Introduction to Explosions and Explosion Safety

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Lecture – 34

Condensed Phase Explosions: Inorganic Explosive And Characteristics of Condensed Phase Explosives, Azides, Fulminates, Acetyl ides, Styphnates, Black Powder, ANFO, Oxygen Deficiency Parameter, Slurry And Gelatin Explosives, Plastic Explosives, Chapman Jouguet Detonation Parameters, Primary, High And Low Explosives

Good morning, you know in the last class we discussed about these condensed explosives, which were derived from hydrocarbon based fuels.

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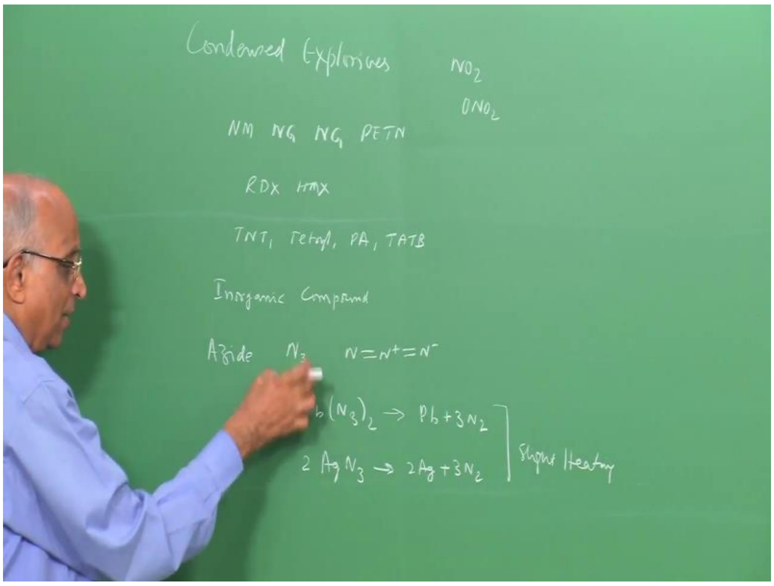

We found that either NO2 or ONO2 that means, either nitrates or nitro compounds are added to the fuels. And we formed let us say nitro methane, we farmed nitro glycol, we farmed nitro glycerin. And also we looked at PETN. These were based on the alkanes. We farmed form cyclo compound they could form RDX and HMX. These were based on alkanes, these were based on cyclo compound. And again from the aromatics, we form TNT we form tetral.

We also form two other substances. And these two substances, where picric acid and TATB. These were the different explosives, which you form from the organic which we call as organic explosives or rather derived from hydro carbon, which are essentially organic based fuels. You know, these structure of these condense explosives was cleared. And we said we would study, the other explosives based on inorganic compounds in the class today.

When we say inorganic, you know instead of having to add NO 2 or ONO 2 to form the, which form the oxidizer which combines with fuels to get the explosives. In case of the inorganic compounds we add substances like let us say, N 3, which we call as a azide radical. What is this azide radical? You know N 3 is unstable. Supposing I have N, N, N over here. You know, it cannot be very stable and the azide combines with let say, let us I to form P b N 3 2 may it to form A g N 3.

And since the N 3 compound name with the azide radical it is not very stable. It sought of dissociates into let us say P b plus 3 N 2. Here, you have may be 2 A g N 3 forming 2 A g plus again 3 N 2. Therefore, it is not decomposes and redly decomposes and even. Slight heating is sufficient to have compounds having azide maybe led azide, silver azide. And other azides to redly decompose and readily give out heat and these become explosives. Therefore, explosives on based on azide.

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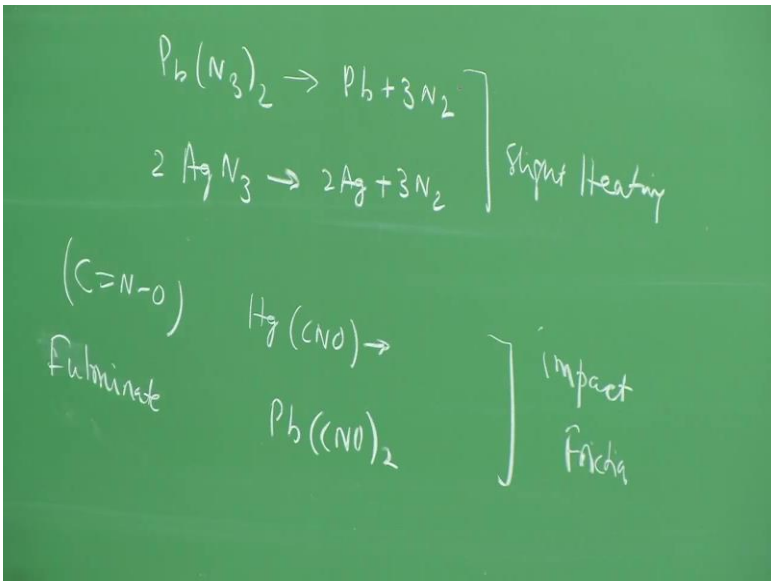

It is not only the azide radical, but also may be the fulminate radical, C N O radical. You know when we says C N O fulminate radical, maybe with mercury you form C N O. And this again dissociates it is not a very stable radical. And you have the fulminate radical and these fulminate radical you have mercury fulminate, you have may be led C N O twice. You know, these inorganic substances, these sort of decomposes fast and not even, if you have slight impact or let us say friction, small amount of friction.

They redly decomposed and they dentate sought of, because they redly supply the energy. And these are known as fulminate radicals. We are mercury fulminate and let fulminate. Well, there is still one more, you know we kept talking of acetylene you they call.

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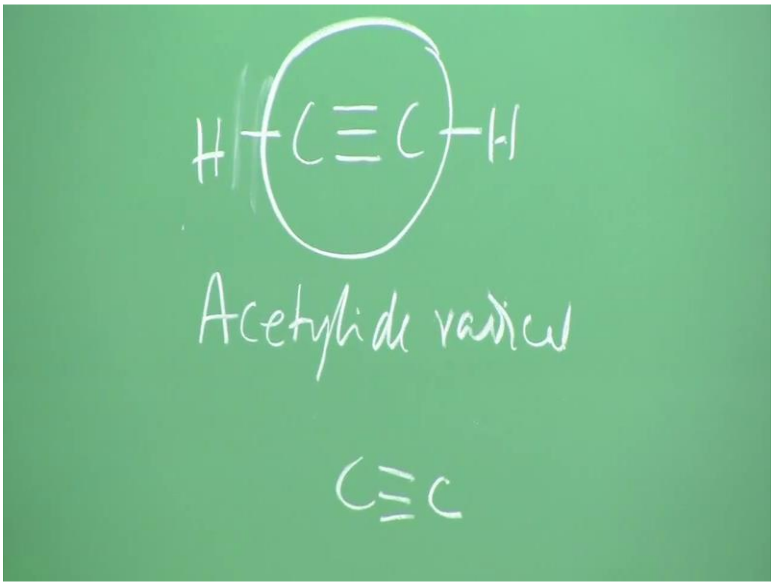

You said triple bond acetylene. We said well acetylene is always not such a good gas. In the sense you know, the triple bond is not that stable, it had something like a positive heat of formation. It is sort of decomposed fast, it is energetic was much I have like d p by d t m was higher. Therefore, you can make use of the acetylide radical. What is the acetylide radical? It is this one, namely the C, C.

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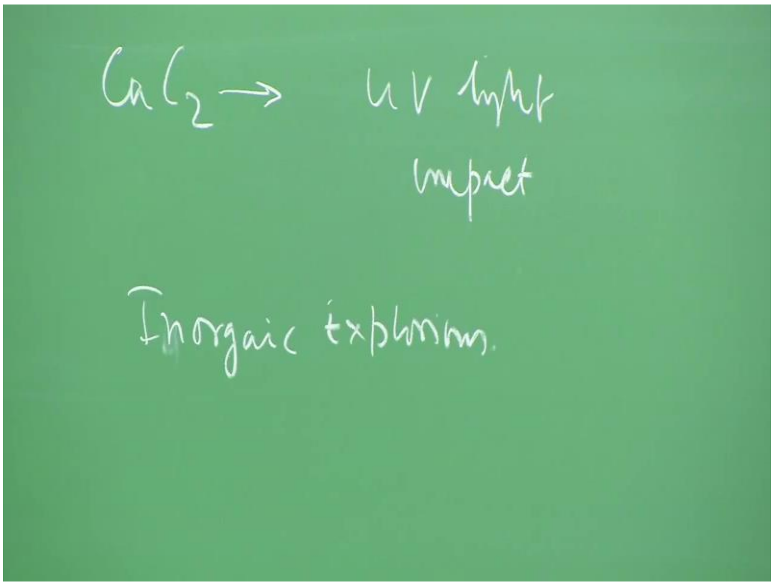

To give you, something like calcium acetylide, maybe other forms of acetylide like calcium are acetylide, silver acetylide and stuff like that, which again rapidly decompose. And these acetylide decompose even some times in presents of some particular let us say, ultra violet light, may be in presents of some light impact. But, impact ((Refer Time: 05:43)) is very sensitive. That means, these fulminate inorganic compounds, explosive compounds, like mercury fulminate is very sensitive to impact.

And in fact, a small amount of mercury fulminate, when added to some non-sensitive compound. And it can be made into something like cracker, which if you through on the wall, it explores. These are known as percussion trackers. Even, if you keep on accumulating silver fulminate one on top of the other. The very fact that you accumulate fulminate itself decomposes them all makes it decompose. Therefore, you have radicals like azide radical, may be the fulminate radical, may be the acetylide radical.

In presents of some of these metals, these form compounds which are known as inorganic explosives. The question you will ask then is let see we talk in terms of radicals, which were based on inorganic substances again mettle to it. Why not you see organic substances as radicals?

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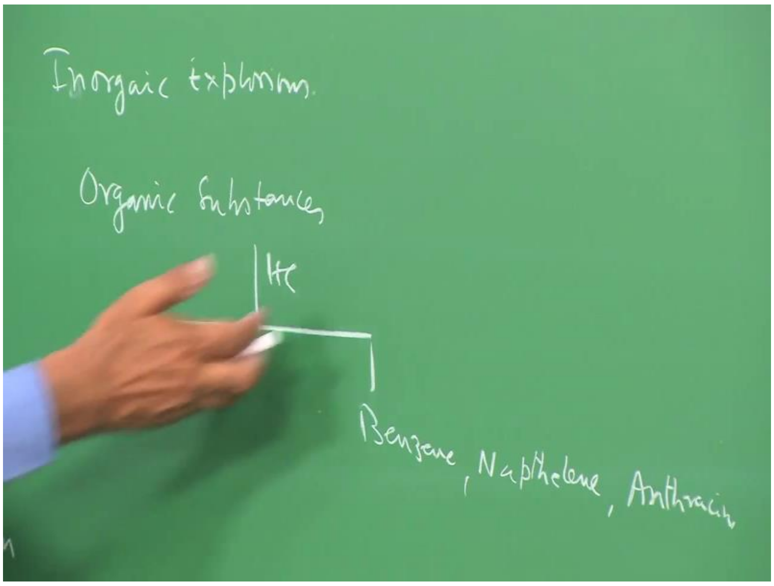

It is possible for us to think in term of both the aliphatic. What did we say aliphatic where? We said well, we had hydro carbons into aliphatic and aromatic substances. Well, in case of aliphatic you have alkenes, alkynes, alkinds and alkadines. And in case of aromatic substances, you had the benzene naphthalene. And the extension of that like let us say, benzene naphthalene. And you could have three of these benzene rings to give ((Refer Time: 07:44)) and so on. It is also possible to from radicals from organic substance let us one typical example.

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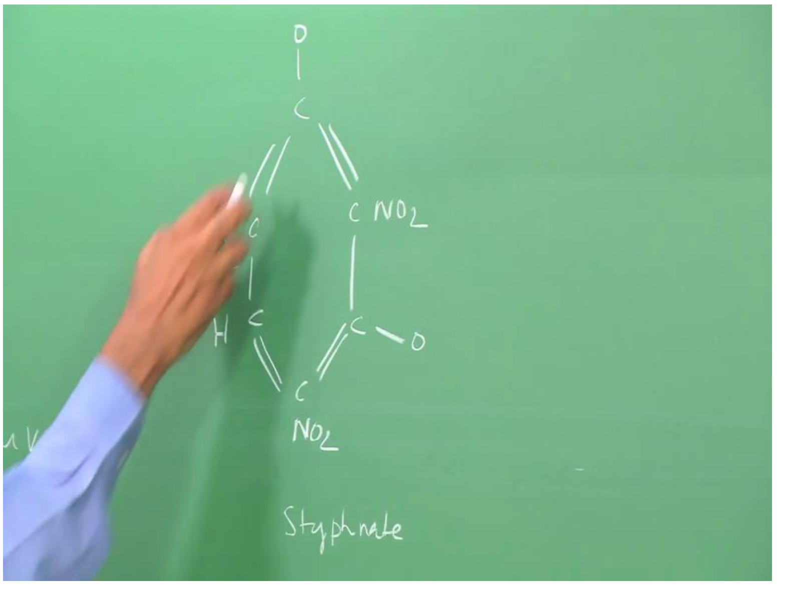

Let us take the aromatic compound. Let us, take benzene. Well, benzene these side is something, which has two alternate double bond with the hexagonal structure C 6 over here two double bonds. Now, what we do is we add a NO 2 it, NO 2, NO2, you had one more NO2 here. Then an oxygen add on oxygen, the hydrogen. That means, you replace 5 of the hydrogen 2 of them by O and the remaining 3 by NO 2. And this becomes what we call as styphnate radical.

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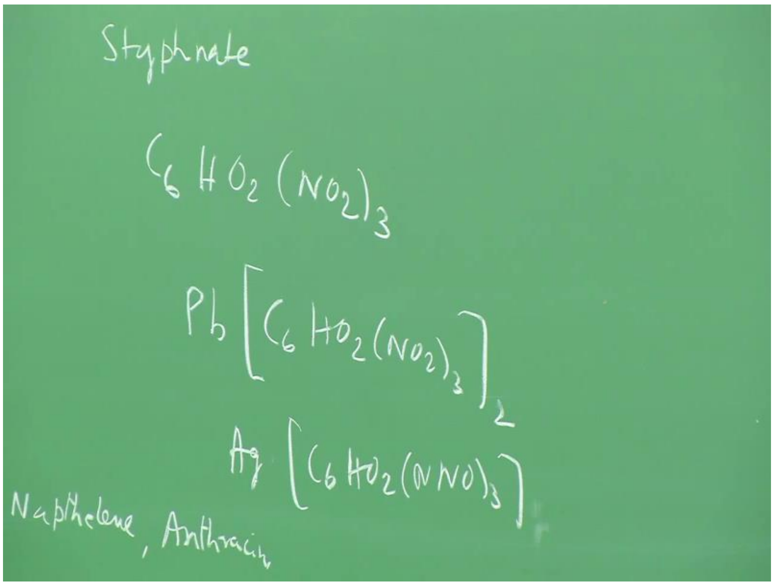

In this case, you know the formula would therefore be C 6, H 1 H over here. O 2 we have O and O 2 and NO 2 3. This becomes say styphnate radical. And you could have let us styphnate P b, then you have C 6 H O 2 NO 2 3 twice. Let us styphnate you could have silver styphnate A g into C 6 HO 2 NO 2, NO 2, because the values of silver is 1. Refer you could have again inorganic compounds based on the styphnate radical.

Prefer compared to the organic explosives, which consisted of may be write from nitro methane to TATB through PETN or RDX, HMX. We talk in terms of the azides namely may be led azide, may be silver azide, we talk of fulminate, like mercury fulminate. We talk in terms of acetylates, we talk in terms of styphnate like led styphnate. And these are all in organic based explosives. In our when we so far we can now close the chapter on the chemistry of explosives by saying.

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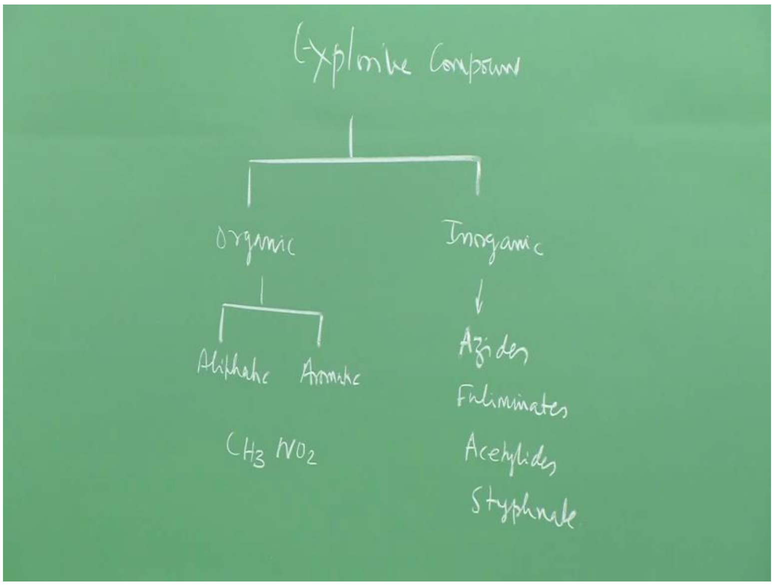

Well and explosives substance could either come from the organic compound or from the in organic compounds. And the organic compounds, which gave as this we have discussed get enough, came from aliphatic compounds, cyclo compounds, cyclo aliphatic from the aromatics, like TNT tetral, picric acid, TATB and of course, tetral also. When we talk of in organic compounds, we talk of azides, we talk in terms of fulminates, fulminate radicals, fulminate mercury fulminate, fulminates.

We talk of acetylates and may be as an example of in organic is where purely in organic, may be styphnate. Well, these are the different types of explosives. But, all these explosives what we are studied or all compounds in that within a molecule, you had both the azide radical and the led azide, let say led over here within the molecule, you had NO 2 and the methane over here. That is these are chemical compounds.

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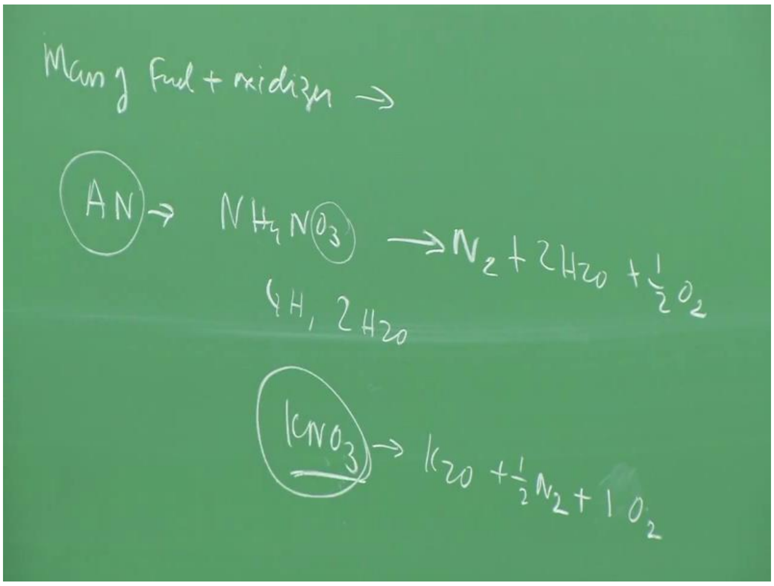

But, we also said an explosives could be a mixture, like a mass of let us, fuel and oxidizer together. Therefore, let us take a look at some typical substances, which are not chemical compounds. But, they are mass of a mixture. And let us see, how these could be formed. Let us go ahead and takes look at 1 or 2 substances. We have been looking at may be the ammonium nitrated.

Ammonium nitrated, when we saw was equal to NH 4 NO 3. Well, if I look at ammonium nitrated. Well, N is neutral that means, N 2 over here 2 N. I have 2 4 of H, which can formed 2 H 2 O that means, 4 of H, 4 of H it requires 2 oxygen. That means, even if I form something like N 2 plus 2 H 2 O out of this particular decomposition. And left with half O 2; that means, I could use ammonium nitrate as an oxidizer, because it has excess oxygen, so also if I look at KNO 3. Well, I could found K 2 O. And may be the nitrogen is left out.

And then I still have 2 and half of O 2. That means, I have 3 O 2, 3 O 2 means 3 by 2 that means, 2 of oxygen is left. Therefore 1 oxygen molecule is left. Therefore, I am still reaching oxygen that means, KNO 3 may be even, may be even some time better than NH 4 NO 3. And in fact, I can use KNO 3, which now has lot of oxygen in a 2 oxygen items, compare to even ammonium nitride, which as this.

And you will recall in the explosion of the toxicity disaster, were in ammonium nitride was there in the ((Refer Time: 13:30)) something likes 7700 tons of it. And it exploded, what happened is you formed all these substances, he got released. And therefore, you had in explosion. That means, it is very oxygen these substance. KNO 3 is even reacher and since KNO 3 is rich as it is in oxygen.

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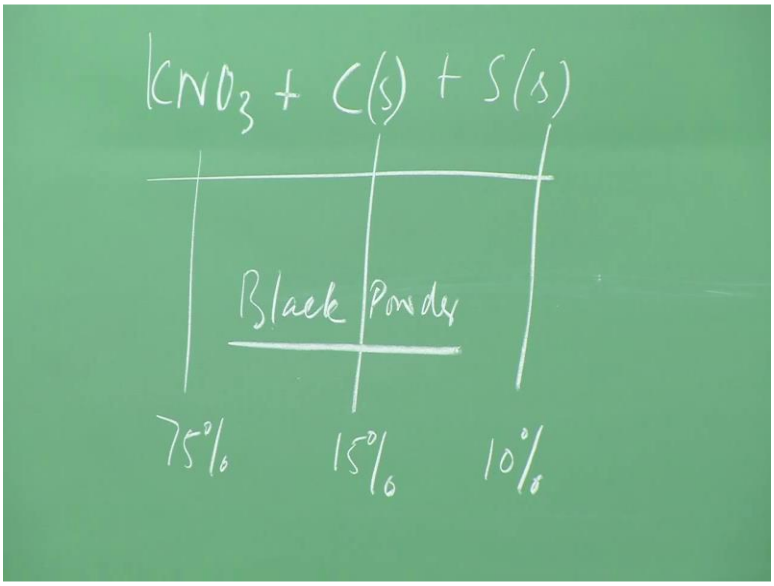

I can use it, I can use KNO 3 plus I had carbon to it. I also add little bit of sulfur to it, may be carbon in the solid form. I had sulfur again in the solid from, any way we KNO 3 is solid. I mix the three together. And this mixture is what is known as a black powder. The composition of black powder is 75 percent, let me put it down below 75 percent of KNO 3 carbon is 15 percent and sulfur is 10 percent.

This black powder is again and explosives substance. And it is use for making the fire crackers, all the creekers we make is generally out of this black powder. And therefore, it consist of KNO3 75 percent by weight, 15 percent carbon charcoal powder by weight and 10 percent of sulfur by weight. Therefore, what is going to be the chemical composition of this particular black powder.

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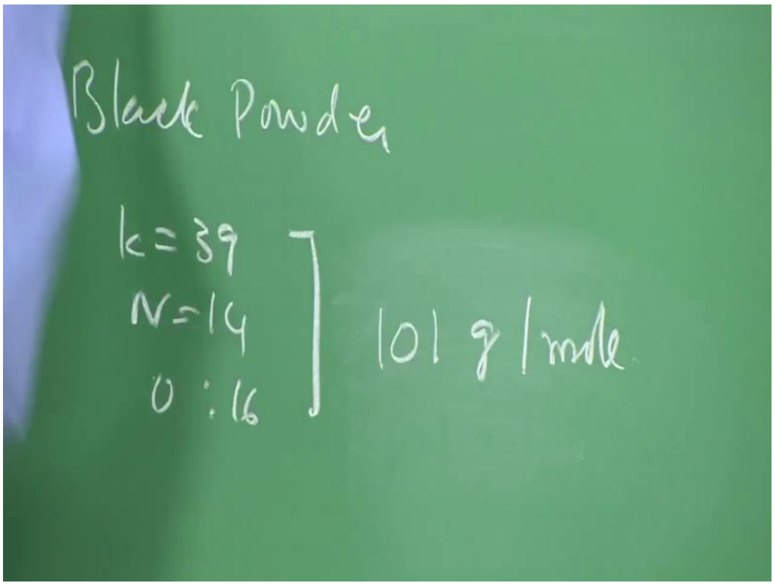

That means, it is again compared to a chemical compound. It is a mixture of these three substances, as a mass of a substance. Therefore, if I were to look at black powder and if I have to look at the chemical composition. Well, what is a molar mass of KNO 3. K as a atomic mass of 39, nitrogen has 14, O as 16. And therefore, KNO 3 is 39 plus 14 plus 16 these of 48 molar math's comes out to be equal to 75, that is 75 gram per mole.

That is the molar math's 48 plus 14, 52, 62, 62 plus 39 no it is 101. 16 these of 48, 52, 62, 62 plus 39 is 101 gram per mole. That is the molar mass of KNO 3, carbon has a molar mass of 12, sulfur has a molar mass of 32 gram per mole. Therefore, this particular composition I would like to converted into particular substance in terms of the molar masses. Because, I would like to find out, what are the products of combustion and what is the heat generated therefore, denoting that this is 101.

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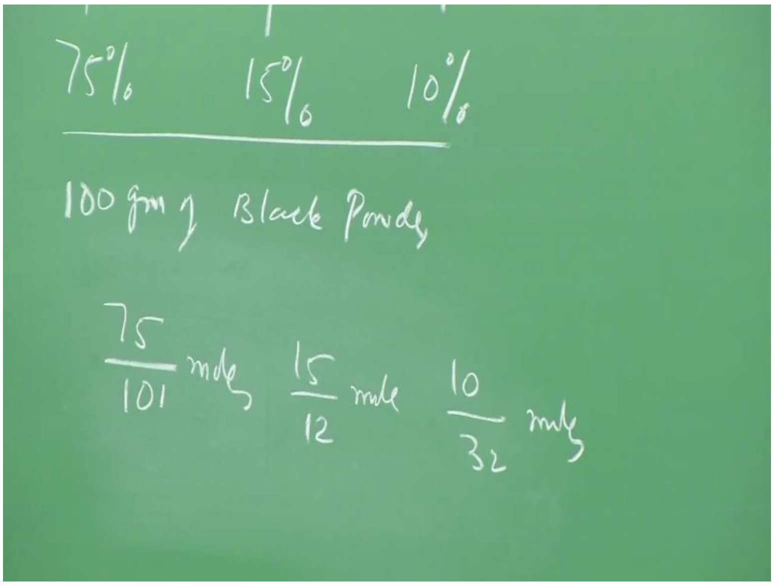

And if I consider let say 100 grams of this particular black powder. The number of moles of KNO 3 in 100 grams is going to be 75 grams divided by 101. So, many moles I have something like 15 grams divided by 12. So, many moles of carbon I have sulfur, which is 10 grams divided by 32 so many moles, and now if I put the mole molar composition over here.

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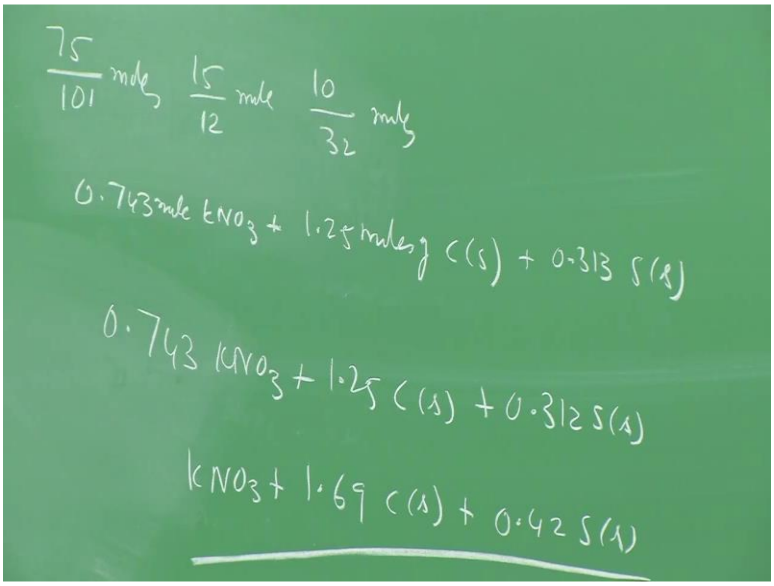

I have this gives me 0.743 moles of KNO3 plus 15 by 12 is 1.25 moles of carbon as a solid plus 10 by 32 is 0.313, moles of sulfur as a solid. And therefore, the chemical ((Refer Time: 17:39)) formula for this black powder will be 0.743 KNO 3 plus 1.25 of carbon in solid form, plus 0.313 of sulfur in the solid form. And if I relate it to 1 mole of KNO 3, I can write it as KNO 3 plus 1.25 by 0.743, which gives me 1.69 carbon plus 0.312 by 0.743, which gives me something like 0.42 of sulfur. This is the composition of black powder by moles.

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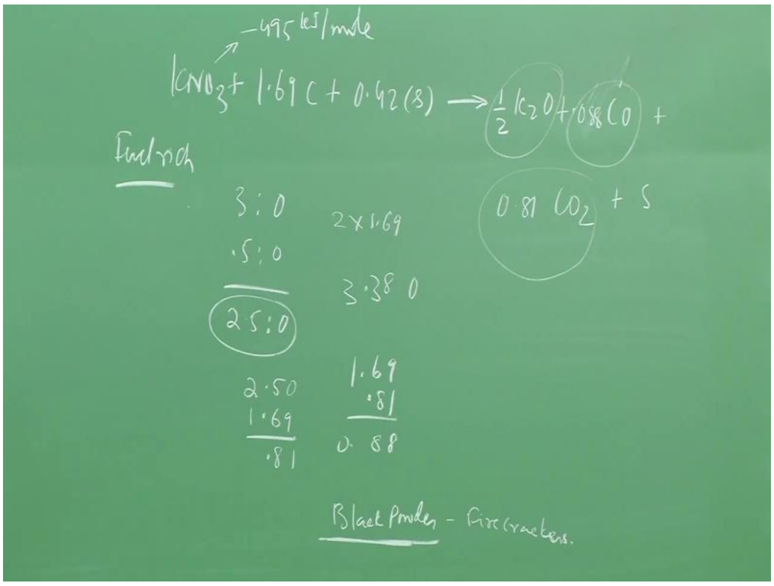

Therefore, if I want to take a reaction of this particular black powder I say I have KNO 3 plus 1.69 carbon plus I have 0.42 sulfur. And I have to find out what are the products to find out what is the energetic of it. I can tell myself now, I do not have any hydrogen here. But, I know K potassium is very reactive. Maybe it could form something like K 2 O. And what I could form is I have 1 K here, it is going to form half K 2 O. And then if it is going to combine here I have three of the oxygen atoms.

Out of which I have used 0.5 of the oxygen atom. Therefore, I am left with 2.5 of the oxygen atoms. And if I look at carbon over here, if it has to form CO 2 I required 2 into 1.69 that is equal to 8 6 to are 3, 6 2 12 13 carry on 3.3 of O atoms. But, I have only 2.5. Therefore, this particular composition we find is fuel rich. And therefore, I cannot form

CO_2 and what it can form is maybe it has to form C O that means, I have 1.69 of C O which is possible, but if I form 1.69 of C O I have 2.5 of oxygen which is still left for me.

And out of which, I have 1.69 of C O which is form I have left with something like 0 here 1. Then I have 6 8 of 14.81, which is still left. And therefore, you know, I can I get some carbon dioxide, which corresponds to 0.81 and 1.69 minus 0.81, 8 8 za 16, 0.88 I have 0.88 of carbon dioxide plus of course, I have sulfur. You know, therefore, I get products of combustion like this I know the heat of formation of K_2O, I know heat of formation of C O I know heat of formation of CO_2 sulfur is an element.

I can find out the heat of this particular reaction. And the heat generated by 1 gram or 1 kilo gram of the black powder. If I take KNO_3 the heat of formation of KNO_3 is largely negative minus 495 kilo joule per mole. And therefore, the energetic of this particular substance is not as high, as we would like it to be because it is large and negative. But, still it has substantial energy release of the order of almost 2000 kilo joules per kilo gram of the mixture.

And it is this black powder as I said which is used for making fire crackers. While discussing this we also found that even this particular mixture what is used in practice. Consisting of 75 percent by mass of KNO_3 something like you have 1.69 say, which corresponds to 15 percent by mass of carbon and 10 percent by mass of sulfur, this is still fuel rich and in general. If you like to see, the weather the prop lance what we have discussed so far including these compounds what we have discussed.

We should find out, whether it is fuel rich weather it is oxidizer rich. And we know that the heat release is the maximum. When completed cum products of combustion are formed or when the composition is stoichiometry. Therefore, we would like to first debate whether, the different compounds we have formed let say the organic explosives may be the inorganic explosives.

And we just took an example of mixture of certain substances like we had KNO_3 with carbon and sulfur took black powder we says something like fuel rich let us take one more mixture.

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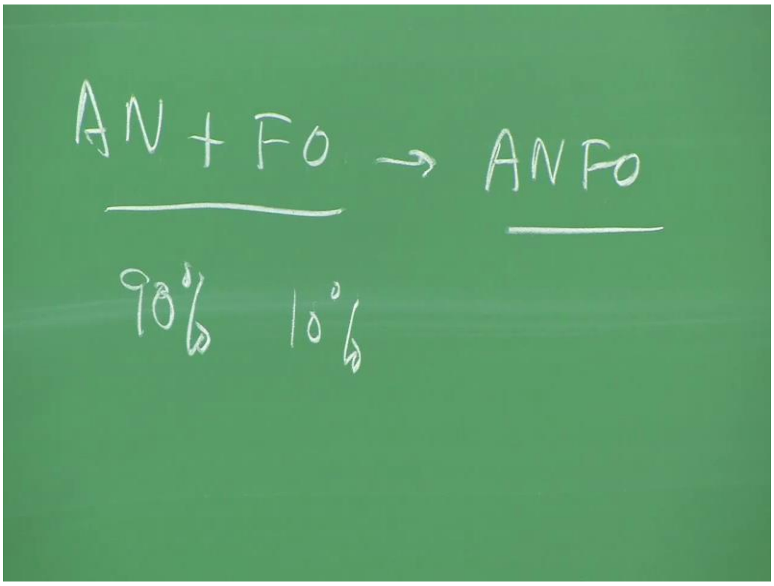

We could have ammonium nitrate, which I just illustrated little later ammonium nitrate. I can use it see, ammonium nitrate is an oxidizer. I can use mix it with fuel oil like diesel or some heavy oil. And now, I get ammonium nitrate and fuel oil is known as AN FO. And this AN FO is again an explosive. Now, it consist of oil and crystal is a study explosive. And it is used for blasting rocks. It is also been widely used by the terrorist for planting bombs. But, that is something which we have to guard against.

But, anyway AN FO is also an explosive. And the composition of AN FO is typically, again fuel rich we have something like almost like 90 percent by mass of ammonium nitrate. And something like 10 percent of the fuel oil in AN FO. Well, these are the different types of explosive and we wanted to see. How many of this explosives are fuel rich weather, it is stoichiometry, whether we can improve the quality of the explosive. Now, let us take, let us start again from the beginning.

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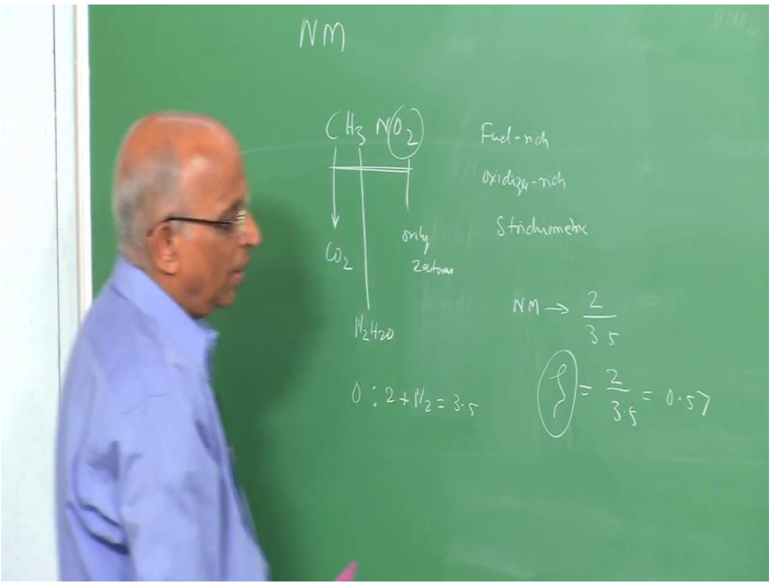

Let us, take one or two examples. Let us, take the example of nitro methane. If we take nitro methane well we are talking of CH 3 NO 2, this was the formula for nitro methane. Should we say this is fuel rich or is it oxygen rich or we say oxidizer rich or is it stoichiometry. How do I decide on this? Insatiately, I tell myself. Supposing completely oxidizer products of combustion are going to be form. I should be able to form from 1 atom of C, I should be able to form CO 2.

From the 3 atoms of hydrogen, I should be able to form 3 that means 1 and a half H 2 O. That means, 3 of H with O. And therefore, to form completely oxidize products of combustion in nitro methane I should have had oxygen equal to 2 plus 1 and half, which is equal to 3.5 oxygen. But, what I have is only 2. That means, only 2 atom of oxygen are available. As compare to 3.5 required, if I want to have completely products of combustion. That means, for stoichiometry mixture of this particular composition.

Well, I should have 3.5 atoms of oxygen, but I have only 2. And therefore, I can say in methane that is in nitro methane. I will have the oxygen atoms are available is 2. If I wanted stoichiometry, I should have a 3.5. Therefore, the oxygen index I can denote by a word zeta. I say zeta is equal to available divided by stoichiometry. And this 2 by 3.5 is something like 0.57. Therefore, we say that the nitro methane has oxygen deficiency that is it is fuel rich. And the oxygen deficiency zeta is 2 by 3.5, which is 0.57.

Let us, take one more example such that the evaluation of zeta namely the available oxygen divided by the stoichiometry for that particular type of composition. If I were to put it again and call it by the term zeta. Now, let us take a look at say nitro glycerin. Well, nitro glycerin let us first write the formula.

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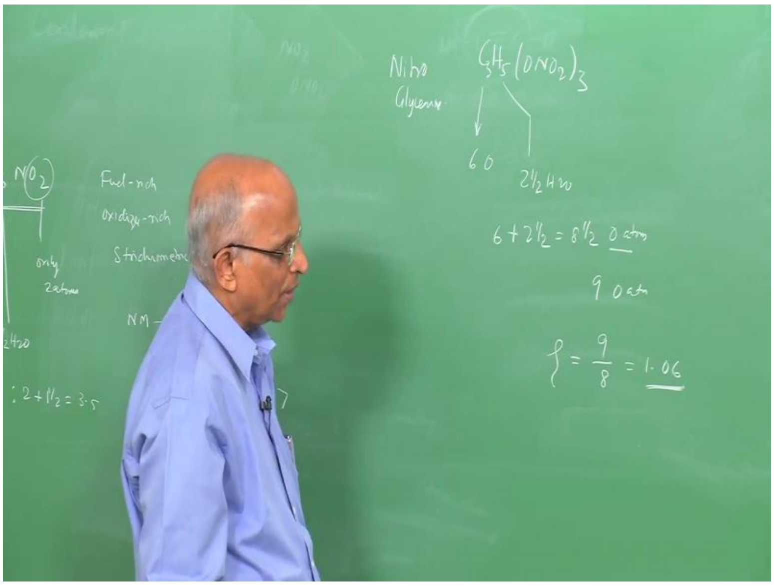

It is equal to propane trivial C 3 H 5 OH 3 in which I have O N O 2. Three propane O H 3 is propane trivial glycerin, I remove the O H by O N O 2, this becomes nitro glycerin. And now, I want to find out whether it is an oxidizer rich or fuel rich. And therefore, now I say for 3 C, I need to form 3 CO 2 that 6 O. I have 5 of hydrogen atom. Therefore, I have 5 and a half; that means 2 and half of H 2 O that means, I need C 6 plus 2 and half that means, I need 8 and half of O atoms to form completely oxidized product of combustion namely 3 CO 2 plus 5 by 2 H 2 O.

But, what I have is 9 O atoms. Apparently, I have more oxygen then what is required for stoichiometry combustion of this particular compound. And therefore, the zeta content that is the oxygen available is 9 to be able to form fully oxidized products I need 8. And therefore, the zeta is equal to 9 by 8 which is equal to 1.06. Therefore, we find while nitro glycerin is oxygen rich with zeta of 1.06. The nitro methane is fuel rich by 0.57. And like this we will be able to calculate the amount of oxygen, which is available in the different explosives. And let see this on a slide.

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S. No.	Condensed Phase Explosive	(kJ/mole) ΔH^0_f	Stoichiometry Fuel rich Oxygen rich	OXYGEN FRACTION ξ	Heat of Combustion (kJ/kg)
I.	Aliphatic –Straight Chain				
I.1	Nitromethane (NM)	– 113	Fuel-rich	0.57	6100
I.2.	Nitroglycerine (NG)	– 380	Oxygen-rich	1.06	7350
I.3	Nitroglycol	– 259	Stoichiometric	1	6350
I.4.	Nitrocellulose (NC)	– 261	Fuel-rich	0.63	3030
I.5.	PETN	– 538	Fuel-rich	0.86	5600
II.	Aliphatic- cyclo				
II.1	RDX	+62	Fuel-rich	0.66	5600
II.2	HMX	+75	Fuel-rich	0.66	5630
III.	Aromatic				
III.1	Trinitro Toluene (TNT)	– 26	Fuel-rich	0.36	4620
III.2	Picric Acid (PA)	– 224	Fuel-rich	0.52	3585
III.3	Tetryl	+20	Fuel-rich	0.42	4570
III.4	TATB	– 154	Fuel-rich	0.33	4031

I show in this particular slide the value of the oxygen fraction zeta in maybe nitro methane be founded to 0.51, nitro glycerin we just said is equal to something like 1.06. Well, if I have nitro glycol it is exactly stoichiometry 1. Nitro cellulose is again fuel rich that means, the zeta value is 0.63. PETN that is Penta Erititrol tetra nitrate has a value of 0.86 again fuel rich. The aliphatic cyclo compound RDX and HMX has again 0.66. And when we look at the aromatic substances may be TNT picric acid tetral and TATB.

Well, it is all fuel rich. That means, in general most of the condensed face explosive these are were the hydro carbon based or organics based explosives. Generally, it is fuel rich except for nitro glycerin, which is oxygen rich. We also show in this particular table the value of heat of formation. And we find well heat of formation is generally negative. In case of nitro glycerin it is minus 380, which is large in negative.

RDX and HMX has positive values of heat of formation, which means they may tend to dissociate a little faster compared to these particular one, since it is positive heat of formation. But, if you look at the heat of combustion per say you find from this very interesting type of data. You find see, when you have a oxygen fraction of 1.06. That means, it is less likely greater than stoichiometry. The heat of combustion is maximum, if you have the if it is something like fuel rich 0.57.

The heat of combustion is lower and if it is 0.63 it is lower 0.86, it is not as high as this. Therefore, we can say, for this class of may be the aliphatic compound in this particular case. When we go towards stoichiometry the heat of combustion slightly increases. Because, when your stoichiometry are 6.3 it is also near to stoichiometry may be 7000 well it is fuel rich well it has come down over here. And therefore, we find that the heat of combustion for fuel resubstances on the low side, because incomplete products of combustion are formed. When you compare this with RDX and HMX well this are fuel rich. And again the heat of combustion is little lower 5600 and 5630 over here. But, when you look at aromatic substances in general for all aromatic substances it is tribally fuel rich. And the heat of combustion is also low. Therefore, let us take the two cases namely the aliphatic based explosives. And also the aromatic based explosives. And plot let us say the heat of combustion has a function of the deficiency of the oxygen, which I show.

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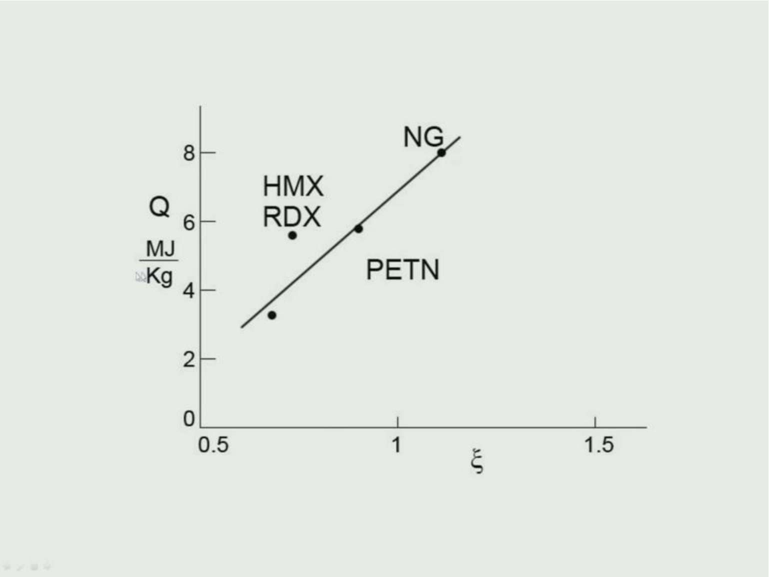

You know, this shows in this I have also included the cyclo base explosives namely, the cyclo try methylene, try nitro amine, cyclo tetra methylene, tetra nitro amine that is HMX is over here RDX, which is over here, PETN is over here, nitro glycerin is over here. As the oxygen contents increases, well the heat of combustion increases. We are talking in terms of mega joules per kilo gram.

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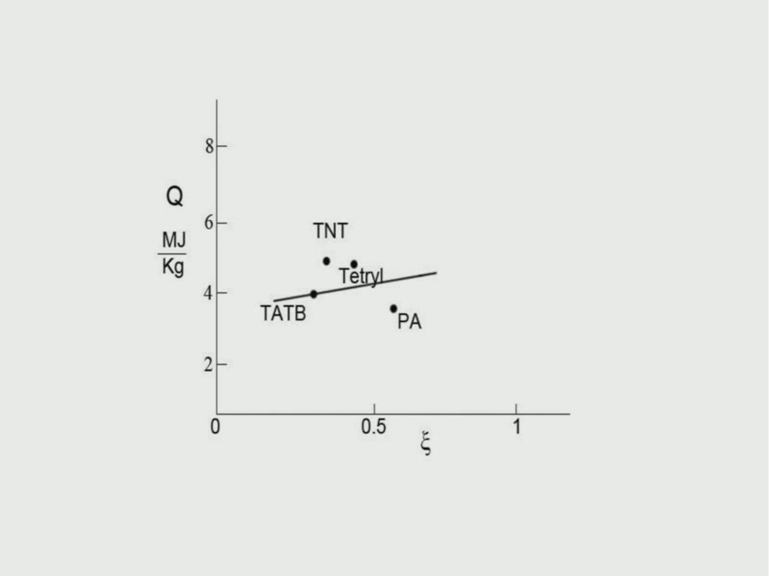

So, if I look at the aromatic compounds. Well, it does not increase, so steeply. But, there is a tendency to increase, you know which very difficult to say whether, it is increasing or not. But in general, there seems to be a small increase with the oxygen concentration. But, in the case of the previous one ((Refer Time: 33:02)), where in you talk in terms of aliphatic and cyclo aliphatic substances well, there is a perceptible increase.

Therefore, because of this particular increase, there is a tendency and we will just consider this particular example in the board. You know, if I can make fuel rich explosive that means, I take something like an explosive like nitro methane.

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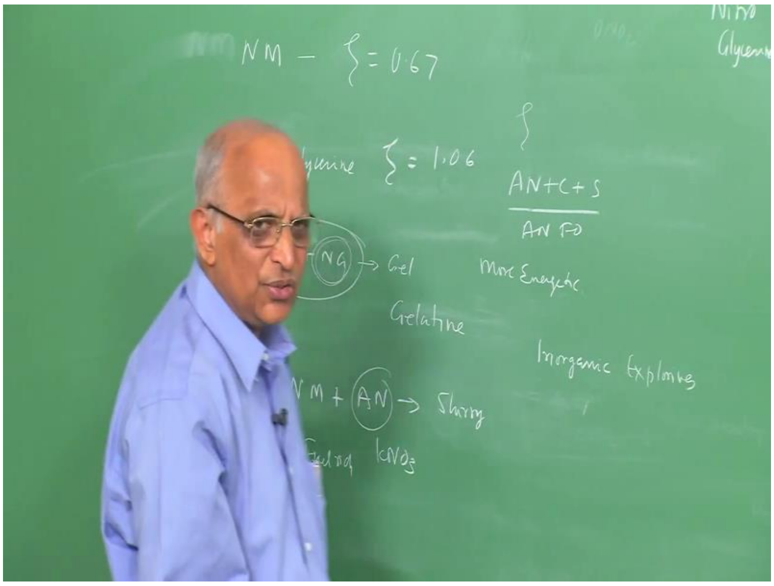

I take, which I know have zeta we said is something like 0.67, which is oxygen deficient. I take something like nitro glycerin, for which I have access oxygen something like 1.06. Know if I can combine nitro methane with nitro glycerin. And now, see nitro glycerin is both are liquids. And I found a slurry of both this things something form a gel of this particular. And this is known as something like a gelatine.

You know, it is a gel substance and it is much more energetic then nitro methane plus something like ammonium nitrate, which is something like a liquid and a solid, something like a slurry type of an explosive. And therefore, the tendency is to use somewhat oxygen rich a mixture of fuel rich and oxidizer rich, increase the oxygen content. And make the particular explosive to be more energetic.

And we do that, by adding or may be the oxygen re substances like or oxygen rich explosives like nitro glycerin or adding something like, ammonium nitrate or you had KNO 3 to some fuel rich explosives. And form slurry of the explosives and these are also used for to create more energetic explosives. Have been seen the role of may be the oxygen index in an explosive. We also saw something like a mixture of a ammonium nitrate plus carbon plus sulfur giving you, something like a black powder we also looked at slurry of ammonium nitrate.

And fuel oil which can be used let us now take a look at some of the characteristic of some other something like the inorganic explosives. We have seen the energetic of the organic explosives let us take a look at the energetic of the inorganic explosives. I show this in one of the slides here.

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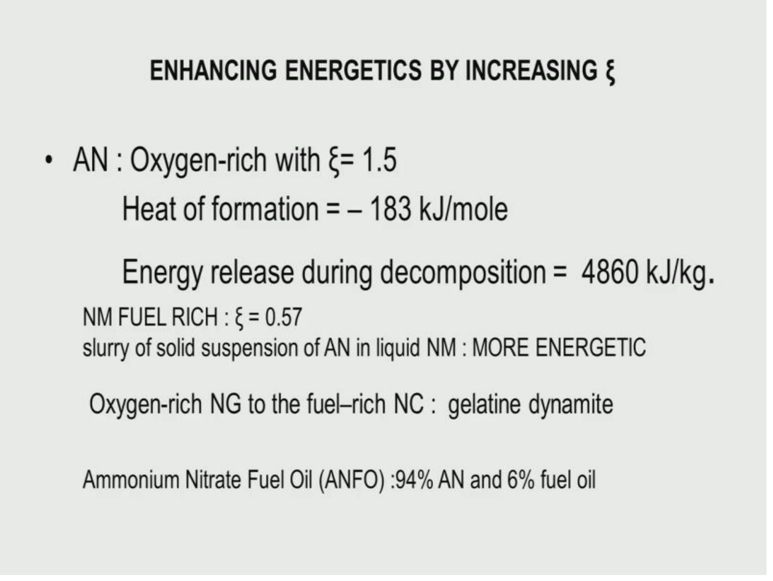

Let us try to get that going. You know I think this particular slide was what we basically saw on the board. Namely, ammonium nitrate is a oxygen rich. And if you look at the oxygen index of ammonium nitrate it is something like 1.5 let us derive this. You know, because this is basic to what we are trying to learn, namely if I take look at ammonium nitrate.

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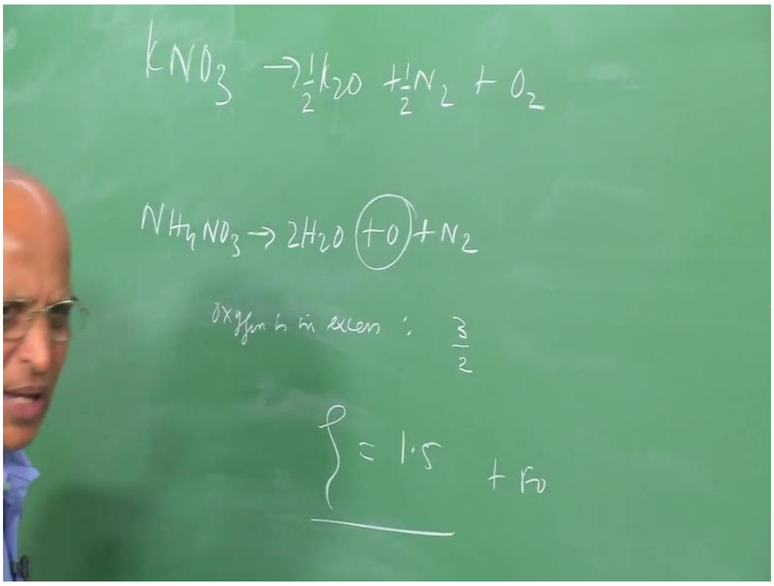

You know, we said it could form something like K 2 O plus N 2, half N 2, half K 2 O plus you have something like oxygen which is left out. And this is for KNO3, if I look at ammonium nitrate NH 4 NO 3. I am looking at maybe the products could be something like H 2 O completely products of combustion are 2 H 2 O. And I have 4 H and 2 O over here. I am left with an O. I am left with N 2. Therefore, we find that well oxygen is in access and the oxygen what I have is 3.

If I want to form completely products combustion I do need O here. What I need is 2. And therefore, what is existing is 3 for stoichiometry combustion I need 2. And therefore, the zeta for ammonium nitrate is 3 by 2, which is 1.5. Therefore, now I can combine this excess oxygen with something like a fuel oil, I have AN FO what is that is what is done the heater formation of ((Refer Time: 37:54)) the ammonium nitrate is of the order on minus 183.

The energy release during decomposition of A N is typically you have the products H 2 O N 2 O it is something like, 4860 kilo grams per kilo joules per kilo gram. Therefore, if I have nitro methane, which we saw is fuel rich with a value of zeta namely the oxygen deficiency. If it is 1, it is stoichiometry it is 0.57 is fuel rich. I make a slurry of solid suspension of ammonium nitrate in nitro methane.

It is much more energetic and this slurry is sometimes used even for blasting and it is also being used as I said in some, for some, causing some heavier damage by blast ways. Well, oxygen which we already saw nitro glycerin to nitro cellules we forma gel substance it is known as gelatin dynamite. And when we talk of ammonium nitrate fuel oil, we said 90 percent or 94 percent ammonium nitrate and 6 percent fuel oil is AN FO, which is again an explosive ammonium nitrate is oxygen rich fuel oil is just a fuel you combine them and form an explosive.

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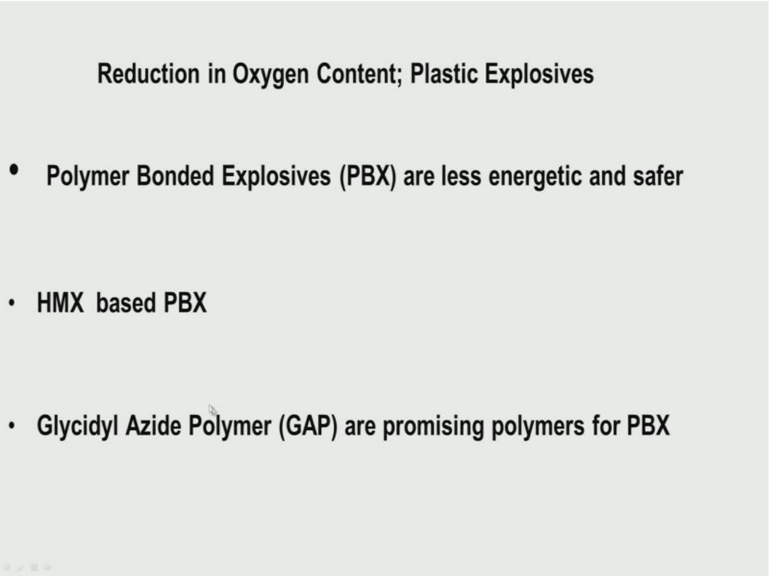

Just like we increase the oxygen content. It is also possible for us to explosive it will increase the fuel content, if we increase the fuel content. Well, what is going to happen, the explosive is going to be less sensitive, that is it is not going to be that energetic. And what how do you reduce the oxygen content by putting maybe some polymer in it like polymer could be nylon, it could be some butadiene, it could be any of the polymer, which we say.

And when we add polymer to an explosive, we say we have plastic explosives, these plastic explosives are very useful in that they are not very sensitive, you have HMX and the RDX. And these you have the substances known as maybe plastic base explosives PBX. That means, your PBX of HMX, RDX and these are not very sensitive. It can be handled much more safely. And the polymer bonded explosives are less energetic and much safer to use.

In fact, one of the polymers instead of using let say, HTPP hydro oxide terminated polibuted e naught, carbooxy terminated polibuted in or nylon naught some other substance. The glesidel assed polymer has more energy and it is much more promising to be used for the polymer based explosives. These plastic explosives or polymer based explosives. Find use in the military for inflicting damage well.

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S. No.	Explosive	Heat of Formation (kJ/mole)	Energy Release (kJ/kg)
1.	Lead Azide	+469	1650
2.	Mercury Fulminate	+386	1755
3.	Lead Styphnate	– 855	1850

These are the types of explosives and you know coming back to the organic explosives like azide, fulminate, styphnate. You know what do we see, the heat of formation of these substances are quite positive. That means, they tend to blow a quite fast compare to styphnate, which is large and negative. But, you also see compare to something like 5000, 6000 kilo joules per kilo gram for the organic base explosives. These are something like almost 1 third to 1 fourth the value.

Let us, has something like 1650 kilo joules per kilo gram, compare to something like almost 7000 kilo joules per kilo gram. Mercury fulminate has 1755. Let ((Refer Time: 41:43)) around 1800 kilo joules. That means, the energy release in some of these, composition are quite small. Therefore, we find that well the inorganic explosives do not liberate that much of energy as a organic explosives.

But, we also told that the N 3 radical, the CNO radical and when we talk of actinide radical they are just waiting to go, that means the sensitivity. For to get to get an explosion started might be very much faster. We have to still consider that and tats something, which we are still left to do in this particular condense explosives.

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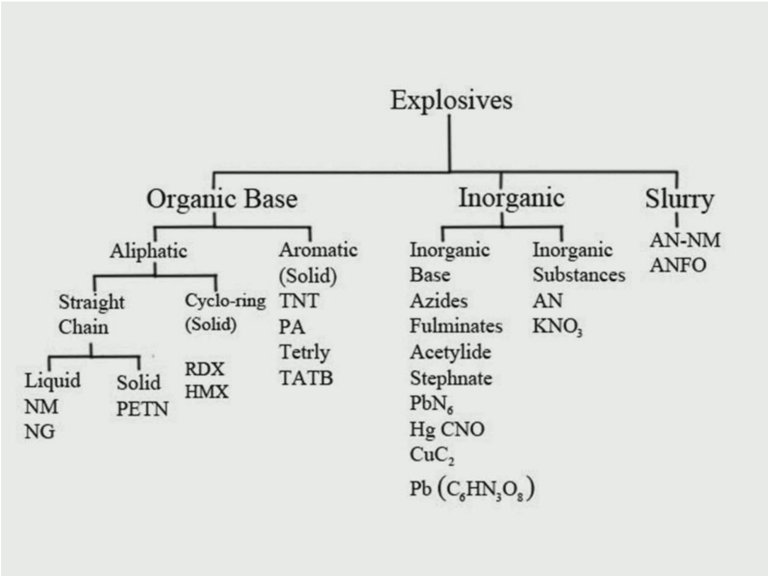

Have we seen all this, we can now summarize what little we learn about explosives has been organic base, inorganic base, slurry explosives consisting of solid and liquid explosive or ammonium nitrate and fuel oil we talk of inorganic explosives. Considering that inorganic substances like ammonium nitrate and KNO 3, KNO 3 with carbon and sulfur could give you black powder.

We have inorganic base substances azides, fulminates, acetylide, styphnate we had organic base and we have said, enough of it namely. The aliphatic and aromatic compounds consisting of nitro methane, nitro glycerin, PETN, RDX, HMX your picric acid, tri nitro cal, ((Refer Time: 43:12)), the tetral, this should have been ((Refer Time: 43:14)) and the TA TB.

These are the different types of explosives and we have seen their energy behavior, how to make it fuel rich that means, having polymer base, polymer will go back to that slide ((Refer Time: 43:27)) we have something like a polymer bonded explosives, the plastic explosives we also said in terms of explosives having more energy by making them oxygen rich so. Therefore, with this background maybe it is time to put the explosive characteristic together.

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S. No.	Explosive	Density (kg/m^3)	Chapman Jouguet Detonation Velocity (m/s)	Detonation Pressure (MPa)
I.	**Aliphatic : Straight Chain based Paraffin**			
	Nitromethane (NM) liquid	1128	6290	141
	Nitrogycerine (NG)liquid	1590	7600	
II	**Paraffin based (solid)**			
	PETN	1670	7900	300
	Cyclo-Paraffin based (solid)			
	RDX	1800	8750	347
	HMX	1900	9160	393
III	**Aromatic (solid)**			
	TNT	1640	6940	190
	PA	---	7300	250
	Tetryl	1700	7510	
	TATB	1890	7860	
IV	**Inorganic (solid)**			
	Lead Azide	4000	5100	230
	Mercury Fulminate	1050	5400	
	Lead Stephanate		7050	
	Ammonium Nitrate		4500	
V	**Slurry**			
	ANFO (6%FO, 94%AN)	880	5500	74

And that is what is shown, in this in this particular slide over here. In this slide, shows you the aliphatic is like some I have nitro methane, nitro glycerin these are liquid explosives we are talking in terms of straight chin, paraffin, coming from pentane that is PETN. We have paraffin base, cyclo base RDX HMX. Similarly, we have aromatic and also the inorganic substances and also slurry explosives like AN FO, if we look at the density content.

Well the densities are not widely wiring for both the aliphatic, as well as cyclo, as well as aromatic the density is r, in the same ball park number around 1500 to 1700 kilo grams per meter cube. But, if we look at the definition velocity, in this is where I have to spend a couple of minutes over here. And what do we say, when we talk in terms of chapmen judge dentations in solid explosives. Well it is the same things, which we talk of maybe...

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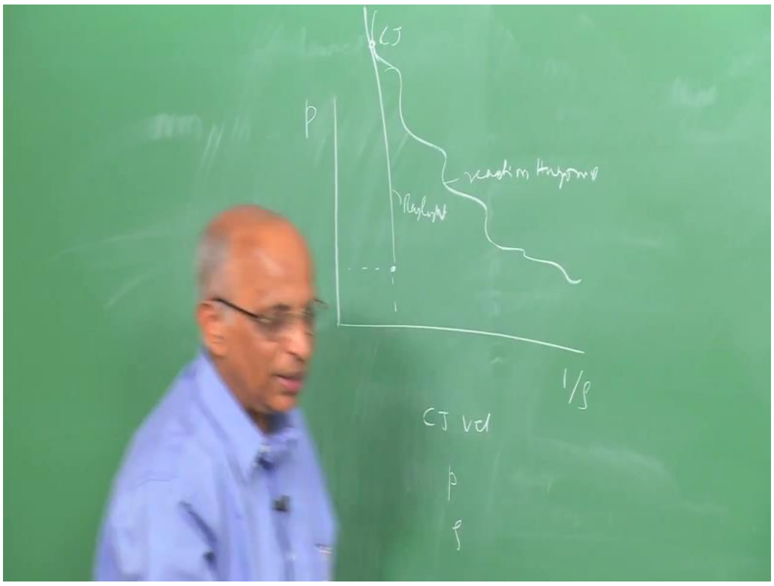

We talk in terms of P we talk in terms of one over row. We say, this is the initial state of the explosive unborn. We have something like a ((Refer Time: 45:09)), which may be a different type of curve. Because, this is something like a reaction ((Refer Time: 45:15)). And to be able to get a chaplin julian definition. Well, I have to have a tangent to it this becomes my chaplin julian velocity. And you know, we can always get chaplin julian velocity by solving the reaction ugonio and the relay line.

And we can determine the velocity once I know the chaplin julian velocity, we learnt in dentations how to calculate the pressure behind the dentations we found out how to calculate the density behind the dentations. And this chaplin julian velocity of a dentations and the pressure are shown in this particular slide for the different ((Refer Time: 45:57)) substances and we find. That may be the paraffin based cyclo substances and PETN. Have somewhat much higher values of chaplin julian velocity.

And also the pressure behind the definition in order to 300 to 400 times the initial pressure that is 300 times the atmospheric pressure. Here, you have know 300 MPa that means, almost like 3000 times the MPa pressure. And when I talk of these liquid explosives well it is somewhat smaller, when we go to the aromatics like TNT, picric acid, tetral and TA TB. The pressures are lower and also the dentations velocity are somewhat lower.

Therefore, the maximum damage or the maximum dentations velocity and maximum pressure are obtained with RDX, HMX, PETN and these are the substances, which generate lot of energy. Because, of the fast definitions what is available that means, the velocities are higher. Then we go to inorganic substances. Well, the values of the dentations velocity are smaller. And also, that the definitions pressure is much lower and if I go to the slurry explosive.

Well, the definitions velocity is almost similar to what we have for the inorganic explosives. ((Refer Time: 47:21)) slurry is also inorganic. But, the definitions pressures are very much lower. Therefore, we see that the chaplin julian velocity are a maximum with such type of maybe the cyclo paraffin base substances. Namely RDX and HMX followed by may be nitro methane, nitro glycol followed by the aromatic substances, followed by the inorganic substances.

Well, the inorganic substances have much lower velocity, much lower pressure behind them. They cannot cause that much damage, but you know something, which we still have to see. Because, of the azides, fulminates, styphnate radicals being somewhat not that stable. They tend to get into dentations much faster. And that is something we will have to characterize the explosives for...

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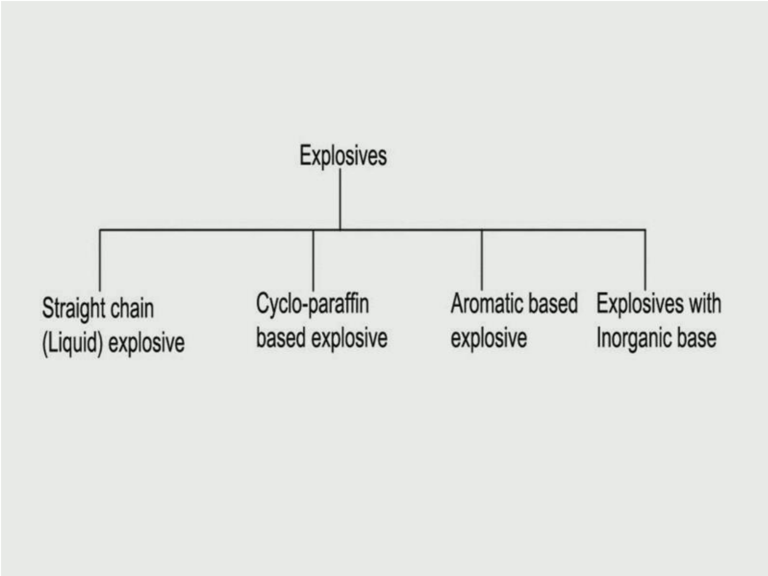

Well, these are the different properties of the different types of explosive and to put things together. We tell ourselves well we looked at the different condense explosives both solid and liquid. We find well, if the explosive is more contains, more relatively more amount of oxygen.

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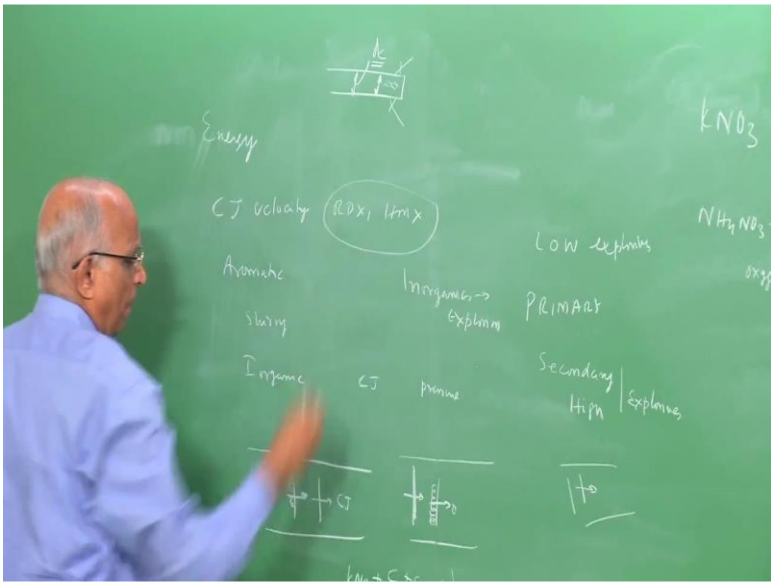

It has more energy in it. We also look that the C J velocity for dentations, we find may be RDX HMX have a higher C J velocity. And higher pressure in the definitions. We also find well the aromatic substances like TNT, the tetral, picric acid, have lower value of C J velocity and also lower pressure. And similarly, the slurry propylene also have lower. But, when they looked at all this things we form the inorganic substances. Namely, the azides, fulminates, the acetylates have very much lower values of C J velocity, and also very much lower values of the pressure in the definitions, which is found in solids. Now, when we talk of the solid explosives in how do we initiate the explosion. Well, we have to form a shock wave in the solid. And this shock wave couples with the chemical reactions. And this is what drives a definitions that means, a shock induces chemical reactions couple with the shock to form a definitions wave travelling with a C J velocity.

And this is the C J velocity we are talking of and in some substances you know the short wave can be found very readily. That means, in the inorganic substances, a little bit of touch or a little bit of heat release is sufficient to start the short wave. Therefore, most of the inorganic explosive, which we dealt with are things which are very sensitive. And such type of in organic explosive, in which a definitions can found very easily are known as primary explosives.

They are primary in anything can start you know, you touch it may be heat release starts a shock wave. And this shock waves combines with the heat behind it and it forms a definitions. Mind you, the pressure behind the definitions is still small the velocity of definitions is still small. But, it definitions very easily, when we talked of may be RDX HMX they release lot of energy, but to be able to initiate a definitions in it. I need to start with a strong shock, the strong shock will generate the chemical reactions.

And then it will dry a definitions, this definitions has a high speed. But, then it generates lot of heat and high detonation velocity. But, I preliminarily required a shock. And this shock can be generated by a primary explosive. In other words, like RDX, HMX, nitro glycerin may be PETN are be what we call as secondary explosives. Or rather, since they have high energy it is also known as high explosives. Study of some substances like we say, black powder, carbon we have sulfur plus KNO 3 cannot really initiated definitions, because even if I have a shock, it takes some time for the chemical heat to get liberated.

The chemical reaction cannot couple with the shock and no detonation is possible. Such types of explosives are known as low explosives. Therefore, one way of classifying the explosives is the primary explosive, a high explosive. The high explosive requires the primary explosive to start a shock.

And this shock can take it forward, while a low explosive cannot definitions. It is just like wood which burns, but which generates lot of energies. One way to be able to arrest a definitions, we said we talk in terms of critical tube diameter. With the diameter of your explosive is less than a critical threshold. Well, the number of cells in the definitions are not sufficient to make it propagate fast it can only go, as something like a sudo definitions or rather you know there is a relief.

Because of the relief there is expansion. And this expansion cools therefore, if ever they want to safely handle. And energetic substance well this diameter must be less than the critical diameter. Well, this is about what we learn in the area of condensed explosives to summarize again we say, well the explosives ((Refer Time: 53:03)) could be something like we say, could be straight chain type of explosive. May be could be a cyclo-paraffin based explosive RDX HMX could be aromatic based explosive. We talked of TNT, tretral we talk of TA TB. And we have explosives with organic base.

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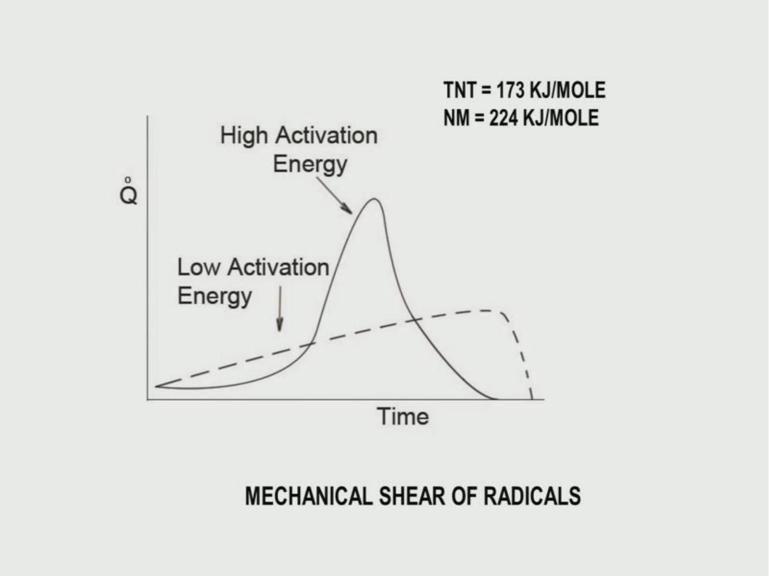

And just to finalize the picture. We tell ourselves to be able to start a definitions and most of the organic substances high values of activation energy. And to unless we have high activation energy I cannot get any induction time and expert in energy release. And this is what really causes an explosive energy release. And therefore, we would most of the explosives are associated with high activation energies. And you get explosive damage, because of this pertain the reaction. It is also possible theoretically.

To be able to shear of the radicals, when you shear of the radicals you start the change reactions. And in this way, you can also initiate a reaction. But, we must remember there is critical diameter to solid explosive below, which it cannot propagate or detonation. Well, to summarize ((Refer Time: 54:17)) the characteristics of explosives we say well a low explosive, like something like black powder does not detonate it can only burn.

A primary explosive, such as the inorganic explosives comprising of excites, comprising of acetylates, comprising of fulminates with detonates rapidly, but does not generate much energy, whereas the high explosives or secondary explosives generate lot of energy. But, it requires a strong shock to detonate. Well, this is all about condense explosives. And may be in the next class we will take a look at let say, the TNT equivalents, suppose some explosion occur in nature. How do you say, what is the energy of this particular explosion are the TNT equivalents.

Thank you.