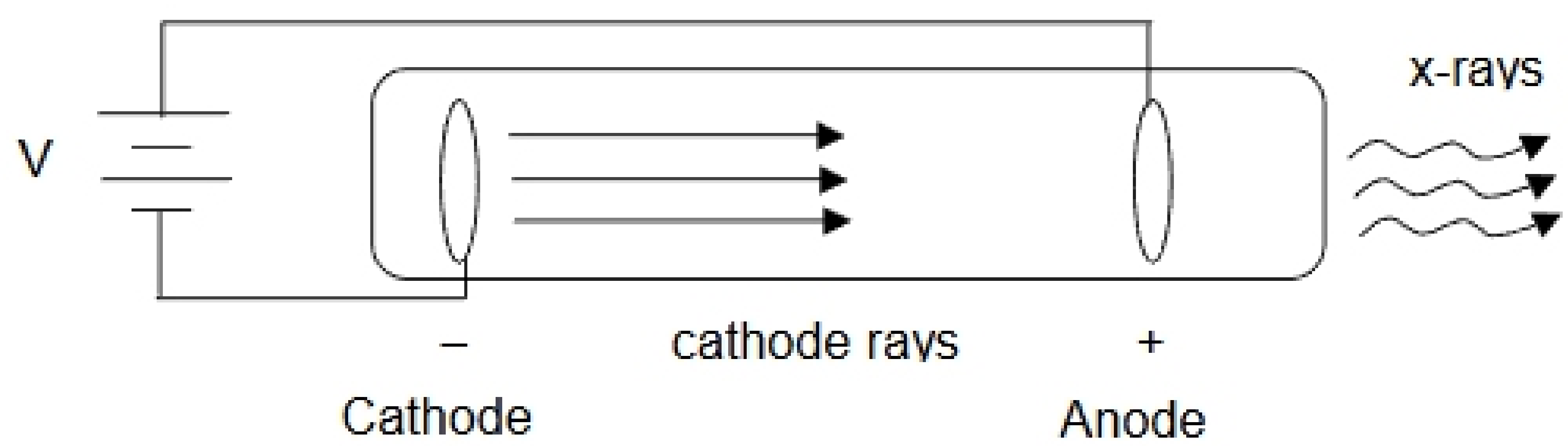
Listed below is a short timeline of the discoveries that led physicists to believe that the world is quantized. By this we mean that there are some measurements which can be made which yield only certain discrete values, like the emission spectra of hydrogen. In this chapter, we will learn about two forms of **quanta**: the electron and the photon. They are discrete packets of electricity and electromagnetic energy, respectively. Later we will learn how other systems like the atom are quantized.

- 1895 - Discovery of x-rays by Wilhelm Röntgen
- 1896 - Discovery of radioactivity of uranium by Henri Becquerel
- 1897 - Discovery of the electron by J.J. Thompson
- 1900 - Derivation of black-body radiation formula by Max Planck
- 1905 - Development of special relativity by Albert Einstein, and interpretation of the photoelectric effect
- 1911 - Determination of electron charge by Robert Millikan
- 1911 - Proposal of the atomic nucleus by Ernest Rutherford
- 1913 - Development of atomic theory by Niels Bohr
- 1924+ - Development of Quantum Mechanics by deBroglie, Pauli, Schrödinger, Born, Heisenberg, Dirac, ...

Forms of Radiation

Cathode Rays

Cathode rays are a type of radiation that is emitted by a heated metal plate in an evacuated tube under a large electric potential. They can be detected when the rays are passed through phosphorous. They can penetrate matter to some degree. They are bent by electric and magnetic field, so they are charged. A diagram of a cathode ray tube is shown below. You may already know that your computer monitor is sometimes referred to as a CRT, which is an acronym for a Cathode Ray Tube.



X Rays

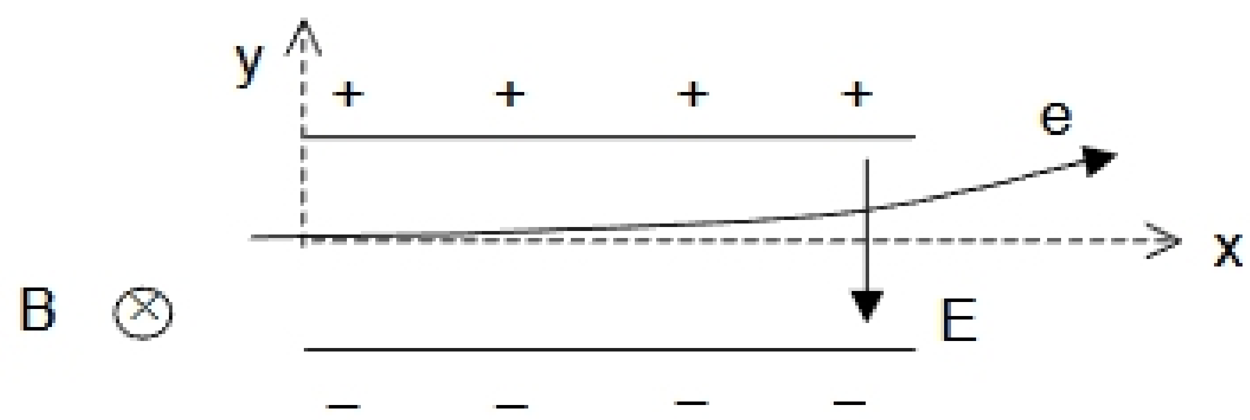
X-rays are a type of radiation observed when cathode rays pass through a material (like glass). They were discovered by Roentgen in 1895. Unlike cathode rays, X-rays are very penetrating and are not bent by electric or magnetic fields. Thus, it is a neutral radiation.

α- β- and γ-Rays

Radioactivity was discovered in 1896 by Henri Becquerel, which is the emission of several rays from substances like uranium. α-rays are one type of emission which is highly ionizing, but not very penetrating. It was later determined by Rutherford that α-rays are helium nuclei. β-rays were determined to be the same as cathode rays, and γ-rays are another neutral radiation like x-rays which are very penetrating. These form the ABC's (in Greek at least!) of radioactive decay products.

e/m Determination of the Electron—the Carrier of Electricity

It was determined by J.J. Thompson that cathode rays are charged particles emitted from a heated electrical cathode. It was known that such heated cathodes lead to an electrical current, so Thompson determined that electricity was quantized into individual charged particles (dubbed electrons). He deduced this by analyzing the motion of cathode rays through perpendicular electric and magnetic fields, as shown below:



Here is a review of the procedure used to determined the charge-to-mass ratio for electrons:

The Lorenz force law is: $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$

In the absence of a magnetic field, with an electric field aligned in the y-direction, we have:

$$F_y = qE_y = ma_y$$

$$\Rightarrow a_y = \frac{qE_y}{m}$$

Let electric field occupies a region of length ℓ through which the cathode rays pass. The cathode rays initially have a velocity v_0 in the x-direction.

$$t \approx \frac{\ell}{v_0} \qquad \text{Time to cross the electric field region}$$

$$v_y = a_y t = \frac{qE_y \ell}{mv_0} \qquad \text{Velocity in y-direction upon exit}$$

$$\tan\theta = \frac{v_y}{v_x} = \frac{qE_y \ell}{mv_0^2} \qquad \text{Tangent of exit angle}$$

The angle θ can be measured in the experiment, and the length of the electric plates is obviously known. The electric field can be determined from the voltage applied to the parallel plates divided by the separation:

$$E = \frac{V}{d}$$

However, we need a way to determine the initial velocity v_0. The trick is to turn on a magnetic field such that the cathode beam is no longer deflected: