**Environmental Chemistry and Microbiology**

**Dr. Anjali Pal**
**Dr. Sudha Goel**
**Department of Civil Engineering**
**Indian Institute of Technology - Kharagpur**

**Module - 6**
**Lecture - 26**
**Radioactivity (Part-A)**

Welcome everyone to our online NPTEL course, Environmental Chemistry and Microbiology. This course will be taught by Professor Sudha Goel and myself, Professor Anjali Pal. We are from Civil Engineering Department, IIT Kharagpur. We have divided this course into 2 parts. The first part Environmental Chemistry will be covered by me. And the second part, Environmental Microbiology will be taught by Professor Sudha Goel.

This is my module 6 and lecture number 26. In my previous modules, I have covered the acids, bases and salts in the first module. In the second module, I have discussed about the chemical equilibrium. In the third module, I discussed about the chemical kinetics. In the fourth module, I covered the catalysts. In the fifth module, I discussed about the chlorine chemistry and nitrogen chemistry.

This is my sixth module and lecture number 26, where I will teach about the radioactivity or nuclear chemistry. This is Part A. This chapter on radioactivity or nuclear chemistry is very interesting chapter. For this field, there are many Nobel Prize.

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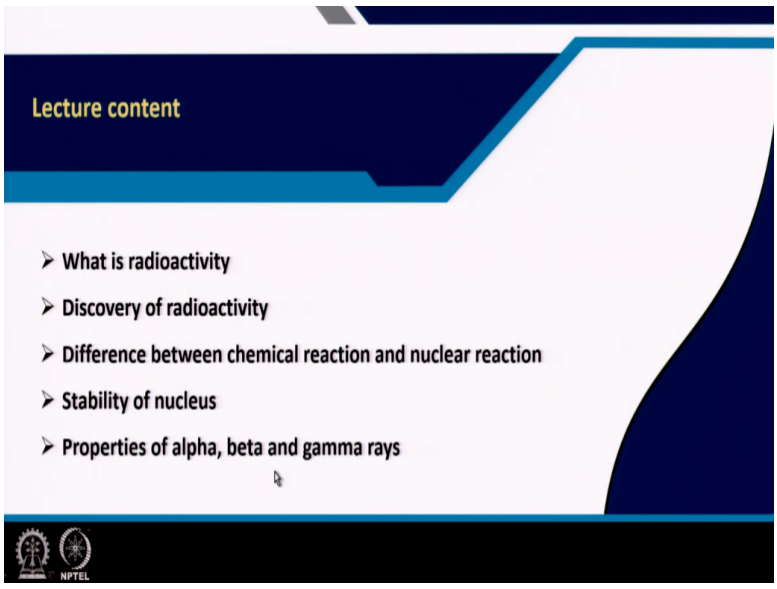

In this lecture, I will discuss the basic thing about the radio activity. Then I will tell the history. I will tell the difference between the chemical reaction and nuclear reaction. I already discussed many things about chemical reaction. But now I am coming to nuclear reaction. So, I will tell you what is the difference between these two. Then we will see stability of nucleus. Finally, I will discuss properties of alpha, beta and gamma rays.

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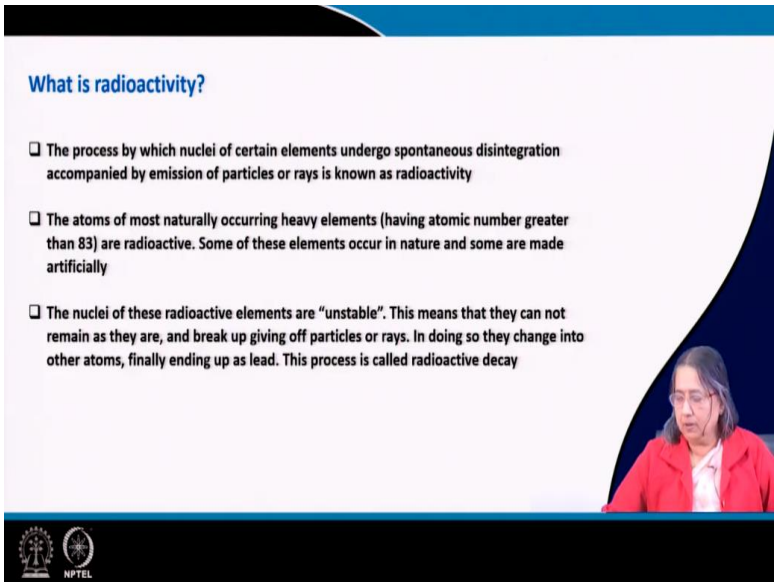


Now, what is radioactivity? You know that some nuclei undergo very spontaneous disintegration. And this integration is accompanied by emission of particles, say particles or rays. Say for example, alpha particle, beta particle. You will see when I will discuss in details about the properties of these particles. Now, which type of nuclei will be unstable? It depends on the atomic number and the neutron proton ratio. Mostly we have seen that atomic number greater than 83 makes a nuclei very unstable and they become radioactive. Some of these are naturally occurring elements and some of them can be formed artificially by man. Radioactivity means they always radiate some particles or some rays. In giving off some particles or rays, they are converted into another atom. Finally, at the end they are transformed into some isotope of lead. This type of decay or disintegration is called radioactivity or radioactive disintegration.

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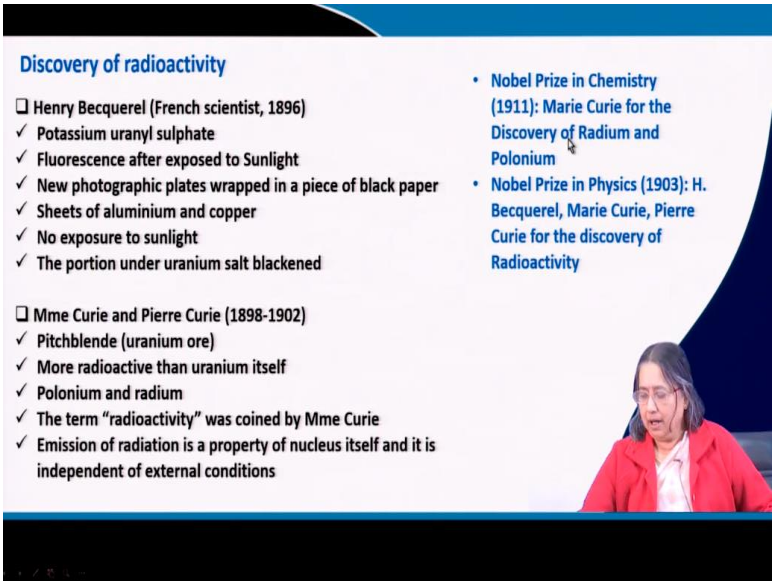


Now, let us see the discovery of radioactivity. You all have heard the name Henry Becquerel. He was a French scientist. In 1896, he discovered this radioactivity. In his family, his father and grandfather were all scientists. They used to take some actually uranyl sulphate (a uranium compound). It has some fluorescence. But to show the fluorescence, it has to be exposed first with some light (say for example sunlight). So, they used to irradiate it with the sunlight. It is a uranium compound and the compound was kept in a bottle. They used to show the fluorescence to the village people. Becquerel tried with this uranyl compound to see whether X-rays are coming out or not. For a few days there was no sun and it could not be exposed with the light. Potassium uranyl sulphate was kept on a table top. Below in the drawer there were some photographic plates. But these new photographic plates were wrapped in black paper. It has been kept in such a way because, if it is exposed to any type of light, then it cannot be used anymore. But after some days when he took out the photographic plate, he observed that it is already exposed. He was surprised to see that because the bottle in which the potassium uranyl sulphate was kept, that was on the table top and the photographic plate was inside that drawer. Moreover, it was wrapped with a black paper. Then how some light can come inside and expose the photographic plate. He again did the same experiment. He wrapped the photographic plates with even with aluminium and copper sheets. But then also it was exposed. Then an idea came to his mind that it must be some type of light or some type of rays that is coming from the uranyl sulphate which is exposing the photographic plate. He repeated the experiment many times, but then he could not understand why it is happening. That time radioactivity was not known. However, his work got published. Now let us come to another scientist whose name you all heard and she is Madame Curie. She was just about to start her research and she was trying to find out some good topic for her

research. She came across with the article of Becquerel. She was very much interested to do research in this area. Then this practical problem was taken up by Madame Curie and her husband Pierre Curie. So, research in this field was continued by them. A lot of research was done by Madame Curie and Pierre Curie. Then it was realised that it is not the property of potassium uranyl sulphate, but it is the property of uranium itself. It means, that any compound which contains uranium may show this type of effect. Then they did with pitchblende which also contain some uranium ore. To some extent it was realised that it is some atomic phenomena and some atoms are radiating something which is spontaneous. It means, nothing can affect or inhibit this property. They used tons and tons of uranium to isolate little amount of uranium. But they realised that pitchblende is showing much more radioactivity than the uranium itself. What is the cause for this? They found two more elements from there and they are polonium and radium. The name polonium came from Madam Curie's motherland Poland. The term radioactivity was also coined by Madam Curie. As radiations are coming out from those elements, that is why it is called radioactivity. I said that this property is independent of any external condition. If you increase the temperature, pressure or if you give some light it does not get affected. It is coming out spontaneously. For this type of phenomena the Nobel Prize in Physics was given in 1903 to Becquerel, Marie Curie and Pierre Curie for the discovery of radioactivity. Madame Curie got the Nobel Prize in Chemistry in 1911 for the second time for the discovery of radium and polonium. So, she got the Nobel Prize twice, once jointly and another single. Now, this is the history of discovery.

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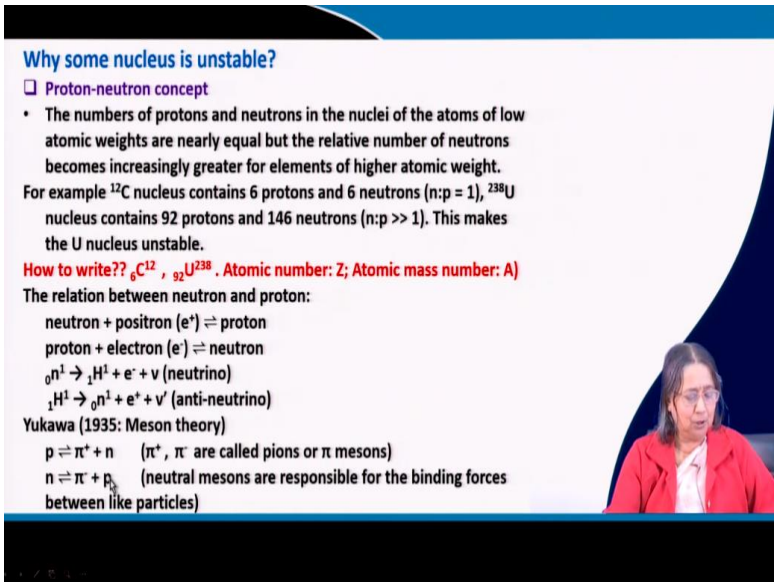

Why some nuclei are stable and some are unstable? This was explained by proton neutron concept. What is this? When the atomic weight is less, then the numbers of protons and neutrons are almost equal. But the relative number of neutrons becomes increasingly greater for elements of higher atomic weight. Let us take carbon as an example. Its atomic mass is 12 and atomic number is 6. You all know that what is atomic mass and what is the atomic number. It contains 6 protons and 6 neutrons. So, the neutron proton ratio (n:p) is 1. So, it is a very stable nucleus. But if you see the uranium. Its atomic mass is 238. It contains 92 protons and 146 neutrons. That means, neutron to proton ratio is much greater than 1. This makes the uranium nucleus unstable. That means, when n:p is 1 or close to 1, it is stable. But as it goes on increasing, then it becomes gradually unstable. According to Bohr model, we all know that in an atom, the nucleus is at the centre, occupying a very small space and in the rest part which is much greater than the nucleus, that space is occupied electron orbitals. In the nucleus, there are protons and neutrons. Each proton has unit positive charge and unit mass while neutron has no charge, but it has unit mass. We all know these from our school days. Electrons have no mass but unit negative charge. So, how will you write the any element when I want to show the atomic mass and atomic number. We can write in this fashion: ${}_{6}C^{12}$, ${}_{92}U^{238}$.

Atomic number usually is represented by Z and atomic mass number is usually represented by A. Now then, A - Z is the number of neutron. In the nucleus there are many protons which are of unit positive charges. So, they should repel each other. It means the nucleus should be broken. But what makes them stable? Actually the short range nuclear force is much higher and it is overcoming the repulsive force. The relation between the neutron and proton can be expressed as follows:

neutron + positron($e^{+}$) ⇌ proton……..(1)

proton + electron($e^{-}$)⇌neutron……..(2)

${}_{0}n^{1}+\rightarrow{}_{1}H^{1}+e-+v$ (neutrino)…….(3)

${}_{1}H^{1}\rightarrow{}_{0}n^{1}+e++v'$ (anti-neutrino)……...(4)

Positron is the positive electron. You have seen this type of reaction ((1) and (2)) in chemical equilibrium also. These are dynamic equilibrium. A neutron, after taking one positron can form proton. Again proton can form neutron after taking one electron. In another way, neutron may give the proton with the electron and neutrino (3). Similarly, proton can give one neutron and positron and then anti-neutrino (4).

This type of equilibrium may exist and mak them stable. Another theory is given by Yukawa in 1935. It is called pi meson theory expressed as follows:

$p \rightleftharpoons \pi^+ + n$…….(5) ($\pi^+$, $\pi^-$ are called pions or π mesons)

$n \rightleftharpoons \pi^- + p$…….(6) (neutral mesons are responsible for the binding forces between like particles)

So, proton can give neutron and positive meson (5). Similarly, neutron can give negative meson and proton (6).

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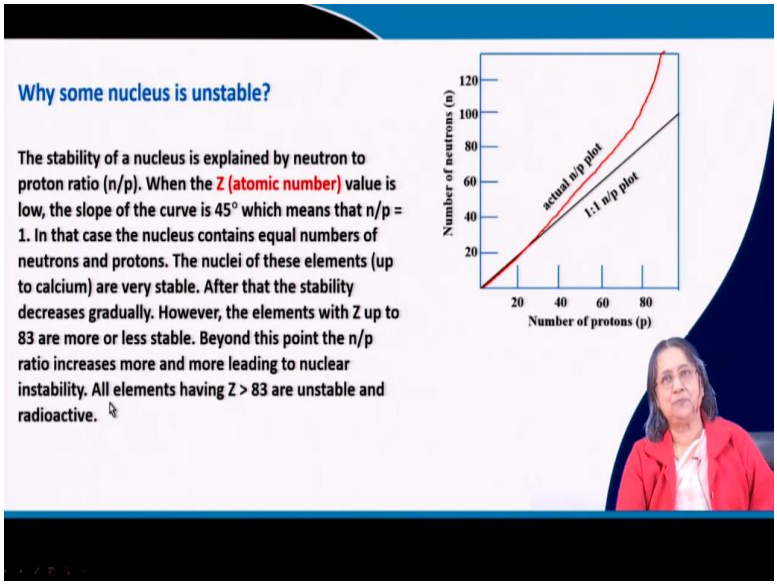


Now, as is shown in the figure (in the last slide), you can see that, in the x axis it is the number of protons (p) and in the y axis it is the number of neutrons (n). Up to 20 you can see that number of protons and number of neutrons are same. Then, as you go on increasing the number of protons, you can see that the curve representing n:p values is deviating from the line representing n equals to p. Actually after 83 all the nuclei are very unstable. All elements having Z above 83 are unstable and shows radioactivity.

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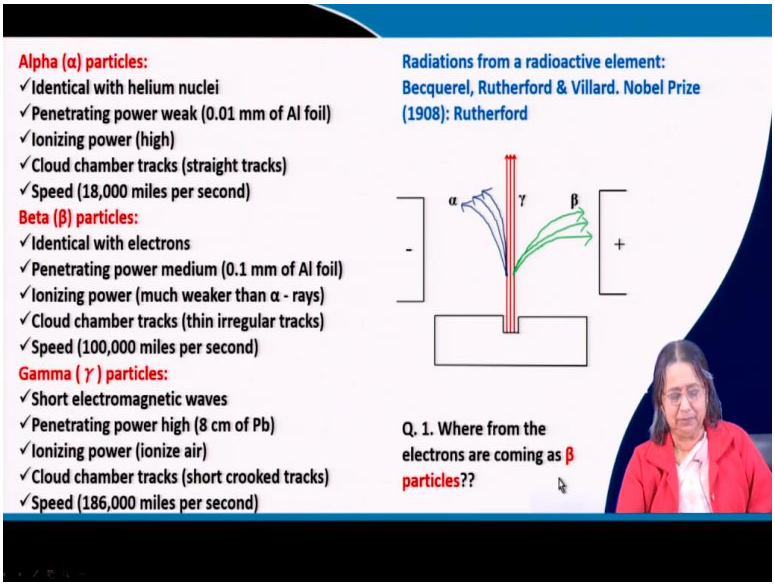


Now, we will see the properties of the particles that are coming out from a radioactive element. A lead block has been shown in the last slide. There is a small hole and some radioactive element is kept. So, some radiations/ particles are coming out as I explained in the previous slide that radioactive elements are disintegrated with the emanation of some particles. When some magnetic field or electric field is kept in a direction perpendicular to the plane of the paper, then these particles are deviated from its path. It is actually deflected. The particles which are deflected towards the negative charge end are the alpha particles, and those towards the positive end are the beta particles. The particles which remain straight (no deflected) are the gamma particles. It is called gamma rays. Now, you can see (in the last slide) that alpha particles are deflected less compared to the beta particles. It is happening so because alpha particles have more mass compared to beta particles. What are alpha particles? Alpha particles are identical with helium nuclei. I can write helium nuclei as ${}_2He^4$. So, atomic mass is 4 and atomic number is 2. So, there are 2 neutrons and 2 protons in the nucleus. There are 2 electrons. Now what is beta particle? Beta particle is nothing but the electrons.

The penetrating power of the alpha particles are weak. How much is that? It is only 0.01 millimetre of aluminium foil. So, you can stop the alpha particles by using this aluminium foil having the thickness of 0.01 millimetre. Ionizing power of alpha particles is very high and it goes by straight line. Speed of alpha particles is almost one tenth of the speed of light. But beta particles are very similar to electrons. Their penetrating power is much higher than the alpha particle. It is 0.1 millimetre aluminium foil. You can see in some books it is written 5 millimetre also. So, it varies from book to book and also the material. Their ionizing power is much weaker than the alpha rays. By means of cloud chamber track you can see that the

track of the beta particles is not straight. They show thin irregular tracks. Speed of the beta particles is approaching towards the velocity of light. But it is not the same. Now, what are gamma particles? These are short electromagnetic waves and the penetrating power is very high i.e., 8 centimetre of lead. They can ionize air. From cloud chamber track, short crooked tracks are obtained. Speed of the gamma particles is same that of the light. Becquerel, Rutherford and Villard studied many of the properties of the radiations from radioactive elements. Moreover, Rutherford got noble prize in 1908 for significant contribution in this field.

Now, you can ask me that where from beta particles are coming? Is it the orbital electrons that it is giving off this beta particle as beta particles are nothing but electrons? No it is not the orbital electron. It is coming out from the nucleus due to some conversion? So, it is fallacy.

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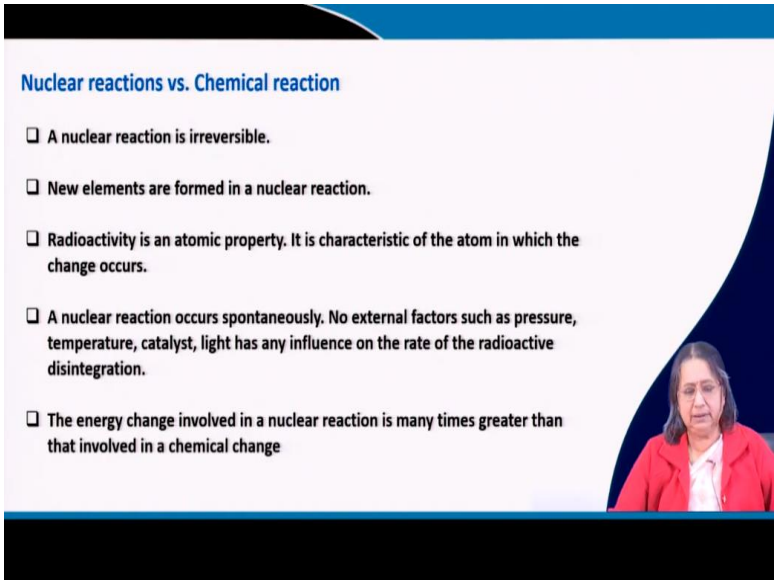


Now, we will see nuclear reactions versus chemical reactions. You have already learnt many things about the chemical reactions and here you are studying the nuclear reaction. So, what is the difference? You know nuclear reactions are irreversible reactions. It means if once alpha particles are emanated, it cannot go back. But in chemical reactions, we have seen, say for example nitrogen and hydrogen are reacting to form the ammonia. Ammonia is also going to be converted to nitrogen and hydrogen. So, when it is at equilibrium, the both processes are taking place. But here, it is not like that and new elements are formed in a nuclear reaction. When something is coming out (like alpha rays, beta rays etc.) then the nucleus of one element is converted to the nucleus of another element. That means the atomic number is

changing. So, element is changing. But in case of that chemical reaction such as in ammonia synthesis, nitrogen is remaining the same, hydrogen is remaining the same but only they are combining with one another to form another compound. Now, radioactivity is an atomic property.

No external factor such as pressure, temperature, catalyst, light has any influence on the radioactive disintegration. But we have seen, in the chemical reaction depending on the pressure, temperature, we can change the speed of the reaction.

Energy change that is involved in nuclear reaction is much, much higher compared to the chemical reaction. It may be 10,000 times higher or even more, compared to the chemical change or chemical reaction.

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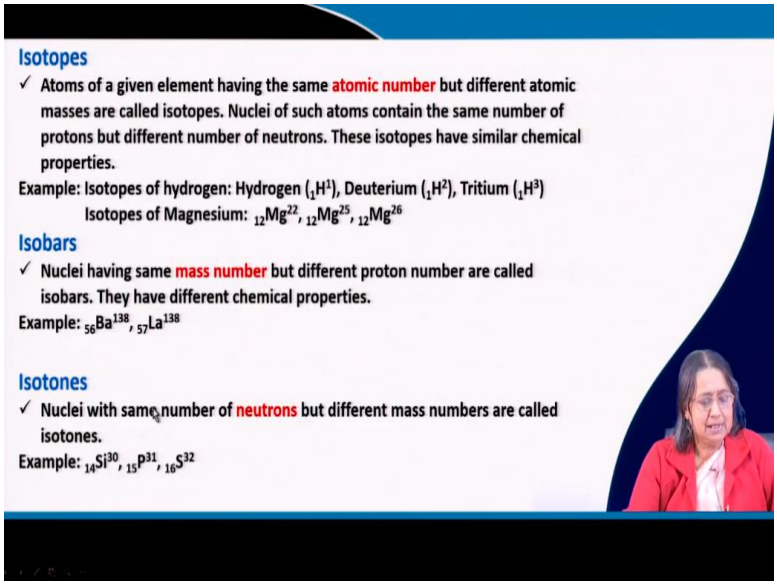


Now, to understand this radioactivity chapter, we must know a few things such as isotopes, isobars and isotones. What is an isotope? Atoms of given element having the same atomic number, but different atomic mass are called isotopes. Nuclei of such atoms contain the same number of protons but different number of neutrons. Examples of isotopes are the isotopes of hydrogen. You know hydrogen has the atomic number 1. So, whatever be the isotopes of hydrogen, it should have the same atomic number. So, hydrogen, deuterium and tritium have the same number of proton i.e., 1 (as shown in the last slide). But the atomic mass is different. So, here in hydrogen it is 1, in deuterium it is 2, in tritium it is 3. So, they are the isotopes. Now, you can see the isotopes of magnesium (last slide). Atomic numbers are same but the atomic masses are different (22, 25, 26) due to the difference in number of neutrons.

Now, let see what are isobars. Nuclei having same mass number but different proton number are called isobars. They have different chemical properties. Isotopes have similar properties, because property is decided by the atomic number. In isobars, the mass number is same, but atomic number, that is the proton number is changing. That means the, they are different elements. Say for example, barium and lanthanum. The mass number is the same, 138 but the atomic number is changing, 56 and 57. So, they are different elements obviously.

Now what are isotones? Isotones are nuclei with same number of neutrons but different mass number. So, they have the same number of neutrons (difference between the atomic mass and atomic number). In case of silicon, phosphorus and sulphur the difference between atomic mass and atomic number is same. So, they are having same number of neutrons but different mass numbers. Obviously, these elements are different.

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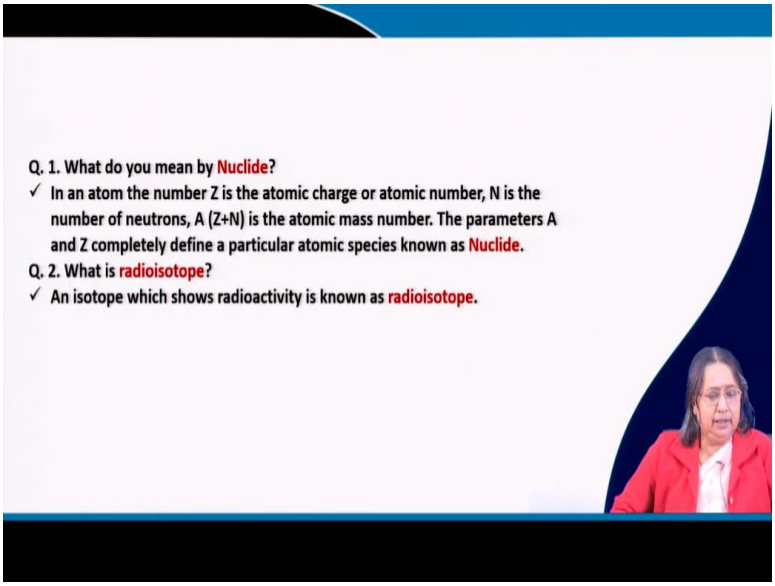


What do you mean by nuclide? In the books, when you go through this chapter, you will see they are writing nuclides. In an atom the number Z is the atomic charge or atomic number and N is the number of neutrons and A is the atomic mass number (A = Z+N). So, the parameters A and Z completely define a particular atomic species. So, if you tell how much is A and how much is Z for a particular element, then you already define some atomic species. This is the nuclide. What is radioisotope? An isotope which shows radioactivity is called radioisotope. So, isotope may be not radioactive. But radioisotope means, they are isotopes, but they are radioactive.

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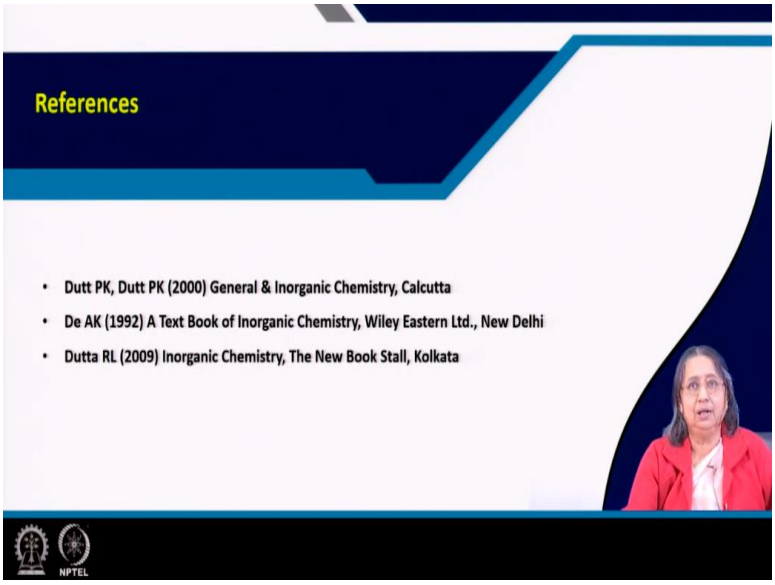


So, for this topic under module 6, you see the same references I have mentioned (last slide). So if you want to read more, you may consult these 3 books. Each one is very good.

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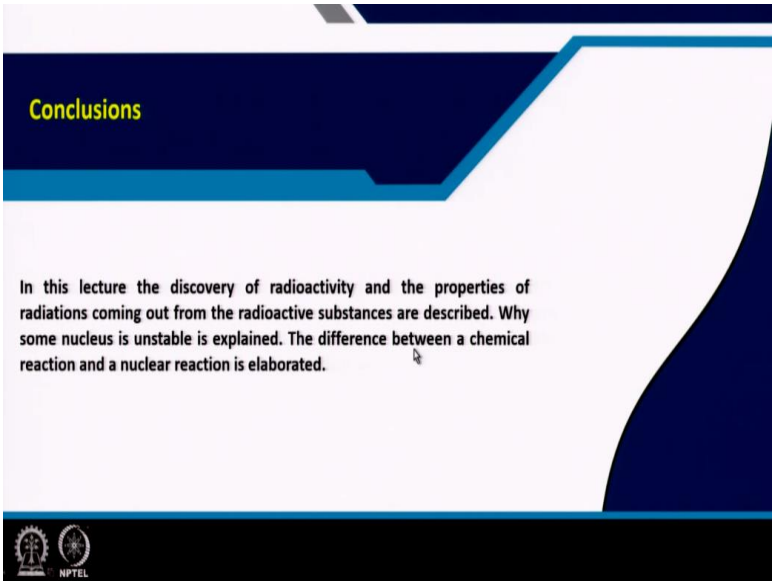


Now, as a conclusion, I can tell that, in this lecture, I have told about the discovery of radioactivity, properties of radiation that is coming out from the radioactive substances and why some nucleus is unstable. I have explained what is the difference between a chemical reaction and a nuclear reaction. Thank you.