Environmental Chemistry and Microbiology
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Module - 6
Lecture - 29
Radioactivity (Part-D)

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 of IIT Kharagpur. We have divided this course into 2 parts. The first part is Environmental Chemistry. It will be taught by me and the second part is Environmental Microbiology which will be covered by Professor Sudha Goel. This is my sixth module and twenty ninth lecture. I have covered acids, bases and salts in the first module. Then in the second module, I covered the chemical equilibrium. In the third module, I discussed about the chemical kinetics. In fourth module, I discussed about the catalyst and catalytic reactions. In the fifth module, I have explained the chlorine chemistry and the nitrogen chemistry. This is the sixth module where I am covering the radioactivity or nuclear reactions. In my previous lectures, I have told you about the fundamentals of radioactivity, the stability of the radio nuclei, the neutron proton ratio. In this lecture, I will cover the following topics: radiocarbon dating, uses of radiation, uses of isotopes, measurement of radioactivity.

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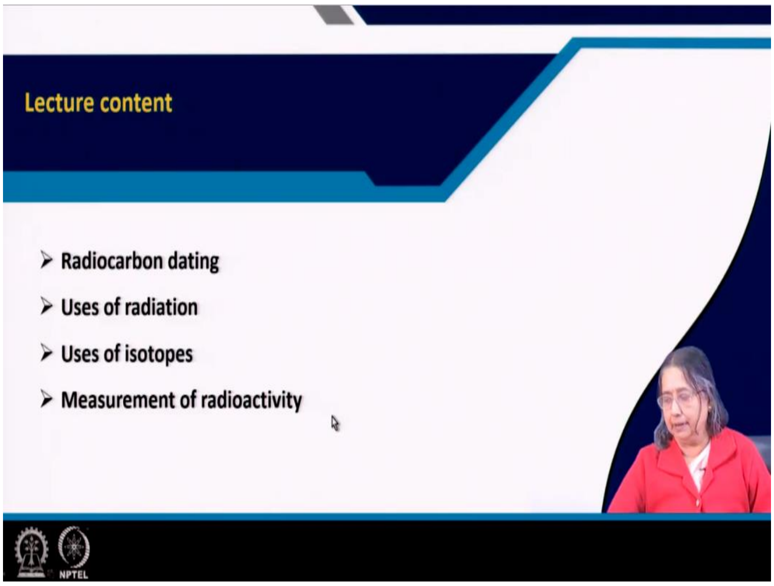

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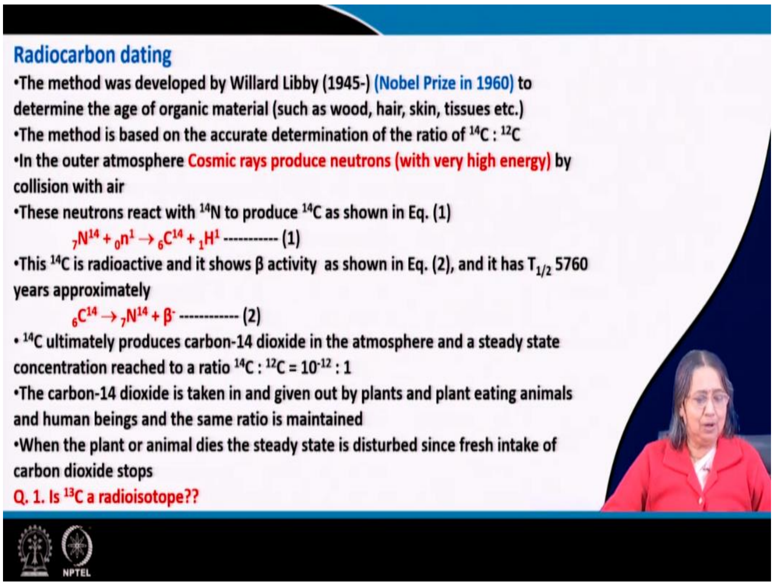

In my previous lecture, I told you that how the age of a rock or an ore can be determined by using the uranium lead ratio or uranium helium ratio. Here I will tell you also similar thing, but not exactly similar. You will see how the ^{14}C can be used for this purpose. The method was developed by Libby. Nobel Prize for this was given in 1962. This is used to know the age of organic material. In the previous lecture, the method was used to know the age of ore, but here it is used to determine the age of the organic material. Organic material can be anything such as wood, hair, skin, some tissues etc. The method is based on the accurate determination of the ratio of ^{14}C and ^{12}C. I already told you that carbon has 3 isotopes. I also told that ^{12}C is the natural, most common and abundant isotope. The other isotopes are ^{13}C and ^{12}C. Is ^{13}C a radioisotope? No, ^{13}C is not a radioisotope. It is also occurring naturally with a very low percentage. But it is not a radioisotope while ^{14}C is radioactive. Now, I will explain this method step by step. It is little bit complicated, but very interesting. We know that cosmic rays are there in the outer atmosphere. They produce neutrons with very high energy. These neutrons react with ^{14}N to produce ^{14}C and proton as shown in eq(1):

$_7N^{14}+{}_0n^1\rightarrow{}_6C^{14}+{}_1H^1$……….(1)

This ^{14}C is radioactive and shows β activity with having half-life of 5760 years, as shown in eq (2):

$_6C^{14}\rightarrow{}_7N^{14}+\beta^-$…………..(2)

^{14}C ultimately produces carbon-14 dioxide in the atmosphere and steady state concentration reached to a ratio ^{14}C:^{12}C = 10^{-12}:1. So, small amount. Then, this carbon-14 dioxide is taken in and given out by plants and plant eating animals and human beings and the same ratio is maintained. So, when the plant dies, the steady state is disturbed since fresh intake of carbon dioxide stops. When a plant dies, then it is not taking anymore the carbon dioxide. Then what will happen?

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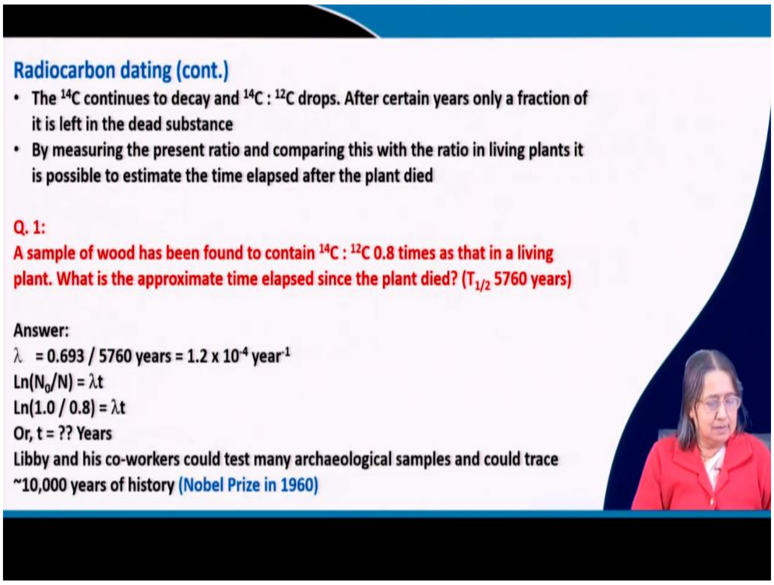

Then the ^{14}C continues to decay and ^{14}C is getting converted to ^{12}C. Then the $^{14}C:{}^{12}C$ is changed and no more remains at 10^{-12}:1. So, after certain years, only a fraction of it is left.

You know the starting $^{14}C:{}^{12}C$ value. If you can measure the present $^{14}C:{}^{12}C$ value by some way, then you can easily tell that how much time has gone. This is the theory. Libby and his co-workers tested many archaeological samples and could trace 10,000 years of history. They have examined many samples. They have done a huge amount of work. Now, let us do one problem. Then you will understand.

Q 1. A sample of wood has been found to contain $^{14}C:{}^{12}C$ 0.8 times as that in a living plant. What is the approximate time elapsed since the plant died? ($T_{1/2}$ 5760 years)

Answer:

λ=0.693/5760 years = 1.2×10^{-4} $year^{-1}$

$\ln(N_0/N) = \lambda t$

Now you can easily calculate t.

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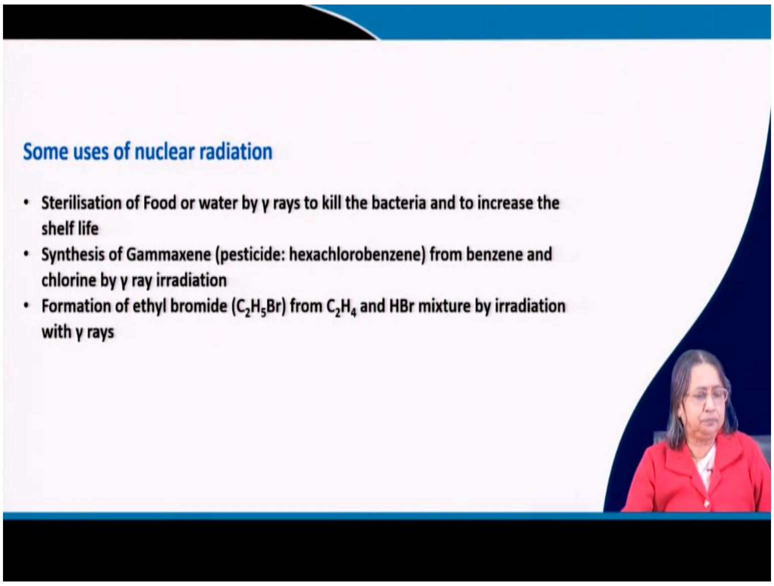

We have already seen the properties of the radiations: alpha, beta and gamma rays. Now we will see their uses. There are many uses of them. You know that radioactivity has severe health effect. It was not known at that time of Madame Curie. Madame Curie died out of cancer. If you work under radioactivity, then you will get cancer. So, it is used for treatment of cancer.

Now, what are the different uses of nuclear radiations? If you keep the food for long period, it will become stale due to the growth of bacteria and will give bad smell. So, to increase the shelf life of food or water, gamma radiations are used to kill the bacteria.

You know about gammaxene. We use it as pesticide or insecticide. It is nothing but hexachlorobenzene. In benzene ring there are three double bonds. So, if you can add chlorine and remove the double bonds then you introduce 6 chlorine atoms in the benzene ring and it will become gammaxene. It is also called hexachlorobenzene and benzene hexachloride (BHC). Gammaxene can be synthesised from benzene and chlorine by gamma ray irradiation. Sometimes UV light is also used for the same purpose. So, gammaxene can be produced. So, this is an application.

Gamma rays are also utilized for the formation of ethyl bromide (C_2H_5Br). Ethyl bromide is produced by the reaction of ethene and HBr. You take mixture of ethene and HBr, and then irradiate it with gamma rays. Then ethyl bromide will be formed.

There are many other reactions. I have picked up only a few.

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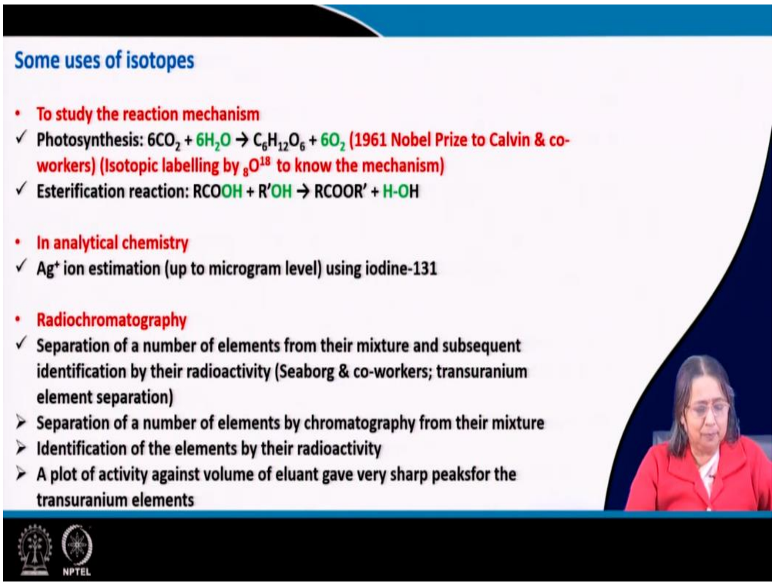


Now, we will see some uses of isotopes. This is not radioisotope.

Equation of photosynthesis is written as follows:

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$……………………(3)

6 molecules of CO_2 react with 6 molecules of water to produce 1 molecule of glucose and 6 molecules of oxygen. Now, one question may come to your mind. Among CO_2 and water, which one is the source of oxygen that is produced? For explaining the mechanism of the reaction (3), Nobel Prize was given to Calvin and co-workers in 1961. It can be done by isotopic labelling. ${}_8O^{18}$ is an isotope of oxygen. Now, you label ${}_8O^{18}$ and take water with this oxygen. Then, you allow the reaction to go on. Then, if you see that oxygen produced, contains the ${}_8O^{18}$, then you will understand that this oxygen is coming from water. If you see that there is no ${}_8O^{18}$, even if you use water labeled with ${}_8O^{18}$, then you will understand that oxygen produced, is coming from CO_2. This experiment is called isotopic labelling.

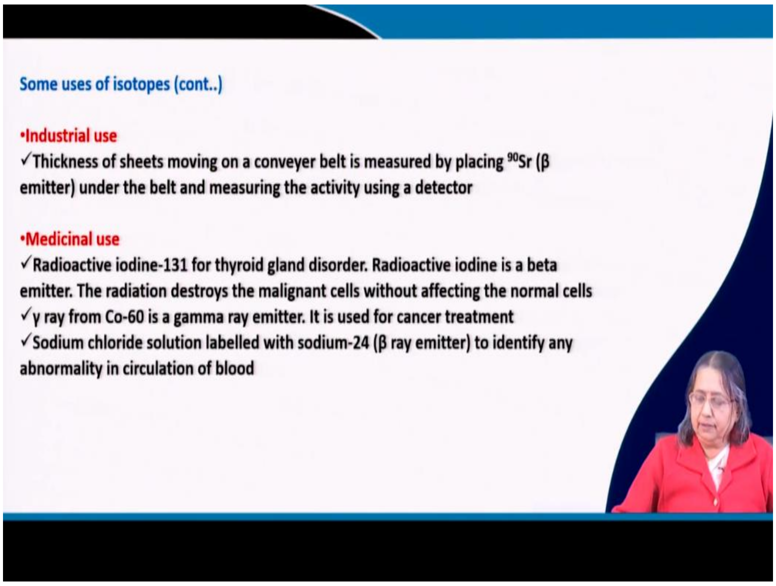
Now, we will see another example. You have already learned esterification and ester hydrolysis. An example of esterification is represented as:

RCOOH+R'OH→RCOOR'+H-OH…………………..(4)

Ester and water is produced in (4). Now the question comes that in water molecule, OH is coming from carboxylic acid or alcohol. This also can be done by ^{18}O labelling. You label the oxygen of alcohol as ^{18}O and see whether the oxygen in water produced contains ^{18}O or not. If the produced water contains ^{18}O then OH in produced water is coming from alcohol otherwise it is coming from carboxylic acid. OH in produced water can come from either of them depending upon the carboxylic acid or alcohol taken.

In analytical chemistry also, you can use isotope labelling. In Ag^+ estimation I have told you in my previous modules that Ag^+ can be precipitated as AgCl if you add some chloride salt such as NaCl. Then you can estimate, how much silver is present. But all Ag^{+} is not precipitated actually. Then, what should you do? To know accurately up to microgram level, you can use KI labelled with iodine-131. Upon addition of iodine-131, silver iodide is formed. You can take out that silver iodide. You have to add some ferric ions to form the hydroxide of it, so that it can be trapped easily as the precipitate. It is a better method in terms of level of detection or level of estimation.

Now, let us come to the radio chromatography. Chromatography, you all know is a method to separate things like some molecules. It can be molecules or it can be ions. After separation, there should be some detection unit so that you can detect it. In radio chromatography separation of a number of elements from their mixtures is carried out and then subsequent identification is done by the radioactivity. Seaborg and co-workers have used this technique to separate the transuranium elements. In a nutshell you can tell that, separation of a number of elements is done by chromatography. In chromatographic technique we first absorb it in some absorbing column and then we elute it with solvents. The things which are present in the mixture, come out one by one. Then we detect it and determine it. After that, identification of the elements is done by the radioactivity. A plot of activity (y axis) against volume of eluant (x axis) is done. You will get sharp peaks for the transuranium element. **(Refer Slide Time: 27:36)**



Now, we will see industrial use. You have seen conveyor belt in the airports and many places like shopping malls. Sheets are used in conveyor belts and they are decayed with respect to time. So their thickness goes down. Thickness is measured by placing ^{90}Sr (β emitter) under the belt and measuring the activity using a detector. Then you know the thickness. In medical field, radioactive iodine-131 for thyroid gland disorder. Say for example, some sodium iodide is pushed and then it goes to the thyroid gland. As it is radioactive, So, it cures the disorder. Radioactive iodine is a beta emitter. The radiation destroys the malignant cells without affecting the normal cells.

Cobalt 60 is a gamma ray emitter. It can be used for cancer treatment. This is also an important application.

Sodium chloride solution labelled with sodium-24 is also beta ray emitter. It is used to identify any abnormality in circulation of blood. It is injected in the veins. After that, if the system is normal, then you should see the activity within 1 hour. You can see the activity in the feet. But if there is some abnormality, it will take longer time to identify the activity in your feet. By this way you will understand whether your blood circulation is normal or not.

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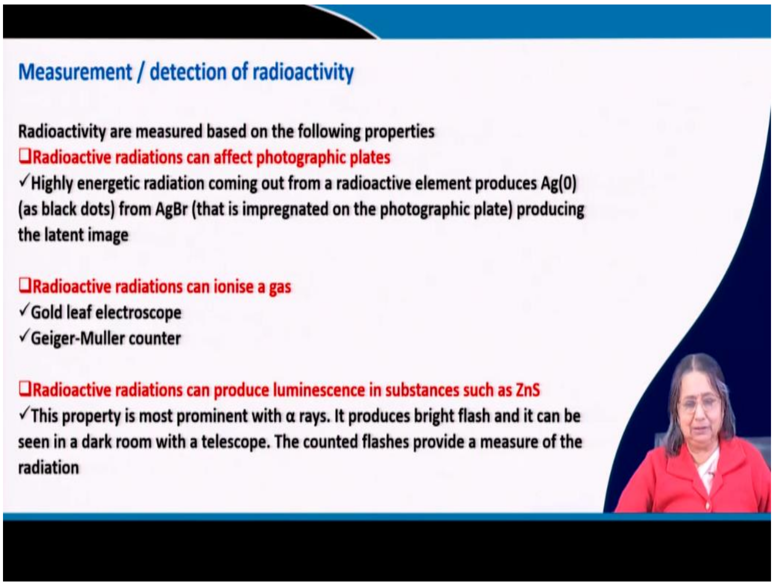

Now, can you tell me how the radioactivity is measured? There are many methods. You have seen the alpha ray has some property, beta ray has some property, gamma rays have also some properties. So, based on those properties, the measurements can be done. One property is that radioactive radiations can affect photographic plates. That is giving something, radiations that is exposing the photographic plate. There is a very nice chemistry in the classical photography. In the photographic film or photographic plate there is nothing but silver bromide. When the light is coming to the silver bromide, it is producing Ag(0). It will produce black spots. It will be producing the latent image. Black dots it will produce. It is a very nice science, chemistry actually. By this way, when the radioactive rays are passing, then photographic plates are exposed. You cannot stop it by putting any aluminium foil or by putting any black paper or by putting some wood. That thing happened there with Becquerel. The another property of radioactive radiation is that it can ionise a gas.

I will show you gold leaf electroscope and Geiger-Muller counter. These two are the instruments by which you can detect or measure the radioactivity. I will show you that later. Another property of radioactive radiations is that they can produce luminescence in substances such as zinc sulphide. This property is most prominent with alpha rays. It produces bright flash and it can be seen in the darkroom with a telescope. The counted flashes provide the measure of the radiation.

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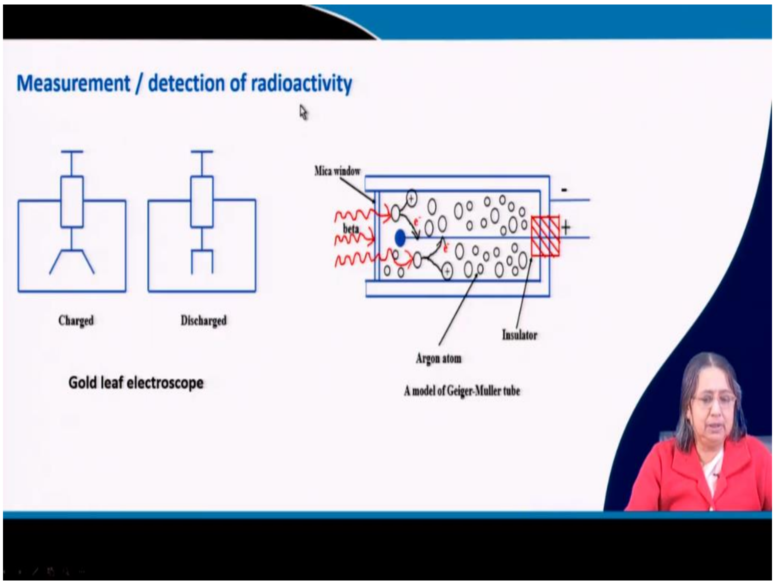

Now come to the Gold leaf electroscope. This is a very old thing. Becquerel and Madame Curie have used this thing. Gold foiled leaves with rod and plate is shown in the last slide. If you keep some charge over the plate, the leaves will repel each other. They will go like as shown for the figure marked "Charged" in the last slide. But if you bring some radioactive element there, they will produce some radiations and they will ionise the air. When the air will be ionised, leaves will be discharged. They will not repel anymore but will get oriented as shown in figure marked "Discharged."

Now we will see about Geiger-Muller counter or Geiger-Muller tube. Argon gas is inside the tube. There is a negative electrode and positive electrode. Through the positive electrode a wire is connected. They are joined and high voltage is passed. Now, when the beta rays are coming, they will ionise the argon gas. It will produce electrons and positive argon gas. Then, these electrons will be discharged near the wire and positive argons will be discharged at other places. Then you will hear some sound like kit, kit, kit. So, from there you will know how much radioactivity is there. This is a portable machine and you can take it from one place to another.

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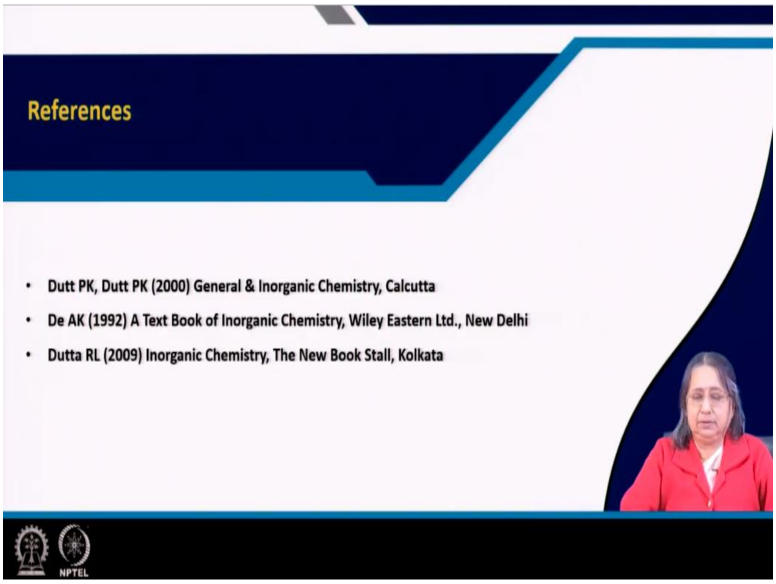

Now, radioactivity has many applications and very interesting properties. When you are using this type of radioactive elements, you have to be very careful because they can cause cancer. There are some special dresses also, special goggles, special equipment etc. to protect us from this type of radioactive radiations. I can refer 3 books for this chapter as shown in the last slide.

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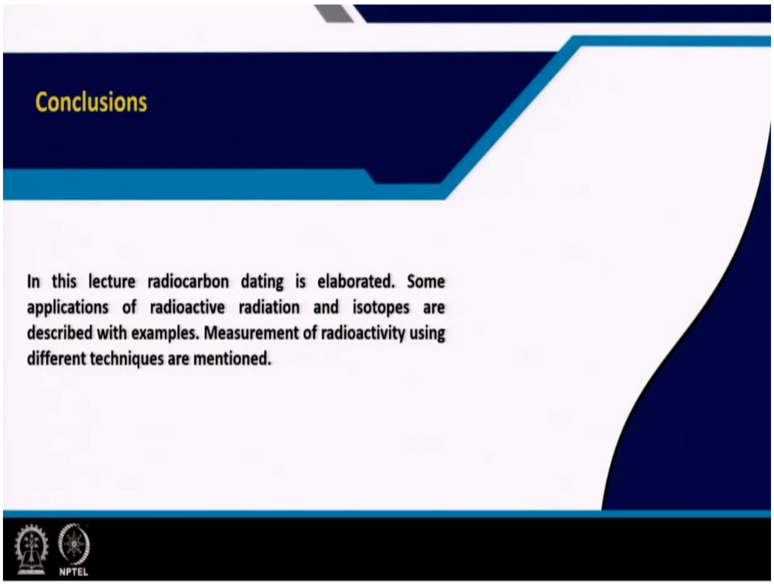

In this lecture, we have discussed about the radiocarbon dating, some applications of radioactive radiations and isotopes, measurements of radioactivity. Thank you.