Scattering Particles of the Atom

Henri Becquerel was studying radioactive substances in the last few years of the 19th century. He had observed that these radioactive substances emit radiations even when there is no external source of energy. This was especially noted of heavy metals - that they spontaneously emit radiations. When Ernest Rutherford studied these radiations, he found that they were two types of radiations. He assumed that they were made up of particles and hence identified two types of particles. One of these could penetrate matter and travel quite far and Rutherford called these beta particles. The particles which could not penetrate very deep into matter were called alpha particles.

In 1900, Becquerel demonstrated that beta particles could be deflected by an electric field and on the basis of their charge by mass ratio, said that they were similar to cathode rays. Some time later, Robert Millikan and Harvey Fletcher managed to get an accurate measure of the charge on an electron. For doing these they had used drops of oil. They managed to impart a charge to very fine drops of oil and then these oil drops were allowed to fall under the influence of gravity. After this, they applied an electric field around these drops and the strength of the field was kept such that it was just enough to stop the oil drops from falling. From this (the strength of the electric field), they were able to calculate the charge on the oil drop with great accuracy.

The principle behind Millikan's experiment is pretty simple. If very fine oil droplets are allowed to fall (because of gravity), then they soon attain a final velocity. This final velocity is called the terminal velocity. If this process is carried out in a chamber where there are no air currents, then the velocity of these particles is influenced by gravity and the buoyant force of air, and they soon attain their terminal velocity of a few millimetres per second. This terminal velocity can be measured and can be used to arrive at the value for the mass of these droplets.

Now, the oil drops are charged. And an electric field can be applied such that these oil drops now move upwards (towards the oppositely charged electrode). When the force due to gravity and the force due to the electric field become equal (that is, the oil droplets are made to float in air), then the charge on the oil droplet can be calculated. The force due to gravity will be equal to mg and the force due to the electric field Eq. When the oil droplets are caused to float, then mg = Eq. In this equation, m is the apparent mass of the oil droplet (actual weight of the oil droplet – the buoyant force of air), g the force due to gravity, E the strength of the electric field, and q the amount of charge on the oil drop.

It is not necessary that the charge be the same on all oil drops. But Millikan found that the minimum charge on the oil drops was 1.60 X $^{-19}$ coulomb. Oil drops carrying a greater charge were found to have charges that were some multiple of this value (3.20 X 10^{-19}, 4.8 X 10^{-19}, 6.4 X 10^{-19}, 8.00 X 10^{-19}, etc.).

Now came the turn of the alpha particles. It was found that they were positively charged, with a charge double that of beta particles, but they had a very large mass, equal to that of a helium atom. Interest in these particles was also great because of the fact that these were positively charged particles. After all, the discovery of positively charged particles after the discovery of the negatively charged electrons completes the picture.

Rutherford concentrated on the study of these alpha particles. He wanted to know how alpha particles would interact with matter. So, along with Geiger, he designed an experiment which has now attained the status of one of the most perfect experiments in the history of science.

Rutherford took a foil (very thin sheet) made of gold. The thickness of this foil was 0.0004 cm. The purpose was to bombard this foil with alpha particles and observe what happens. On the basis of this experiment he wanted to get some clue about the nature of the heavy metals (which emit alpha rays). In order to do this, he enclosed a sample of a heavy metal in a block of lead which had a very small window in it. Alpha particles could only come out through this small window since the thick walls of lead would absorb the alpha particles being emitted in the other directions.

The alpha particles coming out (in the form of a beam) would then hit the gold foil. It was expected that the alpha particles would pierce the gold foil and come out on the other side. So, on the other side of the gold foil, a setup that could 'see' the alpha particles that had travelled through the gold foil was arranged. Rutherford and Geiger had found after many trials that a screen coated with zinc sulphide could be used to detect the alpha particles since each time an alpha particle fell on this screen, that particular spot on the screen would shine. So, a screen coated with zinc sulphide was placed on the other side of the gold foil.

Now the setup for the entire experiment was ready. This whole setup was kept in a dark room, and Rutherford and Geiger would sit in this room for hours counting the bright flashes at different points on the zinc sulphide screen and recording them.

The final results were along the expected lines. All the alpha particles from the beam being emitted from the lead block were found to fall within a circle with a small radius. Rutherford had expected that the alpha particles would get deflected on passing through the gold foil because of interaction with the atoms of gold, but that this deflection would be very small, a maximum of about one degree only. And this was what they had observed. But it is very likely that the textbooks you have read say that Rutherford conducted a very different experiment.

Actually, when Rutherford and Geiger conducted their experiment, what has been described above was exactly what was found. The history is science is not as dramatic and exciting as it is usually made out to be. Let us see what actually happened.

One day, Geiger told Rutherford that a research student named Ernest Marsden had to be given a project. Rutherford said, “Why not get him to repeat the same experiment to check whether some alpha particles are getting deflected at still greater angles?”

When Marsden did this experiment, then the zinc sulphide screen was put not just behind gold foil, but all around it (so that deflection at any angle could be detected). Marsden found that a few particles (1 in 20,000) were getting deflected by more than 90 degrees. Rutherford said of these results, "*It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.*" Be that as it may, he was however not slow to understand the implications of these results.

He concluded that these experimental results could be explained in only one way. You had to accept that all the positive charge and mass of an atom were concentrated in a very small region. He called this region the nucleus. We are told just this much. And this reinforces the idea of science being a romantic endeavour which consists of serendipitous discoveries and flashes of intuition that lead to major breakthroughs.

But it is not enough to stop here when we look at the work that Rutherford did. He was able to come up with an equation that expressed the number (or proportion) of alpha particles that would get deflected at any one angle on the basis of the assumption that the positive charge and mass of an atom was concentrated in its tiny nucleus. On the basis of these equations, he predicted that the deflection seen in the alpha rays would be directly proportional to the thickness of the gold foil, and proportional to the square of the charge on the nucleus of the gold atom. Not only this, he was also able to calculate that the angle of deflection of the alpha particles would be inversely proportional to a fourth of its velocity.

These three predictions were checked by Geiger and Marsden by doing further experiments and they were proved to be correct.

It was only after all this intense labour that Rutherford reached the conclusion that the positive charge and mass of an atom was concentrated at its centre. He called this the nucleus. He also said that the volume of the nucleus was negligible compared to the volume of the atom.

According to Rutherford, it was because the nucleus was so small that most of the alpha particles were able to pass through the gold foil without any deflection – they do not encounter anything large along their paths that could cause them to get deflected. Very few alpha particles go anywhere near the nucleus and get repelled by the positive charge on it causing them to be deflected to some extent. Very rarely do the alpha particles hit the nucleus and get deflected through angles greater than 90 degrees.

On the basis of the number of alpha particles that were getting deflected by 90 degrees or more, Rutherford was able to calculate the size of the nucleus too. According to him, the diameter of the nucleus was about 10,000 times smaller than the diameter of the atom. It is noteworthy that this model does not talk about protons, let alone neutrons.

On the basis of all these facts and calculations, Rutherford had proposed a model of the atom. This model consisted of an atom that had a tiny, positively charged nucleus with the electrons being spread over a large area. You can very easily figure out that if

Thomson's watermelon model of the atom was correct, then the alpha particles would not have been deflected in this manner. According to Thomson's model, the positive charge was evenly spread throughout the atom. If his model had been correct, then all the alpha particles should have encountered the same positive charge while passing through the atom and gotten deflected to the same extent or even not have been deflected at all.

So, we find that once again, new findings had led to the revision of our understanding of the atom. This new model of the atom had a very dense nucleus at its centre which contained all the positive charge of the atom and the electrons were orbiting around this nucleus at some distance. But soon this model was also to be discarded.