Environmental Chemistry and Microbiology

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Module - 6
Lecture - 27
Radioactivity (Part-B)

Welcome 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 are from Civil Engineering Department, IIT Kharagpur. This course is divided into 2 parts. Environmental Chemistry is the first part. I will cover that. The next part is the Environmental Microbiology. It will be taught by Professor Sudha Goel. This is module 6 and twenty seventh lecture. I have explained acids, bases and salts in my first module. In my second module, I discussed about the chemical equilibrium. In the third module, I discussed about the chemical kinetics. In fourth module, I covered the catalysis and in fifth module, I told about the chlorine chemistry and nitrogen chemistry. In this module, I will cover radioactivity. In the twenty sixth lecture I covered radioactivity, part A. Now, it is part B. I already told you that this topic is very interesting topic.

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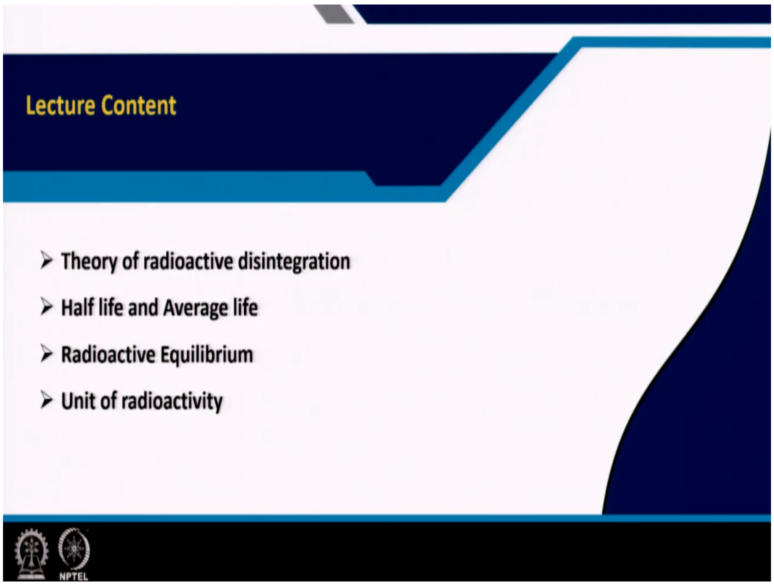

In this lecture, I will tell you something regarding the theory of radioactive disintegration, then half-life and average life, radioactive equilibrium and unit of radioactivity.

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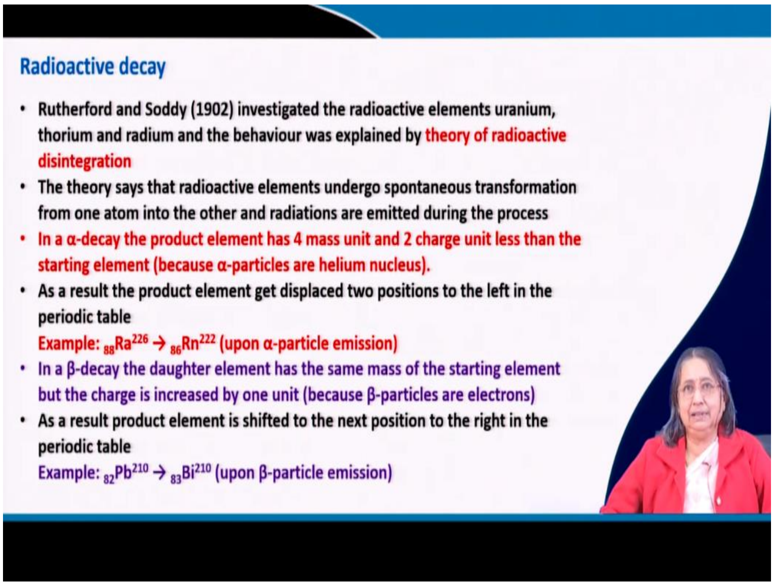

There were two scientists named Rutherford and Soddy. You all have heard the name of Rutherford. He was a very famous person. In 1902, they have investigated the radioactive elements uranium, thorium and radium and explained their behaviour. At that time, radioactivity property was just discovered by Becquerel, Madame Curie and Pierre Curie. Many scientists started their work on this particular topic. Rutherford also started doing some experiments. They have explained the theory of radioactive disintegration. Now, what does it say? The theory says that radioactive elements undergo spontaneous transformation, from one atom into the other and radiations are emitted during the process. The concept is totally new at that time. Previously it was known that an atom cannot be changed to another atom. But when radioactivity was discovered, then first time it is realised that one atom can go to another atom. During that transformation, some particles or radiations are coming out. We know that alpha particle has mass 4 and +2 charge. So, when some nucleus will give out some alpha particles, then what will happen? We will see that the new product element or daughter element is formed which will have 4 mass unit less and 2 charge unit less. 2 charge unit less means its atomic number 2 unit less. But what will be its position in periodic table? We know that periodic table is arranged according to the atomic number, not according to the atomic mass. So, when 2 unit of atomic number will be reduced, then it will go 2 positions to the left in the periodic table. So, when 1 parent element give out 1 alpha particle, then the product element will get displaced 2 positions to the left in the periodic table. Let us consider radium ($_{88}Ra^{226}$). So, 226 is the atomic mass and 88 is the atomic number. So, when radium gives out 1 alpha particle, atomic mass will be reduced by 4 units. It will become 222. The atomic number will be reduced by 2 units. So, it will be 86. It is the position of radon.

In a beta decay, when some nucleus will radiate the beta particle, then what will be the position of the daughter element? Beta particle is nothing but electron. So, in a beta decay, the daughter element has the same mass, because electron has no mass. But the charge of the daughter element is increased by 1 unit. As a result, product element is shifted to the next position (to the right) in the periodic table. An example is given here:

${}_{82}Pb^{210} \rightarrow {}_{83}Bi^{210}$……………………..(1)

Here, lead is the parent element. It has the atomic mass 210 and atomic number 82. After emission of 1 beta particle is emitted. So atomic number will become 83. However, the atomic mass will remain the same, because electron has no mass.

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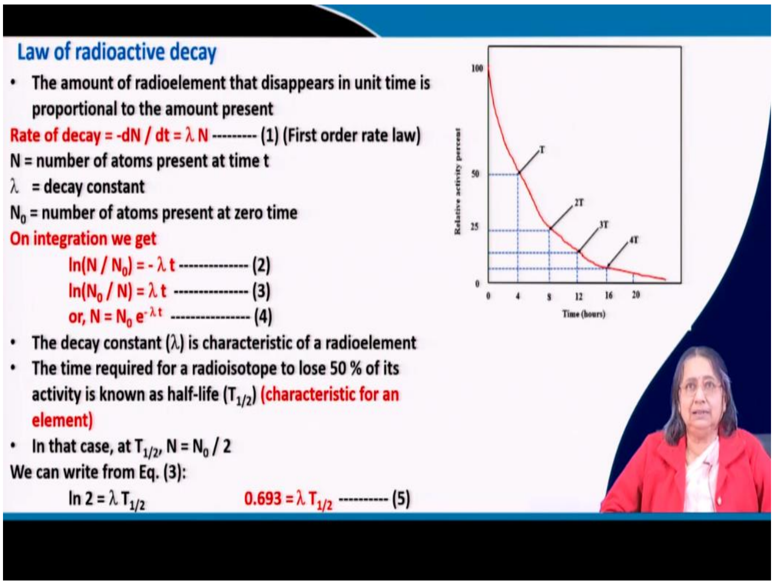

Now, let us see the law of radioactive decay: The amount of radio element that disappears in unit time is proportional to the amount present. You will find similarity with the first order reaction. Here, the rate of disappearance of the radio element is proportional to the amount present. In first order reaction, rate is proportional to the concentration at a particular time. Rate of radioactive decay can be expressed as:

$-dN/dt=\lambda N$…………………………..(2)

Minus sign is given because this is disappearing. In this case, for radioactivity, we write N usually. If you write C, that is also okay. But usually, writing N is the convention. In chemical reaction, we write the rate constant or specific rate constant by small k. But here, we write lambda. It is also specific rate constant. But here we call it decay constant as the parent element is decaying.

Integrating (2), we will get

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

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

or, $N=N_0e^{-\lambda t}$……………………(3)

N is the number of atoms present at a particular time and N_0 is the number of atoms present at starting time. Equation (3) represents an exponential curve. You can see that in the last slide, relative activity percent has been plotted against time. If you start with 100% concentration (initially), then with time, it is exponentially decaying. Like first order reaction, when the concentration come down to its half of starting concentration the time that is taken is called half-life. In chemical kinetics you have written small $t_{1/2}$. But here, usually we write capital T. Then, again when you start with 50% and come to 25%, then another half-life is taken. Say for example if the value of half-life is 4hours then 8hours is required from starting to reaching 25% concentration. Then again if you start with 25%, to reach 12.5% it will take another 4hours. This way, it will go. Now, if you look into the equation, then you will see that, at that case when it is half-life, then you see that $N = N_0/2$. Putting this in (3), we will get,

$\ln 2=\lambda T_{1/2}$

or, $0.693=\lambda T_{1/2}$…………………………(4)

Half-life is independent of initial concentration. It is characteristic of a particular element. λ is also characteristic of a particular element. Radium, say for example, has particular half-life while Uranium, has different half-life. Other radioactive element such as C14 has some particular half-life.

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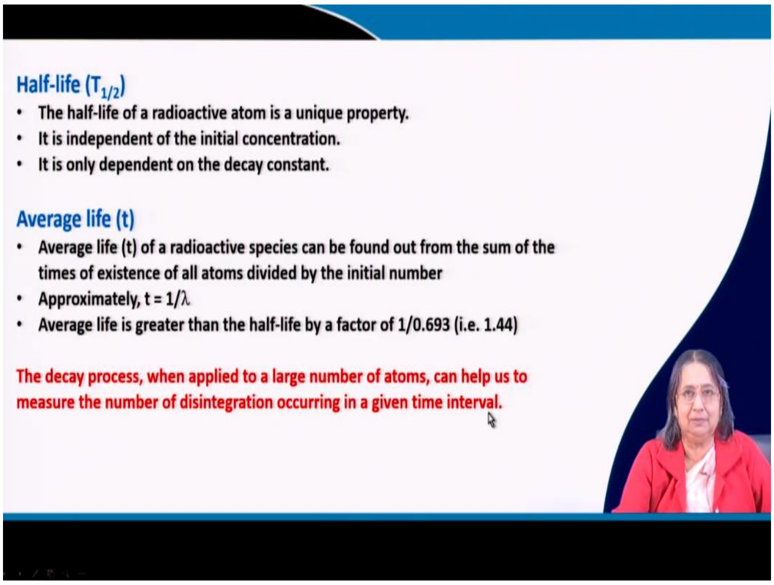

Half-life is only dependent on the decay constant. If you know the half-life, you can easily find out the decay constant and vice-versa if you know the decay constant, you can easily find out the half-life. But average life (t) is little different. Average life of a radioactive species can be found out from the sum of the times of existence of all atoms, divided by the initial number. It is observed that average life (t) is almost equal to 1/λ. On the other hand, half-life is equal to 0.693/λ. So, average life is greater than the half-life by a factor of 1/ 0.693 i.e., 1.44. So, average life is higher than the half-life. The decay process, when applied to large number of atoms; then you will get accurate values. Otherwise, if the number of atoms is small, then you will not get the accurate result.

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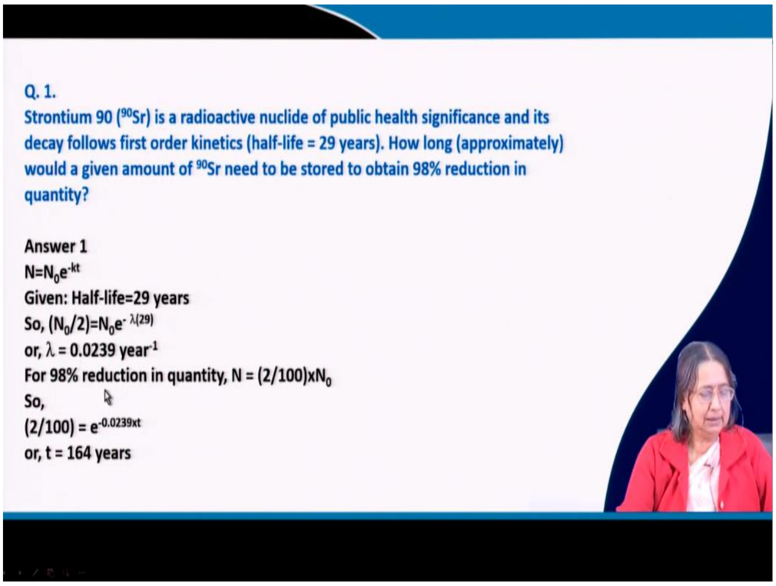

Now, let us do one problem here, based on the half-life.

Strontium 90 (^{90}Sr) is a radioactive nuclide of public health significance and its decay follows first order kinetics (half-life=29 years). How long (approximately) would a given amount of ^{90}Sr need to be stored to obtain 98% reduction in quantity?

Answer:

$N=N_0e^{-kt}$

Given: Half-life=29 years

So, $(N_0/2)=N_0e^{-\lambda(29)}$

or, $\lambda=0.0239$ year^{-1}

For 98% reduction in quantity, $N=(2/100)\times N_0$

So,

$(2/100)=e^{-0.0239\times t}$

or, t=164 years

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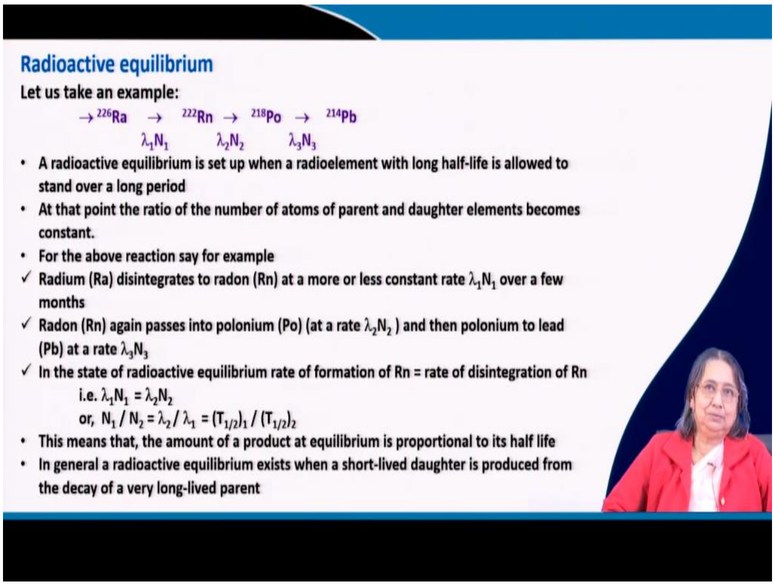

Now, let us see what is radioactive equilibrium. A chain type of reaction has been shown in the last slide starting with radium. In each step an alpha particle is emitted and mass gets reduced by 4. So, it is a chain type of reaction. First radium is converted to radon. Then radon is converted to polonium. Ultimately polonium is converted to lead. So lead is the end product. For first order reaction, we have already seen that rate is expressed as:

$dC/dt=-kC$……………………….(5)

For conversion of radium to radon, rate is $\lambda_1 N_1$. Similarly, for conversion of radon to polonium and for polonium to lead the rates are $\lambda_2 N_2$ and $\lambda_3 N_3$. When a radioactive element with long life is allowed to stand over a long period, then this type of equilibrium will be set up. At equilibrium, ratio of number of atoms of the parent element and daughter element will be constant. In the state of radioactive equilibrium,

Rate of formation of Rn=rate of disintegration of Rn

So, $\lambda_1 N_1=\lambda_2 N_2$

or, $N_1/N_2=\lambda_2/\lambda_1$……………….(6)

Now, λ is related to $t_{1/2}$. So,

$\lambda_2/ \lambda_1=(T_{1/2})_1/(T_{1/2})_2$……………(7)

So, you can say that number of atoms present is proportional to $t_{1/2}$. In general, a radioactive equilibrium exists when a short-lived daughter is produced from the decay of a very long-lived parent.

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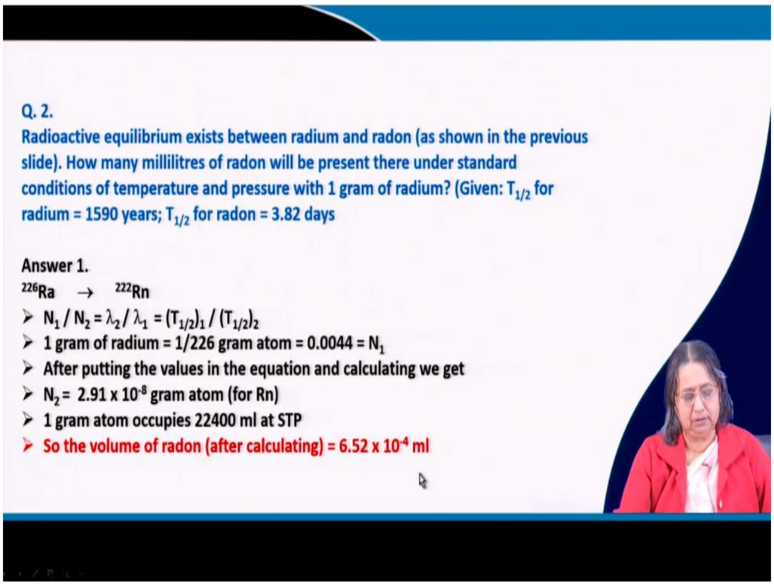

Now, if I put some numerical, it will be clear, more clear to you.

Radioactive equilibrium exists between radium and radon. How many millilitres of radon will be present there under standard conditions of temperature and pressure with 1 gram of radium? (Given $T_{1/2}$ for radium = 1590 years; $T_{1/2}$ for radon = 3.82 days)

Answer:

$^{226}Ra \rightarrow {}^{222}Rn$

$N_1/N_2=\lambda_2/\lambda_1=(T_{1/2})_1/(T_{1/2})_2$

Now 1 gram of radium=1/226 gram atom=0.0044=N_1

After putting the values in the above mentioned equation and calculating we get,

$N_2=2.91\times10^{-8}$ gram atom (for Rn)

Now 1 gram atom occupies 22400 mL at STP

So, the volume of radon (after calculating)=6.52×10^{-4} mL

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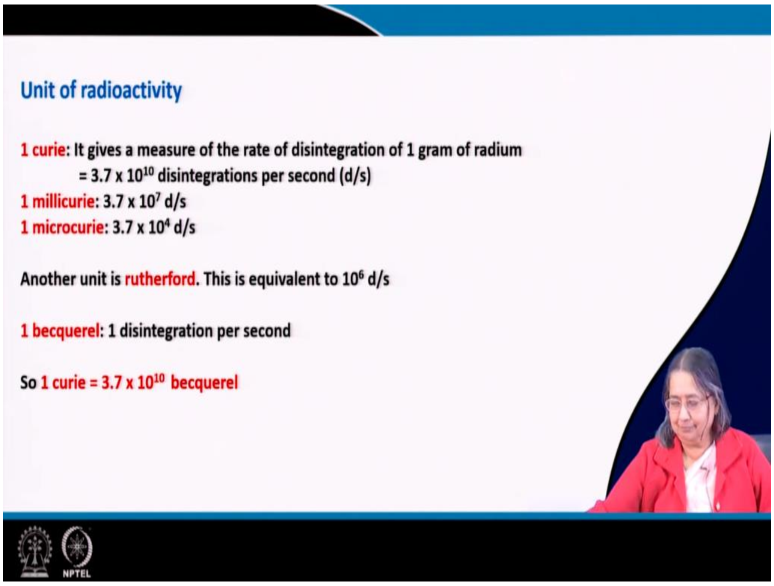

Now, we will learn about the unit of radioactivity: One interesting thing you can see here that Curie, Rutherford, Becquerel are somebodies' name. They are all famous scientists. However, their names in small letters are used as units of radioactivity.

1 curie: It gives a measure of the rate of disintegration of 1 gram of radium

$=3.7\times10^{10}$ disintegration per second (d/s)

1 millicurie: 3.7×10^{7} d/s

1 microcurie: 3.7×10^{4} d/s

Another unit is Rutherford which is equivalent to 10^{6} d/s

1 becquerel: 1 d/s

So, 1 curie$=3.7\times10^{10}$ becquerel

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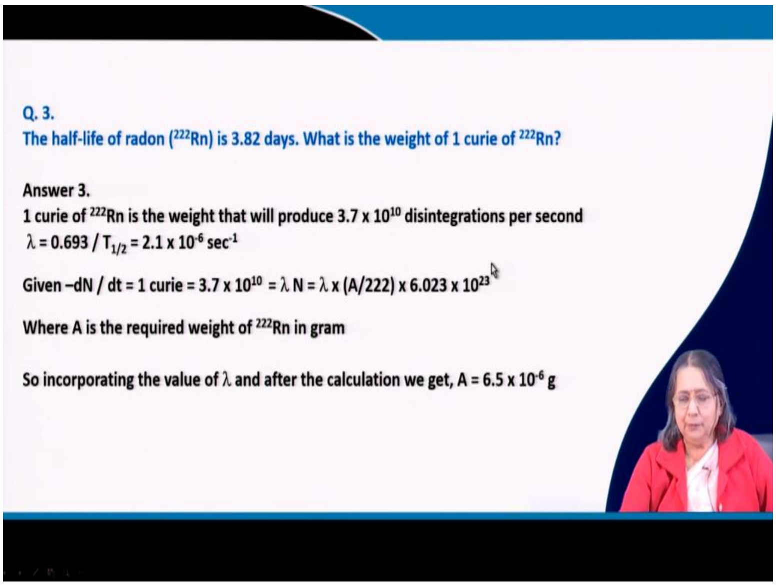

Now, here is another numerical.

The half-life of radon (^{222}Rn) is 3.82 days. What is the weight of 1curie of ^{222}Rn?

Answer:

1 curie of ^{222}Rn is the weight that will produce 3.7×10^{10} disintegration per second

$\lambda=0.693/T_{1/2}=2.1\times10^{-6}$ sec^{-1}

Given $-dN/dt=1$ curie$=3.7\times10^{10}=\lambda N=\lambda\times(A/222)\times6.023\times10^{23}$

where A is the required weight of ^{222}Rn in gram

So, incorporating the value of λ and after calculation we get, $A=6.5\times10^{-6}$ g

You can do it by yourself. If you understood the previous things, then you can easily do it by yourself. But this is just for practice, I have given one.

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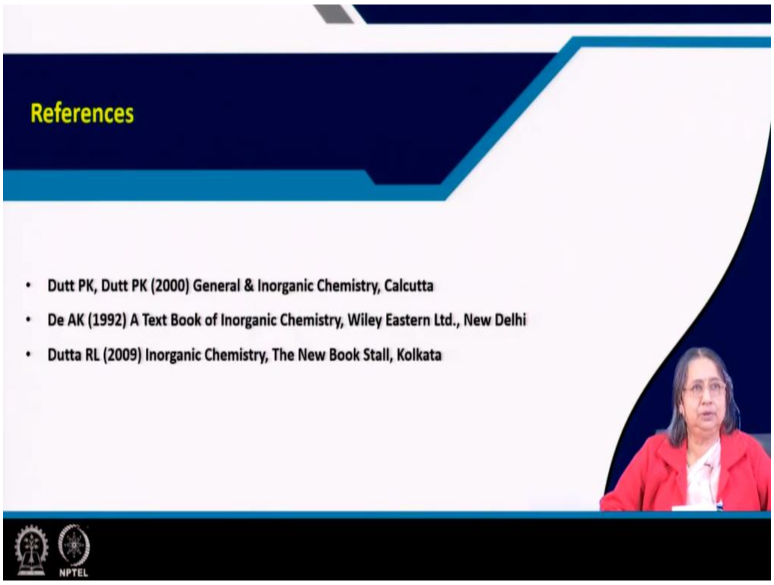
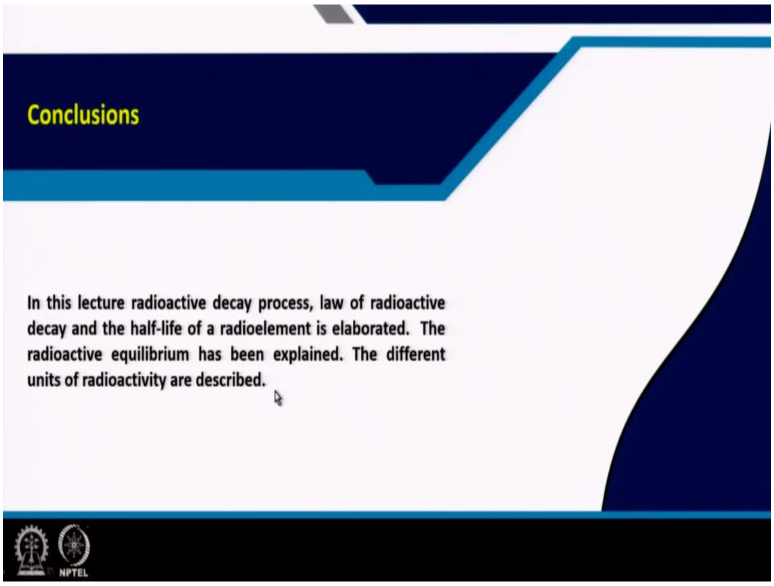


References are given in the last slide. You can read from the 3 mentioned books. **(Refer Slide Time: 31:03)**



Now, in this lecture, radioactive decay process, law of radioactive decay and the half-life of the radio element are elaborated. The radioactive equilibrium has been explained and different units of radioactivity are described. Thank you