Chemical Process Instrumentation
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Lecture - 31
Temperature Measurement

Welcome to week seven, this is lecture 31. So, this is the first lecture of week seven. In this week and the following week, we will talk about temperature measuring instruments we have talked about pressure measurements in last two weeks. In this week and the next week, we will talk about temperature measurement which is another equally important process variable that are measured widely in chemical process industries.

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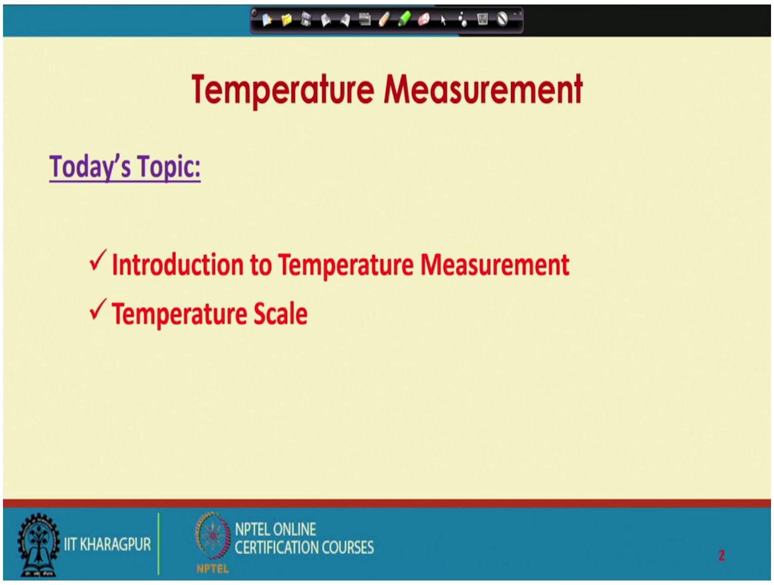

So, today's topic will give a brief introduction to temperature measurement. We will talk about what is temperature and then we will talk about temperature scale.

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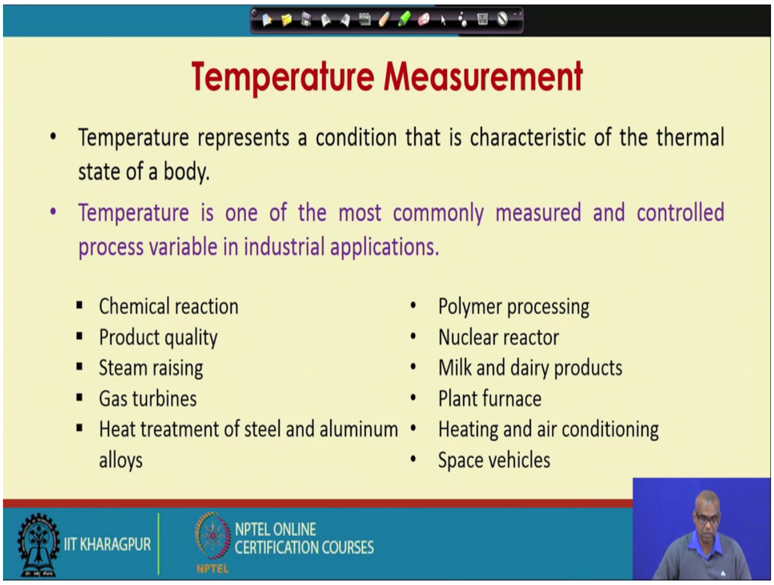

Temperature represents a condition that is characteristic of the thermal state of a body. Temperature is one of the most commonly measured and controlled process variable in industrial applications. There are large number of applications where you need to measure temperature, monitor temperature and control temperature, such as chemical reaction, product quality monitoring or measurement, steam raising, gas turbines, heat treatment of steel and aluminum alloys, ploymer processing, nuclear reactor, milk and dairy products, plant furnace, heating and air conditioning, space vehicles and so on and so forth. So, they are just these are just few examples where you will definitely require temperature measurement or temperature is an important process variables in these applications.

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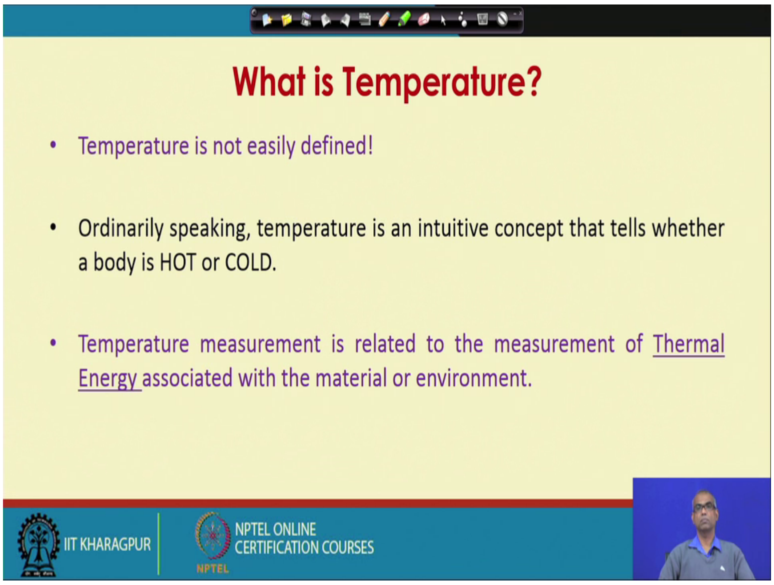

So, what is temperature? Temperature although a so simple word and so familiar word, but its not easily defined. Ordinarily speaking, temperature is an intuitive concept that tells whether a body is hot or cold. Temperature measurement is thus related to the measurement of thermal energy associated with the material or environment. So, essentially temperature measurement is related to the measurement of thermal energy associated with the material or environment.

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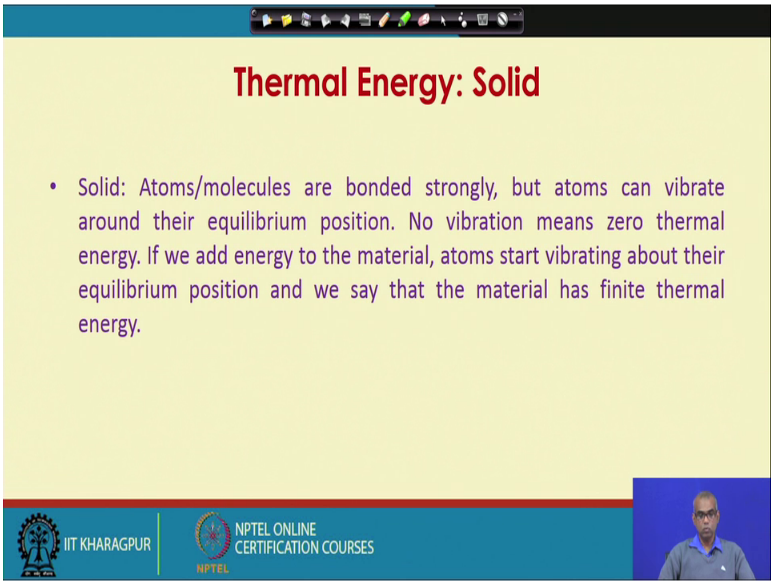

Now, let us talk about thermal energy associated with solid, liquid and gas. Let us start with solid. In solid atoms or molecules are bonded very strongly, but you know that atoms can vibrate around their equilibrium position. When there is no vibration of atom or molecules around their equilibrium position, we say the thermal energy associated with the materials or the molecules is 0. Now, if we add energy to the material atom start vibrating about their equilibrium position, and we say that the material has finite thermal energy.

So, atoms or molecules are very bonded strong are bonded very strongly and that gives them the rigid structure, but atoms can vibrate around their equilibrium position. No vibration means zero thermal energy. If we now supply some amount of thermal energy, let us say I put heater, I use heater to heat up a material. So, the molecules will receive thermal energy and will start vibrating around their equilibrium position. Now, we say that the material has finite thermal energy, but the material is still solid that means they are still bonded strongly and maintain the rigid structure.

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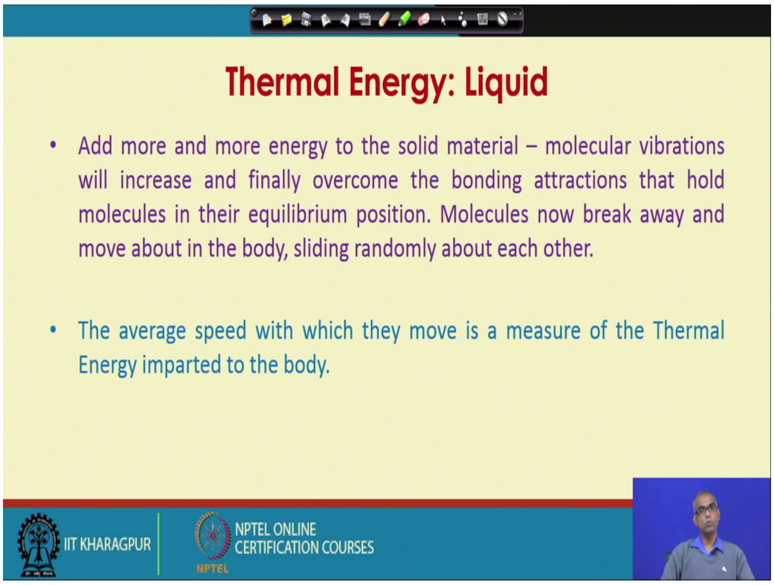

Now, if I add more and more energy to the solid material, molecular vibrations will increase because they will receive more thermal energy, and they will start vibrating more vigorously. So, molecular vibrations will increase. And a time will come when the molecules will overcome the bonding attractions that hold molecules in their equilibrium positions. So, when we go on adding energy to the solid material - molecular vibrations will increase, and finally the molecules will overcome the bonding attractions that hold molecules in their equilibrium position. Molecules will now break away and move about in the body, sliding randomly about each other we now say the solid has been converted to liquid.

Here the average speed with which the molecules move is a measure of the thermal energy imparted to the body. Incase of solid, it was the molecular vibrations, which was indicating of the thermal energy associated with the molecule. When we have added more and more energy to the solid, and it has become converted to liquid, the molecules move about in the body sliding randomly about each other. And we say average speed with which they move is a measure of the thermal energy imparted to the body.

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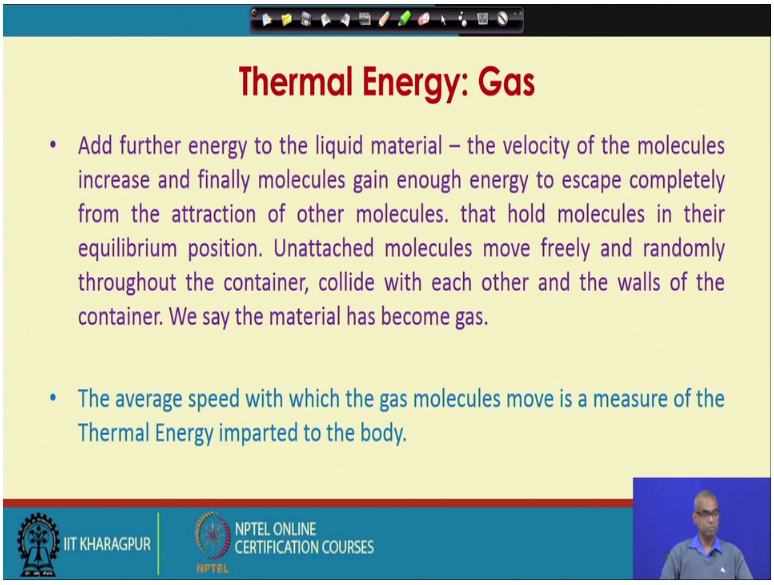

If we now add further energy to the liquid material - the velocity of the molecules increase and finally molecules gain enough energy to escape completely from the attraction of other molecules, that hold molecules in their equilibrium position. So, the molecules now become unattached and move freely and randomly throughout the container, they will collide with each other and the walls of the container. We say that the material has now become gas. So, when you apply further energy to the liquid material, the velocity of the molecules will increase and finally the molecules will gain enough energy, so that they can escape completely from the attraction of other molecules. So, the molecules are no more held in their equilibrium position. The are unattached molecules, they can move freely, and they will move freely and randomly throughout the container, they will collide with each other and they will also collide with the walls of the container. We now say the material has become gas. Again the average speed with which the gas molecules move is a measure of the thermal energy imparted to the body.

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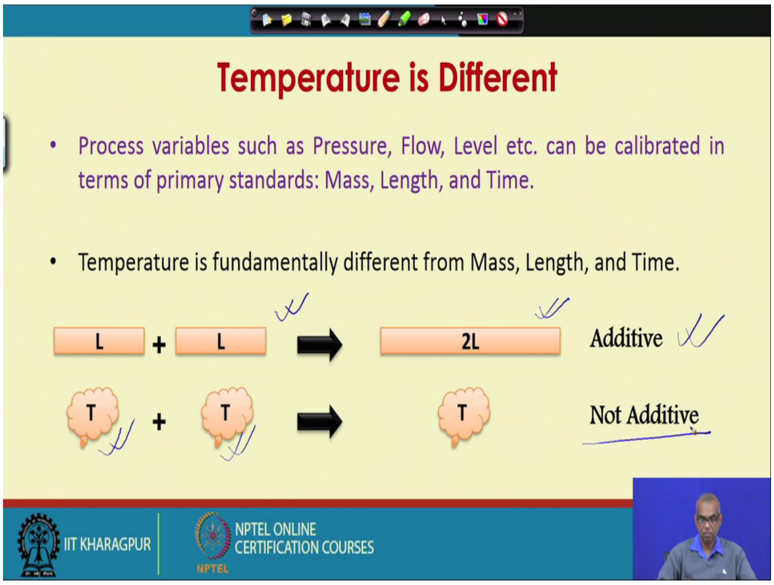

Temperature is actually a different quantity fundamentally. Process variables such as pressure, flow, level etcetera can be calibrated in terms of primary standard such a mass, length and time. So, we are familiar with three primary standard mass, length and time. Process variables such as pressure, flow, level etcetera can be calibrated in terms of these primary standards means we will see that unit of pressure or unit of flow or unit of level can all be expressed in terms of mass, length and time. But temperature is fundamentally different from mass, length and time. You cannot express the unit of temperature in terms of mass, length and time. Let us say two lengths. If we add, you get 2 L. When you add L plus L, so this is additive. But if I add say two liquids to the same temperature T, the temperature does not become 2 T, the temperature is still T. So, it is non additive.

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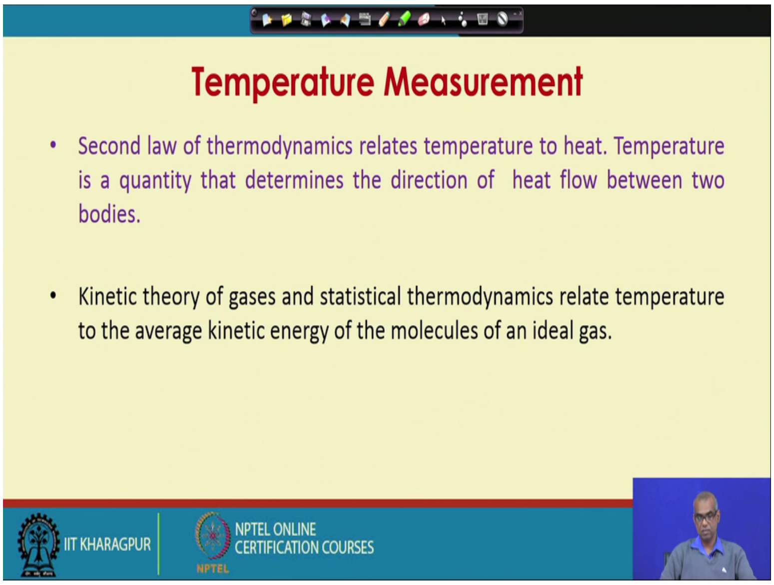

Second law of thermodynamics relates temperature to heat. Temperature is a quantity that determines the direction of heat flow between two bodies; you know that heat will flow from a point of higher temperature to a point of lower temperature. Kinetic theory of gases and statistical thermodynamics relate temperature to the average kinetic energy of the molecules of an ideal gas.

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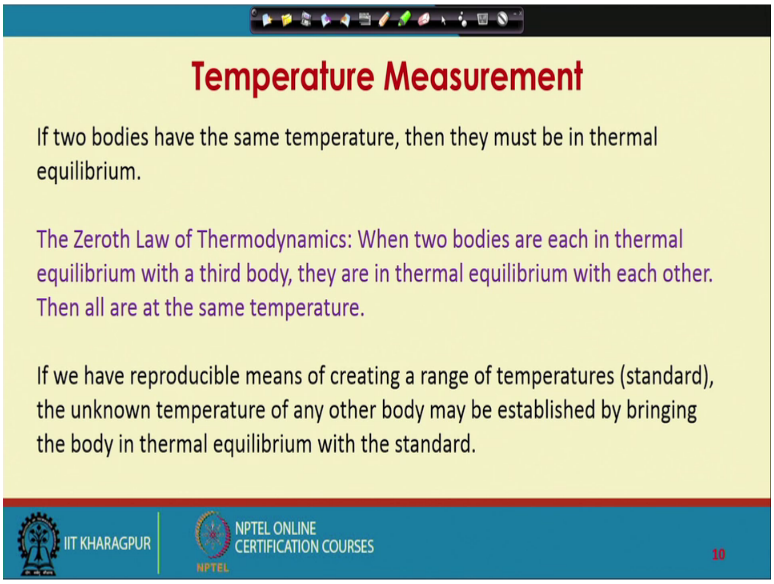

If two bodies have the same temperature, then they must be in thermal equilibrium. The zeroth law of thermodynamics says when two bodies are each in thermal equilibrium, with the third body, they are in thermal equilibrium with each other then all are at the same temperature. If we have reproducible means of creating a range of temperatures let us call them standard, the unknown temperature of any other body maybe established by bringing the body in thermal equilibrium with the standard. So, this is the basic principle of temperature measurement. If we have reproducible means of creating a range of temp temperatures which we call standard or fixed points, the unknown temperature of any other body maybe established by bringing the body in thermal equilibrium with the standard.

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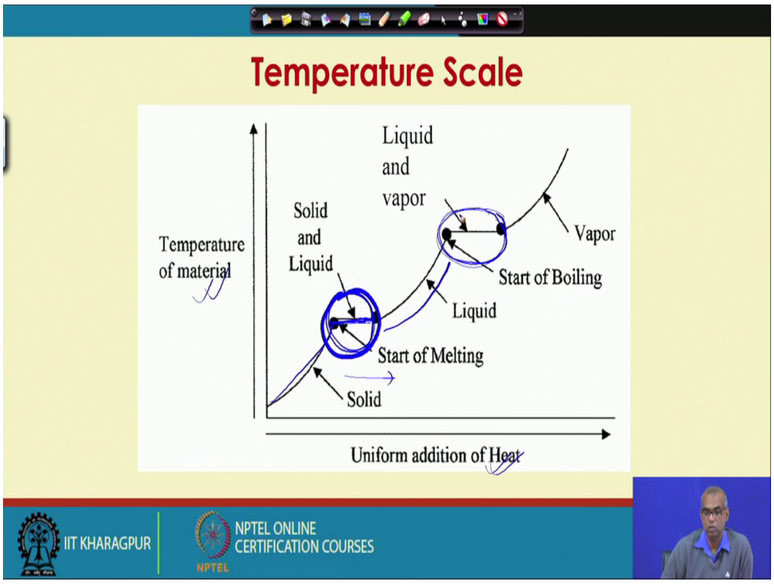

Now, these are the some well known standard temperatures we are familiar with. Consider heating of solid. So, you had initially solid, you are supplying heat to the solid. So, the temperature of the solid material is increasing. Now, there will be a point when melting will start, solid will become liquid. We just have discussed few slides back that when we apply thermal energy the molecules will start vibrating more vigorously, and then they will become liquid. So, when the solid becomes when the solid starts melting, and all the solids have not molten yet, we have a solid liquid mixture or solid liquid equilibrium where you will see the temperature is flat that means, temperature is constant. So, if I take a pure metal and supply heat to it and when the metal starts melting and I will have a solid liquid mixture with constant temperature that condition may work as a standard temperature or fixed point.

Note that here as you supply heat, temperature does not change. When the melting of the solid becomes complete that means, you have only liquid, again the temperature starts increasing. Now, you again know that since you are going on supplying heat, the molecular solid particle has become liquid; now the liquid will become gas or vapour. So, again at a temperature, the liquid will start boiling, and you will have a liquid and vapour mixture or a liquid and vapour equilibrium condition will be reached.

Again you note the temperature doesnt change here upon supply of heat. So, this is another condition where a liquid and vapour state will be in equilibrium and can be considered as a fixed point or standard for temperature measurement. When liquid becomes completely vapour, again the vapour source increase in temperature with supply of heat. So, I have a fixed point condition which is solid liquid equilibrium; I have another fixed point condition which is liquid vapour equilibrium. There are many others and we will talk about those.

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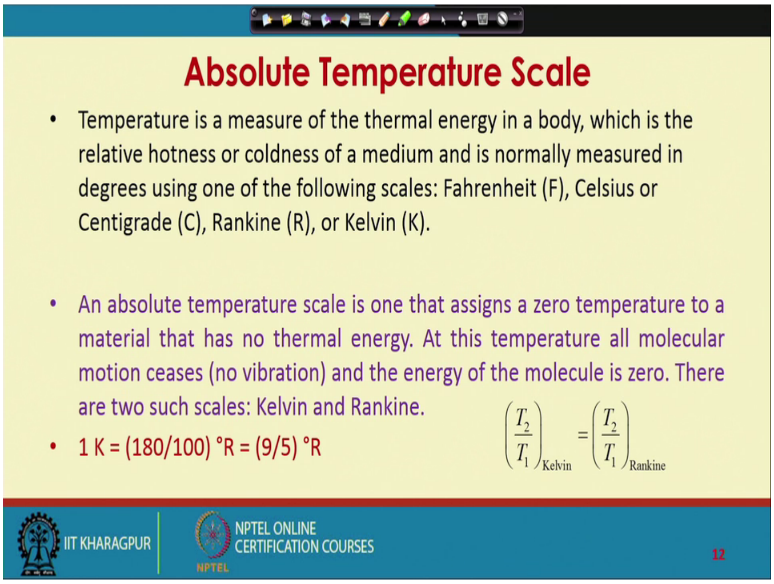

So, we discuss the temperature is the measure of the thermal energy in a body, which is the relative hotness or coldness of the medium and is normally measured in degrees using one of the following scales, Fahrenheit, Celsius or Centigrade, Rankine or Kelvin. An absolute temperature scale is one that assigns a zero temperature to a material that has no thermal energy. At this temperature all molecular motion ceases; that means, there is no vibration of the molecules around the equilibrium position and the energy of the molecule is 0.

So, absolute temperature scale will assign a zero temperature to a material with zero thermal energy; and zero thermal energy corresponds to no vibration of molecules about their equilibrium position. There are two such scales Kelvin and Rankine. The Kelvin and Rankine scale are related as follows 1 kelvin is 180 by 100 degree Rankine or 9 by 5 degree Rankine that means one can be converted to the other easily by multiplying with a factor. So, that is why the ratio of T 2 by t 1 in kelvin will be equal to ratio of T 2 by T 1 in Rankine.

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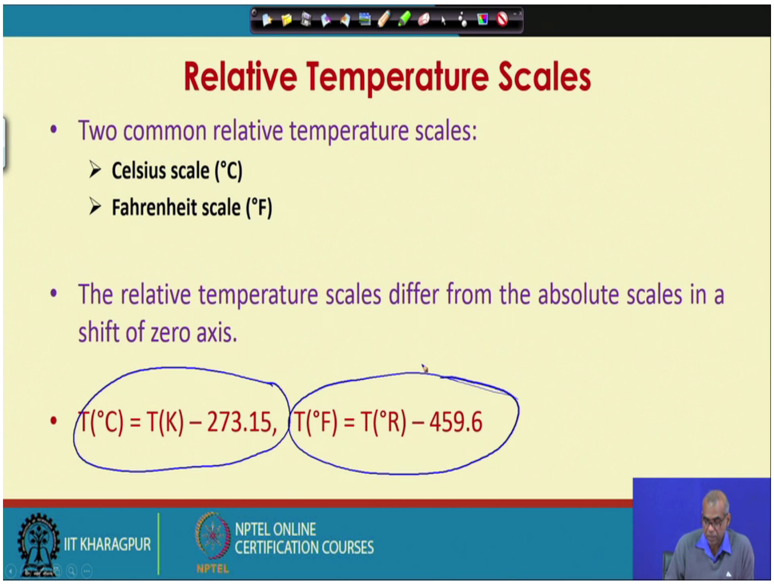

Relative temperature scales, two common relative temperature scales are Celsius scale and Fahrenheit scale. The relative scale differ from the absolute scales in the shift of zero axis. So, Celsius scale and Fahrenheit scale does not give zero temperature to the material with zero thermal energy that is done only by the absolute scales Kelvin and Rankine. Celsius scale and Fahrenheit scales are relative temperature scale, and the relative temperature scale differs from absolute temperature scales in a shift of zero axis. So, the relationship between Celsius and Kelvin is this temperature in degree Celsius is temperature in degree Kelvin minus 273.15 or you have to subtract 273.15 from Kelvin temperature to get temperature in degree Celsius; or if the temperature is given in degree Celsius, you have to add 273.15 to get the temperature in Kelvin. Similarly, the relationship between Fahrenheit and Rankine is as follows. A temperature in rankine will be temperature in Fahrenheit plus 459.6 or temperature in Fahrenheit is temperature in rankine minus 459.6.

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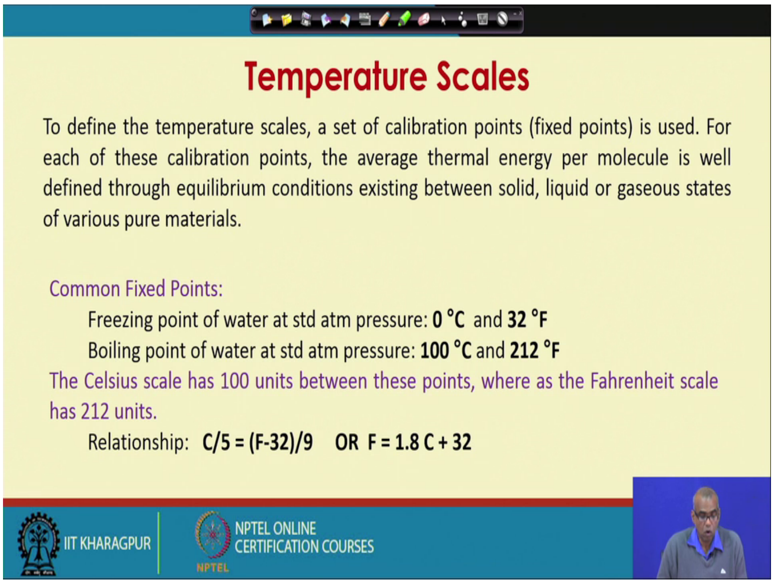

To define the temperature scales, a set of calibration points or fixed points is used. For each of theses calibration points, the average thermal energy per molecule is well defined through equilibrium conditions existing between solid, liquid or gaseous states of various pure metals. So, this is what we just saw through the graph, where we showed how the solid is becoming liquid, and liquid to gas upon application of heat, and there exists solid-liquid equilibrium, and there exists liquid and vapour equilibrium. So, those conditions can be used as fixed points or calibration points.

Common fixed points, freezing point of water at standard atmospheric pressure, it is taken as 0 degree Celsius and 32 degree Fahrenheit. Boiling point of water at standard atmospheric pressure is taken as 100 degree celsius and 212 Fahrenheit. The celsius scale has 100 unit between these points, whereas the Fahrenheit scale have 212 points between these two points. The relationship between Celsius and Fahrenheit is well known C by 5 equal to F minus 32 by 9 or f equal to 1.8 multiplied by C plus 32.

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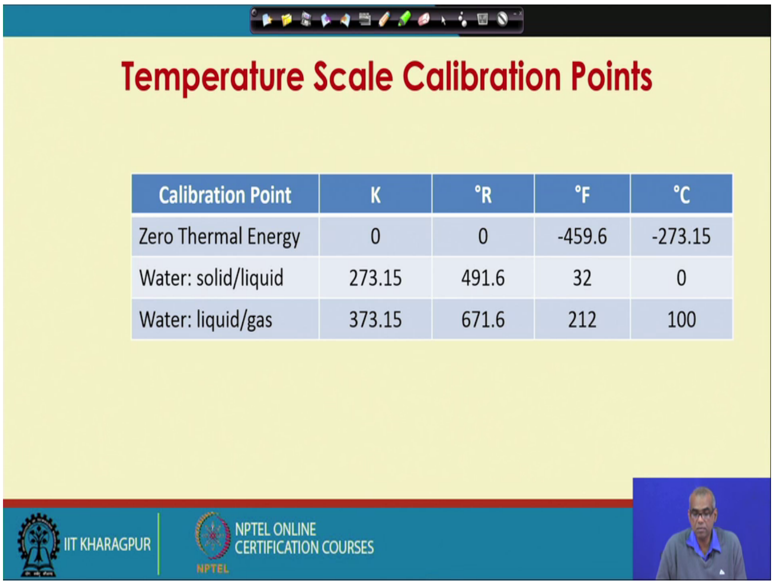

Calibration Point	K	°R	°F	°C
Zero Thermal Energy	0	0	-459.6	-273.15
Water: solid/liquid	273.15	491.6	32	0
Water: liquid/gas	373.15	671.6	212	100

So, this are some calibration points in four different scales two absolute scales and two relative scales. So, zero thermal energy, Kelvin scale and the Rankine scale will associate 0 to it; degree Fahrenheit and degree Celsius will be minus 459.6 and minus 273.15. We have seen this numbers when we solve the relationship between Kelvin, and Celsius, and Rankine and Fahrenheit. Similarly, solid liquid equilibrium for water which is basically just a ice water mixture, we know it is 0 degree Celsius, so 0 degree Celsius, and Fahrenheit - 32 degree Fahrenheit; and Rankine and Kelvin can be found out by adding 273.15 or 459.6. Similarly, liquid and gas equilibrium for water, which is in a boiling conditions; so in Celsius scale, it is 100 degree Celsius; Fahrenheit scale, it is 212; and Rankine and Kelvin can be found out by adding 273.15 or 459.6.

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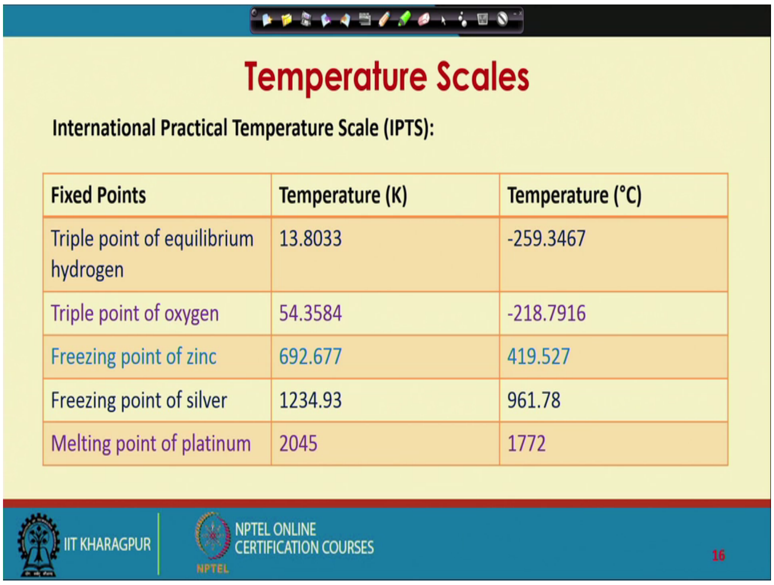

So, here there are some more fixed points, these are recommended by international practical temperature scales. So, fixed points - triple point of equilibrium hydrogen, triple point of oxygen, freezing point of zinc, freezing point of silver, melting point of platinum, corresponding temperatures are given in Kelvin and Celsius.

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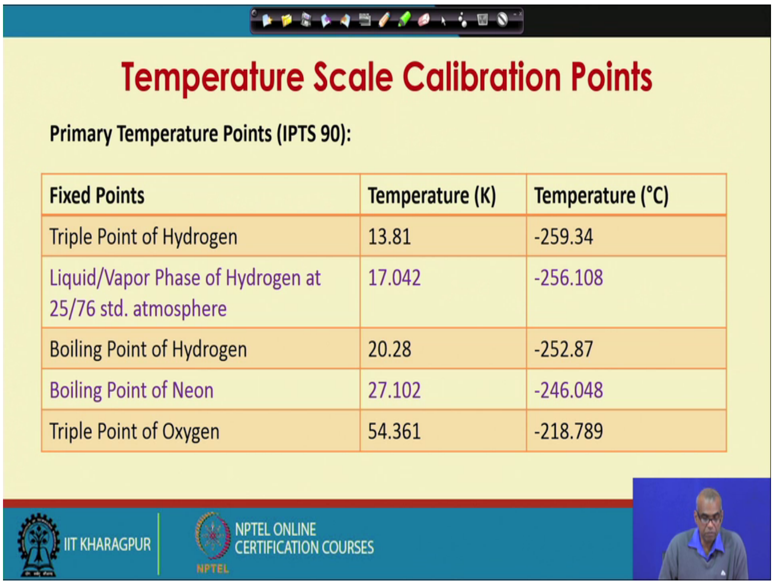

Triple point of hydrogen, liquid vapour phase of hydrogen at 25 by 76 standard atmosphere, boiling point of hydrogen, boiling point of neon, triple point of oxygen. This is primary temperature points IPTS 90.

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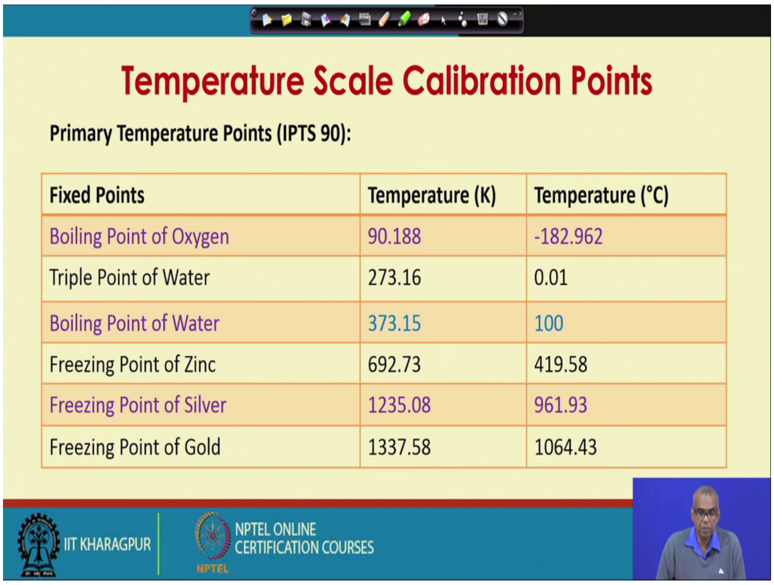

Primary temperature points IPTS 90, some more examples boiling point of oxygen, triple point of water, boiling point of water, freezing point of zinc, freezing point of silver, freezing point of gold.

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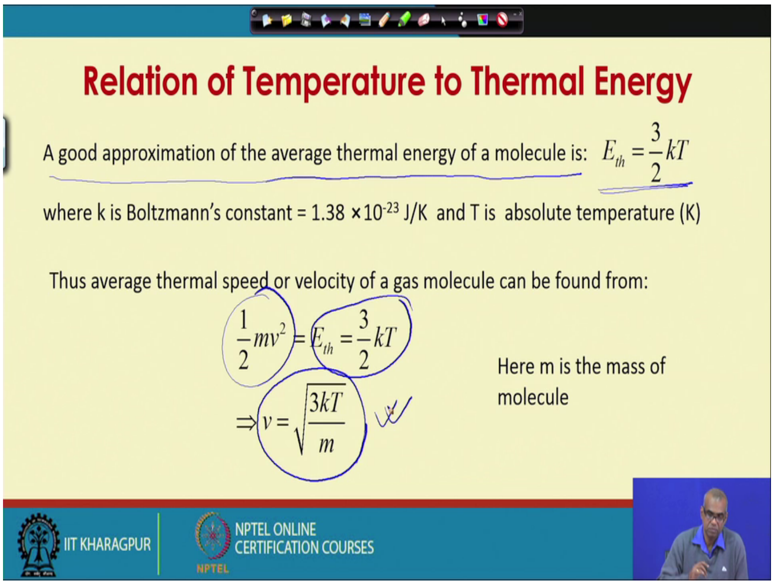

Now, what is the relation of temperature to thermal energy. A good approximation of the average thermal energy of a molecule is 3 by 2 k T. So, a good approximation of the average thermal energy of a molecule is E th which is thermal average thermal energy of a molecule is 3 by 2 k into T, where k is boltzmanns constant in joule per Kelvin; its value is 1.38 into 10 to the power minus 23. So, k is 1.38 into 10 to the power minus 23 joule per kelvin, and T is the temperature in absolute scale Kelvin. Now, if I know the average thermal energy of the molecule, I can find out the average thermal speed or velocity of a gas molecule by equating this thermal energy with the half into mass of molecule times average velocity square, so half m v square. So, half m v square ill equate to average thermal energy 3 by 2 k T. So, from these I can find out the average speed or velocity as square root of 3 k T by m, where m is the mass of molecule

So, we will stop our introduction to temperature here.