X-Rays and Radioactivity

1 X-Rays

In 1895, a German physicist called Wilhelm Roentgen wanted to know if cathode rays could pass through glass. His cathode tube was covered in heavy black paper, so he was surprised when an incandescent green light nevertheless escaped and projected onto a nearby fluorescent screen. Through experimentation, he found that the mysterious light would pass through most substances but leave shadows of solid objects. Because he did not know what the rays were, he called them ‘X,’ meaning ‘unknown,’ rays.

He played with them some more, and found that they could pass through many objects and create an image of them on a screen, including human skin. Roentgen realised that x-rays could be used in medicine when he took this picture of his wife’s hand - the first ever x-ray image. You can see the bones in her hand, and her wedding ring.

Roentgen was the first ever recipient of the Nobel Prize for Physics, awarded in 1901. Later on, more work was done on ascertaining what exactly x-rays were. Here's what was found:

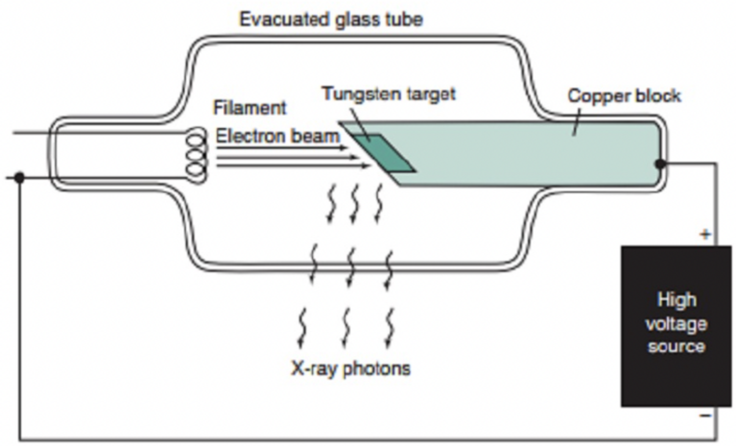
- X-rays are produced when fast electrons strike a solid body.
- They produce fluorescence.
- They will blacken photographic emulsions (this is how Roentgen took the first x-ray.
- They cannot be deflected by electromagnetic fields.
- Travel in straight lines
- Can cause ionisation of the air.
- Can be diffracted by thin crystals.
- They will penetrate most substances, but not all, depending on density and thickness.

As it turns out, x-rays are electromagnetic radiation (same as light), but have a very short wavelength (high frequency). X-rays usually have wavelengths between 10^{-9}m and 10^{-15}m.

2 X-rays in practice

2.1 How to produce x-rays

When an electron falls from a higher orbit to a lower one, it produces a photon whose energy is equal to the energy difference between the orbitals. If the energy difference is large enough, it will produce an x-ray. We can use this idea to produce x-rays.



▲ **Figure 2-1.** Simple x-ray tube.

A hot cathode in a vacuum produces electrons by thermionic emission. A tungsten target is set into the anode. A high voltage across the tube will accelerate the electrons. When the high energy electrons hit the tungsten target, they will emit x-rays as they lose energy. The lead shield with a small slit ensures the x-rays only travel in 1 direction.

We can produce x-rays for use in medicine (for looking at broken bones), engineering (looking at faults in welds/alloys), and to examine crystalline structures. They are also used for looking at baggage in airport security.

If you are continually exposed to x-rays, they can be carcinogenic. Being exposed once or twice (such as getting an x-ray scan in hospital) is perfectly safe, but for the radiologist who has to be perform these scans every day, 9 to 5, it is not safe. This is why, when you get an x-ray in hospital, the doctor will leave you alone while the scan is being done.

3 Radioactivity

3.1 Discovery

If you expose uranium salts to sunlight, then put them in the dark, they will "phosphoresce"; that is, they store the energy from the sunlight and emit it later.

In the later 1890s, a french scientist called Antoine Becquerel wanted to know if fluorescent and phosphorescent substances could emit x-rays. He found that phosphorescent uranium salts could blacken photographic plates, even when wrapped in black paper: there must have been penetrating radiation causing this.

However, he varied the amount of sunlight the salts were exposed to, even not allowing some to be exposed at all, and found that these also blackened the photographic plate. There was something else radiating, but what?

This question was answered by husband and wife duo, Pierre and Marie Curie. They led the separation of substances that naturally produce penetrating radiation. The first one they found was Polonium, named after Poland, Marie's home country. They later identified thorium and radium.

Rutherford experimented with types of radiation. He took radioactive material and looked at what it took to stop radiation from penetrating. He found that some radiation couldn't penetrate paper: he called this α radiation. He also found another type of radiation that was 100 times more penetrating than α radiation, but could still be stopped by a sheet of aluminium: he called this β radiation. He was able to show that both of these types of radiation could be deflected by electric and magnetic fields.

Here, the Curies made yet another breakthrough: they found a third type of radiation that was not affected by electromagnetic fields. It is very strongly penetrating, and could only be stopped by thick lead, reminiscent of x-rays. They called this γ radiation.

3.2 What's actually happening?

As you get higher in the periodic table, the nuclei of atoms get heavier. If an atom has to much energy or mass, it is not longer stable and will tend to decay. What it has too much of determines what type of radiation it gives off.

- If an atom is too massive, it will emit tow protons and two neutrons (basically, a helium nucleus). This is α radiation. They are strongly ionising, but not very penetrating. They will cause fluorescence and blacken photographic plates.
- If an atom specifically has too many neutrons, it will emit an electron, changing one of the neutrons to a proton. This is what β radiation turned out to be. It turns out that these electrons move at speeds between 30% to 70% the speed of light; they are relativistic particles. They are somewhat ionising and more penetrative than α particles, but not as penetrating as γ particles. They have negligble mass.
- If an atom is too energetic, it will emit this energy in the form of electromagnetic radiation. This is what γ radiation is. When they were first discovered, they were mistaken for x-rays; but they can have much shorter wavelengths than x-rays. Since they are electromagnetic waves, they have all the same properties as light, or x-rays, or any other electromagnetic radiation. They can be diffracted, they can be shone on to metal to produce a photoelectric effect, they have no mass. They are not ionising, but very penetrating.

By emitting α and β particles, atoms actually change what element they are. One α particle will decrease atomic mass by 4 (two protons, two neutrons) and decrease the atomic number by 2 (two protons). Meanwhile, because β particles have such a small mass, they will not affect atomic mass. They will, however, increase the atomic number by 1 per particle.

Problem: A uranium atom (Mass no. = 235, Atomic no. = 92) decays to a lead atom (Mass no. = 207, Atomic no. = 82). How many α and β particles were given off in this decay?

The mass change is 235-207=28, which will be entirely caused by α particles, which change atomic mass by 4 each. 28/4 = 7 α particles emitted.

They will decreas atomic number by 2 each. 7 x 2 = 14. So the new atomic number should be 92 - 14 = 78. However, the atomic number of the lead is 82. The remaining, 82-78 = 4, is caused by β particles, which increase atomic number by one each - 4 particles.

So, there are 7 α particles and four β particles emitted.