Radioactivity 2 and Atomic Structure

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1 How to detect radiation

We have already discussed what radioactivity is, and the types of radioactivity. But, since we cannot detect it with our regular senses, how do we detect it?

As we saw earlier, the first scientists to find radioactivity used fluorescence or photographic emulsion. Now, we have better methods of detection.

1.1 Geiger-Muller Tube

The idea of the GM Tube is that the radiation ionises the gas in the tube, which produces an electric current.

A GM Tube consists of a thin wire anode surrounded by a monatomic gas (typically neon) at low pressure, surrounded in turn by a cylindrical cathode. A P.D. is maintained across the cathode and anode (typically 500V). This means that there is an electric field in the cylinder.

If ionising radiation is present, the neutral neon will be ionised into electrons and positive neon ions. These will be accelerated in the electric field. As they move, they will "strike" other atoms and cause further ionisation. Remember that where you have moving charges, you have current. This current can be detected.

Now you may ask, this will work for α and β radiation, which are ionising, but what about γ radiation, which is non-ionising?

Remember that when a photon strikes an atom, it can "excite" the atom; that is, it will absorb energy from the photon. This energy will then later be emitted via another photon. Photons are not affected by electric fields and move in all directions around the tube, being absorbed by other atoms. This causes a chain reaction of atoms throughout the tube becoming excited and then releasing photons, which can then be detected.

You can add an electric counter to this setup, and this apparatus is called a **Geiger Counter**.

1.2 Solid-State Detector

Diodes, transistors and semiconductors are affected by heat and radiation, and we can use this to detect if radiation is present.

Consider a p-n junction with gold electrodes at either end. If a voltage is connected in reverse bias, no current will flow. If radiation passes through the diode, it "knocks out" some electrons in the junction, which causes a small pulse of current to flow despite the reverse bias. The size of the pulse indicates the amount of radiation present.

In essence, a solid-state detector is a p-n junction (diode) in reverse bias.

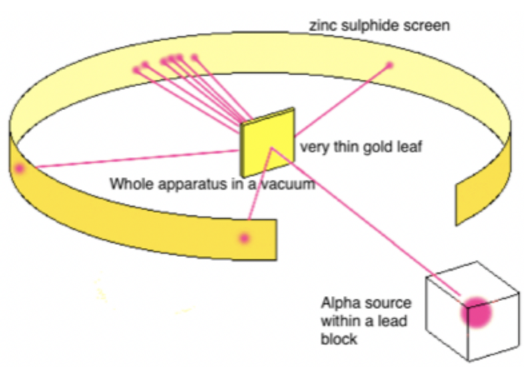
2 Atomic Structure

Recall that Thomson showed the existence of negatively charged particles in an atom (electrons). Since atoms are electrically neutral, but contain negatively charged particles, this implies that there must be a positively charged particle also in the atom to 'cancel out' the negative charge to produce an overall neutral charge.

Now, the race was on to firstly, detect the positively charged particles, and secondly, determine how they were arranged in the atom.

Thomson himself was the first to suggest a possible configuration for the structure of an atom. He said that the positive and negative electrons were uniformly distributed throughout the atom, sort of like raisins scattered inside a plum pudding. This is why it became known as the "plum-pudding" model.

In 1909, Geiger and Marsden carried out the following experiment:



- Place a thin sheet of gold foil in front of a beam of alpha particles.

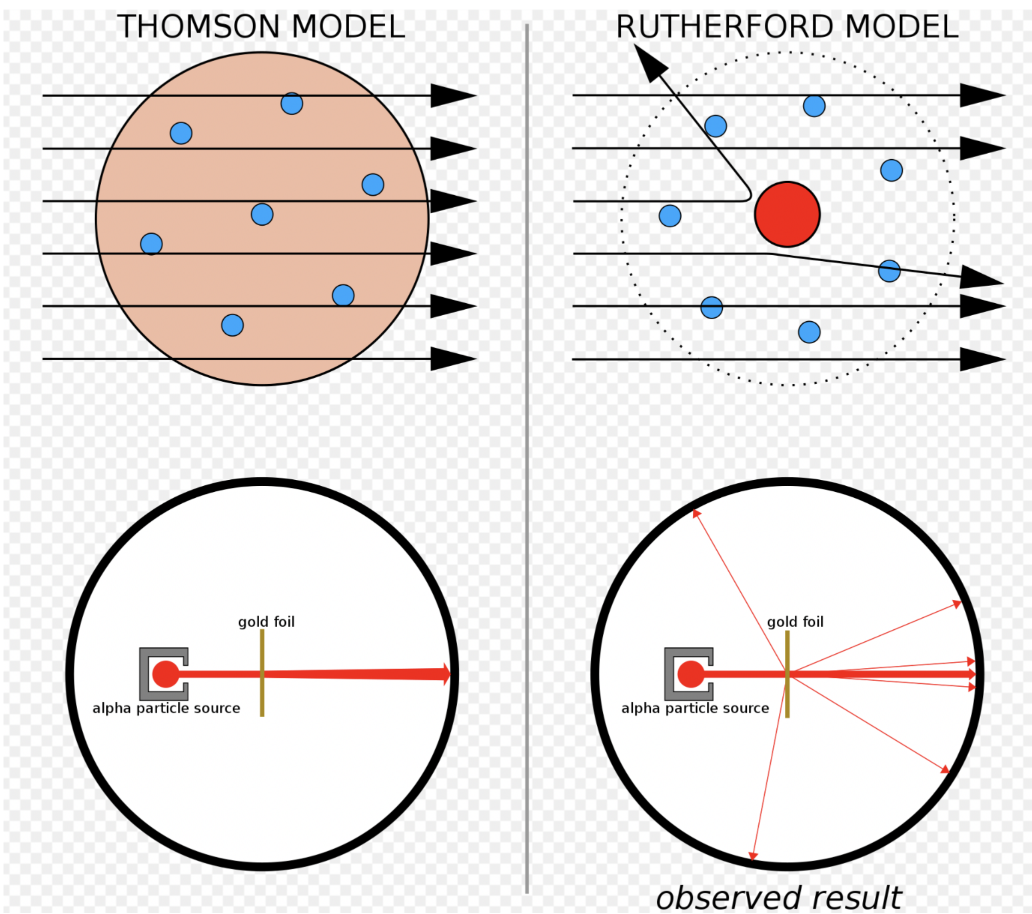
- Detect the angle at which the alpha particles are deflected using a zinc screen.

The way in which the particles are deflected indicates how the gold atom is structured.

A particle shot at an atom structured like the plum pudding model (one dense ball) would strike it, and be deflected straight back the way it came. So, what was actually observed?

In practice, most particles were not deflected at all, or at a very small angle. However, about 1 in 8,000 particles were deflected at a very large angle, some even striking back where they came from.

Rutherford used this as a clue to determine a new model for the atom: the Rutherford model. In this model, the atom consists of a very dense center (the nucleus), with the electrons orbiting it, like the rings of Saturn.



It took another 10 years to actually isolate the proton as a separate particle.

2.1 Rutherford discovers the proton

Rutherford found that if you shoot alpha particles into the air (mostly nitrogen, with little bits of other gasses), you would see little sparks of light. These "sparks" produced trace amount of hydrogen.

To make this experiment more controlled, he isolated a cylinder of pure nitrogen, and shot alpha particles into it. Once again, he saw the sparks and was able to detect hydrogen in the nitrogen. So, somehow, nitrogen atoms bombarded with alpha particles will produce hydrogen atoms.

This proves that nitrogen atoms "contain" hydrogen atoms. Rutherford coined the term "proton", coming from protos, the Greek word for "first".

2.2 Chadwick discovers the neutron

They now could work out how many electrons and how many protons there were in each atom, in order to make them electrically neutral. They could also measure the mass of the electron, the proton and the overall atom. There was a problem; the atom was too heavy. There seemed to be extra mass in the atom that was not accounted for by the electrons and protons. This implies that there is an electrically neutral particle also in the atom, which would account for the extra mass.

The problem was solved by one of Rutherfords students, James Chadwick. He bombarded beryllium with alpha particles. He didn't realise this at first, but this caused neutrons to be knocked out the beryllium. By placing paraffin wax (which consists mostly of hydrogen) in front of the beryllium, the wax was bombarded by neutrons, which in turn caused the wax to emit protons. The radiation from the wax could be detected by a GM Tube.

If you put all of this in an electric field, you will find that only the radiation from the wax (the protons) will be deflected. The radiation from the beryllium was unaffected by electric fields, proving that it was electrically neutral. Chadwick had isolated the neutron.

2.3 Atomic Number

With all of this research being done, Henry Moseley made the connection that atomic number, or the order of the periodic table, corresponded to the number of protons in the nucleus. As such, the number of protons determined what element you had. For a neutral atom, this also determined the number of electrons orbiting the nucleus.

In 1906, experiments by Boltwood and interpreted by Soddy showed that different Thorium atoms were capable of having different numbers of neutrons, not changing overall charge, or what element the atom was, but changing the mass of the atom. These are called isotopes.

If, for whatever reason, you want to separate different isotopes, you can do so with a **mass spectrometer**. A mass spectrometer first ionises the atoms, then accelerates them through a strong magnetic field. Atoms with a lower mass will be able to move faster than those with higher mass. So, the atoms will be split into "rings", with the atoms of smaller mass having a smaller orbital radius.

2.4 Spectroscopy

If you heat an atom (give it extra energy), it will emit that energy in light. It was discovered by Bunsen and Kirchhoff that no two elements give off the same spectrum. If you examine the light with a spectrometer (that is, look at it's rainbow), you will notice a number of bright lines: those are it's line spectra. These line spectra will depend on what element emitted it.

3 Bohr Model of the Atom

After developing the Rutherford model, we still had questions about the atom. If electrons and protons were oppositely charged, why are do the electrons orbit the nucleus instead of being attracted to it and colliding into the nucleus? Combined with this, and some spectroscopy experiments, Niels Bohr developed a new model for the atoms that explained how spectra could be produced.

Bohr noticed that electrons orbiting an atoms seemed to follow a set of rules, which became known as the Bohr Postulates:

- The electrons in an atom can only occupy certain orbits or energy levels, which are quantised (they can only take certain values).
- Electrons can move between energy levels by either absorbing or emitting energy in the form of a photon.
- The energy of the photon either absorbed or emitted by moving between energy levels is equal to the difference in energy levels between the orbitals.

To find the energy of a photon, we use Planck's Equation: $E = hf$, where E is energy, h is Planck's constant and f is the frequency of the photon.

Line spectra are therefore the specific energy levels that are emitted when an electron jumps between allowed orbitals.