

so here we are going to talk about thermal properties of matter and what we mean by thermal properties of matter would be discussed through these topics some of them are

so we are going to talk about a concept of temperature a temperature um so relationship between different temperature scales that is the celsius and the fahrenheit scales and then will introduce this concept of absolute temperature um and it will be followed by thermal expansion a thermal expansions of solid liquid and gas all three of them this would include the anomalous expansion of water near 4 degree centigrade and then we talk about specific heat specific heat of solids liquids and gases again and then change of state as an application of hit input to the system we'll talk about how phase changes or the state of a system changes and this will have you know concept of latent heat and finally we will talk about heat transfer ok so these are broadly the seven topics that we are going to discuss and so let us start with the concept of temperature

so what we mean by the concept of temperature is the following a most likely you and i have never met and never have shaken hands with each other however if both of us are maintaining a healthy life then our body temperature is about 37 degree centigrade and then we when we shake hands we are in thermal equilibrium and even if the fact that our feet or the nose could have slightly different temperatures but when we shake hands with each other we do not feel any difference in temperature which means that we are at thermal equilibrium with our surroundings

so consider a case when you keep a ice cold water on a table a and in another case you keep a hot cup of tea on the table

so what will happen is that if you wait for u long enough and consider this to be a hot summer afternoon when you have usually have a summer vacation the ice cold water will the temperature of the ice cold water will rise and the temperature of the hot cup of tea will go down okay and if you again as i said that if you wait for long enough the temperature of both these things that is the ice cold water to begin with and the hot cup of tea will u come at thermal equilibrium with the surroundings

so this is the concept of thermal equilibrium that any body left to itself will have to eventually come in thermal equilibrium with the surroundings and again this word therm or has come from these word thermos which means heat is the latin word a which it has come from and it means heat okay

so a

so let us see some to how to formalize these things and

so the way the thermal equilibrium is established is via the transfer of heat from a body to another body or from a body to its surroundings

so we can say that heat is actually a form of energy which gets transferred from one system to another or the system to its surrounding and by virtue of a temperature difference that exists between them okay

so there are two at least two points which are of relevance here let me write them down for you

so they are let us call it as a

so how much the temperature of the body body changes when a certain amount of amount of heat is added or extracted

so that is a relevant question that what is the what is the change in temperature when you add a certain amount of heat or you take away a certain amount of heat from a given body and the second thing is that that whether a change of state occurs due to the a application or the removal of heat ok

so these are some of the questions that will have to deal with when we talk about thermal properties of matter and what happens when a certain amount of heat is applied or added or removed from the system

so since we have uh smoothly and gradually have come to the conclusion that heat is actually a form of energy which flows or which gets transferred from one body to another or from a body to its surrounding and because of which the temperature changes of the concerned body

so how do we measure this temperature

so let us talk about measurement of temperature which is our second topic of discussion as i have written it down earlier

so to measure temperature we would need a device which is called as thermometer all of you know thermometer when there is a rise in temperature of the body ah you must have always used it in order to measure the temperature of the body above the normal one in order to assess that how much of fever one has and

so thermometer is not a new thing ah it's only that we have to understand that how it works what is the principle on which it works

so as again as said that it is a

so will use it using a thermometer

so again this part means ah heat ah which is slight variant of that which is thermos ah and a meter means a measuring device ah

so the most common form of thermometer is a mercury in glass thermometer

so let us just see that

so mercury in glass it is written like this

so mercury in glass thermometer

so which uses the fact that this mercury which is a liquid would ah the temperature when the temperature increases the volume of mercury will increase or the mercury will expand as the temperature is enhanced

so this change in volume or the expansion of mercury is used to indicate the temperature of a body and

so it consists of will draw it very soon it consists of a a mercury field glass bulb ah which is connected to a capillary tube okay

so when the mercury is heated then ah it expands into the capillary tube and with this amount of expansion being proportional to the ah the change in temperature or the rise in temperature and the outside of the of the glass in which the mercury is there

so outside of the glass is marked with divisions

so that we know how much of expansion has occurred compared to its initial situation before the application of heat

so basically these are that's pretty much the uh the working principle of a mercury thermometer mercury in glass thermometer

so the popular choices for measuring these temperature are ah are two ah namely the celsius scale and a fahrenheit scale and the way we can understand them is the following

so let us draw a thermometer here

so this is the mercury and

so this is ah is

so this is a mercury field bulb ah which is enclosed in a glass tube and the glass tube has marking here ah i'll do the marking in a while and

so this shaded part is the mercury

so when you dip this end onto a hot object this mercury will expand and how much it expands will be shown in a scale that is on the outer glass of this thermometer

so this is one i will draw another in order to explain the the two scales of

temperature

so let us call this as a celsius scale and let us call this as fahrenheit scale by the way this celsius was formerly known as centigrade

so this used to be called as centigrade scale as well

so i have drawn two ah such thermometers and now i have to do the markings or the readings on the outer class ah the capsule of the thermometer in order to do that now these two thermometers keep in mind that they measure from the ice point to a steam point i will define what they are

so ah

so when ice melts at one atmosphere of pressure that is called as the ice point in the celsius scale that is marked as 0 degree c c would correspond to celsius okay and

so this is one of the points in that scale and the other point which is called the steam point where water starts to boil and this is again at one atmosphere of pressure and this is called as 100 degree centigrade

so there are hundred divisions uh which are marked on the ah you know on the outer wall of the i of course not going to mark 100 divisions but there are 100 divisions in between these two the namely the ice point which is here and the steam point which is here ok and ah the same thing in the fahrenheit scale is at

so i will draw it to scale in this its at 32 degree fahrenheit and 212 degree fahrenheit

so this is steam point i will just write steam for now and this is ice point i simply write it as ice

so these are the the two scales that are commonly used it can be you are all familiar with this when you see news in either in television or you actually read news in newspaper in india the outside temperature or the temperature of the day is always coated in celsius while in united states of america it's mostly coated in fahrenheit while it's also true that the body temperature is never coated usually never coated in celsius and the body temperature is coated in fahrenheit and the normal body temperature of any healthy human being is 98.6 fahrenheit degree fahrenheit uh which corresponds to 37 degree centigrade

so i'll uh tell you this uh relation and from there we'll also try to derive a relation between the two scales okay

so human normal human body temperature ah is ah 98.6 fahrenheit ah equal to 37 degree centigrade but mostly as i told you that medically this is quoted all over the world now ah just to have a comparison between the two thermometers i hope to have drawn them to scale that is the length of the thermometer is same in both the cases ah the mercury is shown here

so the eyes point which means that the water starts freezing or the eye starts melting at zero degree centigrade here and the water starts to boil or steam starts forming at 100 degree centigrade and the same is at the fahrenheit scale it's at 212 degree fahrenheit for the steam point and 32 degree fahrenheit for the ice point

so now it's worth mentioning that as degree centigrade uh one division in the celsius scale i am using centigrade is actually celsius one degree in the celsius scale is a greater than 1 degree in the fahrenheit scale because there are 100 degrees and as opposed to

so 100 degrees or 100 divisions in the in the celsius scale ah which corresponds to hundred and eighty divisions between two hundred twelve minus thirty two hundred and eighty ah divisions in the fahrenheit scale scale thus ah a celsius scale ah is ah 180 divided by 100 which is 9 over 5 times larger

so one division in the celsius scale is 9 by 5 times larger than that of a fahrenheit scale and this could be easily used in order to draw a relationship between the two scales and in order to do that ah let us write down a formula which is fairly simple and must have seen it somewhere that

so c let us talk about the temperature in ah celsius scale to be c which is equal to f minus 32 ah multiplied by 5 over 9 f minus 32 was done to offset this the two ice points to be same because the ice point is 32 fahrenheit whereas this is 0 degree centigrade

so in order to offset that we have subtracted 32 from the fahrenheit reading and it has to be multiplied by an inverse of 9 over 5 in order to get the reading in the celsius scale

so typically we have a $c \text{ over } 5 \text{ equal to } f \text{ minus } 32 \text{ over } 9$ is the relationship that is there between a celsius reading for temperature to a fahrenheit reading for temperature

so you can understand that a reading of minus 20 degree centigrade

so a minus 20 degree centigrade would correspond to ah which is ah

so a minus 20 over 5 into 9 is equal to f minus 32

so that would be giving me 9

so this is minus 180 over 5 which is minus 36 ah equal to f minus 32

so f is equal to minus 4 degree fahrenheit

so a minus 20 degree centigrade is equal to a minus 4 degree fahrenheit that's the conversion all right

so this is uh the the relationship between the two scales the namely the celsius and the fahrenheit scales and one can use this relation in order to get any temperature reading in one scale and convert it to another

so let us talk about a third scale of temperature which is not used in day to day life but it has enormous scientific importance and you would understand the about the scientific importance in just a while

so this is called as kelvin scale

so the kelvin temperature scale all right

so ah the kelvin temperature scale was proposed or rather introduced by lord kelvin who is a scottish physicist and each division in that scale is ah represented by a kelvin

so each degree or each division whatever you want to call is represents one kelvin and please do remember that it is not degree kelvin it is simply kelvin and the reason is that in si unit using the three base units such as that of length mass and time ah temperature cannot ah be expressed

so in the s i unit this is taken as a fourth base unit which is temperature this t is not temperature it's time

so you have to have another one temperature in order to have a base unit for temperature in um in the si unit

so that's why it's not degree kelvin it's simply kelvin

so when we quote a number say 200 kelvin we just simply say 200 k ah by the letter capital k where k ah is after the after its inventor kelvin all right

so why why is it important and why is it introduced in scientific content and why can't we simply do with the celsius and the fahrenheit scales that we have introduced earlier there is as i told that there is a certain amount of important social importance associated with this and uh

so one kelvin is a same as one degrees centigrade

so the divisions in the kelvin scale is same as that of the celsius scale ah every now and then i keep making this mistake of saying a centigrade but please do understand it as celsius but they are same it's just formerly known as centigrade

so ah the

so the how the concept of absolute temperature is used using the kelvin temperature scale

so one can define an absolute zero temperature below which no physical substance can exist

so it is not physically possible to go below an absolute zero which is the zero of the kelvin scale remember when we talked about the celsius scale and the fahrenheit scale we really talked about a 0 degree centigrade to 100 degree centigrade and a 32 degree fahrenheit to 212 degree fahrenheit and both were benchmarked against the ice point at one end and the steam point at the other other uh while at there are you know lower than the ice point that is possible and like the temperature can go up to minus 30 degree celsius in cold countries such as canada and there could be a temperature which is much more than 100 degree centigrade ah the the fire on the oven has temperature much more than that while a mercury in glass thermometer is unable to measure that

so ah scientifically even if we don't need them in day to day life scientifically it's important to talk about temperatures which are lower than 0 degree centigrade and larger than 100 degree centigrade and this is exactly that the kelvin temperature scale does exactly that

so the ah

so there is a conversion that is possible between the celsius scale and the kelvin temperature scale and the relationship is very simple it's a linear relationship it's 273.15 okay

so this T is the temperature in the kelvin scale kelvin temperature scale and T_C is the temperature in the celsius scale

so any temperature in the celsius scale has to be added this number 273.15 which is an experimentally observed number in order to get the temperature in the kelvin scale okay

so ah ice point where T_C is equal to 0 corresponds to 273.15 kelvin

so this is in kelvin ah

so this is 273.15 kelvin is the ice point in the kelvin scale of temperature while the steam point is 373.15 kelvin and since we know the relationship between the fahrenheit and the celsius scales we can also convert it ah can convert a absolute scale or the kelvin scale of temperature to its fahrenheit counterpart usually that is not required

so ah just to have these pictorially representing i am showing you a cartoon of these two temperature scales

so this is 273.15 kelvin which corresponds to zero degree centigrade and this is a 373.15 kelvin which is equal to 100 degree centigrade

so ah these are the conversions of ah of these two temperature scales ah that are of relevance for us now ah as i told that this 273.15 is a number that is almost pulled out from the hat or just you know pulled from the from nowhere ah we are now going to justify this number and how it comes and as i told that it is an experimental fact and the experiment can be demonstrated by doing a constant volume gas thermometer where the these number would be justified

so let us ah discuss constant volume gas thermometer um

so

when a gas is heated or it's some temperature or some heat is applied to it ah the pressure of the gas increases and when the gas is extra the heat is extracted from the gas the temperature is lowered okay and assuming uh that the gas is kept at a constant volume ok

so it is kept inside a container and the container has a fixed volume

so this is the basis for ah

so the change in the gas pressure with temperature is the basis for measuring this or using this constant volume gas thermometer

so let's see that how it looks like

so this is a vessel a container the container has a some substance let us say it is a liquid for now whose temperature needs to be measured and you can you need to know the uh

so this is at a given temperature and we don't know the temperature of this and there is now another container inside it which contains a gas this contains a gas and the gas is this this is connected to a manometer which looks like this

so there is mercury here and there is a sort of mercury all the way here

so this is mercury remember that while we talked about measurement of pressure we have introduced these manometers which are usual devices that are used for measuring pressures and is the same manometer there is a reference level which is here of mercury and this height this height is h and this is an evacuated space this is the glass filled bulb or sorry the gas filled bulb

so this is a gas filled bulb here this is immersed in a substance whose temperature substance whose temperature is to be measured and because this gas is immersed in this substance or the liquid as the temperature of the liquid rises the gas will expand and in order to keep its volume same will have to adjust the right hand of the manometer tube the level of mercury in the right hand of the manometer tube

so as to keep the reference level same and this height h will be the indicator of the pressure that the gas is exerting on the liquid so the change in temperature of the substance will be proportional to the the pressure the change in temperature will be proportional to the pressure and since the pressure is proportional to the height difference between the reference level and this level on the other hand of the or the right hand of the manometer

so this temperature difference in the substance will be reflected in the height of the of mercury in the right hand of the manometer with respect to the reference level

so this is a simple working condition of a constant volume gas thermometer

so what is seen is that if one does an experiment with this setup

so it is seen that the pressure which is which is proportional to as i told that the pressure is proportional to the height and the height one can measure using a scale

so this pressure is

so this is the pressure which as i said is proportional to the height and this is the temperature and let us say we denote it in degree centigrade for now it will show

so this is the zero degree centigrade this will show uh linear behavior uh in this

so this is say 100 degree centigrade and this is 200 degree centigrade and

so on okay

so it will show a linear behavior the pressure will increase linearly as the temperature of the substance is raised or its enhanced

so it will meet the y axis at some point ok now if we imagine a negative temperature scale which does not happen but suppose we talk about a negative temperature scale and extrapolate this line to on to the x axis to the temperature axis on the negative side this will meet the x axis at 273.5

so this value is 273.15 sorry 273.15 and why is it called as absolute 0 this

ah 273.15 in the um in the
 so this minus 273.15 in degree centigrade
 so you remember the relation that we have written down earlier
 so t equal to t_c plus 273.15
 so now here t_c is equal to minus 273.15 if i add it to one 273.15 it becomes
 equal to zero kelvin
 so this is in kelvin and we get a zero kelvin and this zero kelvin as i said
 that is ah denoted as the absolute zero because this region is having a
 negative pressure which is you cannot compress anything to any pressure less
 than ah 0 that is negative pressure cannot arise for a real substance
 so no substance can physically be cooled beyond this point because if it
 can be done then we would get a negative pressure which is unphysical which
 is not permitted
 so that's why it's called as the absolute zero now you understand that this
 number came from such an experiment and that tells very succinctly that this
 is the absolute zero below which ah no substance can be cooled
 so uh just another thing that comes from here is that the pressure comes as
 proportional to temperature because of this plot where we see a straight line
 so pressure is proportional to temperature
 so that tells us that p by t is equal to constant which we ah get in as
 one of the gas laws that you will see in when you study gas laws in the in
 subsequent chapters now while studying thermal properties of solids we cannot
 ignore talking about thermal expansions of of all these thermal expansion of
 matter thermal properties of matter we cannot talk we cannot talk rather
 escape talking about thermal expansion of solids liquids and gases
 so let us talk about the thermal expansion of solids ah this is something that
 is not new to you you must have seen this when we talked about the young's
 modulus and the thermal stresses being developed due to application of
 temperature but nevertheless will do it again very quickly ah
 so this thermal expansion of solids ah happen ah when heat is applied or
 there is heat given to a system then the dimensions of the system changes of a
 solid material changes and the dimensions changing means the length can
 change if it is a one dimensional material or if it is a two dimensional
 material the area can change or if it is a three dimensional bulk material
 then the volume will change ah with temperature
 so suppose we have this figure once again which is this is your initial
 length l_0 and this is the change in length Δl
 so Δl that is the extension or the expansion of the material can be
 written in terms of its original length as l_0 and $\alpha \Delta t$ where α
 is called as a linear coefficient of expansion and just for making it more
 clear we will use a l here just that it is a length expansion
 so Δl equal to $l_0 \alpha \Delta t$ now talk about ah area
 expansion
 so this area expansion can be seen as like this
 so this is my original area a_0 and this has area a_0 plus Δa where Δa
 is the increase in area and similarly Δa can be written as $a_0 \alpha \Delta t$
 and Δt
 so i am skipping all the details understanding that you know about this the
 Δl is proportional to $l_0 \Delta l$ is also proportional to the change in
 temperature Δt and αl is simply used as a proportionality constant
 and
 so is αa here which is used as a proportionality constant and if we talk
 about a volume ah then
 so this is my v_0 and and this is my v_0 plus Δv i hope you can see that

so this is a volume
 so this the original volume is this and this has a volume V_0 plus ΔV and
 so $A_0 \Delta V$ equal to the initial volume and the αV and ΔT now
 it is also easy for small temperature changes to establish a relationship
 between α_l , α_a and α_v
 so how we do that is the following let us take this $A_0 \Delta A$ to be A_0
 α_a and ΔT
 so i can write down the final area A to be A_0 plus ΔA which is equal
 to A_0 plus $A_0 \alpha_a \Delta T$ and this is equal to $A_0 (1 + \alpha_a \Delta T)$ now
 A_0 in this particular case when you have A_0
 so this can be
 so these area that we are talking about has got two dimensions length and
 breadth say for example and similarly
 so this in order to have a relationship between α_l and α_a we look at
 this result as well
 so which is equal to l equal to $l_0 (1 + \alpha_l \Delta T)$ and now
 apparently i should get this area by taking or by squaring it up
 so that i if i have a square area which is undergoing an expansion that will
 simply be l into l
 so the new area will be l into l
 so if i square it up i will have i'll have this A which is equal to l square
 which is equal to l_0 square and $(1 + \alpha_l \Delta T)^2$ now i
 can expand it this inside term which is like an $\alpha_l^2 \Delta T^2$ plus
 α_l square ΔT square and if i commit myself to small change in
 temperature
 so if ΔT is not very large then ΔT^2 will be even more or
 even smaller and in which case i can neglect the last term and i will have a
 l_0 square and $1 + 2 \alpha_l \Delta T$ writing this l_0 square as nothing but
 A_0
 so i will have $A_0 (1 + 2 \alpha_l \Delta T)$
 so now writing A anyway as l square
 so i have this relation A equal to $A_0 (1 + 2 \alpha_l \Delta T)$ now if
 you compare it with this equation then you would definitely get that α_a
 equal to twice of α_l and similarly A_0 make taking a cube of this in
 order to get a relationship between α_v and α_l one would get it as
 α_v equal to three α_l
 so the linear coefficient of A_0 or or the coefficient of linear expansion is
 related to the coefficient of areal expansion by this relation and the
 coefficient of volume expansion is related to the coefficient of linear
 expansion by this relation
 so let us now have a look at typical values which we always do A_0 take a look
 at the typical values of these coefficients of expansion typical values
 for α_l i am only coating the the linear coefficient of expansion but you
 know that A_0 that can be used in order to get the areal coefficient as well as
 the volume coefficient of expansion
 so these are the list of materials now we are talking about solids
 so this is the α_l this is in 10^{-5} kelvin inverse A_0
 just to get the dimension correct let us write down a formula that we have
 written down earlier
 so it is a Δl which is equal to $l_0 \alpha_l \Delta T$ A_0 this is the
 relation that we have written down for the change in length now this A_0
 quantity Δl on the left hand side has the same dimension of l_0 on the
 right hand side
 so they would cancel each other and as a result α_l will have the dimension

of inverse of change in temperature which is same as inverse of temperature
so we are using the kelvin scale of temperature
so this is equal to kelvin inverse and the value is coated in units of μh in
a scale of 10 to the power minus 5 .
so it's the the unit becomes ten to the power minus five and then in μh in
kelvin inverse
so aluminium μh this is equal to two point five μh brass equal to one point
eight iron equal to 1.2 μh copper equal to 1.7 μh gold which is 1.4
and glass which is the pyrex variety this has point three two
so these are some of the typical numbers for the μh the linear expansion of
solids and one can understand that a glass has a much smaller coefficient of
linear expansion than that of aluminium
so let us look at the also some of the data for the volume coefficient of
expansion we will not provide data for this they are available in any
textbook or any data book that you come across let us only give a behavior of
 α_v which is a volume coefficient of expansion
so α_v for copper and α_v for copper looks like this and
something similar to that μh this is the temperature now we are expressing in
kelvin and this is α_v again 10 to the power minus 5 kelvin inverse and we
see that its only
so this is about 250 kelvin which is μh still below zero degree centigrade μh
it is linear and then it becomes non-linear
so we are you know mostly talking about the linear regime where the
temperature changes are small
so this is something like 500 kelvin and
so on now one interesting question is that μh when you have a hole in a
solid
so what happens to holes
so there is a hole of arbitrary shape in say a sheet of iron or a sheet of
aluminium or brass
so as you change the temperature of this sheet what happens to this hole does
it expand or does it contract or does it remain the same and the question is
pertinent and important because of the fact that the entire
so this is that material solid material it could be two dimensional it could
be three dimensional does not matter
so this material expands and
so what happens to the holes does it actually shrink and in order to answer
that let us look at this figure which is μm
so these are μh let us look at μh
so these are the tiles μm and
so its a three by three pattern made of tiles however the middle one is
missing ok
so there is a hole just as this one we have taken pattern in order to
understand it better there is a μh there is a hole there or there is a gap
there there is no tile there otherwise this area is tiled with all these are
tiles of certain material okay now what happens is that when μh one heats it
up μh it takes μh i will try to draw it to scale
so that you understand better
so these are this the expanded view of the tiles and each tile has expanded
so each tile as if had expanded and the holes have also the hole has also the
hole which is at the middle has also expanded now take a ninth tile which is
missing which is made of the same material and heat it to exactly the same
temperature difference μh
so that it has the same temperature difference as this case

so i take a ninth tile and induce the same Δt by heating now this ninth tile which was say like this when it was not heated now so this is the original size the inside is the original size of the ninth tile and once when its heated it takes this ah is this form or this shape expanded shape now this ninth tile which is of the same material and apply the same amount of heat will now exactly feed this void space so that tells us that no matter what the shape of the hole is the hole also expands when it's subjected to a heat so

that's pretty much about the thermal expansion of solids there are of course many other things which are important but we will not go into that too much of details more than this let us talk about a very important thing which is called as a anomalous behavior of water near 4 degree centigrade which is an expansion property of water which is a liquid and what is so special about 4 degree centigrade is what we are going to see you