Chemical Process Utilities
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Lecture – 48
Pressure Levels and Terminology - I

Welcome to the pressure levels and terminology aspect of chemical process utilities. Now let us have a brief outlook that what we are going to cover in this particular lecture. Since pressure is a very important phenomenon of all chemical engineering operations. So, we will discuss about the pressure concept of pressure and other related definitions which are attributed to the pressure.

Then we will discuss about the concept associated with the behavioural aspect of gases and apart from this, we will discuss certain numerical problems attributed to this particular approach. So, let us talk about the different definitions which are closely associated with the concept of different pressures and different other aspects which are attributed to their utilities. Now let us talk about the atmospheric pressure, the atmospheric pressure.

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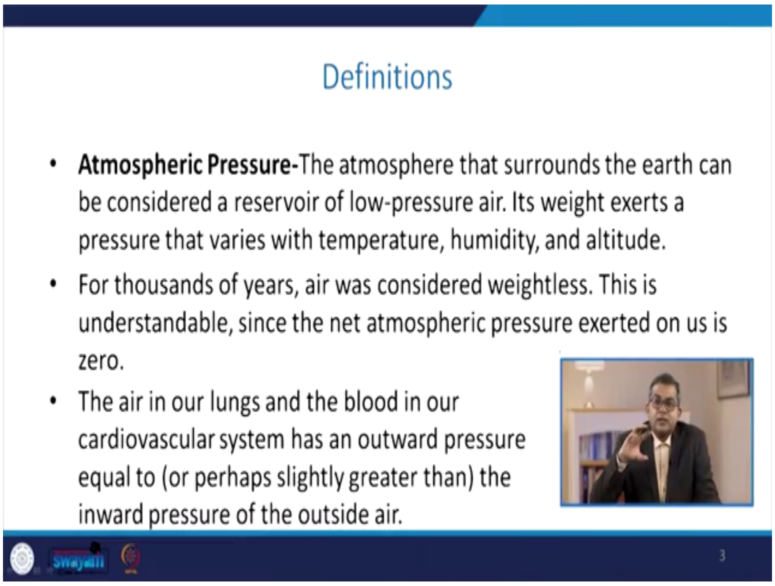

The atmosphere that surrounds the earth. It can be considered a reservoir of low-pressure air. Its weight exerts, a pressure that varies with temperature, humidity and altitude. And this particular phenomenon is very important while considering the pressure approach to the various engineering applications. For thousands of years, air was considered as weightless and this is understandable that the net atmospheric pressure exerted on us is zero.

The air in our lungs and the blood in our cardiovascular system has an outward pressure, equal to or sometimes perhaps slightly greater than, the inward pressure of outside air. That is why there must be a balancing between the 2 objects.

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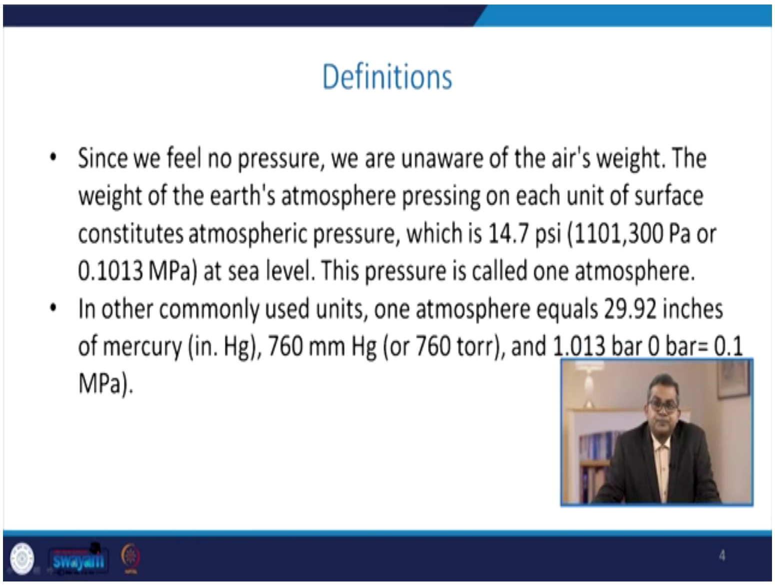

Since we feel no pressure, we are unaware about the air's weight. The weight of earth's atmosphere, pressing on each unit of surface, constitutes atmospheric pressure which is 14.7 psi or 1101.3 pascal or zero.1013 mega pascal at sea level. Now this pressure is called one atmosphere in in other commonly used units one atmosphere is equal to 29.92 inches of mercury, 760 mm of mercury or 760 torr and 1.013 bar that is equal to point one mega pascal.

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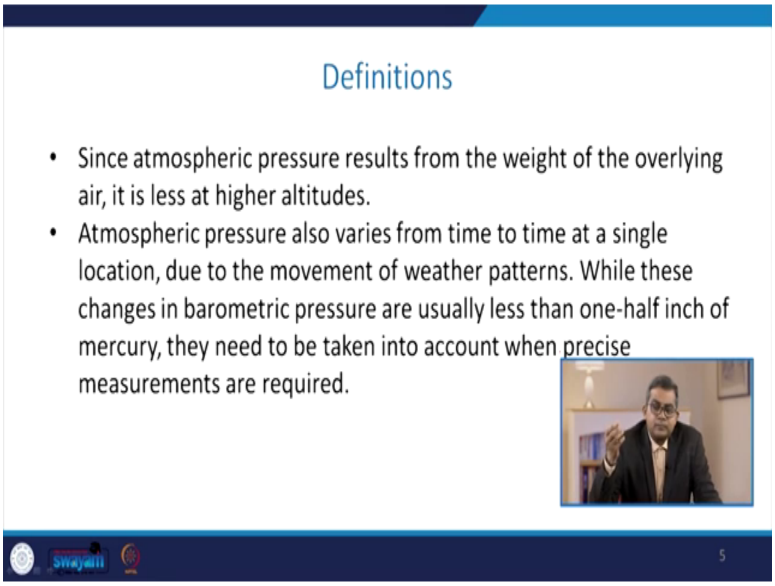

Now, since atmospheric pressure results from the weight of the overlying air, it is less that higher altitudes. Now atmospheric pressure also varies from time to time at a single location due to the movement of weather patterns. While these changes in barometric pressure, they are usually less than one half inch of mercury. Now they need to be taken into account when the precise measurements are needed.

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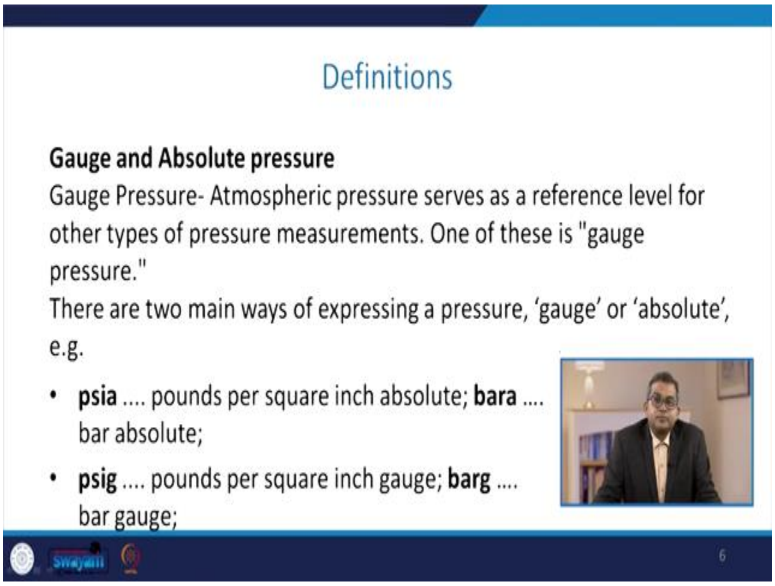

Now, let us talk about the gauge and absolute pressure. Now the gauge pressure, atmospheric pressure, serves as a reference level for other type of pressure measurements and one of these is the gauge pressure. Now there are 2 main ways of expressing the pressure. One is the gauge pressure and second one is the absolute pressure. For example, psia that is, the pounds per square inch absolute or bar absolute. Similarly, the psig that is, the pounds per square inch gauge that is barg or bar gauge.

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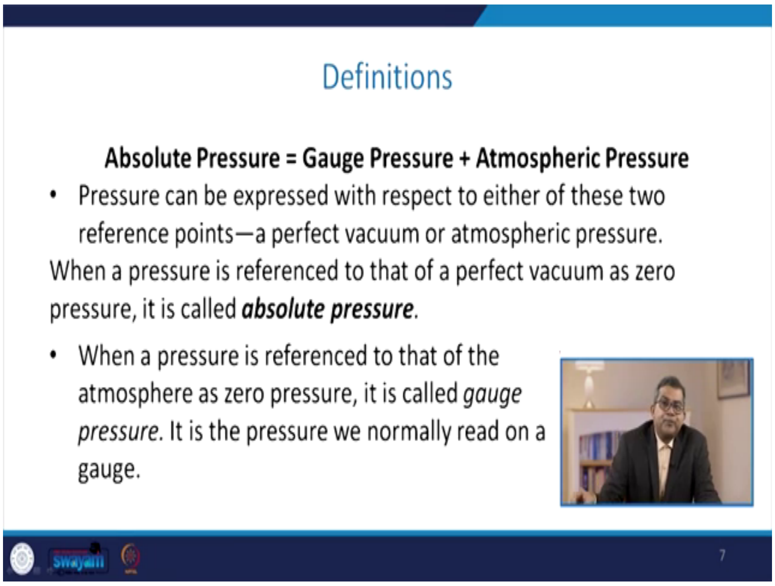

Now absolute pressure is usually equal to the gauge pressure plus atmospheric pressure. Now this pressure can be expressed with respect to either of these 2 reference points, a perfect vacuum or atmospheric pressure. Now, when a pressure is referenced, to that of a perfect vacuum zero pressure, it is called the absolute pressure.

Now when a pressure is in referenced with to the atmospheric pressure, then atmospheric pressure is termed as a zero pressure and it is called the gauge pressure. It is a pressure we normally read on a gauge

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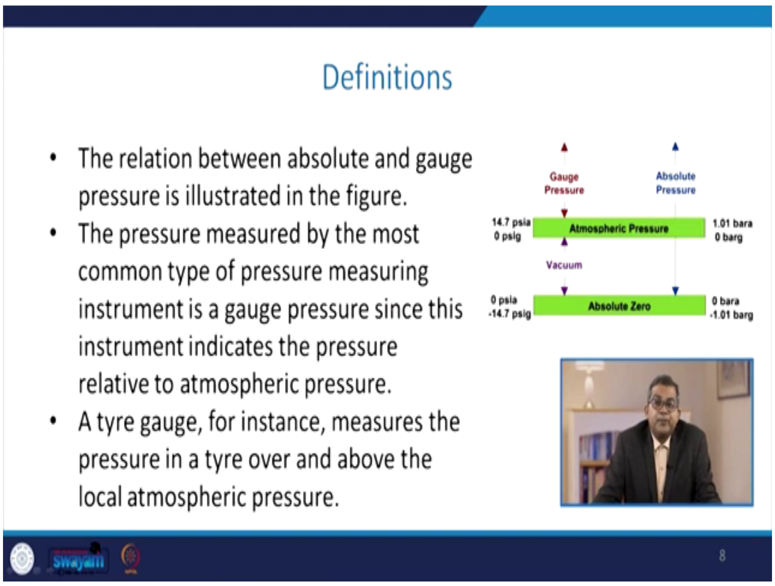
Absolute Pressure = Gauge Pressure + Atmospheric Pressure



Now, the relation between the absolute and the gauge pressure is illustrated in this particular figure. Now here you see that this is the absolute zero that is zero psi or zero bar atmosphere. Now here this is the vacuum and it is 14.7 psi or 1.01, bar absolute. So, this is the gauge pressure and absolute pressure. Now, the pressure measured by the most common type of pressure measuring instrument is a gauge pressure.

Since this instrument indicates the pressure relatively to the atmospheric pressure. So, this sometimes referred as the atmospheric one, a tyre gauge, for instance, measures the pressure in a tyre over and above the local atmospheric pressure.

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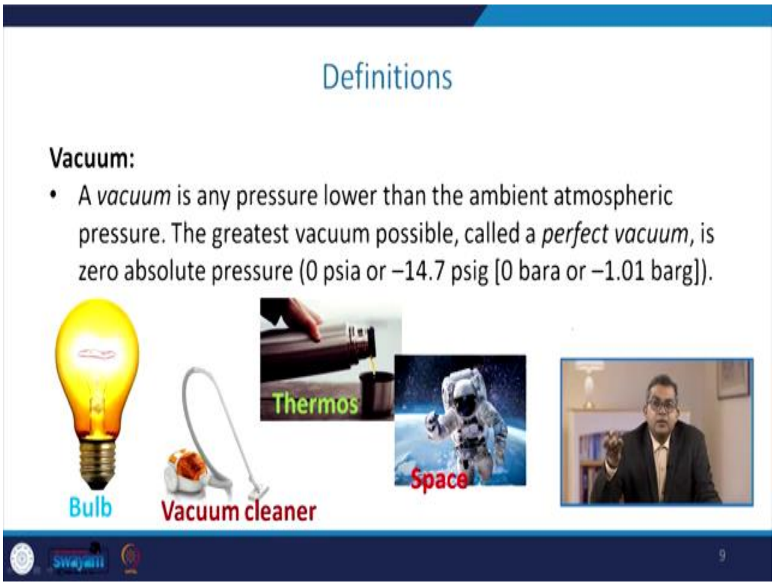

So now, let us talk about the vacuum and all of you. They are practically know that this was a previously used the electrical bulb. Now vacuum is any pressure lower than ambient atmospheric pressure. The greatest vacuum possible that is called the perfect vacuum, is zero absolute pressure or zero psi or the −14.7 psig or zero bar atmosphere or zero 1.01 bar on gauge.

Now there are various utilities they are attributed to the vacuum. One is the electrical bulb previously it has been used in a mass scale. Then all of us are aware about the vacuum cleaner than a vacuum thermos and above all, in the space utilities.

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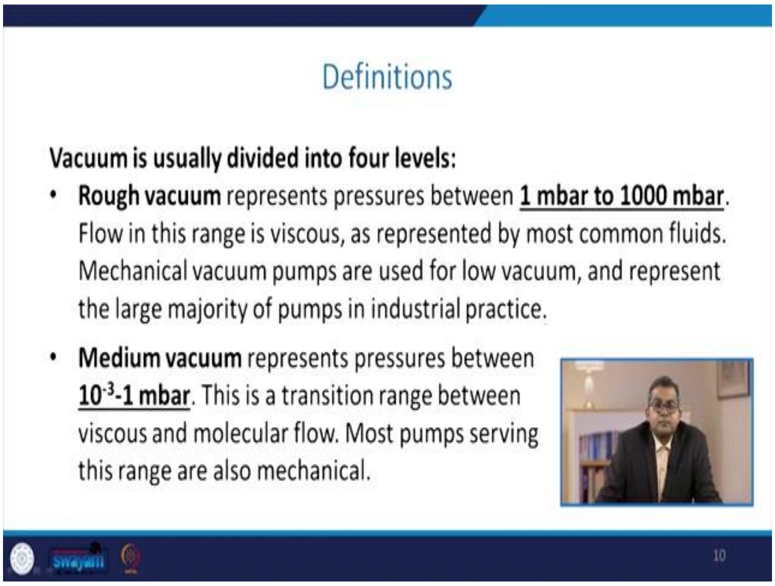

So, vacuum is usually divided into 4 different levels. One is the rough vacuum it represents the pressure between one millibar to 1000 millibar. Now flow in this range is viscous, as represented by most common fluids. Mechanical vacuum pumps are used for low vacuum and represents the large majority of pumps in industrial practice. Next is the medium vacuum, this represents the pressures between 10 to the power −3 to 1 millibar.

Now this is a transition range between the viscous and a molecular flow. Most pump serving this range are also mechanical, then the high vacuum.

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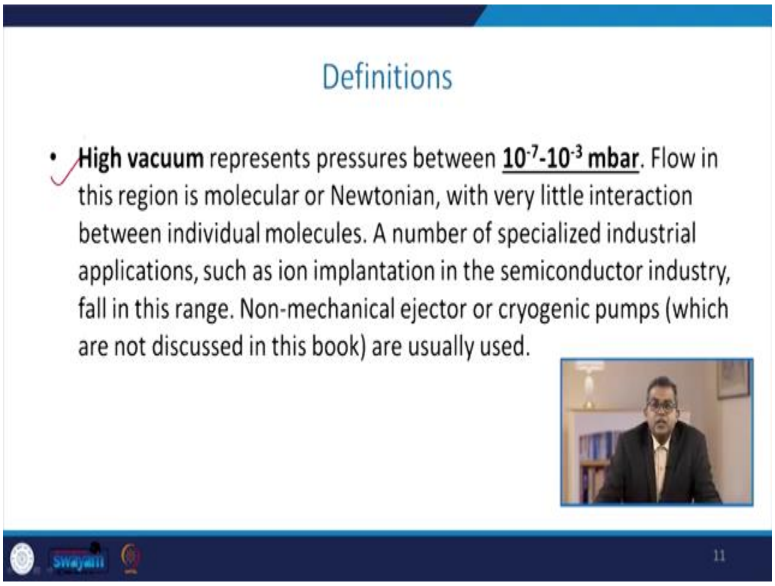

Now this represents the pressures between 10 to the power −7 to 10 to the power −3 millibar. Now flow in this particular region is molecular or Newtonian, with a very little interaction between individual molecules. A number of specialized industrial applications such as ion implantation in the semiconductor industry fall in this particular range non mechanical, ejector or cryogenic pump which are not discussed in this particular aspect they are usually used.

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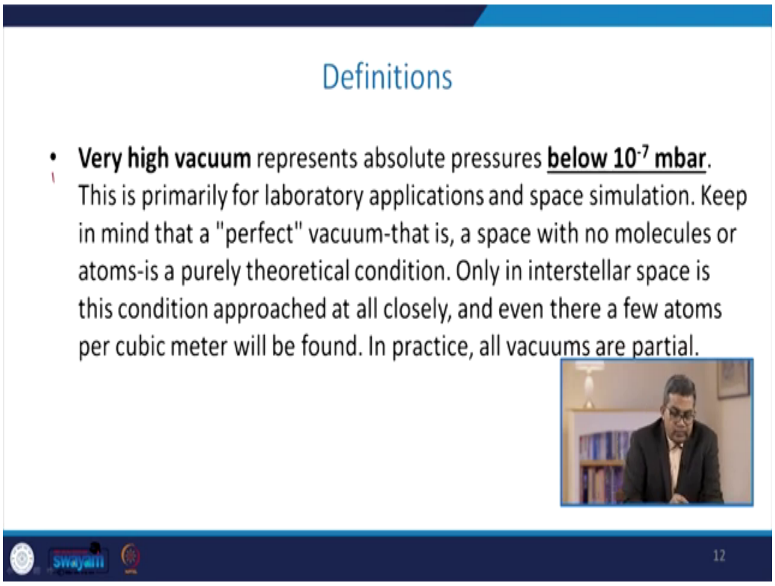

Very high vacuum: Now this represents absolute pressures below 10 to the power −7 milli bar. Now this is primarily for laboratory applications and space simulations. Now, keeping in mind that a perfect vacuum that is a space with no molecule or atom is purely theoretical condition only in interstellar space. In this condition is approached at all closely or even there is a few atoms per cubic meter will be found. In practice, all vacuums are partial.

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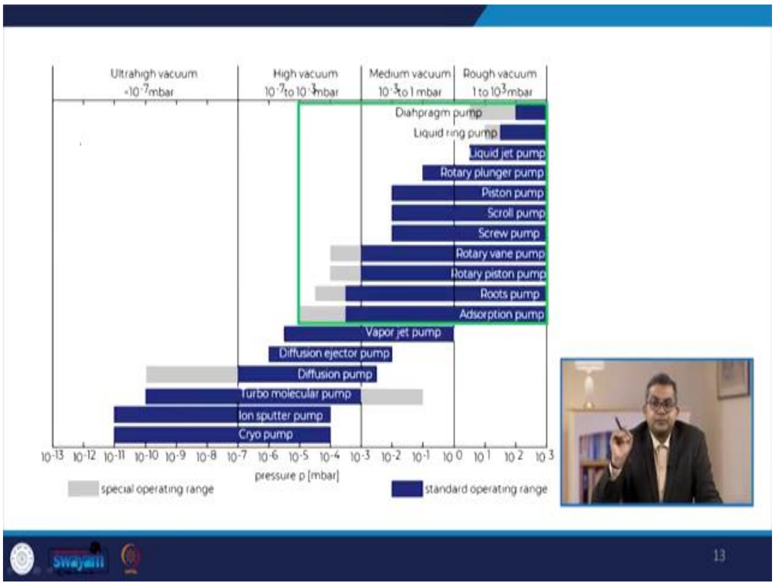

Now here you see that we have represented different type of application, with a different type of pressure range like here. You see that we are talking about the rough vacuum you have, the liquid jet pump, the rotary plunger pump, piston pump, scroll pump, screw pump, then rotary vein, pump, etcetera, then the medium vacuum 10 to the power −3 to 1 millibar. Some sort of you can say the rotary, plunger, etcetera and the vapor jack pump they are most common.

Then the high vacuum that is 10 to the power −7 to 10 to the power −3 milli bar. Then the diffusion, ejector pump, diffuser pump and turbo mechanical or turbo molecular pump or ion sputter pump and cryo pumps. So, all these are attributed in this particular approach.

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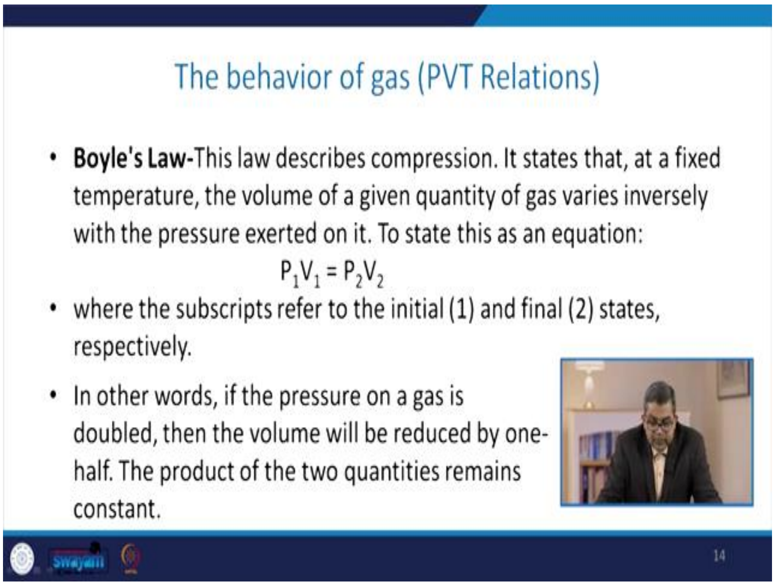

Now PVT relations. Now, if you recall the thermodynamic behaviour, then we cannot overlook the importance of pressure volume temperature relationship. These are the mathematical correlations and that develops between that only 3 measurable quantities that is pressure, volume and temperature. Now these are the very useful information pertaining to the prediction of gaseous behaviour.

Now, when we talk about the gaseous behaviour, we cannot overlook the importance of ideal gas and you see that this ideal gas equation or ideal gas, behaviour or ideal gas law. This is attributed to 2 laws. One is the Boyle's law and second one is the Charles law. So, the Boyle's law, this particular law, describes the compression. It states that, at a fixed temperature, the volume of a given quantity of gas varies inversely with the pressure exerted on it.

Now to state this particular aspect there is a mathematical correlation that is called the P 1 V 1 is equal to P 2 V 2. Now here, this 1 represents the initial and 2 represents the final stages respectively. In other words, if you say that if the pressure on a gas is doubled, then the volume will be reduced by one half this product. The product of 2 quantities remains constant.

Now this is a very useful information, but again this, it overlooks all kind of irreversibilities associated with this particular gaseous law like molecular interaction and it says that the volume of the molecules they are very small.

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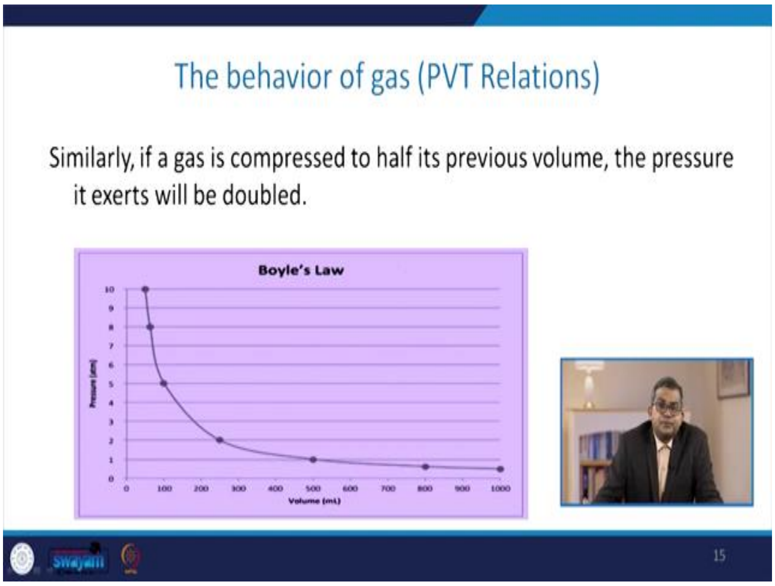
Boyle's Law;

$P_1V_1 = P_2V_2$



Now similarly, if a gas is compressed to half of it is previous volume, the pressure or whatever it exerts will be doubled. Now, here you see, this is the representation of the Boyle's law. Now, if you keep on increasing the pressure, then subsequently the pressure will volume will go down. So, all these, the pressure and volume both are inversely portion.

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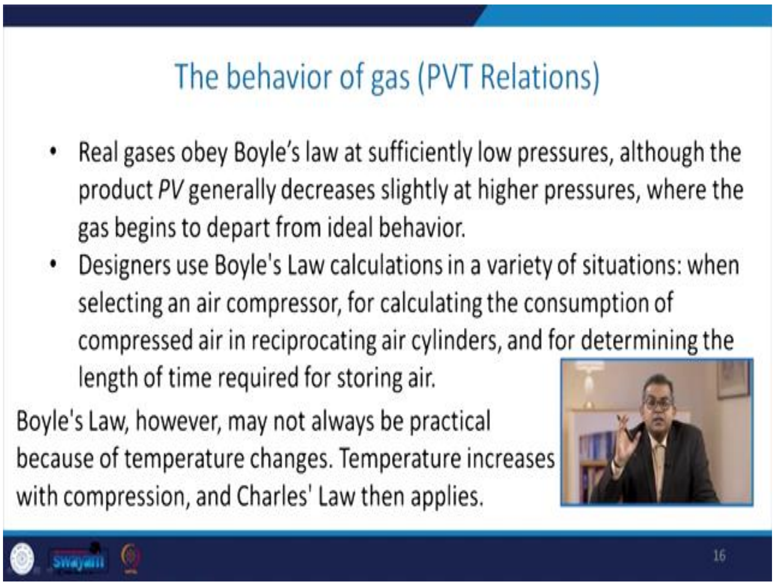

Now in real gas, the real gas obeys the bias law at a at a very low pressure or sufficiently low pressure. Although the product PV generally decreases slightly at a higher pressure. Now where the gas begins to depart from ideal behaviour. Now designers, they use the Boyle's law calculation in a variety of situation, when selecting an air compressor for calculating the consumption of compressed air in reciprocating air cylinders and for determining the length of time required for storing gas.

So, Boyle's law, however, may not always be practical because of the temperature changes. When you apply the pressure or the volumetric approach, then definitely the pressure changes will take place. Now temperature increases with the compression and then Charles law applies. So, because this is again some sort of irreversibility and that is why to incorporate the temperature effect the Charles law is used to predict the behaviour among the pressure, volume and temperature.

So, let us talk about the Charles law. Now, the Charles law, this law states that, at constant pressure, the volume of a gas varies directly with it is absolute temperature. The absolute temperature is the temperature measured with the kelvin scale. The kelvin scale must be used because zero on the kelvin scale corresponds to the complete stoppage of molecular motion.

Now measurements show that the at a constant pressure, the thermal expansion of real gas at sufficiently low pressure and high temperature, conforms closely to Charles law.

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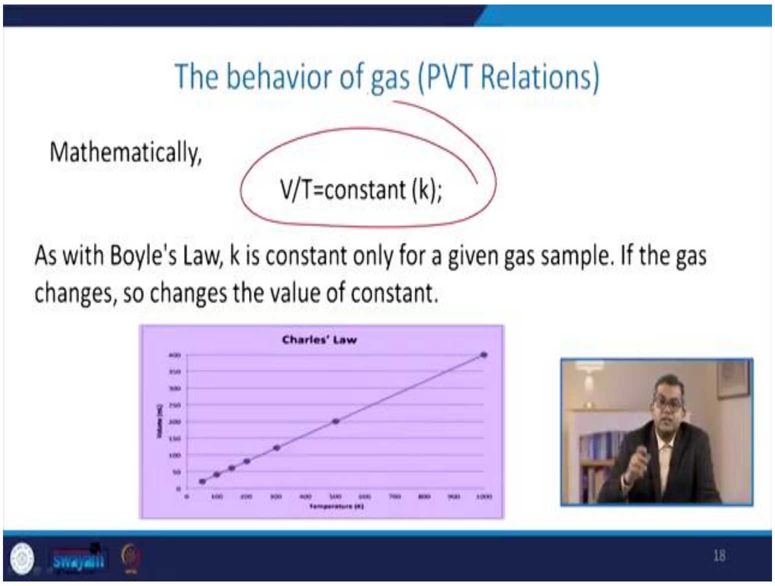

Now mathematically it can be represented, as V over T is equal to constant. Now, as with Boyle's law, the k is constant only for a given sample. If the gas changes so, it changes the value at constant level. Now here you see that if we change the volume, then the temperature profile adopts this particular behaviour.

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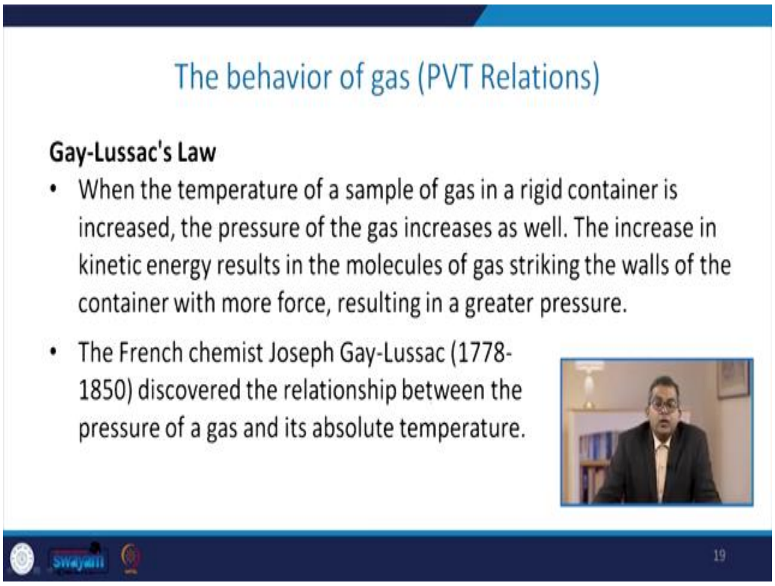
Mathematically, the equation can be represented as;

V/T=constant (k);



Now another law which is very important that is called the Gay-Lussac's law. Now, when the temperature of a sample of a gas in a rigid container is increased, the pressure of the gas all increases as well. The increase in the kinetic energy results in the molecules of a gas striking to the wall of the container, with more force, resulting in a greater pressure. So, French chemist Joseph Gay-Lussac in 1778 to 1850. He discovered the relationship between the pressure of a gas and its absolute temperature.

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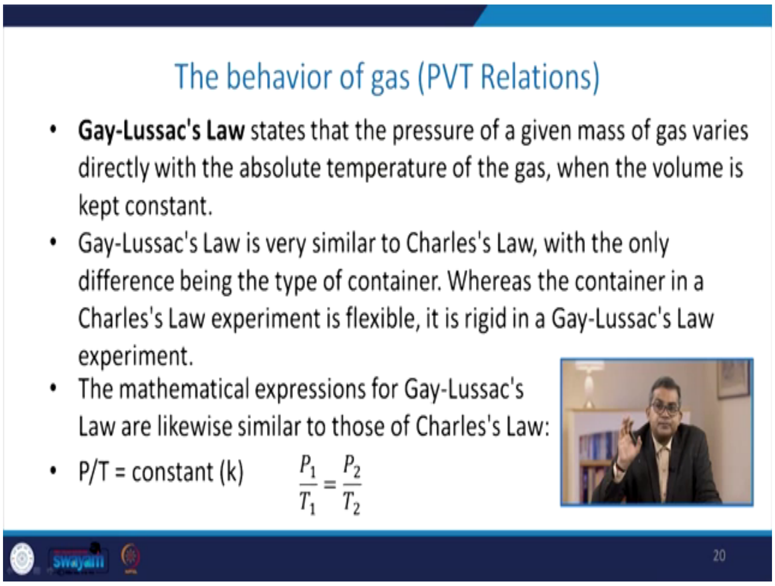

Now this law, the Gay-Lussac of law, states that the pressure of a given mass of a gas varies directly with the absolute temperature of the gas when the volume is kept constant. Now the Gay-Lussac law is very similar to the Charles law, with the only difference, being the type of container, whereas a container in the Charles law experiment is flexible. It is rigid in the Gay-Lussac's law experiment.

The mathematical expression for Gay-Lussac law are likewise similar to those the; what we have studied in the Charles law that is P over T equal to constant. So, P 1 over T 1 is equal to P 2 over T 2.

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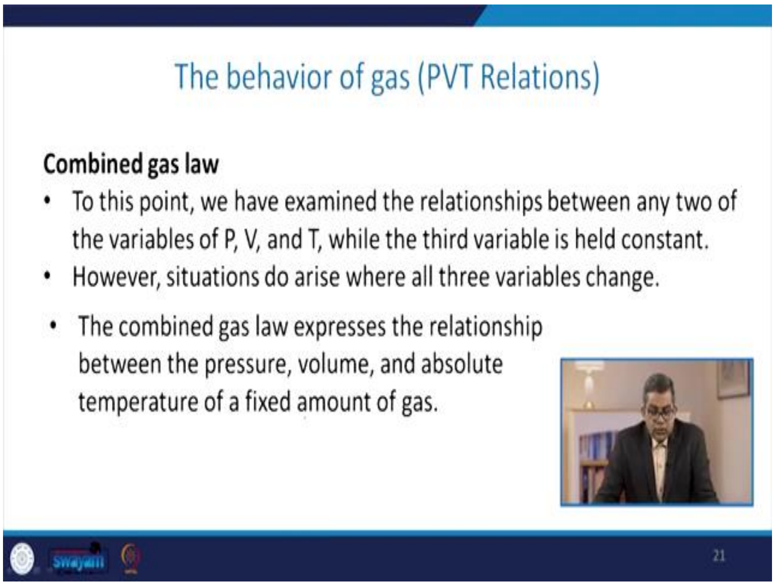
Gay-Lussac's Law;

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$



So, we discussed Boyle’s law, Charles law and the Gay-Lussac law. Then there is a need to develop a combined law for the prediction of a pressure volume, temperature behaviour of any gas. Now at this point, if you see that we have examined the relationship among the 2 of the variables pressure, volume and temperature, while the third value variable is at constant. However, sometimes the situation does arise where all 3-variable change.

Now the combined gas law expresses the relationship between the pressure volume and absolute temperature of a fixed amount of gas. So, when you talk about the combined gas law problem, only the amount of gas is held constant.

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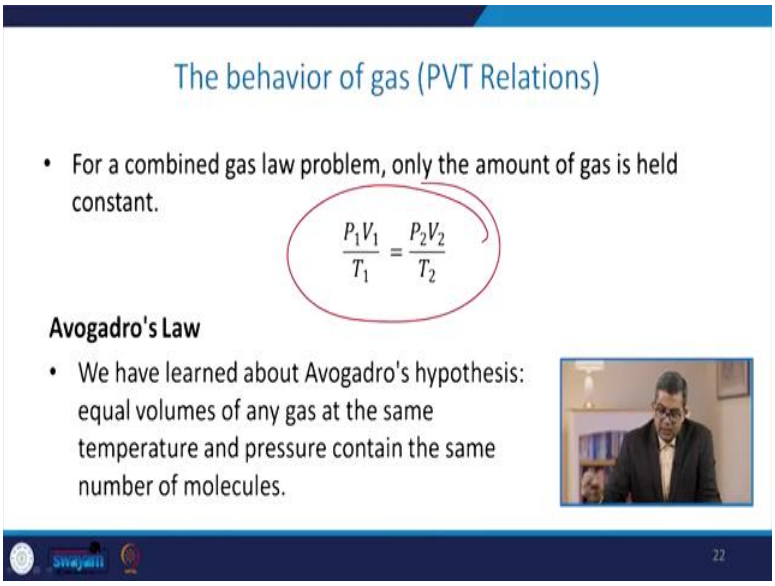

And this is your combined gas law that is P 1 V 1 over T 1 is equal to P 2 V 2 over T 2. Now let us talk about the Avogadro's law. It is again very important law when predicting the behaviour aspect of the gas. Now we have learned about the Avogadro's hypothesis that is equal volume of any gas at the same temperature and the pressure contains the same number of molecules.

Now it follows that the volume of a gas is directly proportional to the number of moles of gas present in that particular sample. So, Avogadro's law states that the volume of a gas is directly proportional to the number of moles of gas when the temperature and pressure are held constant.

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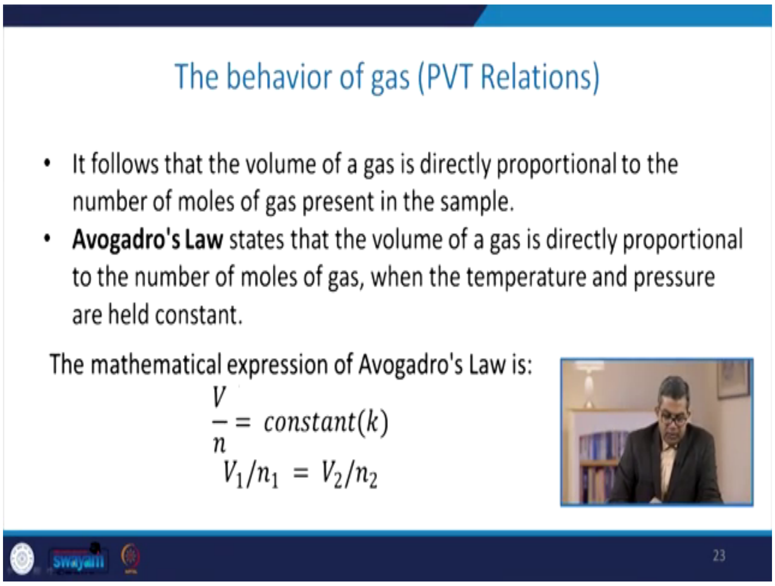
For combined gas law problem, only the amount of the gas is held constant.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$



So, the mathematical expression of Avogadro's law is V over N is equal to constant or V 1 over N 1 is equal to V 2 over N 2. Now, where N is the number of moles of a gas and k is as usual or constant. Avogadro's law is in evidence whenever you blow up a balloon, the volume of the balloon increases, as you add number of moles gas to the balloon by blowing it up.

Now, let us talk about the ideal gas law and all of us are aware that this is the benchmark for predicting the real behaviour of the gaseous system may be a single gas or maybe a mixture of the gases and it is very important. Because it provides the difference in formation for predicting the other thing and by this way you can analyze or you can anticipate the behaviour in a rough sketch.

So, the ideal gas law, the combined gas law shows that the pressure of a gas is inversely proportional to the volume and directly proportional to the temperature. Avogadro's law shows that the volume or pressure is directly proportional to the number of moles of gas.

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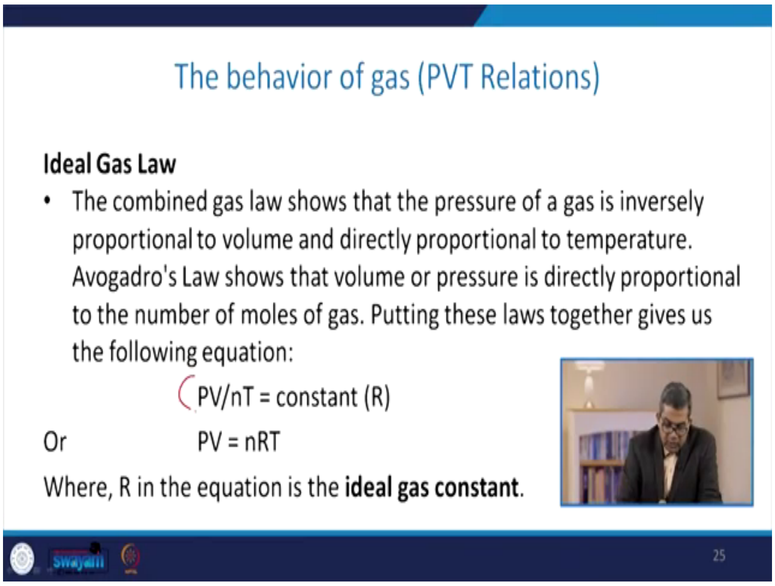
Avogadro's Law states that the volume of a gas is directly proportional to the number of moles of gas, when the temperature and pressure are held constant.

The mathematical expression of Avogadro's Law is:

$$\frac{V}{n} = constant(k)$$

$$V_1/n_1 = V_2/n_2$$



Now putting these lot together, this particular equation is developed that is PV over nT is equal to constant and that is r that is universal gas, constant or sometimes it is referred as ideal gas, constant and the mathematical representation is PV, is equal to nRT.

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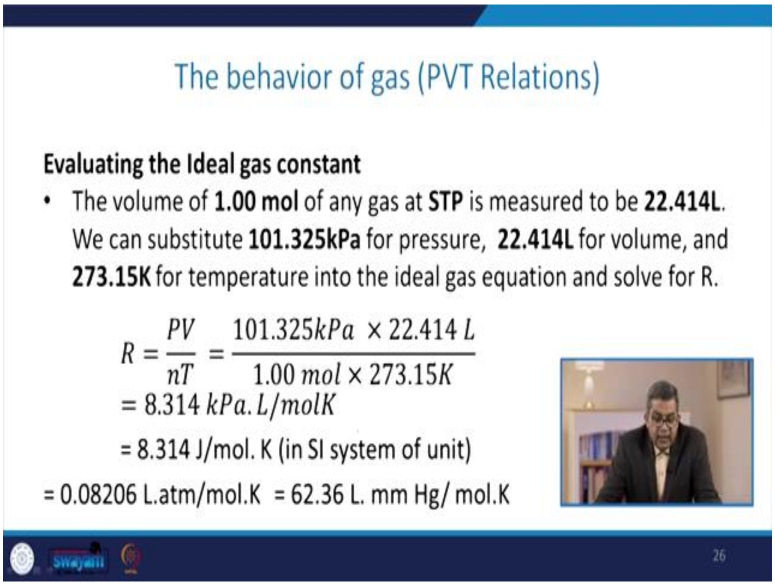
Ideal Gas Law

$$\frac{PV}{nT} = Constant\ (R)$$

$$PV = nRT$$

Where, R in the equation is the ideal gas constant.



Now let us talk about the evaluating the ideal gas constant. The volume of 1 mole of any gas at STP is measured as 22.414 liter. Now we can substitute 101.325 kilo, pascal for pressure and 22.414 liter for volume and 273.15 kelvin for temperature into the ideal gas equation to solve R and then R is equal to PV over nT. And let us take that we have one mole of gas. This is the pressure and this is the volume and this is the number of moles and 273.15 kelvin is the temperature.

It comes out to be 8.314, kilo, pascal liter per mole kelvin or in other word if we, intend to write in SI system of unit, it comes out to be 8.314 joule per mole kelvin in SI unit is or 0.08206 liter atom per mole kelvin or 62.37 liter mm Hg over mole kelvin.

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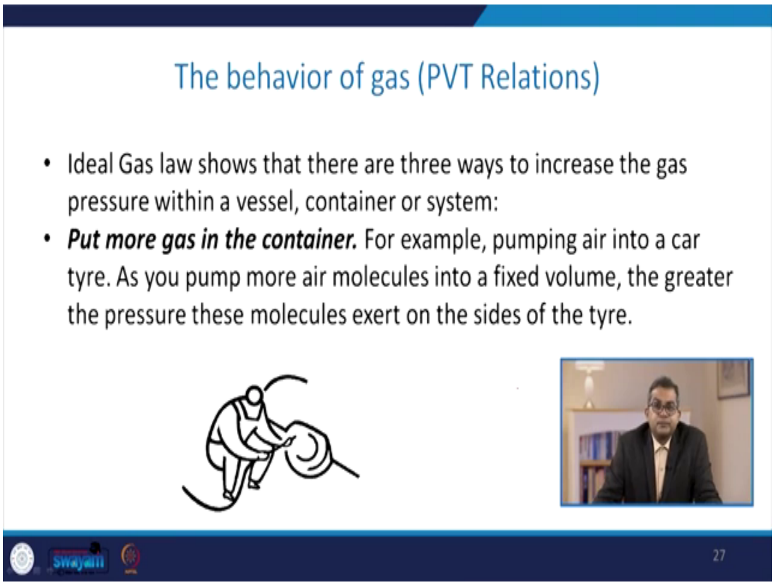
For evaluating Ideal gas constant

$$R = \frac{PV}{nT} = \frac{101.325kPa \times 22.414\,L}{1.00\,mol \times 273.15K} = 8.314\ kPa.L/molK$$

= 8.314 J/mol. K (in SI system of unit)

= 0.08206 L.atm/mol.K

= 62.36 L. mm Hg/ mol.K



Now this ideal gas law shows that there are three ways to increase the gas pressure within a vessel a container or system. Number one is that put more gas in the container, for example, pumping air into the car tyre. As you pump more air molecules into the fixed volume, the greater the pressure, these molecules exert on the sides of the tyre. So, these are the sides and the pressure may be exerted on the higher side, if you pump more and more air inside the tyre.

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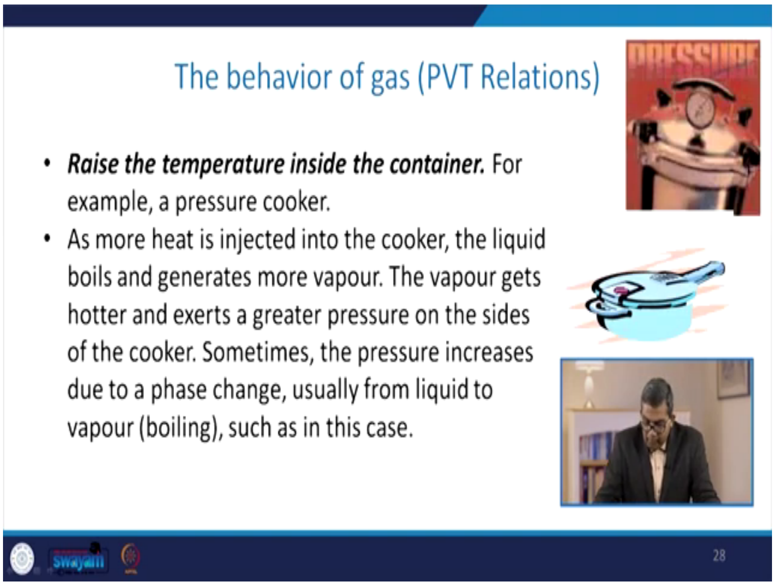

Now second is the raise the temperature inside the container. For example, a pressure cooker. Now, as more heat is imparted into the cooker, the liquid boils and generates more vapor. The vapor gets hotter and exerts a greater pressure on the sides of the cooker and sometimes the pressure increases due to a phase change, usually from liquid to vapor boiling such as in this particular case.

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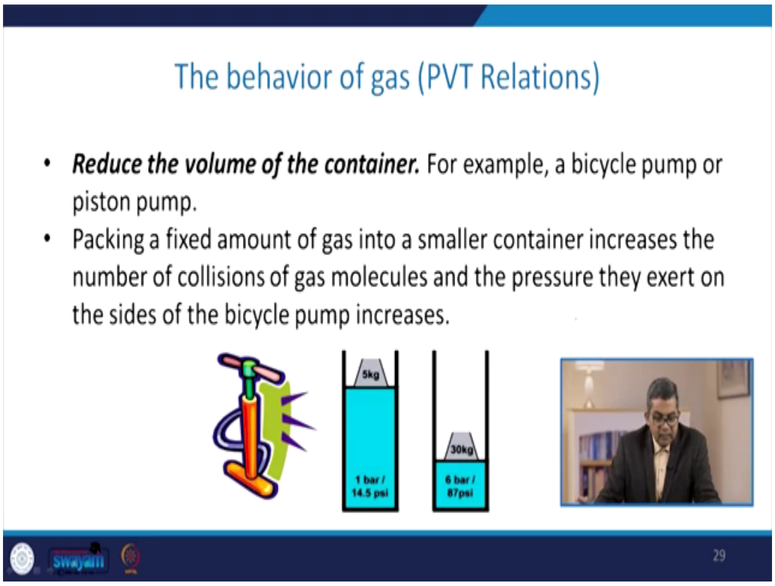

Now, third, is the reduce the volume of the container, for example, a bicycle pump or piston pump. Now packing a fixed amount of a gas into a smaller container increases the number of collisions of the gas molecule and the pressure they exert on the side of the bicycle pump this increases.

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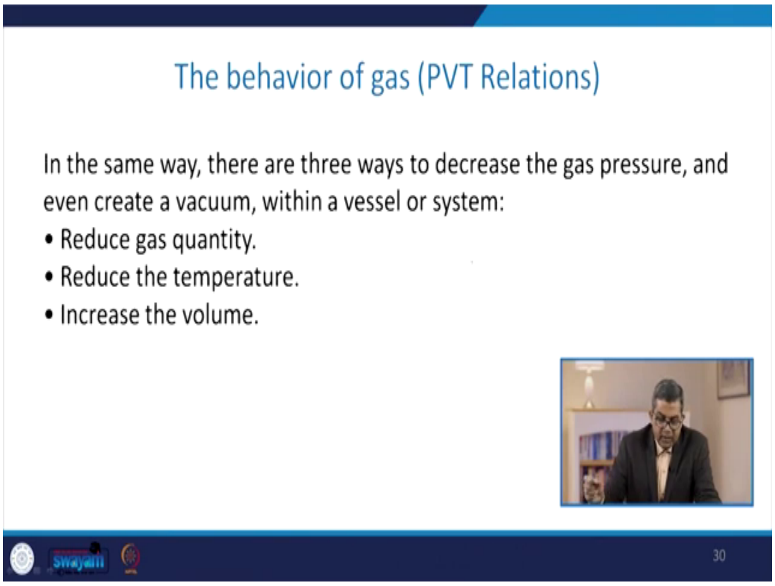

So, this is again a very important aspect. In the same way, there are three ways to decrease the gas pressure and even create a vacuum within the vessel or system. One is the reduce the gas quantity second is reduce the temperature and third one is increasing the volume.

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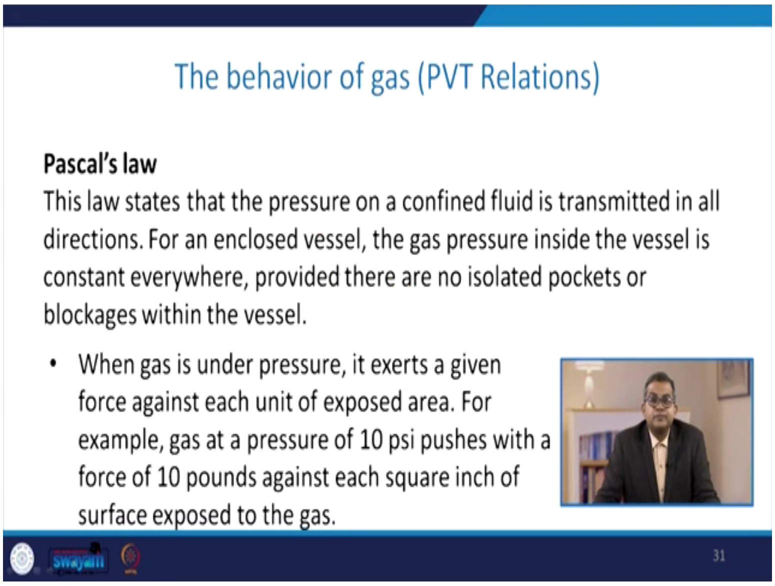

Now let us talk about the Pascal's law. Now this law states that the pressure on a confined fluid is transmitted in all direction for an enclosed vessel. The gas pressure inside the vessel is constant everywhere, provided there are no isolated pockets or blockage within the vessel. When gas is under pressure, it exerts a given force again each unit of exposed area, for example gas at pressure of, say, 10 psi pushes, with the force of 10 pound against each square inch of surface exposed to the gas.

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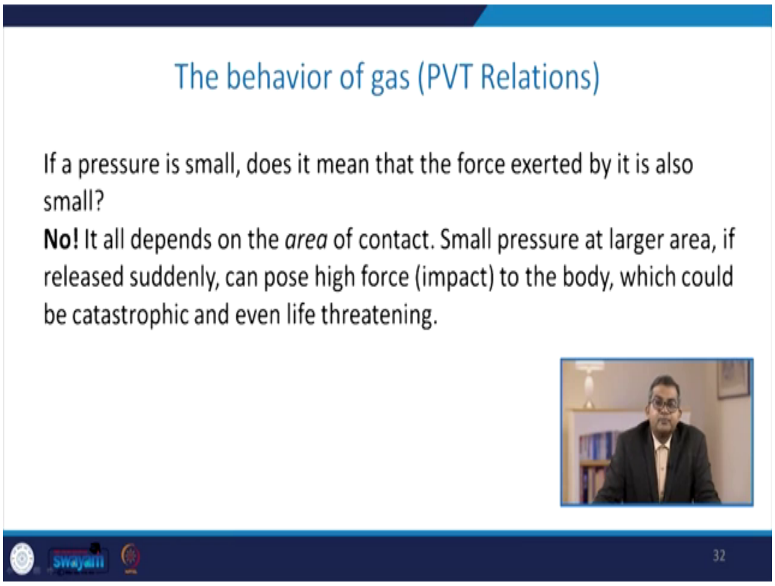

Now, if a pressure is small, does it mean that the force exerted by it is also small answer is no. It all depends on the area of contact, a small pressure at larger area, if released suddenly it can pose high force that is impact to the body which could be catastrophic, even life, threatening.

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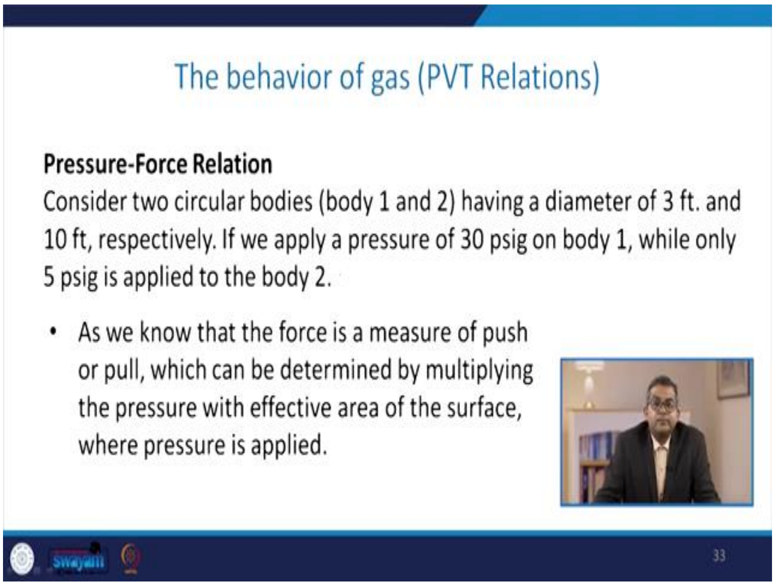

Now let us talk about the pressure force relationship. Now, consider 2 circular body. Let us say the body 1 and a body 2. They are having a diameter of say, 3 feet and 10 feet respectively. If we apply a pressure of 30 psig on body 1 which is having the diameter of 3 feet, while only 5 psig is applied to the body 2. So, as we know that the force is a measure of pressure or pull which can be determined by multiplying the pressure with effective area of surface where the pressure is applied.

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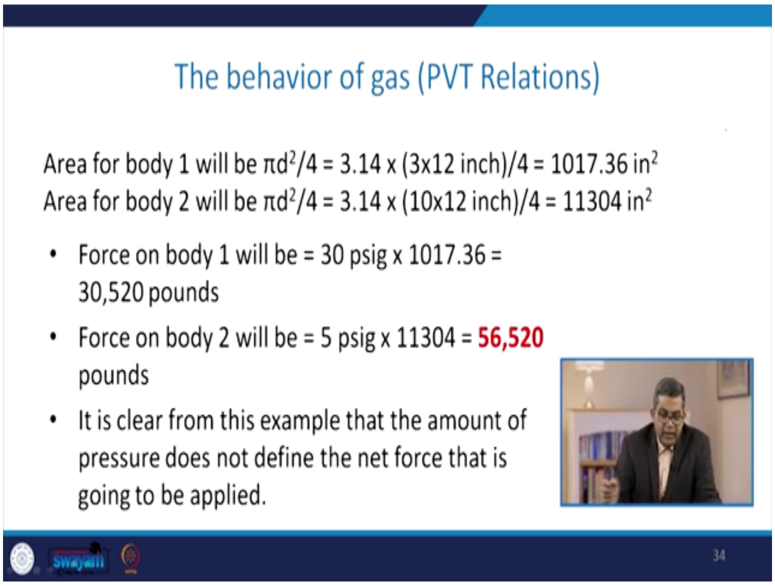

So, the area for body one will be pi d square by 4 and that is 3.14 into 3 into 12 inch over 4 and that comes out to be 1017.36 square inch. And if we talk about for body 2 which is having the diameter is of 10. So, pi d square by 4, it is equal to 3.14 into 10 into 12 inch over 4 and that comes out to be 11304 square inch. So, the force on a body one will be 30 psig into 1017.36 and that comes out to be 30 520 pounds.

Whereas in if we talk about the force on body 2 that will be 5 psi into 11304 and that comes out to be 56,520 pounds. Now it is clear from this particular example that the amount of the pressure does not define the net force and that is going to be applied. Now let us solve one numerical problem.

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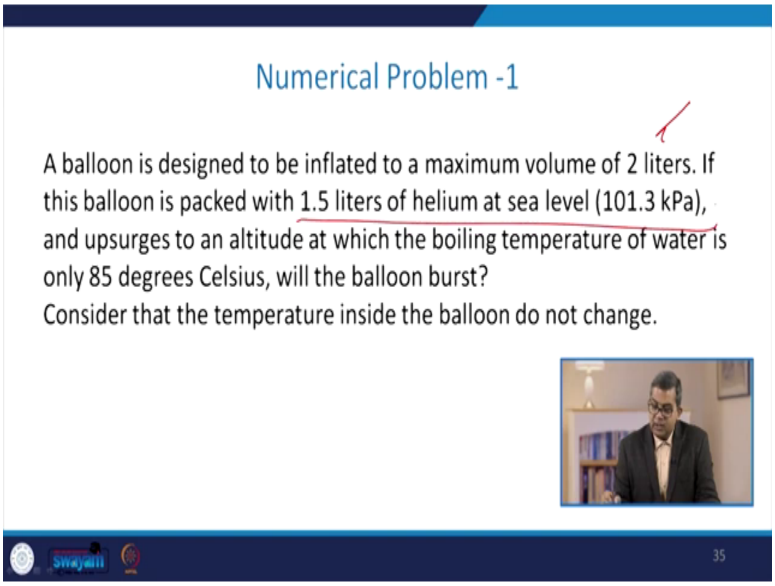

Now here a balloon is designed to be inflated to a maximum volume of say, 2 liter. Now, if this balloon is packed with 1.5 liter of helium at sea level and the sea level, the atmospheric pressure is termed as 101.3 kilo pascal and upsurges to an altitude where at which the boiling temperature of water is only 85 degrees Celsius. Will the balloon burst? Now, the consider you may take the assumption that the temperature inside the balloon do not change.

Now, as this particular question is hinting about the change in the temperature, so, let us first visualize the process, so, we know that the boiling point of water at sea level is 100 degrees Celsius. So, if we talk about the boiling point of water decreases linearly with the rise in altitude, therefore, using the cross-multiplication method, we can calculate the pressure at 85 degree Celsius which is given in that particular question.

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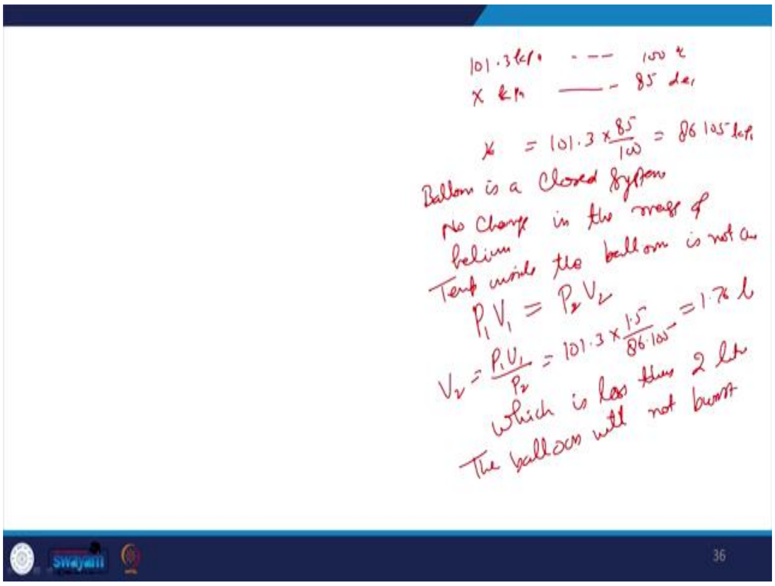

So, 101.3 kilopascal say 100 degrees Celsius. Now it is say, let us say that x kilo pascal 85 degree Celsius. So, this x is equal to 101.3 into 85 by 100 and that comes out to be 86.105 kilo pascal. Now, as we know that the pressure level at this, the point of consideration, so, we need to know about the final volume of the balloon at that particular pressure. Now as balloon is a closed system and there is no change in the mass of helium.

So, also the temperature inside the balloon is also not changing. So, let us take this help of this particular formula. P 1 V 1 is equal to P 2 V 2. So, V 2 is equal to P 1 V 1 upon P 2 and that is 101.3 into 1.5 upon 86.105 and that comes out to be 1.76 liters. Now this is less than 2 liters, so, obviously the balloon will not burst that is the answer.

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Solution 1;

As the question is hinting about the change in boiling temperature of water. Let's first visualize the process

We know that the boiling point of water at sea level (101.3 kPa) is 100 deg.C

The boiling point of water decreases linearly with the rise in altitude. Hence, using cross multiplication method, we can calculate the pressure at 85 deg. C

101.3 kPa ----- 100 deg. C

x kPa ----- 85 deg. C

$$x = 101.3 * \frac{85}{100} = 86.105\ kPa$$

Now, as we know the pressure level at the point of consideration. We need to know about the final volume of balloon at that pressure!

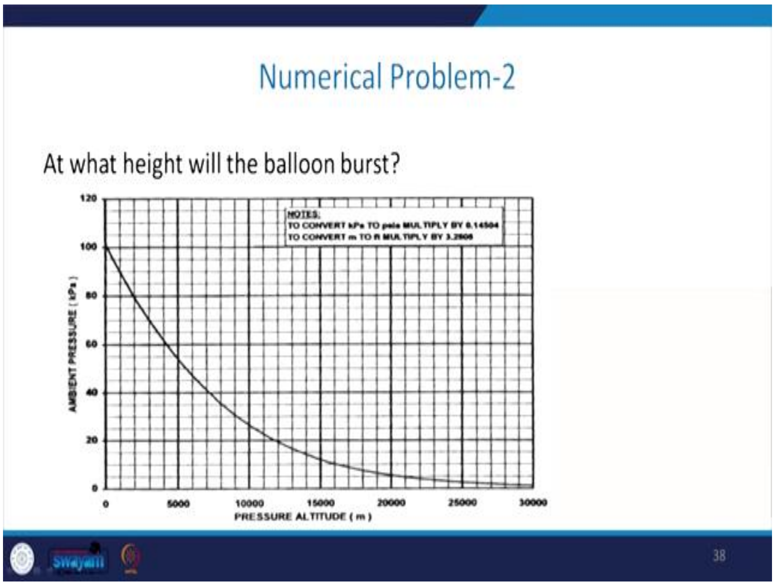
As, balloon is a closed system, there is no change in mass of the helium gas. Also, the temperature inside the balloon is not changing

Hence, we can apply the boyle's law, as;

$$P_1V_1 = P_2V_2$$

$V_2 = \frac{P_1V_1}{P_2} = 101.3 * \frac{1.5}{86.105} = 1.76\ liters$ **which is less than 2 Liters**

Hence, the balloon do not burst.



Now again, if we take the additional aspect that at what height the balloon will burst that means we have to take the similar data which we indicated in that in the previous problem. So, here we can apply directly the Boyle's law to obtain the pressure where the final volume will become 2 liters.

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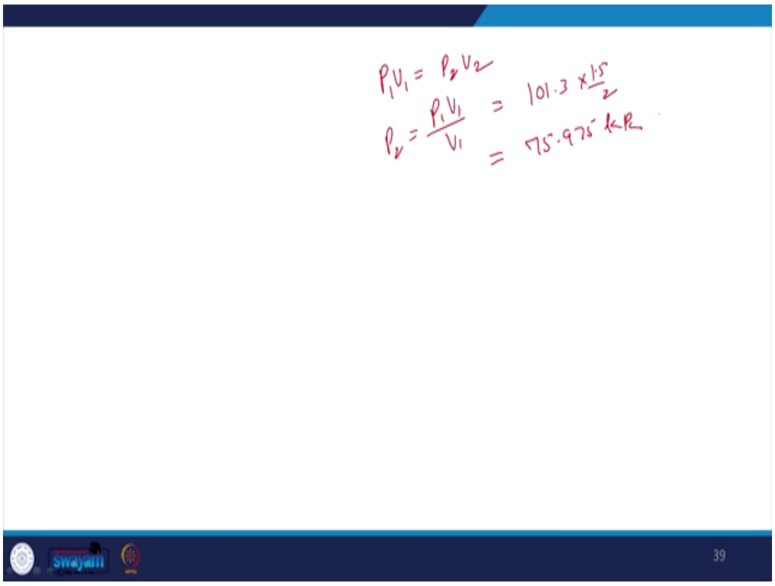

So, in that case, P 1 V1 is equal to P 2 V 2. Here the P 2 is equal to P 1 V1 upon V 1 and that is 101.3 into 1.5 by 2 and that is 75.975 kilo pascal and then we can see the help of this particular plot to describe that when this particular balloon will burst. So, if we match this 75.975 to this particular plot.

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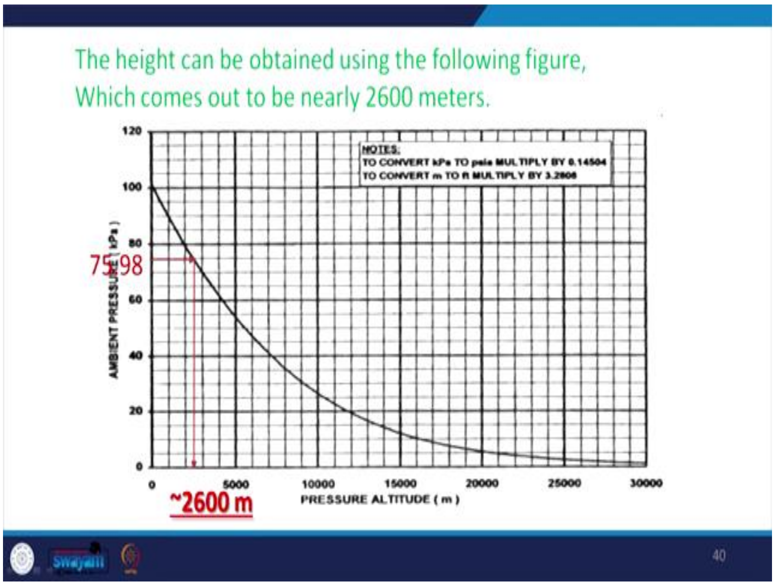
Solution 2;

Hence, we can directly apply the boyle's law to obtain the pressure where the final volume becomes 2 liters

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2} = 101.3 * \frac{1.5}{2} = 75.975\ kPa$$



And that comes out to be 2600 meters. So, this is the point that 75.98 kilo pascal and then, if we match, then it comes out to be 20 around 26 meter. So, in this particular lecture, we discussed the different aspects of pressure and different terminology. We considered couple of examples, for the convenience and if you need to help or if you wish to have further reading.

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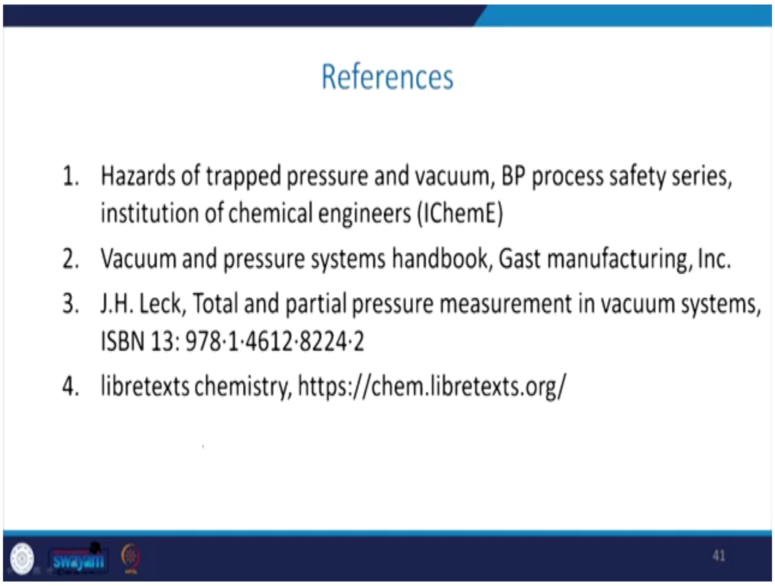

You can, we have been listed four different references. You can have a look of all those references if you wish. Thank you very much.