

now why this is important is ah because it has tremendous importance on marine life on the fishes and other marine animals which are there in say lake or some static water body is very important for them so while most materials they expand when heated but a few do not okay for example the water at zero degree centigrade when it's heated its volume actually decreases till the temperature reaches 4 degree centigrade and from 4 degree centigrade onwards water starts behaving normally because the volume increases with change in temperature okay however between 0 degree centigrade to 4 degree centigrade to remind you 0 degree centigrade is called the ice point where water starts freezing or ice starts melting ah is when you have that the water actually the volume of water decreases in this temperature range which is 0 to 4 degree centigrade okay now this means that for a given mass of water it has a minimum volume um or or a maximum density in that region or near that four degree centigrade so just to tell you once more the same statement is that ah the for a given mass of water or just to write a given mass of water water has minimum volume or maximum density ah at four degree centigrade is in the vicinity in the very close vicinity of 4 degree centigrade and if we want to uh sort of express this result in terms of you know of a figure it can be shown as this

so

this is the the volume of

so the volume of 1 kg of water water

so and this is in  $10^{-3}$  meter cube and ah this is my temperature scale and this is in  $^{\circ}\text{C}$  i mean in degree centigrade

so what happens is that that the the volume actually starts decreasing as i told you and then it starts increasing at this

so it's decreases from a one point triple zero one three to a a value which is ah 1 exactly at 4 with that many decimal points and rises to about 1 point i am writing it here 1.0 at about close to maybe

so this is close to 100 degree centigrade

so this is not drawn to scale

so i am breaking the scale here um and also probably a breaking of a scale is needed here ah

so this is at this is 4 degree centigrade and this is 0 degree centigrade and this is around maybe 100 degree centigrade well centigrade degree centigrade is written

so this is like 0.4 and 10 and this 100 degree centigrade

so at 4 degree centigrade the volume of water is minimum which touches a value ah which is equal to 1

so that that it is the value is equal to 1 at 4 degree centigrade ah while the value is at zero degree centigrade it's one point triple zero and one

three and as a result if you draw the density uh and the density will uh also go from some value which is and we go like this and this is at 4

so this is again at  $t$  in degree centigrade and this is density and this density has a value exactly equal to 1 and it increases from a value close to very close to 0.9998 and reaches

so at 0 degree centigrade it's 0.99985 and it reaches a value 1 exactly equal to 1 at 4 degree centigrade and say this is something about something or 10 degree centigrade okay

so this is pretty much the behavior of water and this is called as the non-monotonic

so this is non-monotonic it's not monotonic monotonic means either it's increasing in the range that we are talking about or it is decreasing in the

range that we are talking about while this has a dip here which shows a minimum here or which translates into a maximum here in the density profile as the temperature is varied now why as I told ah this is very important from marine life and why is it

so so let us try to understand and as a

so basically in marine life particularly in countries which are near the poles or which are very closed countries as I told Canada is one of the coldest countries and there this problem is quite important

so what happens is that when the air temperature drops especially in the winter season the surface of the air gets chilled okay and suppose the air temperature is still ah above 4 degree centigrade

so the surface level of water gets chilled ah it becomes heavy and it goes down okay and the level below comes up and you know that gets again comes in contact with the air which is cold but still above 4 degree centigrade and this process continues till all the water reaches a temperature of 4 degree centigrade okay now say during night time or when temperature falls ah below 4 degree centigrade ah then or reaches say 0 degree centigrade then ah the upper layer ah freezes ah

so this upper layer freezing ah has an impact on the layers that is below

so this frozen layer or the layer of ice is acts as an insulating sheet for the heat to percolate down or go down to the ah layers ah to the water layers or the water below okay and between as we told that between zero and four degree centigrade ah density of water is maximum

so ah this level which is at 0 degree or between 0 and 4 degree will the density being ah maximum will uh stay on the

so so it basically uh it doesn't sink

so uh further cooling below zero degree centigrade ah sorry below four degree centigrade makes the surface layer to be less dense than the layers below

so since it is less dense than the layers below ah it will float on top and also importantly this layer of ice or the frozen water acts as an insulating sheet for the heat not to be able to percolate down to layers below and hence the the marine life will survive without the entire lake frozen

so the top of the lake will be frozen with a certain thickness of ice being formed on the top and the rest of the water is still maintained at 4 degree centigrade making it possible and convenient for the marine life to survive

so and it's as I said that it's possible because of this particular anomalous behavior of water that happens between 0 and 4 degree centigrade in which the volume contracts upon heating between 0 to 4 degree centigrade and beyond that as I said that it acts normally

so ah having talked about ah about this heat and properties of heat and temperature and the concept of thermal equilibrium and the concept of you know thermal expansion of solids mostly solids and now we have talked about thermal expansion of liquids it is important to understand the one concept which is called as a specific heat capacity and this is all what you have learnt in your school level that the specific heat capacity is defined as the amount of heat required to raise the temperature of a body by one degree and so it is understood that a greater amount of heat is required to raise ah the temperature to of a substance to higher values

so the amount of heat is proportional to ah two things

so let us change the title here and let us talk about specific heat capacity

so ah the amount of heat  $q$  let us call it  $q$  is proportional to one mass of the substance and the temperature difference

so mass of the substance is  $m$  and the temperature difference is  $\Delta t$  ok

so  $q$  is proportional to  $m$  and  $\Delta t$   
 so  $\Delta t$  is as you understand it's  $t_2$  minus  $t_1$   
 so  
 $t_2$  is the final temperature and  $t_1$  is the initial temperature and  
 so  $q$  can be written as  $q$  proportional to  $m$  and proportional to  $\Delta t$   
 so  $q$  is equal to some  $c m \Delta t$  where  $c$  is the proportionality constant and  
 is called as the specific heat capacity which of course has a  
 value or rather the SI unit is expressed in joule per kg  
 degree centigrade ok  
 so the heat is expressed in joule the mass is expressed in kg and the  $\Delta t$   
 is expressed in degree centigrade  
 so this has a unit which is joule per kg degree centigrade and just to quote  
 some values for the specific heat to have every time we quote a value is to  
 impress upon the fact that you should know some representative values of  
 substances that you are exposed in everyday life and  
 so we are talking about specific heat capacity of some solids and well solids  
 and I will also club liquids its only the gases to be treated separately for  
 the reason that I will come to in a while and  
 so solids are  
 so materials solid materials are um  
 so its aluminum ah  
 so  $c$  is nine  
 so this is in joule per kg  
 so this is 900 copper is  
 so these are for solids ah copper is 387 glass again its pyrex glass its  
 840 and iron is ah 452  
 so these are for the solids and let's also write down some liquids such as  
 water at fifteen degree centigrade  
 so this has a value which is ah four one eight six ah mercury ah  
 so this is let me check the number yeah  
 so this is 4186 and mercury is 139 and the glycerin is ah 2410 now this  
 number might be confusing to you and this is nothing but it's equal to 1 ah  
 its equal to one when you write it in terms of one kilo calorie ah per kg  
 ah degree centigrade ok  
 so this is ah we are very familiar with ah whereas this for water at least we  
 are not too familiar with the joule per ah in the units of joule per kg degree  
 centigrade but this is equal to 1 kilo calorie per kg degree centigrade  
 so this is for the specific capacity for solids and liquids and the gases  
 need a special mention for the reason that you need to mention uh that  
 whether you are keeping the gas at constant pressure or at constant volume now  
 this question does not make too much of a difference uh when you are dealing  
 with solids and liquids for for gases they ah definitely make a lot of  
 difference  
 so we'll call about will call the specific capacity for gases of of gases  
 and  
 so  
 specific capacity  $c_p$  ah we denoted by this ah letter  $c_p$  at constant  
 pressure um is let us call it as  $c_p$  and  $c$  at constant volume call it as  $c_v$   
 and some representative values again for certain gases which are very  
 familiar to us  
 so a gas and its  $c_p$  again in joule per kg degree centigrade and  $c_v$  joule  
 per kg degree centigrade and  
 so a nitrogen um has a  $c_p$  of 1040 whereas a  $c_v$  of 39 that is a specific heat  
 at constant volume as 739 carbon dioxide ah which is as you all know that

is denoted by  $c_{p,CO_2}$  this is equal to 833 and this is 638 J/kg·K  
so and water vapor at 100 degree centigrade  
so we are not talking about water but we are talking about water vapor at the  
steam point which is equal to 2015 and 1520 and oxygen let us write  
it with  $c_{p,O_2}$  it is equal to 912 and 651  
so one important thing that comes out is the fact that your  $c_p$  is always  
greater than  $c_v$  does the specific heat capacity which appears as a  
proportionality constant for the amount of heat required to raise the  
temperature of a certain mass of substance or heat the gas by a temperature  
through a temperature difference of  $\Delta T$   
so that at constant pressure is always greater than that at constant volume and  
as I said that it does not make a difference for solids and liquids but it  
makes a difference for the gases and as you can see that the numbers are quite  
different they are really quite different and in order to understand this  
you'll have to wait till the thermodynamics chapter where you learn that there  
is an additional amount of work that is done at constant pressure  
which creates a change in volume and that is why your  $c_p$  is always greater  
than  $c_v$  and there is a relationship between  $c_p$  and  $c_v$  which can be derived  
for a gas which is either a monatomic gas or a diatomic or a triatomic gas  
all right  
so we have looked at a number of things including the heat capacity the  
thermal expansion properties anomalous expansion of water then we talked  
about the temperature scales their interrelationship between a Celsius  
and the Fahrenheit scale the Kelvin scale of temperature and most  
importantly the concept of absolute zero and from there to get a gas law out of  
it which is  $p$  is proportional to  $T$  or  $p/T$  is a constant let us look at  
some of the important temperature values which one comes  
across in different branches of physics  
so that you have a ready reference of some numbers in front of you  
so these are these are mainly for your information and but they are quite  
useful at times or when you are trying to read a journal or a paper or a  
newspaper and when these numbers are quoted then you would know that what they  
mean  
so  
so a temperature now I am expressing Kelvin and a phenomena which are very  
important and have consequences in different branches of physics  
so a 4.2 Kelvin is when helium liquefies  
so it is the liquefaction temperature or when the helium a gas is converted  
to a liquid helium this that's the temperature I want to say one thing that  
is the constant volume gas thermometer that we have discussed the glass  
bulb that we have drawn earlier the gas contains is usually a lighter gas  
which is either a hydrogen or a helium  
so and the liquefaction temperature is 4.2 Kelvin  
so I will not write the Kelvin here I will simply talk about this and just the  
number  
so 20 Kelvin is when hydrogen liquefies hydrogen liquefies interesting  
that hydrogen also can be liquefied and there is a liquid hydrogen  
available which happens at 20 degree Kelvin with 20 Kelvin 20 Kelvin you will  
have to be correct it's at 20 Kelvin 20 Kelvin as you understand is far  
below zero degree centigrade which is the freezing point of water or the ice  
point as we say as I told you that for scientific importance which are  
beyond our day to day needs or you know the day to day input is usually  
restricted between 0 degree centigrade and 100 degree centigrade or 32  
Fahrenheit 32 degree Fahrenheit to 212 degree Fahrenheit whereas there are

temperatures which are of importance uh scientific importance which are much below that or higher than that

so 77 is when nitrogen liquefies ah if you have gone to a sort of science museum which has a liquid nitrogen show they usually you know project it as a show in which liquid nitrogen is seen to coming out from from a container making fumes out which are very cold fumes and do not ever try to put your hands into that because these temperatures are very cold it's 200 degree below ah below the ice point and anything that comes in contact you have to be very careful in handling those temperatures and

so that's when nitrogen liquefies that's a liquid nitrogen that is shown there and in fact in some of the movie shows or some of these tv television serials when they show that a lot of smoke is actually coming out and it's not hot smoke it's really the smoke coming from the you know from the liquid nitrogen ah 273 kelvin all of you know that water freezes which is 0 degree centigrade for your ready reference i will use this

so water freezes here ah three hundred ten kelvin is human body temperature as i told you the doctors will never tell you ah 310 kelvin is the body temperature that you have or you have a little more than that if you have fever they'll say that it's it's over and above 98.6 degree fahrenheit or in some exceptional cases they will talk about 37 degree centigrade which is a normal body temperature but it's not usually coated in terms of kelvin ah 373 is when water boils ah 600 when ah lead melts

so melting of lead ah which you see in the at the end of the edges end of the pencils that melts at 600 kelvin ah which is ah much beyond 100 degree centigrade or 200 degree fahrenheit

so ah 6000 is the surface temperature of the sun ah sixteen thousand kelvin is the core temperature of earth ah  $10^{10}$  kelvin is the core temperature of sun and  $10^9$  is the core temperature of of the hottest stars ok

so these are some of the temperatures which are ah usually you would see in scientific articles and scientific journals ah

so these are really large temperatures and we are talking about the hottest stars and not like the white dwarfs which are nearly gone when you read about stars and then you know that the content of stars is really the helium gases which are always burnt in order to make the stars glow but some of these stars have the entire content of helium nearly used up and they are no longer nearly like dead stars ah white dwarf is an example of such things which are which are usually taught at higher level

so we will not elaborate on that but these are starting from 4.2 kelvin close to 0 kelvin all the way up to  $10^9$  kelvin we there are different phenomena that are important scientifically to remind ourselves we were discussing thermal properties of matter and we were particularly talking about specific heat specific heat capacity and the way it was defined ah is that the amount of heat that is required to heat up a substance and thereby causing a change in temperature is proportional to the mass of the substance and is proportional to the change in temperature ah that it induces because of the addition of heat

so if you write this with an equality we would need a proportionality constant which is called as specific heat capacity which depends on a particular material now let us look at how specific capacity is measured so specific heat capacity is measured by an apparatus called as calorimeter so what is the calorimeter calorimeter is ah essentially an apparatus like a thermos which you have seen where hot coffee or hot tea is stored especially in offices which is having some kind of insulating wall and

so if there is a insulating wall outside and there is an inner space where there is a particular substance is kept and one can measure the temperature by using a thermometer such as a mercury in glass thermometer that we have talked about earlier

so there is a fluid here  
so

there is a fluid here whose temperature can be measured by using a thermometer and

so this thermos or the calorimeter does not allow heat to leak in or heat to come from the surrounding to inside however if there are two three substances that are kept in this inner flask or inner container then the the you know flow of heat is possible provided there is a temperature difference between the two between those constituent substances

so even though heat is not coming in from outside heat in the form of energy can flow from one substance to another such as if one has kept tea and ice cubes then according to law of conservation of energy heat will flow from the hot tea to the ice cubes and finally if one waits for long enough and equilibrium will be achieved in the system

so this is by and large the apparatus and let us see through an example how this apparatus can measure the specific capacity of an unknown substance

so let us do this by a numerical example

so will write down the problem

so it is an example problem

so in an experiment to find the specific heat capacity of a metal of mass of a block of metal say block of metal of mass 0.2 kg at 150 degree centigrade is dropped in a copper calorimeter whose mass is let us call it as the mass of the calorimeter its equal to 0.25 kg sorry the mass of the calorimeter is taken as point one four kg and this calorimeter contains water or 0.25 kg water at 27 degree centigrade the final temperature

so this final temperature means that after the thermal equilibrium is established

so the final temperature is 40 degree centigrade compute the specific heat capacity of the metal it is given that i use a shorthand notation now the specific capacity of water

so we will call it as  $c_w$  this is equal to a four point one eight into ten cube joule per kg kelvin and the copper calorimeter has a specific heat capacity i will call that as  $c_c$   $c_c$  stands for calorimeter  $w$  stands for water

so this is equal to 0.38 into 10 cube joule per kg kelvin ok

so just to summarize the problem that we want to know the specification of a certain block of metal

so a 2.2 kg block of metal is dropped into a copper calorimeter which has a mass 0.14 kg and this calorimeter contains 0.25 kg of water at room temperature which is usually taken as 27 degree centigrade once this is dropped the block of metal was initially at 150 degree centigrade

so the after the thermal equilibrium is achieved that is heat will flow from the hot block of metal to the cold water after the thermal equilibrium is achieved then the final temperature is 40 degree centigrade

so using these data one has to compute the specific heat capacity of the metal and it's given that the specific heat capacity of water is this and the specific heat capacity of the calorimeter copper calorimeter is this ok

so i will remove this for now in order to do the problem  
 so the basic principle is that that the heat that flows out of the metal block  
 is absorbed by the water and the calorimeter  
 so these two quantities of heat would be same in order to compute and one has  
 to compute the specific capacity of the metal  
 so let us ah you know write ah  
 so m  
 so data given um data given m m ah which is mass of the metal is equal to  
 0.2 kg ah  
 so the um  
 so initial temperature of the metal let us call it as  $t_{m1}$  equal to ah  
 point uh sorry ah its 150 degree centigrade ah and  $t_{m2}$  that is the final  
 temperature of the metal ah would be same as the final temperature that is  
 coated here which is forty degree centigrade all right  
 so  $\Delta t$  um this is equal to ah  $t_{m1} - t_{m2}$  which is equal to  
 110 degree centigrade and since 1 degree centigrade is same as 1 division in  
 the kelvin scale kelvin temperature scale we can just simply call this as 110  
 kelvin thats the temperature difference ah the initial temperature minus the  
 final temperature  
 so the heat lost  
 so heat lost by the metal block  
 so  $q_m$  is equal to  $c_m$  which i need to find ah m is 0.2 kg and my ah  $\Delta t$   
 t which is ah  
 so that is my the heat required  
 so this will be in joule  
 so this is like 22 cm and in joule now ah the  
 so this heat is lost by the metal block now it has to be the same amount of  
 heat has to be gained by the water that is present and the copper  
 calorimeter ah  
 so ah the for the temperature difference for both calorimeter and copper ah  
 is  
 so  $\Delta t$  for um which is for water  
 so this is for the metal  
 so this is 40 degree centigrade minus 27 degree centigrade which is equal to  
 13 degree centigrade which is nothing but equal to 13 kelvin ah  
 so the specific heat of water is given  
 so the amount of heat gained by the water plus calorimeter  
 so  $q_w$  plus  $q_{\text{calorimeter}}$  ah this is equal to  $m_w c_w \Delta t$  ah which is  
 uh  
 so this is  $w$  ah water and the calorimeter  
 so this is let's just call it simply as  $\Delta t$  and plus ah m for the  
 calorimeter c for the calorimeter and the same  $\Delta t$   
 so this comes out as if you do this simple algebra it comes out as 13.5 plus  
 0.703 into 10 cube joule with the data that are given here ah  
 so this is the heat gained by the water that is kept in the calorimeter and  
 the copper calorimeter itself  
 so my let us call this as  $q_{\text{total}}$   
 so  $q_t$   
 so according to the principle of calorimeter  
 so  $q_{\text{total}}$  should become equal to  $q_{\text{metal}}$  and if i equate equation one say  
 to equation two i will find  $c_m$  to be equal to point six four nine into ten  
 cube and joule per kg inverse kelvin inverse ok ah  
 so this is the specific heat capacity of the metal block that is needed to  
 find out and the calorimeter ah finds out is the apparatus which finds that

out ok

so ah

so this way for any unknown liquid the specific heat capacity can be determined now let us look at another very interesting phenomena which is called as change of state and how a change of state is actually accompanied by ah the latent heat

so we'll have to understand the concept of latent heat the word latent means slipping or dormant or which is not ah perceivable or observable

so we know that there are three states of matter which we are continuously talking about in various contexts which are solid liquid and gas and they have their own properties that we have seen there are values of different quantities physical quantities we have seen their experimental values and so on now ah one can actually achieve a change of phase or a change of state that is one can go from one state of matter to another state of matter either by addition of heat or by removal of heat and this change in phase is ah is possible in a day-to-day experiment and this will be accompanied as we'll discuss soon will be accompanied by a latent heat

so

normal normally we understand that when we add heat or remove heat from a substance the temperature would rise or fall depending on the situation now there are situations in which the temperature does not rise or does not fall even if heat is added or removed let us take this example of say this is a thermos flask ah and there are um ice t

so there is ice t ah sorry t plus ice cubes which are known as ah ice t say for example

so this ah t and there are ice cubes there now what you do is that you put it under a flame

so you are heating it up you are heating it up and ah this is just a container or it could be you know a sort of flask that we have said ah just a container for now and one is heating it up what will happen is that the and if you have a thermometer somehow that you can insert it ah here and record the temperature you will see that there is no change in temperature for some time and that sometime is till all the ice cubes melt when all the ice cubes melt it will be only tea remaining there in liquid form and the heating more the temperature will start rising again okay and

so apparently the purpose of the heat is not to increase the temperature and the temperature remains at zero degree centigrade

so just to summarize it once more that you have some tea there and ice cubes that are kept in a container and you have started heating it up and you are measuring the temperature and you see that heating for some time the temperature does not rise and the mercury or the reading of the thermometer stays at 0 degree centigrade which is the freezing point or which we have called as the ice point and when all the ice cubes melt then only the temperature starts rising

so in that intermediate phase when the temperature does not rise the purpose of heat is actually not to increase the temperature but to do something else and that something else is in the form of melting the ice and if i want to draw this ah as a plot for ah

so temperature in degree centigrade and time which time could be measured in minutes or seconds depending on how much of ice t we have or rather t and blocks of ice

so we leave that unit for now

so what we'll see is that for some time the temperature does not rise for some minutes or seconds whichever unit we are measuring it and then it starts

rising and then what happens is that it will be again there is a plateau a plateau is a flat line and which happens at 100 degree centigrade ah well we have written degree centigrade

so this is 0 and this 100 degree centigrade and then it starts rising again we have simply just talked about this part where the temperature does not rise we have not talked about this plateau which we are just coming in a while now also have a look at ah this diagram here you can now it is this that we have three

so we let's draw a slightly bigger equilateral triangle

so if this vertex of the equilateral triangle we have a solid

so this is a solid and there is a container containing a liquid and there is another container containing gas ok

so these are the three states of matter and one can go from one state to another ah just like what we have seen just a while back that the ice cubes upon heating are melting and becoming water and that's the so a solid is becoming a liquid

so these processes let us name these processes before we go ahead

so these processes is called this is called melting its also called as fusion in some books you will see them as fusion ah this is called freezing

so when you keep water in the deep refrigerator where in the part of the fridge which makes ice that is where when a liquid is transformed into a solid ice and this is called as evaporation

so conversion of liquid into its gaseous form is called evaporation and the reverse process is called as condensation ah similarly ah this from solid to gas directly which are which is not very common even though some materials show this property that directly from the solid phase it goes to ah gaseous phase camphor is one such example we will give another example interesting example this is called as sublimation and the reverse is again called as condensation that is going from a gaseous phase to a solid phase is called as ah condensation

so

what happens in this part is that the water starts to boil because now from here we had at this point let us name them let us call them as a b c d and e ah in this part ice melts and what happens to this ah

so this a b part the ice melts in this part the water warms up water warms up and the heat required or rather the heat needed for the water to warm up will follow this ah equation  $q = mc\Delta t$  where  $q$  equal to the heat  $m$  is the mass of the substance and  $c$  is the specific heat of the substance and  $\Delta t$  is the temperature difference here the temperature difference is 0 and 100 minus 0 which is 100 degrees or 100 kelvin and then here what happens in this part that is this part cd is that the water boils and again the temperature does not rise again the temperature does not rise and even if heat is being given because we are scanning it as a function of time which means that we have put a burner or a flame and subjected the system to that flame so its heat is continuously getting into the system or its heat is added to the system suppose we are going from increasing in time or if you actually also want to call it as heat and in which case we can also talk about removal of heat if we go from the from the right to the left but right now we are going from the left to the right and here water starts water boils and this the water will boil till the point that all water is converted into vapor when all water gets converted into vapor with the addition of heat the temperature then starts rising once again

so it is basically water vapor warms up ok

so i hope this figure is clear we drawn temperature versus time time over

which ah this system is subjected to heat this part the temperature does not rise and the system undergoes from a solid to a liquid phase so all the ice melts when all the ice melts the temperature starts rising again now this at this point water starts boiling which means the system now is a combination of liquid and vapor and when all the liquid gets converted into vapor then the temperature starts rising once again so this is typically a phase diagram or rather the showing of different phases when a change of state or a change of phase occurs due to addition of heat we can also talk about as i said that removal of heat in which case we actually move ah in the reverse direction you