Introduction to Atmosphere and Space Science

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Lecture – 03
Evolution of Earth's Atmosphere

Hello. So, in the first module we will be trying to understand few important aspects about the Earth's Atmosphere. So, this module will be an introduction to Earth's atmosphere, we will not look into the processes. We will try to understand the atmosphere in it is whole size and we will try to quantify various important physical parameters, how large or how small or how significant or how insignificant these parameters are.

So, today we will talk about the Evolution of the Atmosphere. So, the atmosphere that we know today is the oxygen and nitrogen and few other gases. We have this; we have to understand was the atmosphere the same from the eternity.

Let us say since the beginning was the atmosphere existing in the same chemical composition all was it different, if it was different how did we get here. I mean, what was the atmosphere in the beginning and what are the processes which made sure the atmosphere was today it was in this concentration with oxygen dominant. So, that life exists on this planet, right.

So, we will try to give a historical perspective of the physical and chemical processes which resulted the atmosphere in a ratio of 78 to 21 between nitrogen and oxygen. So, we will start our discussion by understanding the atmosphere once again let us say.

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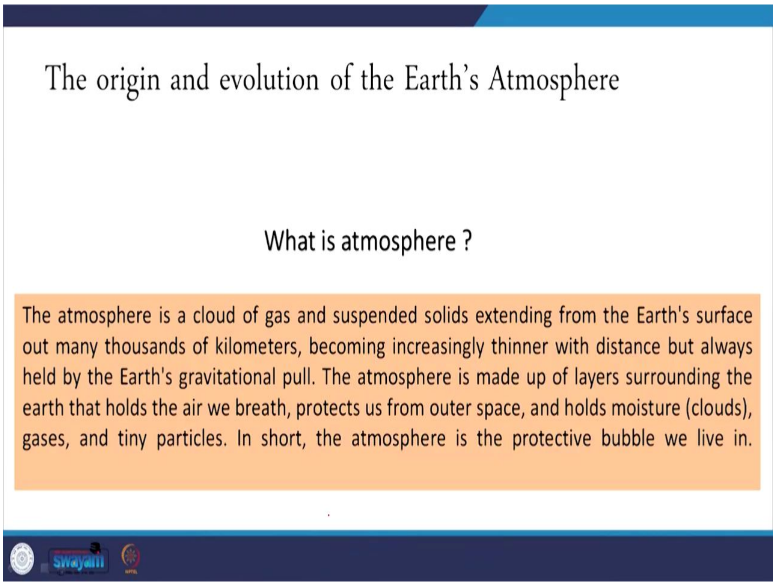

So, I will read it out for you the atmosphere is a cloud of gases and suspended solids extending from the Earth's surface out to many thousands of kilometers, becoming increasingly thinner with distance, but always held by the Earth's gravitational pull.

The atmosphere is made up of layers surrounding the Earth that holds the air that we breath, protects us from the outer space and holds the moisture, gases, and tiny particles. In short let us say the atmosphere is the protective bubble that we live in. So, we live in this bubble. So, on the surface of the; so, atmosphere is the thin layer of gases which is held by the gravitational pull of the Earth and extends nearly to let us say 800 or 1000 kilometers, right.

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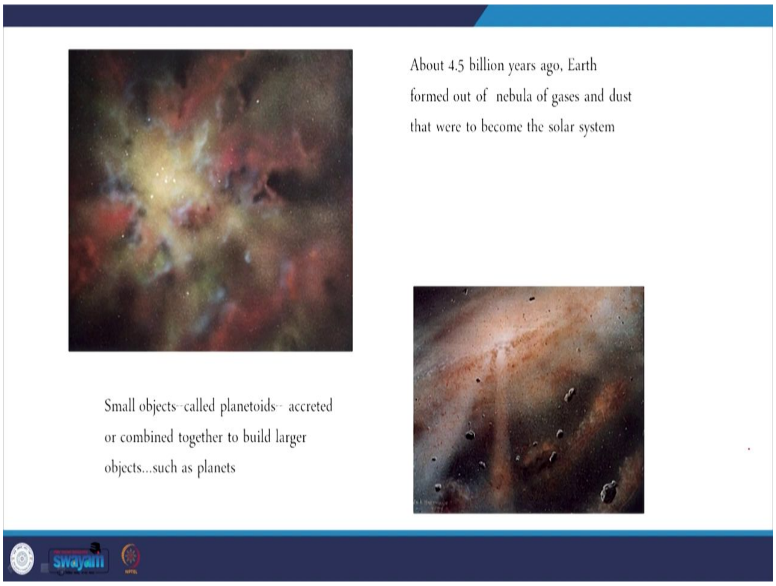

Now, how does how did this atmosphere came into existence? So, we should start at this point of let us say around 4. 5 billion years ago when the Earth formed; so, the Earth formed nearly 4.5 billion years ago. So, when the Earth formed out of the nebula of gases and dust particles, rocks that were to become the solar system.

So, this gases and dust were to become the solar system; so, Earth formed out of these gases and dust. And with time what happened is smaller objects called as planetoids, a created or came together or combine it to form or to result in to larger objects which are called as planets.

So, Earth formed out of these planetoids; I mean, larger objects came together agglomerated and then it resulted into the formation of a rocky surface or rocky planet to that which we call as Earth, fine.

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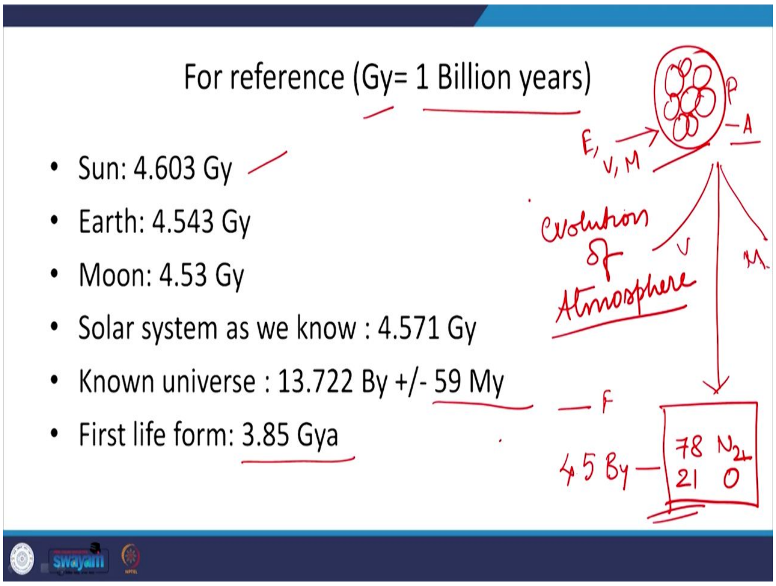

So, far reference from here onwards let us say, we need to have a reference for the timescale. Let us say, we talk about today what is today, today is something which has which has an absurd amount of time of 5 4.5 billion years let us say. So, giga annum is 1 billion years let us say. So, this age of Sun is 4.6 giga annum; 4.603 giga annum, Earth is 4.543 billion years, Moon is 4.53 billion years.

So, solar system that we know as today is 4.571, solar system is the point where we have the Sun planets and rest of the rest of the things. Known universe the age of known universe is 13.722 billion years with a plus minus of 59 million years and the first life form existed on this planet or originated in this planet nearly 3.85 billion years ago, ok.

So, this is the reference; I mean, so now, so we are let us say 4.5 billion years after the formation let us say we call the formation. Now, this formation this after this of amount of time we have the 78 percent nitrogen and 21 percent oxygen, this is the present-day chemical composition

Now so, in the beginning we said it is the small objects which came together and formed what are called as planets; so, we call this as the planet. Now, our journey will start from the point of atmosphere at this beginning to this point. So, this is the entire discussion can be simply called as the evolution of atmosphere.

Now, one thing we should keep always in mind is that the processes that I am going to explain can be can actually be similar to any other planet. Or to begin with we can simply we can simply say that not just the Earth the Venus or the Mars the rocky planets must all have formed in the similar way and if the conditions were suitable, they should also have the atmosphere which is just like us.

So, in this discussion not only we will see the processes which led from here to here or we will also see the processes which were deviated away for other planets, let us say for example, Venus or Mars things like that, ok.

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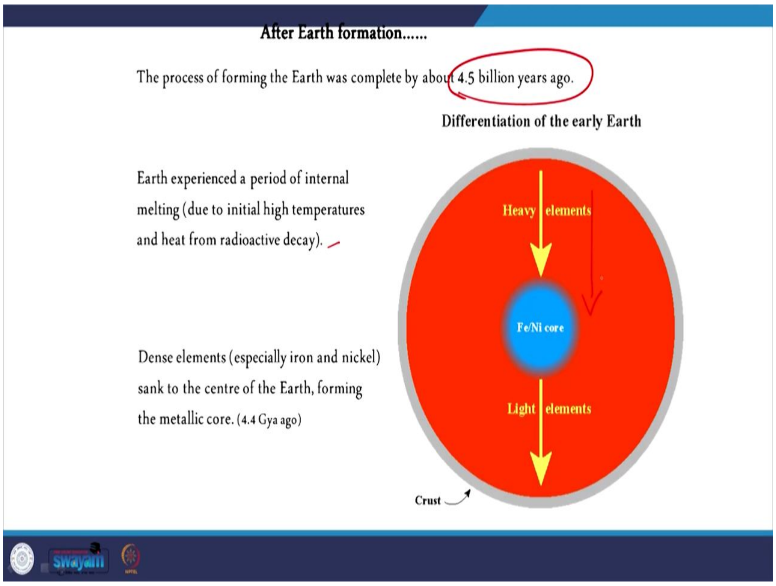

Now, so at the formation when immediately when the Earth formed the process of Earth formation was complete before 4.5 billion years. At that time what has been thought I mean, all this discussion the entire discussion is based on the theories, few things have been verified by kind of experiments or measurements or observations, few things were more acclaimed to be true.

So, if you believe the fact that 4.5 billion years ago the formation of Earth has occurred already, Earth experienced a period of internal melting due to the enormous amount of heat and pressure of when the when the objects come together by the means of gravity. So, the gravity is the only thing which is pulling these objects together right, forming out of nebula of gases due to the internal high temperatures and heat from the radioactive decay. There was a lot of heat; that means, the Earth experience the period of internal melting I mean period of internal melting.

So, the dense elements heavy elements like iron nickel metals sank to the core, they sank to the core; I mean, they started going deep and getting accumulated at the core of this planet.

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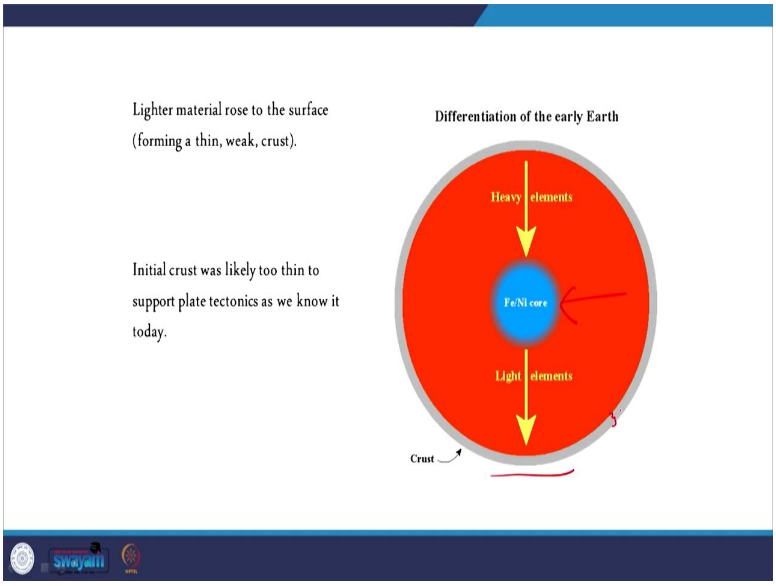

And the lighter elements for example, gases or any other lighter species started to rise to the surface. They started occupying the surface and the heavier element started occupying the core; that means, that was the time when the core was formed. So, we know that right now today we know that the Earth's core is a molten iron core. We have which is rotating so, right.

So, this started at the very beginning when the heavier element started going towards the core, the differential of the Earth, and the lighter elements came to the surface. So, the initial crust I mean the crust that resulted from the lighter elements was too thin just to be able to support, tectonics as we know today, so yeah.

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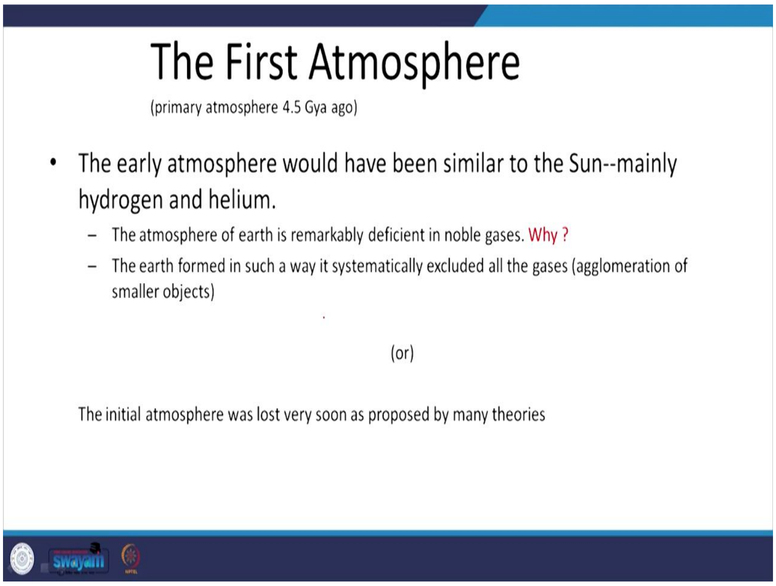

So, let us talk about the atmosphere. So, that was the formation of the rocky planet itself, now about the gases. Now, there are there are many numbers of theories which will give you, how the atmosphere must have resulted, how the initial atmosphere, how the or how the primordial atmosphere must have resulted. Generally, when the objects come together and if they are started to come together by the action of gravity then it will systematically get rid of the gases because the gases are light and they are volatile in nature. So, they tend to go out of these out of this agglomeration, right.

So, the early atmosphere would have been similar to Sun because this cosmos is hydrogen and helium. So, it must have the early atmosphere must also have been similar to hydrogen and helium just like Sun, ok. The atmosphere of the Earth was I mean the one contradiction here is that the atmosphere of the Earth is remarkably deficient in noble gases. This is one contradiction which gets away with the assumption and it is assumed that the Earth formed in such a way that when the objects, when the rocky objects came together it got rid of the volatile substances by itself.

So, it systematically excluded all the gases, all the volatile substances were systematically excluded in such a way or it may also be possible the initial atmosphere was lost as soon as the Earth formed itself. So, initial atmosphere the primordial atmosphere was lost as the Earth formed. So, this; there are many aspects which support each of these theories and let us see what the merits and demerits of the each of them, ok.

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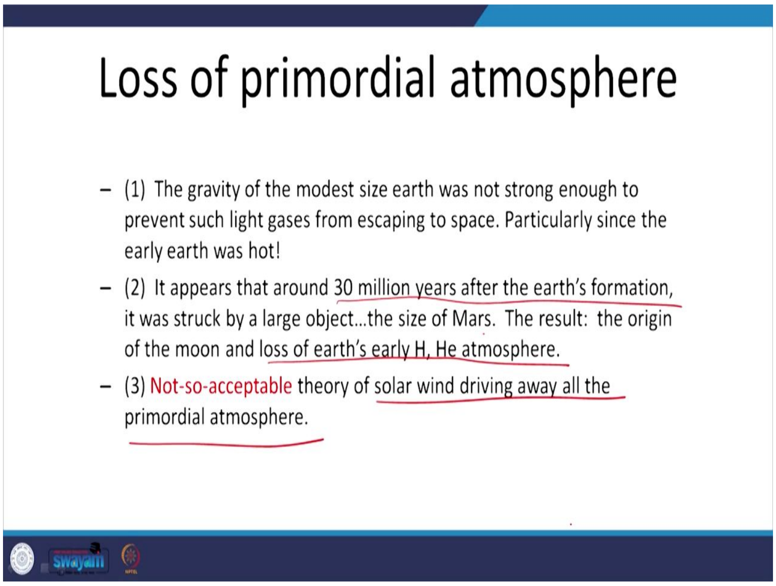

Now, the loss of primordial atmosphere is a very important process which began the formation of the Earth's atmosphere. So, the gravity of the modest sized Earth was not strong enough to be able to hold the gas, this is a very agreeable theory of course, it is a it is not a planet in it is complete shape or not in it is complete size. So, this Earth the provided a gravity which is feeble for or in comparison to the root mean square velocity of the gas so, the gas must have escaped.

So; that means, that there were there were large chunks of masses which came together and formed the Earth and there was also gas, there was dust, there was a lot of dust. But this initial gravitational pull was not sufficient to be able to hold the hydrogen and helium gases or volatile substances, if there were any and it escaped; that means, that the primordial atmosphere was lost as soon as the Earth formed.

The slightest idea of the formation of the planet was to be treated at the same time when the primordial atmosphere was lost. So, to support this it appears that nearly around 30 million years after the Earth's formation, let us say 4.5 billion years minus 30 million years it was struck by a large object the size of MARS and as a result the origin of Moon and loss of Earth's hydrogen and helium atmosphere.

So, another theory which supports the or which looks at the at the loss of primordial atmosphere is that after some time it was struck by a very heavenly object and this also resulted in the formation of Moon this is another theory. And not so not so acceptable theory

I mean it is not so accepted because is that solar wind driving away all the primordial atmosphere which is not accepted actually.

Because the solar wind solar wind also comes with the fact that nearly 4.5 million years ago Sun was not as active or as energetic as we see today and the solar wind must not be. So, powerful enough to drive away the hydrogen and helium that exists or the primordial atmosphere that we call away from the Earth, it is not it is not physically feasible.

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So, this is just an artistic impression of the Earth being struck and then resulting in to the Moon and loss of the primordial atmosphere.

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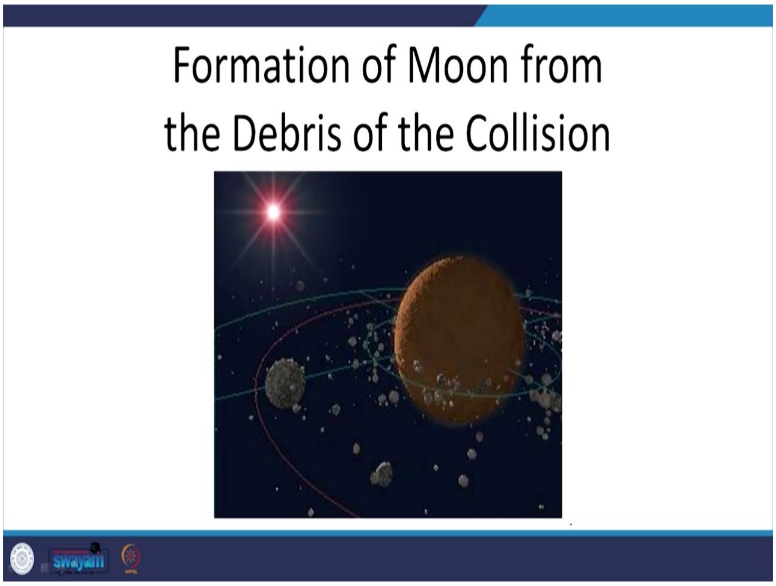

Now, it is accepted that this debris must have resulted in the formation of Moon that is not a point of discussion now.

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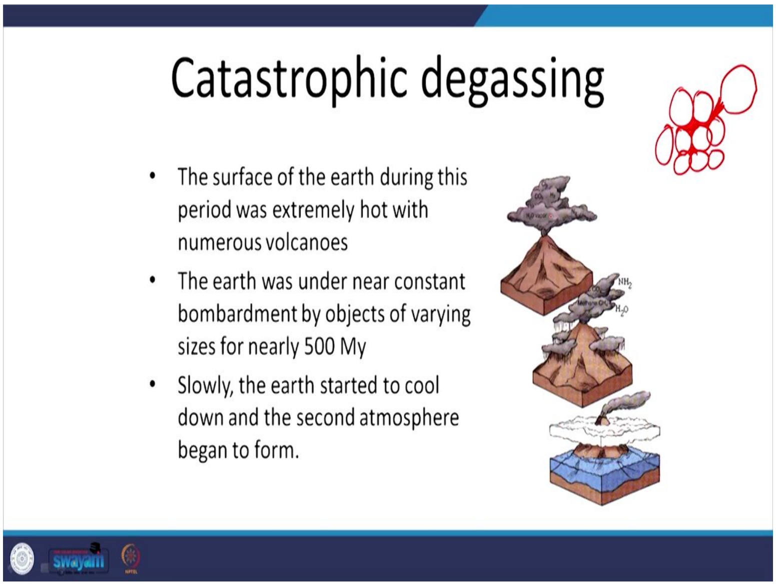

Now, what happened is the surface of the Earth was very hot that time and due to the due to the coming together of large objects large objects what happened is lost lot volatile substance was trapped between these large objects. So, this these voids that you see, it was assumed that there was a lot of volatile substances which will trapped in these areas', volatile substances or gases anything, there is a lot of volatile substance which was trapped in this.

And since the temperatures were hot it, it so happened that it resulted in to large volcanic eruptions. The surface of the Earth during this period was extremely hot with numerous amounts of volcanoes. So, these volatile substances being heated to very large temperatures inside have to find a way out; so, this led to the formation of volcanic eruptions

So, the Earth was under near constant and at the same time Earth was also under a nearly constant bombardment of objects of varying sizes for nearly 500 million years. So, as a result of all these things so, volcanic eruptions happen there is it released a lot of gases into the atmosphere. So, slowly the Earth started to cool as a result of this volcanic eruptions and the resulting rains Earth started to cool and the secondary atmosphere started to begin started to form.

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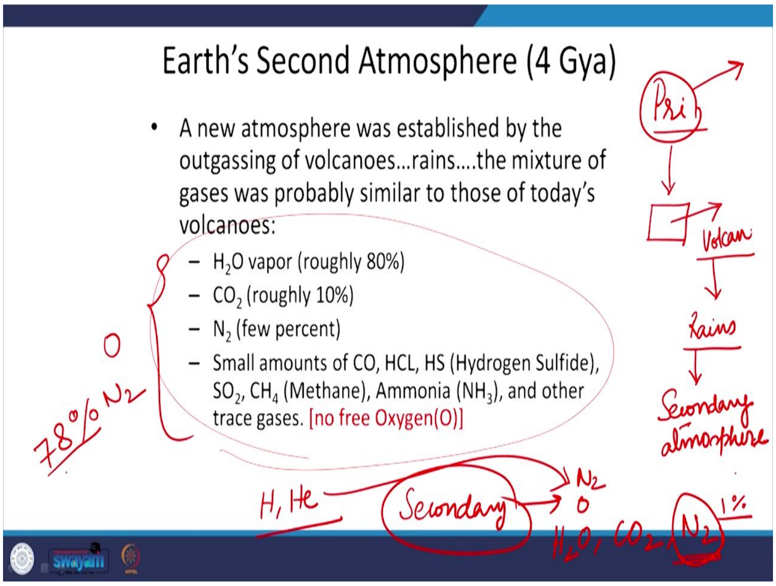

Now, so, if now the point is you have a primordial atmosphere which was existing at the same amount of time when the Earth formed. Now, we are we have enough reasons to believe that this primordial atmosphere was lost; I mean, this is not to be discussed then after the primordial atmosphere. Then there, then you talk about the volatile substances which are trapped between the planetoids let us say and these volatile substances resulted in to volcanic eruptions volcanic eruptions and these volcanic eruptions resulted in the formation of rains and formed what is called as the secondary atmosphere secondary atmosphere, ok.

So, new atmosphere was established by the out gassing of volcanoes rains the mixture of gases it was probably similar to the; I mean, volcanic eruptions the chemical composition of volcanic eruptions is pretty much known. So, it is it we can safely assume that this chemical composition must also have been same at that time which is nearly 80 percent of water vapor.

So, it is mainly the water and carbon dioxide and nitrogen and small amounts of things like hydrogen sulfide, methane, ammonia, hydrochloric acid and other trace gases and one important aspect that you have to understand here is that let us say here there is no free oxygen that is available.

So, the volcanic eruptions have released a lot of water vapor into the atmosphere, a lot of water vapor. Let us not talk about condensation, if this water vapor condenses then you will get water, let us go step by step. So, the volcanic eruptions have provided a lot of water vapor, nitrogen, carbon dioxide into the atmosphere.

So, now the secondary atmosphere is secondary atmosphere is mainly this; I mean, second atmosphere is just the water vapor, carbon, dioxide and nitrogen.

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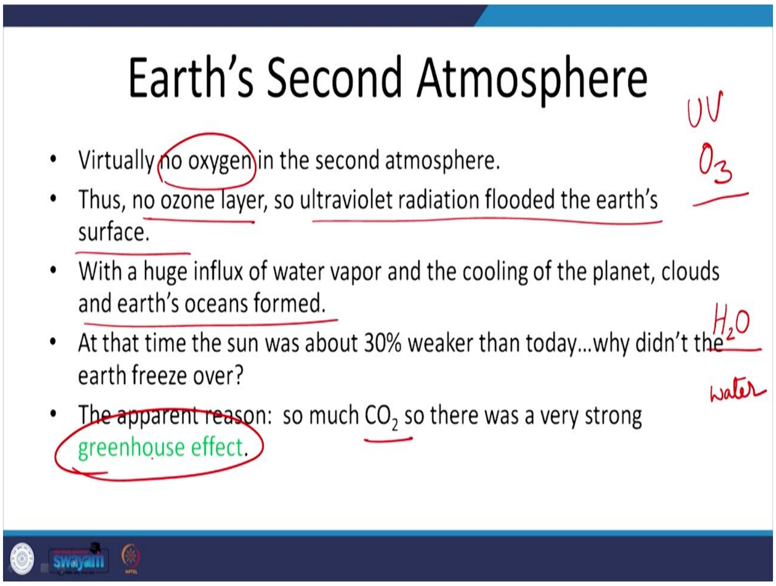

Now, what happened after that; so, what happened after that. So, at the secondary atmosphere virtually, there is no trace of oxygen, right. Now, what I am doing is I am trying to build up a connection between this atmosphere which is which you call as the secondary atmosphere; secondary atmosphere to an atmosphere which is reach in N2 and O that is it.

Now, my idea is the primordial atmosphere which is hydrogen and helium. So, I have to get from here to here. So, now, I have introduced a secondary atmosphere which is mainly dominant in H2o and CO_2, that is it, a very small percentage of N_2.

Now, you should always remember this N_2 which is per simply, let us say which is let us take it to be 1 percent to be modest let us say. This N_2 which is 1 percent should be, we should get from this 1 percent to 78 percent N_2. So, we are very far I mean the journey is very long because. So, the atmosphere must have been just water and other CO_2 and N_2 things like that. And from here we have to travel all the way when we get 78 percent N_2. Let us see how we get there.

The secondary atmosphere, there was no trace of oxygen, there was no trace of free oxygen in the secondary atmosphere, ok. Thus, if there is no oxygen, there is no ozone layer of course, and; that means, that ultraviolet radiation must have flooded the Earth's surface just like anything. So, there is; so, ultraviolet radiation is consumed by ozone actually, ok. So, for the formation, for the breaking both of them, ultraviolet radiation comes handy for the ozone. So, when there is no oxygen itself there is no point, we can expect ozone to be present. So, there is no ozone layer.

So, ultraviolet radiation flooded the Earth's surface with a huge influx of water vapor and the cooling of the planet, clouds of oceans clouds of clouds and Earth's oceans form. So, I said let us not talk about the canonization now we talked about the condensation. So, there is a lot of water vapor and if there is cooling this water vapor will condense and result in the formation of water, liquid water yeah.

So, at the time the Sun was now one more important aspect which kind of competes with this understanding is that at that time the Sun was about 30 percent weaker than today; exactly like 4.4 billion years ago the Sun must have been not as bright as it is today. So, 30 percent weaker so, why did not we freeze over I mean, it is naturally that I mean so, we at this time we are at the temperature for nearly let us say 35 degrees average temperature, but. So, had the Sun been 30 percent weaker than today the temperatures must have been very low right naturally. So, it must be in a condition that what water must have frozen or it may rain right as crystals.

But it is also one important aspect which counters this is that the apparent reason, but that there is so much of CO_2. So, CO_2 is able to hold the heat radiation and keep the planet warm.

So, this additional amount of CO2 that we had in the beginning must have been able to keep an average temperature of these Earth at a level when the water does not just freeze and result into a ice planet. And so, this is this CO2 must have given a very strong greenhouse effect, ok.

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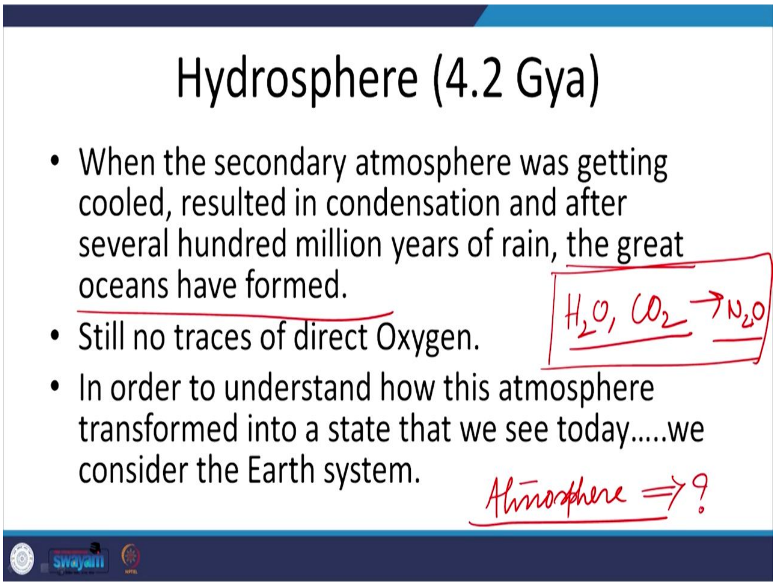

Now, so, at the 4.2 billion years ago let us say when the secondary atmosphere was getting cooled. So, secondary atmosphere getting cooled means, the water vapor getting condensed or forming into the liquid water resulted in the condensation and after several hundred million years of rain. So, it must have this condensation happened or several hundred million years of time and resulted in the formation of the great oceans. So, it is, ok.

So, still water has not dissociated; I mean, it is the molecule is still the water molecule. So, there is still no direct trace of oxygen. So, it is still the H2O and CO2 which are dominant in this atmosphere, the secondary atmosphere. In order to understand how this atmosphere transformed into a state from this to N2 and O. we need to understand, we need to bring something else.

Atmosphere transform related state that, we see today we need to consider the Earth as a complete system; that means, that in order to understand how this chemical composition changed from here to here we do not just talk about the atmosphere, we talk about the Earth's system itself we just do not talk about the atmosphere. So, just discussion about the atmosphere is not sufficient, let us say what else we need.

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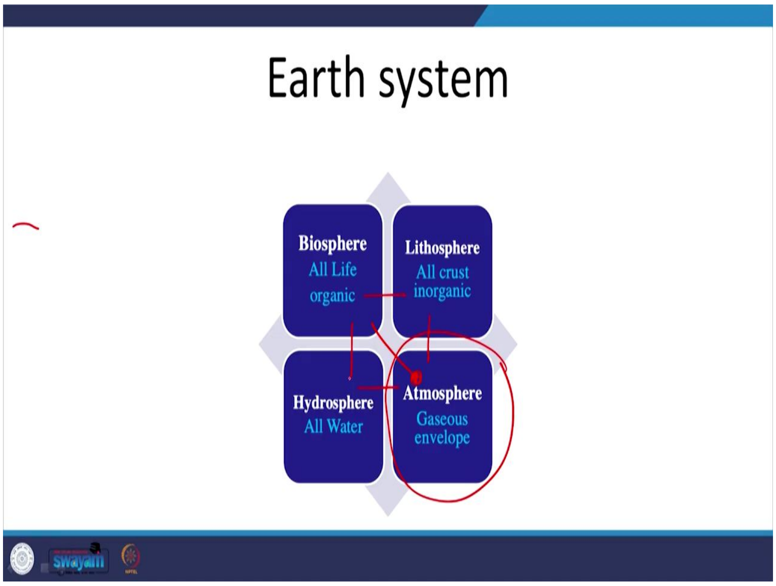

We need complete Earth system to understand this. Earth system comprises of 4 different subsystems let us say; the biosphere involves comprises all the living matter all life or organic matter; lithosphere is all the crust which is inorganic, hydrosphere is all the water and the atmosphere which is the gaseous envelope that we see.

So, now we want to understand how things are changing in atmosphere. So, my point is let us not just talk about atmosphere, these four regions are inter coupled with each other if you want to understand something that is happening here, we better couple this with all other three.

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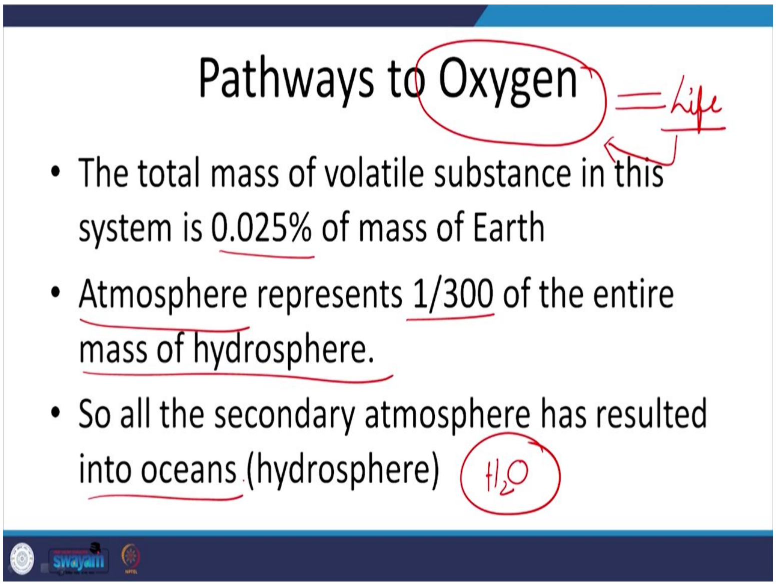

Then we will see how the oxygen has resulted. Ultimately, we have to understand oxygen or how oxygen has how oxygen came into existence. One important aspect is oxygen is life and life is oxygen. So, these two are inter couple, we have to get to the point where how oxygen has resulted and then we will see how, life has added to the addition of added to the inclusion of oxygen into the atmosphere.

So, the total mass of volatile substances in this system; in the Earth system that we see. In this total mass of volatile substances in this system is nearly 0.025 percent of the mass of earth; that means the total mass of gas, liquid whatever it is the volatile substance is very small in comparison to the mass of Earth very very small, ok. And off this very very small percentage, the atmosphere, the gaseous envelop represents only 1 by 300th of the entire mass of hydrosphere.

So, all the secondary atmosphere has resulted into oceans; yes, all the secondary atmosphere is the H2O all of the water vapor that was there was thrown into the atmosphere by the volcanic eruptions have resulted into the formation of the great oceans, ok. So, water is there. So, oxygen is also there in the in the ocean system, but is with the hydrogen; I mean, in the in the form of water vapor water.

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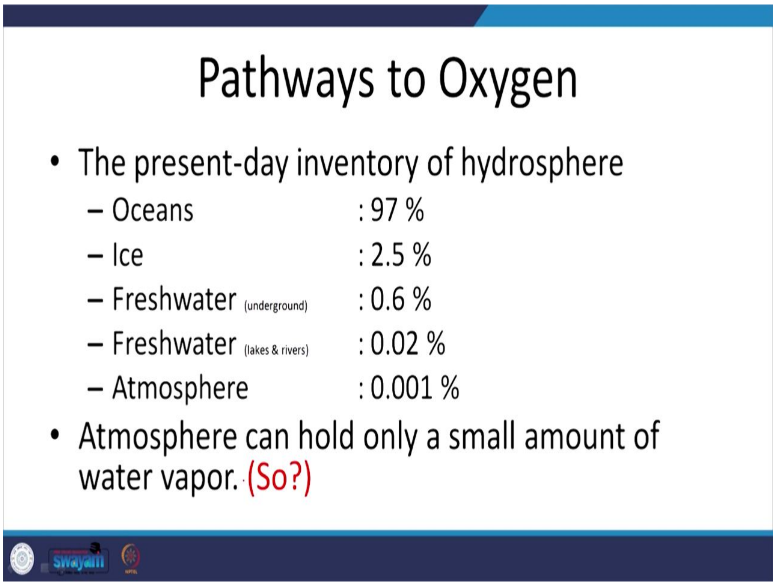

Now, the present-day inventory; I mean, today let us say today, if you see how the hydrosphere is existing in different-different forms. You see that the hydrosphere is existing as a 97 percent in the oceans, this is the inventory of hydrosphere, how much of water is there everywhere, ice in the form of ice as 2.5 percent, fresh water 0.6 percent, fresh water lakes and rivers 0.02 percent atmosphere as water vapor it is 0.02 percent. So, this is a very small number that you see here.

So, atmosphere so; that means that, of the total hydrosphere, atmosphere has the ability to hold very very small amounts of water vapor.

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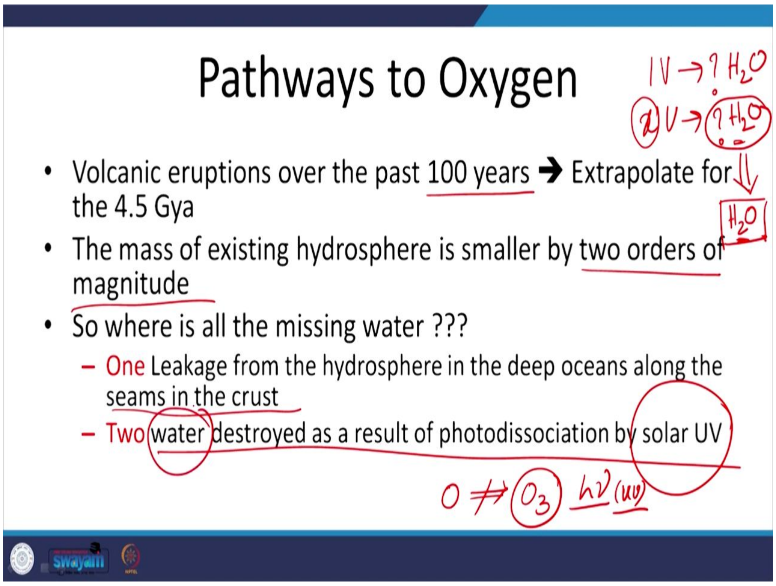

Now, just to be just to make sure so, if you want to see let us say if the volcanic eruptions have resulted in the formation of water liquid water in oceans and rivers, ok. Let us say, how much amount of volcanic eruptions just let us quantify how much volcanic eruptions must have happened, how many volcanic eruptions must have happened and how much amount of water must have been brought into the hydrosphere, if you have if you want to have a number let us say.

Let us take volcanic eruptions over the past 100 years to be indicative of let us count for the past 100 years how many volcanic eruptions have happened. If you take this to be an indicative of a century let us say, let us extrapolate this number over the entire 4.5 million years. Then if one volcanic eruption is able to release certain amount of, let us say certain amount of H2O, certain amount of water. Then, this x number of volcanic eruptions which happened over the period of 4.5 billion years must have released again a proportionate number of H2O, right.

Now, if you this; if you put this proportionate number of H2O in comparison with the amount of H2O that is available in hydrosphere today, these two numbers should compare or I mean they should have some relation, you understand. So, you take one volcanic eruption if it is releasing certain amount of water vapor you take x number of volcanic eruptions which happened over the period of 4.5 billion years and that must have brought in this much amount of water.

Then you see that this then you compare this number, this number with the amount of hydrosphere that you have today. What you will realize is that the mass of existing hydrosphere is very very small by 2 orders of magnitude; you see the 2 orders of magnitude in comparison to what should have been present; that means, there is a lot of water missing; so, where did all the water go?

So, where did all the water I mean so, this is you have a closed system. So, there is nothing which is escaping away from the Earth system into the space except for hydrogen. There is nothing which is escaping the Earth system, not the heavy elements, not the gas nothing, right.

So, in that case where has all the water gone? I mean 2 orders of magnitude; we have smaller amount of hydrosphere, ok. So, one there are 2 theories here actually, there are 2 theory; one theory is that one theory is that leakage from the hydrosphere. So, you have the oceans and from the deep oceans water must have leaked into the crust or into the core itself and into the into the into the inside of the inside of the Earth along the seams of the crust is one theory,

So, in order to account for the missing amount of water one theory was that there can be a possibility that the water must have leaked into the planet itself. The second theory is that water destroyed as a result of photo dissociation by solar ultraviolet. Water this lost water is actually nothing, but that is destroyed as a result of photo dissociation by solar ultraviolet radiation, ok.

Let us see what is solar ultraviolet; I mean, I have already said that in the beginning there was no oxygen there was no free oxygen there is so, there is no possibility, that there is no way that you can think about ozone when now once ozone is not there you have a free ultraviolet photons which are coming onto the earth. So, ultraviolet has the ability to dissociate water, ok, this is another theory.

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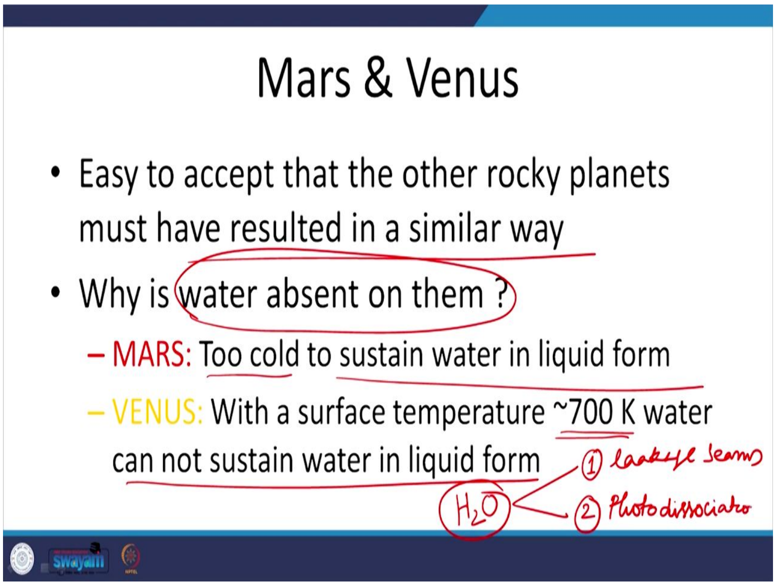

So, if it is the case the easy very very easy to accept that now. So, far the processes which have which we have which we have discussed so far, all the processes must have been the same for any other rocky planet. So, there is no reason for us to believe the process must have been different because they also came together from the rocks and they formed.

So, volatile substance must have been trapped of course, yes and volcanic eruptions must have been there and they must have released a lot of water vapor. All these things must have been the same for the Mars and Venus. So, it is very easy to accept that other rocky planets must have must have resulted in a very similar way.

So, why is water absent on them I mean today, we see water on this planet, but we do not see water on other planets, right. So, Mars I mean for example, Mars the conditions are too cold to be able to sustain water in liquid form that is true. There is ice on water of course, there is ice on Mars of course, and Venus with a surface temperature of nearly 700 Kelvin already water cannot sustain liquid form. So, it must have escaped

So, today I will stop with this. Now, we are at the point that we have to see we have to account for the missing amount of water and for this missing amount of water we have theorized two theories; one is leakage across the seams right, another is photodissociation.

So, in the next lecture we will see how the missing amount of water can be accounted. So, we have to see if the water has actually leaked into the Earth's crust along the seams or we have to see if the photo dissociation has a very important role to play to bring in free oxygen into the atmosphere. So, we will continue with the next class.