Environmental Chemistry and Microbiology

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Module - 6
Lecture - 28
Radioactivity (Part-C)

Welcome everyone to our online NPTEL course of Environmental Chemistry and Microbiology. This course will be taught by Professor Sudha Goel and myself, Professor Anjali Pal. We both are from Civil Engineering Department, IIT Kharagpur. We have divided this course into 2 parts. The first part is Environmental Chemistry. It will be covered by me and the second part i.e., Environmental Microbiology, will be taught by Professor Sudha Goel. This is my twenty eighth lecture (module 6). In this module, I am covering the radioactivity chapter or nuclear chemistry. In my previous 2 lectures, I have discussed about the fundamentals of radioactivity. In this lecture, I will cover the following topics: Radioactive disintegration series, nuclear transmutation, artificial radioactivity, and age of the ore or rocks.

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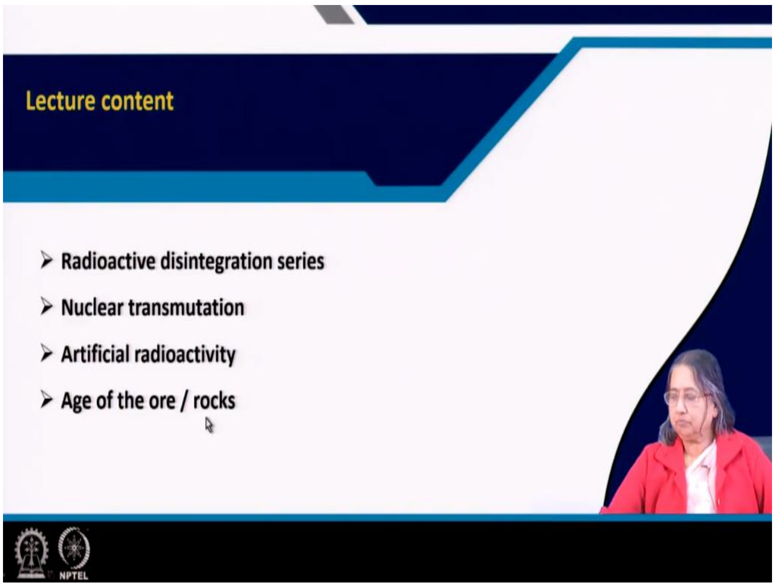

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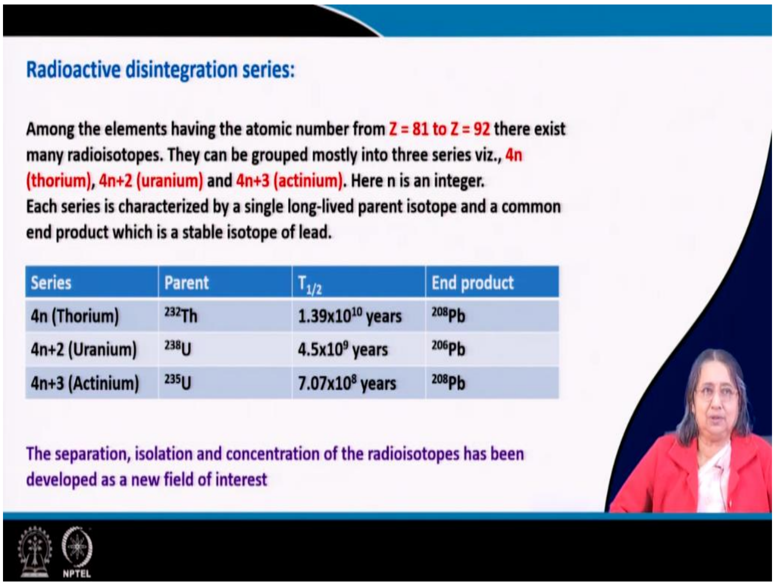

Firs we will see radioactive disintegration series:

We already know that there are many radioactive elements. Mainly among the elements having the atomic numbers from Z = 81 to Z = 92, there exist many radioisotopes. By now you know what does it mean by Z and radio isotope. They can be grouped into 3 series. One series is defined by thorium, i.e., 4n series. Another is by 4n + 2, i.e., uranium series. The third one is 4n + 3, i.e., actinium series. Here n is an integer. Each series is characterised by a single long-lived parent isotope and a common end product which is a stable isotope of lead. What is 4n, 4n + 2 and 4n + 3? If you divide atomic mass number by 4, then you will see that remainders are obtained 0, 2 and 3. Now, $T_{1/2}$ is also one of their characteristics. Half-lives of thorium (1.39×10^{10} years), uranium (4.5×10^{9} years) and actinium (7.07×10^{8} years) are written in the last slide.

So, when there are many radioisotopes formed, it is very important to separate them to study their properties and to use it for other purposes. So, this is very important field.

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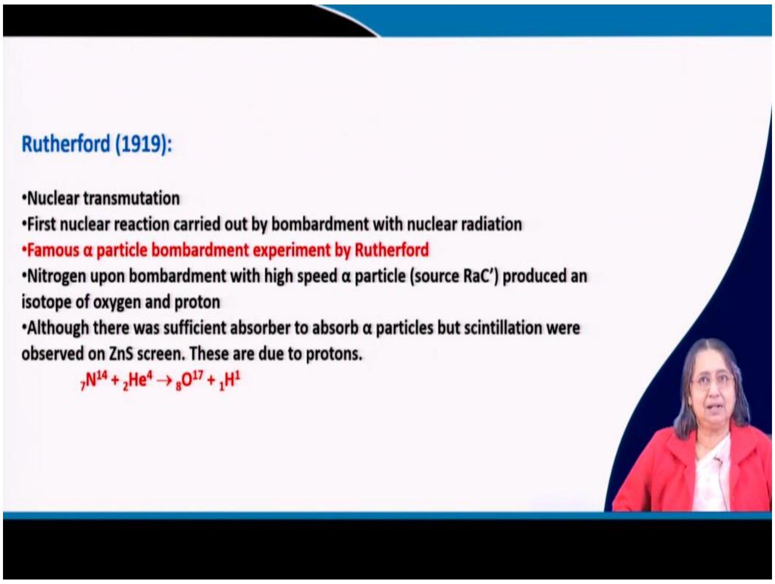

Now, we will see a very important experiment done by Rutherford in 1919 (nuclear transmutation). Nuclear transmutation means some type of reaction by which one nucleus is transformed into another. Previous to this, we did not know that one atom can be transformed into another. For the first time, Rutherford did it. The famous alpha particle bombardment experiment was done by Rutherford. Nitrogen upon bombardment with high speed alpha particle produced an isotope of oxygen and proton. RaC' was used as the source.

$_7N^{14}+_2He^4\rightarrow{}_8O^{17}+_1H^1$……….(1)

Mass number of oxygen is 16, but here it is 17. So, it is an isotope of oxygen and 8 is atomic number. Proton is also produced. Although there was sufficient absorber of alpha particles, still he has observed the scintillations, flashes, bright flashes absorbed on zinc sulphide screen. So, what is the reason for that scintillation or flash? These are due to the protons that is produced. But you know that when he wanted to publish it, people did not believe. They thought that it is the impurity. Oxygen was already there, so, it is not produced. But, finally it is proved by him that it is the product of nitrogen. So, it is called nuclear transmutation, i.e., conversion of one nucleus to another nucleus.

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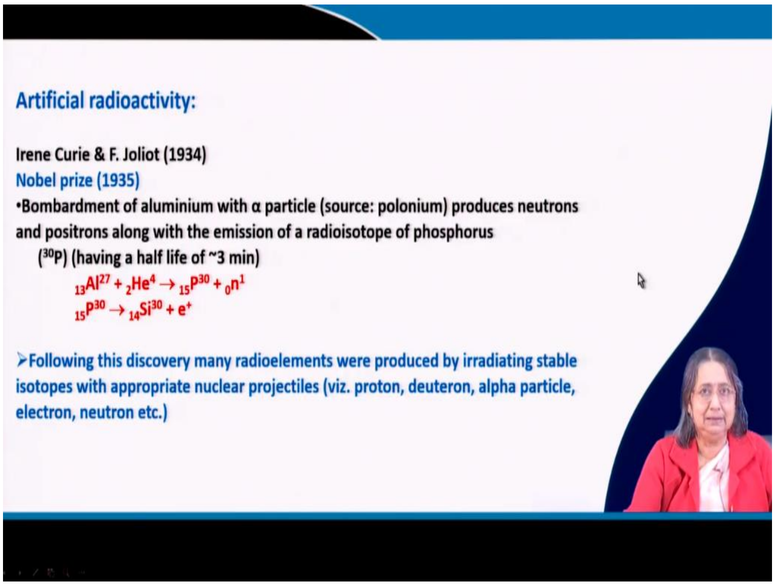

Another important experiment was done by Irene Curie and F. Joliot. Irene curie was the daughter of Madame Curie and her husband was F. Joliot. They were also doing some experiment to find out the neutron. They got the Nobel Prize in 1935 for artificial radioactivity. Till now, we have only seen that radio activity is coming out from heavy nucleus and that is spontaneously coming out. It is natural radioactivity. But they have discovered artificial radioactivity. How they got it? They have bombarded the aluminium with alpha particle. Polonium was the source of alpha particle. It was observed that neutrons and positrons were produced along with the emission of radioisotope of phosphorus.

$_{13}Al^{27}+_2He^4\rightarrow_{15}P^{30}+_0n^1$……………………..(2)

$_{15}P^{30}\rightarrow_{14}Si^{30}+e^+$……………………………..(3)

$_{15}P^{30}$ is the artificially produced radio isotope of phosphorus. $_{15}P^{31}$ is the natural isotope of phosphorous. $_{15}P^{30}$ has half-life of only 3 minutes. It has transient existence. In the second step it is converted to silicon ($_{14}Si^{30}$) and positron (e^+).

Following this discovery, many radio elements were produced by irradiating stable isotopes with appropriate nuclear projectiles (viz. proton, deuteron, alpha particle, electron, neutron etc.)

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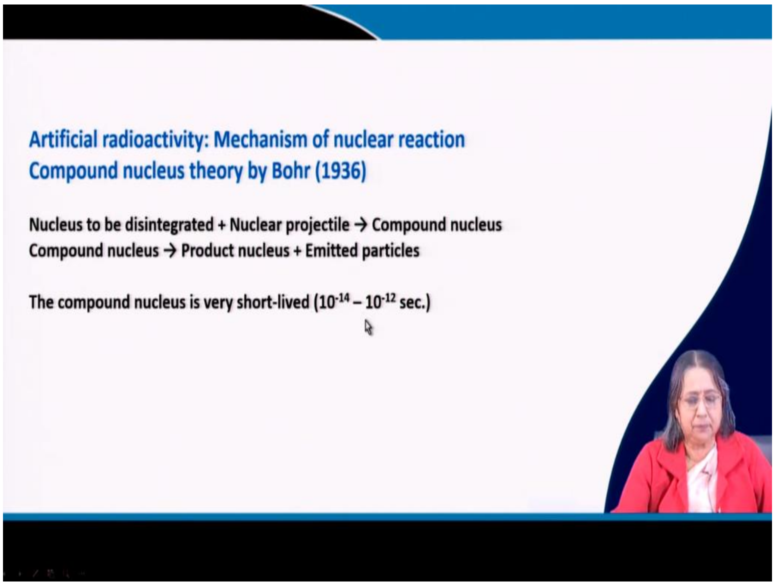

Regarding artificial radioactivity some mechanism has been given by Bohr in 1936. It was proposed that the combination of nucleus to be disintegrated and nuclear projectile will produce compound nucleus. The compound nucleus is very short-lived (10^{-14}-10^{-12} sec).

So, compound nucleus will be forming the product nucleus and with the emission of particles.

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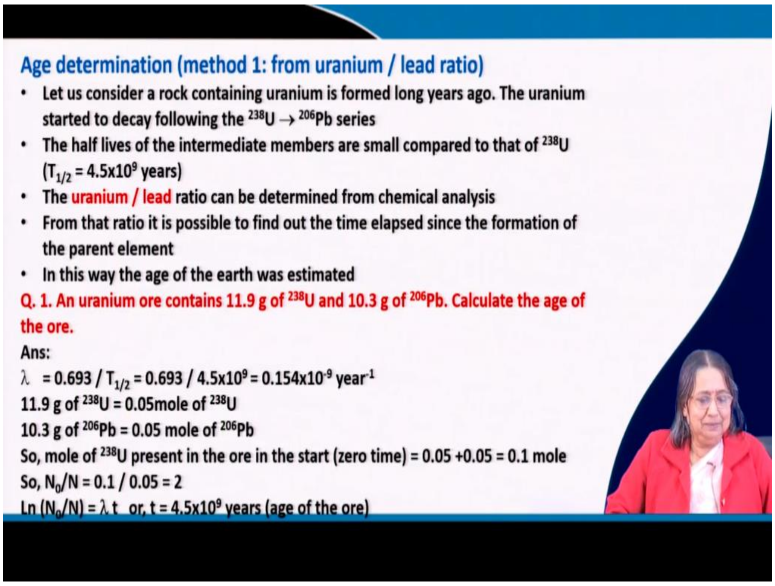

Now, determining the age of a rock or ore is a very important application of radioactivity. There are 2 methods which I will discuss. The first method is the uranium/lead ratio. From the uranium lead ratio, you can determine the age of the rock. Let us consider a rock containing uranium. This is formed long years ago. The uranium started to decay and ultimately it will be converted to lead. Now, the half-life of the intermediate members is very small compared to ^{238}U.

Half-life of uranium is very large (4.5×10^9 years). By chemical analysis, it is very easy to determine uranium lead ratio. From that ratio, it is possible to find out the time elapsed since the formation of the parent element. That is the age of the ore. In this way, the age of the earth was also estimated and good result was obtained. Now, let us do one problem:

Q1. A uranium ore contains 11.9 g of ^{238}U and 10.3 g of ^{206}Pb. Calculate the age of the ore.

Answer:

$\lambda=0.693/T_{1/2}=0.693/(4.5\times10^9)=0.154\times10^{-9}$ year^{-1}

11.9 g of ^{238}U = 0.05mole of ^{238}U

10.3 g of ^{206}Pb = 0.05mole of ^{206}Pb

So, mole of ^{238}U present in the ore in the start (zero time) = 0.05+0.05 = 0.1 mole

So, $N_0/N = 0.1/0.05 = 2$

$\ln(N_0/N) = \lambda t$ or, $t = 4.5\times10^9$ years (age of the ore)

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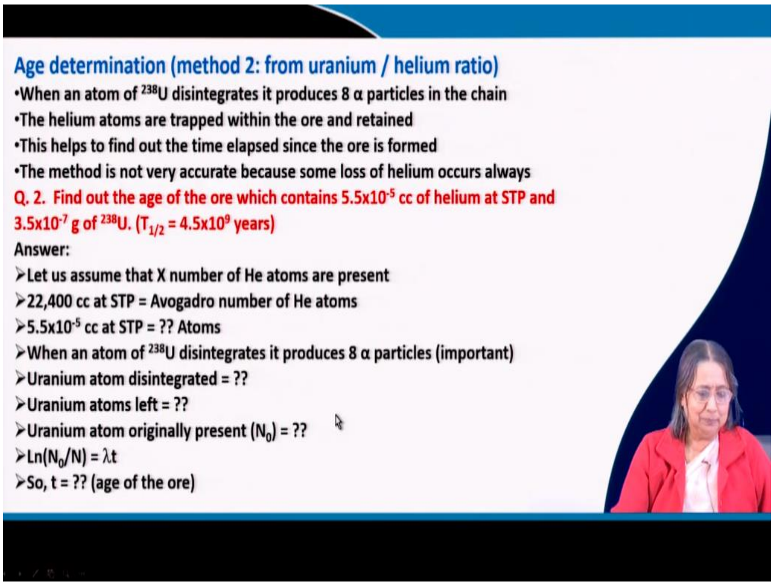

There is another method which is uranium/helium ratio. Why helium is coming? It is so because it is giving out alpha particle. Alpha particle is nothing but helium nucleus. How can you know that it is helium? You can easily find out from atomic spectra. When an atom of ^{238}U disintegrates, it produces 8 alpha particles in the chain. So, after leaving 8 alpha particles, it goes to the end product, lead. The helium atoms are trapped within the ore and retained. It helps to find out the time elapsed since the ore is formed. You have to know how much concentration of helium is produced. From there, you can know that how much time has passed. This method is not very accurate because some loss of helium always occurs. Some helium escapes out by diffusion. Now, let us solve a numerical problem.

Q 2. Find out the age of the ore which contains 5.5×10^{-5} cc of helium at STP and 3.5×10^{-7} g of ^{238}U. ($T_{1/2} = 4.5\times10^{9}$ years)

Answer:

Let us assume that X number of He atoms are present.

22400 cc at STP = Avogadro number of He atoms

From this we can easily calculate number of atoms present in 5.5×10^{-5} cc volume at STP

When an atom of ^{238}U disintegrates it produces 8α particles.

So we can find out number of uranium atoms disintegrated and number of uranium atoms left.

We know how many atoms were there initially.

From the formula, $\ln(N_0/N) = \lambda t$, we can find the age of the ore

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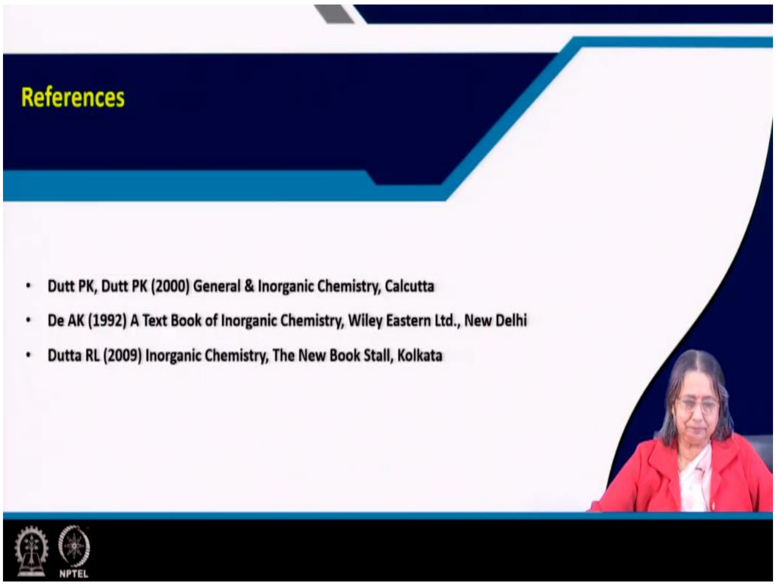

The references have been provided in the last slide. In some books you will find it is written how to find age of the earth in a way similar to the last two problems. This is also called geological clock.

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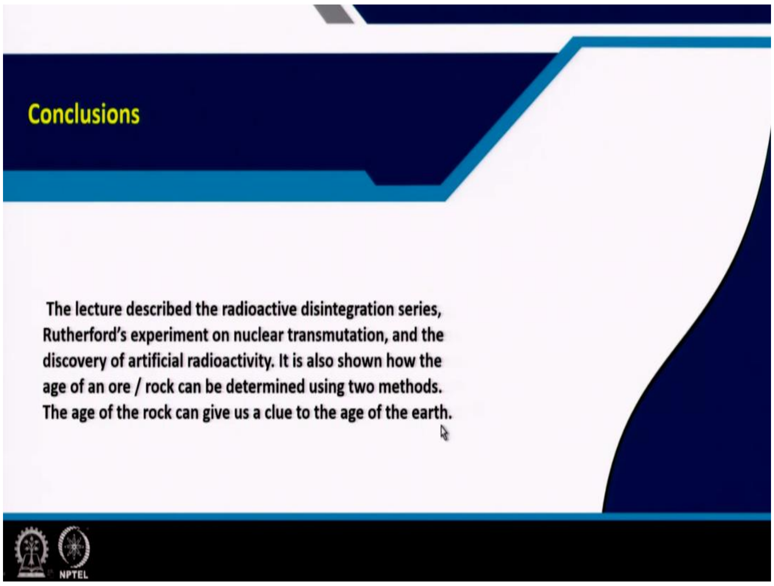

So, in this lecture, we have seen what are the radioactive disintegration series, the Rutherford's experiment on nuclear transmutation and then artificial radioactivity which is developed by Irene Curie and F. Joliot. Finally, we have seen that how the age of rock or ore can be determined by using two methods. Thank you.