

let us now take a look at what we have learnt earlier and revise it once again for the sake of clarity

so if you remember that we have talked about inelastic materials and plastic materials we haven't made a great deal of distinction between the two but there is a subtle difference between inelastic and plastic materials the inelastic materials do not exhibit a specific trend of deformation as a function of the applied force in fact they may not deform at all which i will give an example or the deformation caused could be partially recoverable or reversible when the load or the force applied is being removed so however the materials which are permanently deformed even when the load is removed are called as plastic materials ok

so what i wish to state is that that all plastic materials are inelastic materials while all inelastic materials are not plastic materials let me elaborate this statement a little more take an example of a steel rod steel is a very well known material and it has been discussed in the context of elasticity quite a bit the steel rod remains rigid for low to moderate tensile forces further increase of the forces shows a linear elastic regime where hooke's law is valid which i have told you earlier while if we increase the force or the load further then beyond a certain value the material breaks or the material fractures

so thus at low or moderate tensile forces steel behaves like an inelastic material but this is not plastic distinguish it between a plastic material now while at very large forces when it breaks it demonstrates a plastic behavior

so if we summarize this discussion of the distinction between inelastic materials and plastic materials we could say that the plastic materials are the subsets of the inelastic materials so all plastic deformations are inelastic deformations where hooke's law is not obeyed but all inelastic deformations again for which the hook's law is not obeyed are ah are not plastic deformations let me also at the same time revisit the microscopic concept of elasticity which could actually enhance your knowledge about elasticity and make you understand the notion of elasticity which we have been talking about better

so from the intermolecular and the inter atomic forces perspective one can understand the elastic behavior take the short short piece of metallic wire such as a straightened paper clip you have seen those paper clips if you just open these windings and straighten it up is what we are talking about as a short wire

so if you try to stretch it along its length okay and if the stretching forces are small the wire will not break

so what happens at the atomic level is the following

so one has slightly increased the average distance  $r$  between the atoms which constitute this wire this metal wire and however the attractive forces between the pairs of atoms is able to restore the tensile forces that is given by you okay

so now just do the opposite that is apply a compressive force uh or a compressive stress

so you should try to shorten the length of the wire

so if you do that for again for short compressive stresses the repulsive forces between the pairs of atoms combats or it resists uh the compressive stresses

so the the further observations will reveal that it is fairly difficult to compress a metal and

so that the repulsive force must be really very large

so that ah

so that one even for you know small distances between the atoms okay

secondly once a metal is broken by large tensile stresses or compressive stresses given to them they cannot be joined together

so even for a distance as small as a millimeter or even a fraction of a millimeter the attractive forces are effectively negligible or they are nearly zero

so let me now uh do a dimensional analysis of the young's modulus to make you understand it better we go back to this very familiar equation which is  $y = \frac{f}{A} \cdot \frac{\Delta l}{l_0}$ . to remind you uh you have seen this expression a number of times why is the young's modulus  $f$  is the force or the load that is given to the material in order to cause either stretching or compression  $A$  is the area of cross section of the material  $\Delta l$  is the change in length and  $l_0$  is the original length of the material  $i$

so this is truly written as stress over strain and just to remind you that this stress could be compressive stress or it could be tensile stress

so in any case you have the stress which is the force over area given by  $m \cdot l \cdot t^{-2}$  the reason being that the force is always written as a mass into the acceleration

so this is mass and this is the acceleration which is distance divided by time square or velocity divided by time and  $A$  goes as which is the area of cross section goes as  $l^2$  square and the strain is dimensionless

so i'm just simply writing a 1 there

so the whole thing is actually newton is the unit for the force and divided by the  $s^2$  unit for area is meter square

so  $y$  has the unit newton per meter square i shall list out some of the materials which are used in day-to-day life also they are used as construction materials i'll write down their maximum allowable the stresses and the compressive stresses and the shear stresses

so to begin with

so let's just make this table

so we have a material and then we have tensile strength newton per meter square compressive newton per meter square and shear strength again in newton per meter square

so iron its  $117 \times 10^6$  to the power 6  $550 \times 10^6$  to the power 6  $170 \times 10^6$  to the power 6 steel  $500 \times 10^6$  to the power 6 of  $500 \times 10^6$  to the power 6  $250 \times 10^6$  to the power 6 break  $10 \times 10^6$  um this is  $35 \times 10^6$  to the power 6. 4 concrete which is  $2 \times 10^6$  to the power 6  $20 \times 10^6$  to the power six two into ten to the power six two hundred into ten to the power six two hundred into ten to the power six  $200 \times 10^6$  to the power 6 and we have wood pine wood which is  $40 \times 10^6$  to the power 6  $35 \times 10^6$  to the power um 6 and 5 into  $10^6$  to the power 6.

so these are the maximum allowable stresses for each of these materials

so we were talking about the strength of materials ah i have listed some of the materials which are very familiar to us and we have seen that if the stress on a certain object is too large it will cause either permanent damage or it will cause fracture and make the material to break some of these materials which are listed on the left are very familiar to all of you they are used as building materials they are iron steel brick concrete aluminum wood especially pinod and we have listed the maximum tensile strength maximum compressive strength and maximum shear strength all in newton per meter square and if one is making a structure with any of these materials such as iron steel brick concrete aluminium or wood one should never cross these numbers and in principle while making structures they should be something

like 10 percent of these numbers and should not exceed more than that in any case

so just to bring to your attention that iron has the tensile strength to be reasonably large which is  $117 \times 10^6$  whereas the compressive strength is more than three times of that and the shear strength is again  $117 \times 10^6$ . similarly the steel has 10 times strengths and compressive strength and shear strength to be much larger whereas brick has a small tensile strength and reasonably large compressive strength and that's why

so brick is good under compression ah but it's not when it's uh exerted to tension and similarly a concrete also ah is used for pillars or vertical columns um because the compressive strength maximum compressive strength is about  $20 \times 10^6$  newton per meter square whereas the tensile strength is small which is  $2 \times 10^6$  meter newton per meter square so when one uses them in buildings they use reinforced concretes in which the iron rods are inserted into the concrete structure and which perform much stronger than without them and it's good for the stability here you can see a beam that's been acted upon by a force at the middle which is like a compressive strength that is given to the beam and the beam uh shows a deformation um in the middle and these kind of deformations are to be kept in mind while building structures

so now let's discuss uh another thing which is very important from the experiment point of view that's experimental determination of young's modulus

so here we wish to understand that how experimental determination of young's modulus for a material of a wire can be determined ah

so if you look at the picture there are two wires a and b a is called the reference wire and b is the experimental wire for which we need to know the young's modulus

so there is a scale system as a measuring device which consists of a main scale and a vernier scale initially both these wires are given some small but finite weight

so that they are elongated and straight both these wires have same area of cross section and length

so the initially the meter reading is noted when the weight in both these wires the reference wire and the experimental wires are same and then the experimental wire is loaded with some more weights which causes an elongation and again the reading is noted the difference between the two vernier scales that is when they are equal weights as compared to when there are unequal weights are the difference between that is taken as the elongation

so let us assume that the initial radius the radius of both the wires is equal to  $r_0$  and initial length is equal to  $l_0$

so elongation due to the weights is equal to  $\Delta l$  and suppose mass causing the elongation is equal to  $m$

so the young's modulus can be written as

so its  $\frac{mg}{\pi r_0^2}$

so this is the stress divided by the strain okay

so since all these quantities such as  $m$ ,  $\Delta l$  and  $l_0$  all are quantities that we know for using this formula we can find out the young's modulus of the experimental value

so ah now we shall talk about some examples to what we have learned

so far and let us have two plots which depict stress versus strain for two materials two different materials and they look like this

so let's call the plots as a and b so these are stress versus strain

characters for two materials say two wires and they look like this the question is that one which material has larger young's modulus second is which of the two is a stronger material and the answer would be b in both the cases and let's try to understand why that is the case the young's modulus  $y$  is defined as the ratio of stress to strain so it's this versus this okay since b has a steeper slope as compared to a so b has larger young's modulus and a has smaller young's modulus and to answer the question second question that is which one of them denotes a stronger material again the answer would be b the reason is that that to cause the same strain you need bigger stress for b so to cause a strain of this much a stress of this is required however to cause a strain of again the same amount a much larger stress is required so strength this b material has more strength as compared to the a material so here ah in the next example let us compute the bulk modulus of water from the data that is given so the initial volume of water is given as 100 liters the pressure increase is given by  $\Delta p$  which is equal to 100 atmospheres and just to let you know that 1 atmosphere is equal to  $1.013 \times 10^5$  pascals and 1 pascal is equal to 1 newton per meter square so if you need to calculate the bulk modulus from this data so bulk modulus is given by  $\Delta p$  divided by  $\Delta v$  divided by  $v_i$  and  $\Delta v$  is  $v_f$  minus  $v_i$  which is equal to 0.5 liter so if you put in all these things which are 100 atmosphere which is equal to this pascals and into 100 liters divided by 0.5 liters then this thing comes out to be equal to  $2.026 \times 10^9$  pascals which is equal to ah  $2.026 \times 10^9$  meter per newton per meter square so ah the question is that why do water so water seem to be having a large bulk modulus in fact the gases have more bulk modulus because they are compressible so more the compressible the fluid is more bulk modulus it will have so the bulk modulus from the data is given by  $\Delta p$  over  $v_i$  which is equal to  $\Delta p$  into  $v_i$  divided by  $\Delta v$  and this is 100 atmosphere  $1.013 \times 10^5$  pascals into 100 liters divided by 0.05 liter so this will come in pascals and which is equal to zero two  $2.026 \times 10^9$  pascals which is equal to two point zero two six into ten to the power nine newton per meter square so this is the bulk modulus of water for a pressure given to be of hundred atmosphere when the liquid has expanded from hundred liters to hundred point five liters so as a third example let us see the again the computation of bulk modulus now not for a liquid but for a solid copper cube which is uh 10 centimeters of edge and it's subjected to a pressure hydraulic pressure of  $7.0 \times 10^6$  pascal and given that the bulk modulus of copper solid copper is  $140 \times 10^9$  newton per meter square so we again use this formula as  $\Delta p$  divided by  $\Delta v$  over  $v_i$  do not forget to convert your  $v_i$ 's which are in 10 centimeters whole  $q$  or this is equal to 0.1 meter whole cube which is equal to 0.001 meter cube and your  $\Delta v$  is what is wanted so  $\Delta v$  divided by  $v_i$  becomes equal to a  $\Delta p$  divided by  $B$  and this  $v_i$  can go upstairs ah for you to compute  $\Delta v$  which is the change in volume of the solid copper cube and this can be when you put in all these values  $\Delta p$  is  $7 \times 10^6$  pascals this is  $140 \times 10^9$  newton per meter square and this is equal to 0.001 meter cube and this is

almost equal to point  $5 \times 10^6$  to the power minus 6 meter cube so that is the change in volume that you will have for a solid copper cube when it's subjected to a hydraulic pressure of  $7 \times 10^6$  to the power 6 pascals

so let me write down a problem

so there are two wires each of diameter 0.25 centimeter one of steel and the other of brass as shown below I will just show the diagram in a moment the unloaded length of the steel wire is 1.5 meter and that of the brass wire is one meter compute the elongations of the steel and brass wires given  $\gamma_{\text{steel}} = 20 \times 10^{-10}$  the power ten newton per meter square and brass  $9 \times 10^{-10}$  to the power ten newton per meter square

so the diagram is

so the loads that are these are subjected to is steel the steel wire is subjected to a load of four kgs and the brass wire is subjected to a load of 6 kgs and you need to calculate the elongations of the steel and the brass wires let us do this problem

so there is a rigid support here there is a steel rod which is loaded with a weight 4 kg

so this is steel and this is 1.5 meter long there's a one meter long brass wire which is loaded with a 6 kg this is brass and this is 1 meter the diameter of both are 0.25 centimeter which is equal to  $25 \times 10^{-3}$  to the power minus 4 meter  $\gamma$  of steel is equal to  $20 \times 10^{-10}$  to the power 10 newton per meter square  $\gamma$  for brass to be  $9 \times 10^{-10}$  to the power 9 newton per meter square so we shall use this formula which is well known to us its stress divided by the strain which is this

so the extensions are going to be computed as  $f \times 10$  divided by  $a \times y$  and hence for steel

so the extension in steel let's call it  $\Delta l_{\text{steel}}$  that's going to be uh now there are two weights acting on the steel wire which is 4 kg and 6 kg assuming the wires are massless

so you have 10 kg of weight being supported by the steel wire

so this will be like 10 kg and taken  $g$  to be taken as 10 meters per second square it will be 100 newton uh and 1.5 meter is the length divided by  $\pi \times 25^2$  into  $10^{-8}$  into 4 and the  $\gamma$  to be given as  $20 \times 10^{-10}$  to the power 10 ah and this will be in meter if you do this simplification this comes out to be  $1 \times 10^{-4}$  ah meter whereas the same thing done for the brass we have a  $\Delta l_{\text{brass}}$  and now the weight that the brass wire supports is ah 6 kg

so it will be 60 newton ah into 1 divided by  $\pi \times 25^2 \times 10^{-8}$  to the power minus eight into four now the brass ah has a young's modulus which is  $9 \times 10^9$  ah i'm sorry this is  $9 \times 10^{10}$  to the power 10

so this will be  $9 \times 10^{10}$  and if you simplify this this comes out to be  $1.35 \times 10^{-4}$  meter thus the brass wire has a little more expansion than the steel wire the steel wire even though it's loaded with a larger weight it still is more difficult to cause elongation in the steel wire as compared to the brass wire let's do a problem on young's modulus elastic properties of matter now let us talk about a titanium alloy

so a cylindrical specimen of a titanium alloy having an elastic modulus of one zero eight giga pascal as we have uh told you many times that the elastic modulus or the young's modulus in practical units is represented by this pascal or giga pascal whereas we know that one pascal equal to one newton per

meter square

so ah

so this and an original diameter of 3.9 millimeter will experience only elastic deformation when a tensile load two thousand newton is applied compute the maximum length of the specimen before deformation if the maximum allowable elongation is zero point four two millimeter

so ah titanium alloy is given um the elastic modulus or the young's modulus which means the same thing in this case ah is given and also the original diameter is given it is experiencing only an elastic deformation which means we are fully in the elastic limit when a tensile load of 2000 newton is applied

so compute the maximum length of the specimen before it starts deforming and it's given that the maximum elongation is 0.42 millimeter ok

so to solve this the initial area of the cylinder is a zero pi d zero by two square where d zero is the initial diameter which is given as three point ah nine millimeter

so d zero equal to ah three point nine millimeter

so now the original length ah is related to the deformation ah let us call this original length to be say  $l_0$  which is related to the deformation by this simple formula where  $\Delta l$  is the elongation which is given the maximum elongation is given ah the young's modulus or the elastic modulus is given and the tensile load is given to be 2000 newton ah  $A_0$  is given

so now we can put everything here and calculate

so this is my elongation this is my young's modulus then there is a pi and then there is a 3.9 into 10 to the power minus 3 there is a square there divided by 4 into 2000 newton so this 4 is coming because there is a  $d_0^2$  square by 4 and if you calculate that this becomes 0.257 meters which is equal to 257 millimeter

so this is the maximum length of the specimen before it starts deforming

so having uh understood a number of things about elasticity

so far and also that we have discussed plastic behavior and plasticity and the difference therein with inelastic materials let us now look at certain quantities or rather certain terms which are of importance not only in the context of physics or the mechanical properties of solids but in the context of your daily life or even in the context of chemistry that you would see ah and which are also about the properties of matter and we haven't discussed them very explicitly ah a number of things such as let's just list them out one it's called as toughness ah to its brittleness ah three its hardness for say for example resilience and maybe five as stiffness you may have heard these terms that appear on the board in the context of something else and also in the context of properties of matter let us now try to give a formal definition to it

so that you understand it better and what they have got to do with the modulus of elasticity and

so on okay

so let's just talk about start with this toughness that we have written it there and let's define toughness

so it's the ability of a material to absorb energy to absorb energy and plastically deform without rupturing

so ah here it goes ah its the ability toughness is the ability of a solid material to absorb energy and deform uh in an inelastic or a plastic manner without breaking apart or without rupturing

so it's actually the the amount of energy per unit volume ah that a material can be subjected to before it ruptures or before it breaks apart the

examples can be given in the following fashion that you see materials like ceramics which have small toughness which means that they actually break apart when they are subjected to a tensile or a compressive stress so even then they are very strong materials so the ceramics are actually strong materials where they're low on toughness whereas rubber is actually a tough material but it's weak in terms of its strength okay

so we give examples of ceramics as having low toughness whereas rubber to be having a high toughness ok ah let us go to this second quantity called as brittleness

so this you may have heard of when you have talked about materials in chemistry

so a material is called as brittle when its it breaks when it's subjected to a stress and

so without undergoing any kind of significant deformation

so it just breaks

so it's

so it breaks ah being subjected to stress without undergoing significant deformation under strain

so ah technically speaking they absorb a very small amount of energy prior to fracture and uh even when they have very high strengths

so ceramics and glasses for example they do not deform uh plastically and uh they actually break very easily under stress

so they are known as brittle materials in fact some of the polymers such as polystyrene they are also known as brittle materials and even steel which is known to be quite tough at very low temperatures can become a brittle material similarly if you have gone to these shows where they show the utility and various things with liquid nitrogen ah you might have seen that they actually dip their hands inside the jar containing liquid nitrogen but they wear sort of gloves in order to put their hands in and the reason is that the bones become extremely brittle at that temperature the liquid nitrogen temperature which is actually the boiling point of nitrogen is about 77 kelvin

so it is not advisable to touch liquid nitrogen by bare hand let's talk about the third quantity which we have listed down such as hardness

so hardness is the measure of how resistant a solid is to a permanent shape change when an applied force is given

so there are different kind of hardnesses such as scratch hardness indentation hardness etc

so it's the property which says that or rather it's a measure of how resistant ah material is to a permanent shape change when subjected to a subjected to an applied force

so ah glass materials have a lot of hardness as compared to soft materials such as copper or aluminium

so let's look at the next property called as resilience

so it is a capacity of the material to absorb energy when it's elastically deformed and then ah when the inner energy is released ah upon unloading ok

so resilience is the capacity of a material to absorb energy when it is deformed elastically and then the energy which it has absorbed is released released upon unloading

so ah once it absorbs energy when it's loaded and one after that when it's unloaded that is the load is taken off then it releases energy and it is obtained from the area of the stress versus strain graph

so let us take a typical stress versus strain graph

so till this is the elastic limit

so let us call this strain as  $\Delta x$  elastic and this is the stress which is equal to  $f$  over  $A$  let's just denote it by  $\sigma$

so the area under this curve till the elastic limit is called as the resilience

so what is uh

so the energy that is absorbed and hence released upon unloading is given by  $\int \sigma dx$  which is the stress and  $dx$  from  $0$  to  $\Delta x$  elastic and now because this will give the area of this

so this is my value of  $\sigma$  here

so this has to be taken half of it because we are only talking about the area of a triangle and not the area of the whole rectangle that appears here

so this is equal to half  $f$  over  $A$  and  $dx$  from  $0$  to  $\Delta x$  elastic which is equal to half  $f$  by  $A$  into  $\Delta x$  elastic

so that is the  $U$  resilience

so ah this is the energy stored and hence released upon unloading for which measures the resilience of a given body now let us look at the last one

which is the toughness rather stiffness sorry not toughness its stiffness toughness we have already talked about which is what we have begun our discussion with

so stiffness is defined as the ratio of the of the steady force acting on an elastic body to the resulting displacement

so it's the ratio of the the force that is applied to the body and the displacement that occurs due to the applied force ah

so as such a stiffer material has a higher ah stiffness has a higher ah elastic modulus sorry elastic models

so stiffness is a measure of ah or rather the elastic modulus is a measure of stiffness the higher the elastic modulus higher is the stiffness

so having learnt about the elastic properties of matter we shall consider now the effects of temperature which we have missed out

so far and as we know that temperature plays a very important role in everyday life ah

so it will play also an important role while discussing the elastic properties of matter

so because of temperature the stress that is developed it is called as a thermal stress and

so we shall discuss thermal stress in next days class and we shall also talk

about ah the elasticity of different components of human body ah and how they are different than the solids that we have discussed

so far you