Blossoms - Elasticity Lesson

[MUSIC PLAYING]

Hello, everyone. I'm Sourish. And what you just saw me doing with this slingshot is an application of a very beautiful concept called elasticity. Now, elasticity is a very useful concept used by engineers and scientists to look at how solids change shape and size when subjected to forces. Its applications are all around us. From the small rubber bands that you may use to wrap your lunchboxes to a very large structure such as a bridge, elasticity is at work in all these solid objects.

As another practical example, let's consider this metal ruler. When I apply a load at one of its ends as such, it bends and I feel pressure at the tip of my finger exerted by the ruler. The more I bend it, the more pressure I feel at my fingertips. And if I relax the load, I see that this ruler regains its original shape.

Now, isn't this behavior of the metal ruler very much like that of the rubber band in the slingshot? If I keep pulling this rubber band, I feel more tension pulling at my fingers. And as I relax this tensile force, the rubber band regains its original shape. This particular behavior we observe in both the metal ruler and the rubber band is by virtue of the respective materials, namely steel and rubber, being elastic.

So elasticity can simply be understood as the property by virtue of which a solid material will try to resist change in shape and size when loaded by some external force, and as the load is removed, the deformed solid regains its original form.

Now, let's do an activity with a goal to explore this concept of elasticity with some simple solids. In this next activity, we will be using the simple solids and applying a pull or a push force on them. We'll try to observe two things-- the first, how much force we need to deform the solid by a small amount, and the second being how far I can deform the solid such that it regains its original shape once the load is removed. I'll see you in a few minutes.

I hope you enjoyed this activity. Before we go on to more exciting activities, let's discuss what you observed just now. When I did this activity myself, I found that the force required to deform these solids by the same small amount varied. I hope your own observations are similar to mine.

Based on this observation, we may draw our first main inference that some of these objects seem to be more stiff than the others. The second important observation that I made in my experiment was that all these objects could regain their original form when the load was released only if the deformation was limited to a certain extent. I hope your own observations are also similar to mine and you found that the maximum amount of elastic deformation varied across these solid objects.

Now, recall that we refer to elasticity as the property of a solid by virtue of which it resists change in shape and size when subjected to forces, and once the force is removed it regains its original undeformed state. Since the objects in the previous activity all demonstrated these two main properties within certain range of deformation, we can infer that these objects behave elastically within their respective elastic regimes. Outside its elastic regime and until the solid object breaks, we can say that the material behaves inelastically.

To understand elasticity better, let us consider a spring of negligible mass with a small bob attached to one of its ends. When the small bob is pulled towards the right by an applied force F_A, the spring tries to oppose the tendency of change in length by applying a reaction force F in the opposite direction of the applied force.

To describe this behavior mathematically, we can assume that F_R varies directly proportional to the change in length delta taken to the power n. The proportionality constant k is known as a spring constant. The spring constant is a measure of the stiffness of the spring. The higher the value of k, the stiffer is the spring.

The special case when the exponent n equals 1 applies to the case of a linear spring, and the force deformation equation is then referred to as the Hooke's law. When the mass is negligible or when the deformation occurs very slowly, then the applied force will equal this reaction force, as per Newton's second law of motion.

This very simple model captures the essence of elasticity. And for a general solid, it can be considered to be made up of many tiny springs connected to each other. Even in this case, the mathematical description of force due to deformation of the solid although more sophisticated, it still is an extension of the simple spring model. You can learn more about this in college level physics and engineering classes

For now, let's consider the rubber band that I used as a slingshot in the beginning of the lesson. I can pull this rubber band slowly in a controlled manner and observe the amount of force using a force meter. I can then plot an increasing sequence of measured forces and corresponding changes in length of the solid as points on a force versus deformation graph.

If the points lie on a straight line, then we can say that Hooke's law of linear elasticity holds. The slope of this straight line can help us determine the spring constants from such measurements. Most solid materials obey Hooke's law in their elastic regime when the deformation is relatively small.

In this next activity, we will be generating a similar force versus deformation data for a rubber band under uniaxial loading conditions. What we will do is this: we will take a rubber band and slowly increase the force in a controlled fashion and measure its extension. Then we will look at the data on a force versus deformation graph. Let's meet after the next activity.

Wasn't that fun? You generated your own force versus deformation data. So how do the results look? Did you get a straight line or was it a more complicated shape? When I did this experiment, I got this curve. I hope it resembles some of yours. Good work, everyone.

Now, let's try to analyze this data. In the previous activity, all or some of you may have noticed that although the rubber band behaves elastically, meaning that it regains its original size once the load is removed, its force-deformation curve need not follow a straight line. Owing to such observations, the elastic property of rubber is classified as nonlinear elastic. The word nonlinear here means that the force versus deformation curve is not a straight line.

This distinction is illustrated in this figure. Please note that the x- and y-axes are not to scale since rubber can undergo very large deformations. Different materials can have different shapes in their force-deformation curves. These curves are very useful. For example, using such a curve one can predict how much force is needed to change the shape or size of a solid by a prescribed amount.

Now, this curve is hiding a little secret. It's trying to tell us something about the energy stored in the rubber band due to stretching. So when I stretch a rubber band, I do work on it, and this work gets stored in the stretched material as potential energy.

The area under the force-deformation curve is actually the total potential energy stored in the material due to elastic deformation. We can use this potential energy to perform some mechanical work by converting it to kinetic energy.

In the beginning of this lesson, you saw me trying to hit a bull's eye with this sling shot. So there I converted the potential energy stored in the rubber band to the kinetic energy of the projectile. Energy from the slingshot could also be released as sound that we hear on recoil, heating of the rubber, and work done against some frictional force-- for example, air drag-- which always tries to stop any motion.

Nevertheless, can we at least say that in the case of the rubber band slingshot, most of the potential energy gets converted to kinetic energy? If we know this answer, then we can actually predict by how much we should stretch the rubber band such that when released it will perform a desired amount of mechanical work.

So let's try to find an answer to this question in our next activity. In this activity, we will try to launch a small object using the rubber band from our previous activity as a slingshot. And then we'll try to analyze the proportion of potential energy that was converted to kinetic energy of the small object. So I'll meet you after this next activity.

I hope you enjoyed this activity. This was a challenging exercise, and well done to all of you. Isn't it great that this toy slingshot can also help us in our science experiment! Note that the kinetic energy of the projectile at launch is a positive number that is less than the potential energy of the rubber band before its release, since the potential energy is also converted to other forms of energy.

For, example, at the time when the matchstick loses contact with the rubber band, the released potential energy has been converted to kinetic energies in both the projectile as well as the rubber band. Additionally, there is also some energy lost as sound heard when the rubber band is released, heating of rubber, friction at the two pegs where the rubber band is fixed, air drag on a rubber band while in motion, and due to friction and inelastic deformation at the contact between the rubber band and matchstick.

Therefore, the ratio of kinetic energy of matchstick at launch to the initial potential energy stored in the rubber band before its release must be less than 1. When I did this experiment, I found this ratio to be 0.07. Based on this observation, we can infer for my rubber band-matchstick set up the initial assumption that most of the potential energy of the rubber band is transferred to the matchstick is not quite right. A significant portion of the potential energy is converted to other forms of energy.

The ratio that we got, can we say it is an accurate representation of the true ratio? Probably not. We were not using the most accurate experimental setup. And we made some assumptions along the way. So we know that this estimate of kinetic energy to potential energy ratio is not perfect and has some error in it. Can you try to identify what factors or assumptions could have introduced an error in this estimate? Try to discuss this with your classmates and teacher. I'll be back in a few minutes.

I hope the discussion went well and you were able to identify multiple sources of error. Here are a few factors that I think affected our experiment and calculations. The measurements of parameter such as mass and length that went in our activities 2 and 3 may not have been very precise. Additionally, the approximation we do while fitting a continuous line to the data by eye and then performing the numerical integration to calculate the potential energy can also introduce error.

This error introduced into our ratio calculation due to imprecise measurements can be termed as measurement error. The measurement errors can be reduced by using more precise measurement technology, computers, and more involved mathematical techniques.

An accurate mechanical testing requires a more sophisticated setup, such as a computer-controlled Universal Testing Machine to generate the force-deformation data. The fitting of the continuous line and integration can be performed accurately by use of computer algorithms based upon mathematical theories.

Moreover, we made some assumptions to arrive at our numbers. For example, we assumed that in the previous activities the rubber band was completely in its elastic regime. We also assumed that the kinetic energy of the rubber band is perfectly transmitted to that of the projectile.

Our launch setup was quite crude. We did not account for any force due to the air on the projectile in our initial velocity calculation. Also in practice, there can be slight deviations in the angle of projectile launch which can cause error in our range measurements. This we did not account for in our simple equations.

The error introduced by the inaccurate mathematical description of the experiment can be termed as modeling error. Modeling error and reduced by incorporating the previously unaccounted factors in the mathematical description of the mechanics. I hope the sources of error and potential solution approaches that you have identified include some of the ones that I have suggested. If you have some more, we would like to know more about them.

Now, let's summarize what we have learned so far in this lesson. First, you were introduced to the essential definition of elasticity. And then you used some practical examples to appreciate the distinction between elasticity and inelasticity.

Secondly, you got a flavor of the underlying mathematical models through the simplest model using linear springs and the Hooke's law. Then through a simple experiment, you discovered that rubber, which you have seen in many applications around you, can show nonlinear elastic behavior.

Finally, you utilized a simple rubber band propelled projectile motion to study the potential to kinetic energy conversion and gain an appreciation about how measurement and modeling errors can affect your data analysis.

As future engineers and scientists, when you will be working on practical applications of elasticity, you will find yourself repeating this exercise of creating mathematical models, performing experiments to determine parameters in the model, analyzing the observed data, and validating your model.

Speaking of real world applications, can you try to identify some practical examples where elasticity plays a vital role? Is there any particular application which you would like to develop as an engineer in future? As food for thought, here are some examples.

Welcome back. This brings us towards the end of this lesson. I'm sure you have made a long list of engineering applications. And I also hope that you have started to think about studying elasticity as engineers and scientists. The application of prosthetics is another example of how the knowledge of elasticity is helping engineers and doctors to assist amputees walk and sometimes even run.

In this lesson, you have been introduced to the concept of elasticity and its innumerable applications. I hope you have enjoyed this lesson and also learned something new in the process.

Hello, teachers. I would like to thank you for introducing this BLOSSOMS lesson on elasticity to your students. Through this lesson, in addition to sharing knowledge, I would like to introduce students to the joy of learning and using the subject of solid mechanics early on in their education.

I chose elasticity because it forms the stepping stone to the general subject of solid mechanics, and it is reasonably easy to introduce at a high school level. Also I hope that this hands-on multimedia approach to teaching will complement your own method of inspiring the students to pursue science and engineering careers.

The primary focus of this lesson is to introduce the students to elasticity, which is one of the fundamental concepts in the understanding of physics of deformation in solids. As you would know, its applications are extensive-- from man-made engineered structures to naturally occurring solid structures, such as trees, rock formations, and even the human body.

The topic is commonly taught in high school physics curriculum around the world using the linear elastic framework of Hooke's law. With this lesson, we will approach the subject from a slightly more general perspective-- that of nonlinear elasticity.

The advantage of this approach is that in addition to giving the students a broader view of elasticity with this general paradigm, we as teachers can take a hands-on approach to explaining the subject using simple, readily available soft objects, such as rubber bands.

Complimentary to our primary focus, this lesson can also give students a glimpse in generating meaningful data for physical systems, performing analysis, and finally, using the knowledge gained in a practical application. This will enable students to appreciate that science and math that they are learning in school are important from a practical perspective and will hopefully interest students in education and career in engineering and sciences.

In terms of prerequisites, some definitions and concepts that will be essential for a good appreciation of this lesson will be that of a pure solid and its distinction from a pure liquid, then displacement, velocity, acceleration, force, work, energy. Additional concepts that might be helpful are simple functions of single variables, numerical integration, such as finding area under the curve, and kinematic equations of projectile motion.

I am of the opinion that the main essence of elasticity can be captured by the simple force versus deformation relationship. However, as you would know that for a more rigorous description, one needs to bring in the concepts of mechanical stress and strain.

I avoid using them in this lesson because a satisfactory discussion of stress and strain would require a much more sophisticated mathematical machinery. In case you have already introduced the students to these concepts, feel free to incorporate them in the relevant discussions.

Now, in terms of the activities that we have planned out, the first activity is to get the students quickly into the groove of our suggested learning by "doing" approach. The main objective of the first activity is to enable the students to be able to distinguish different solid objects based on their capacity to deform under load.

Here is a short demonstration of this activity. Here I have suggested some materials with varying degrees of stiffness as well as the extent of maximum elastic deformation. Please feel free to substitute them with analogous materials.

The activity 2 is the first of the two more detail-oriented activities. Here is a demonstration of activity 2. Beginning of experiment.

End of experiment. In my experiment, the pointer stick was not very helpful as it was getting tilted during the experiment. So I used the numbers that corresponded to the level of the rubber band end from which the plastic cup was suspended. Just be careful about that when you do the experiment.

The goal here is to have the students perform an experiment to generate force versus deformation curve and then analyze the nature of elasticity. Note that here we perform a force-controlled experiment where we increase the load in multiples of a known weight.

If you have a force measuring device at your disposal, you may also conduct this activity as a displacement-controlled experiment by changing the length of the sample in small steps or fixed length and reading off the force measuring device. Feel free to substitute the coins with some other known weights that can cause the rubber band to deform. Also, I prefer to use rubber bands which are slightly wide, so that I can staple them at the ends.

The larger width will also be useful in launching the projectile in activity 3. If time is limited, you may choose to analyze the data from one of the teams. Activity 3 is, in my opinion, the most challenging one. Here is a brief demonstration of activity 3.

I would suggest using some light projectile, such as a matchstick or an eraser, for safely conducting this activity. The problem with using a light projectile will be measuring its mass. My suggestion will be to weigh the projectile beforehand in a physics or chemistry lab by electronic scales or beam balance.

Since the projectiles will be moving fast, it may be difficult to pinpoint the location of its first hitting the ground. It might be a good idea to draw a grid of uniformly spaced parallel lines that are oriented perpendicular to the direction of launch on the floor, say, at every 4 inch interval.

This grid can be drawn in the approximate neighborhood of the projectile's horizontal range for the prescribed stretch of the rubber band. This will help the student to observe the location of first touching the ground within a tolerance equal to this line spacing. Again, if time is limited, you may choose to analyze the data of only one of the teams.

Here are some of the items that I used for activities 2 and 3. The setups for activities 2 and 3 are only suggested setups. It is absolutely OK to adjust the design to accommodate your local class environment, as long as the force versus deformation curve and the kinetic energy to potential energy ratios can be calculated from these two activities.

In addition to providing the relevant formulae, we have included in Microsoft Excel sheet that might be helpful in fast analysis of these two activities. In terms of venue, I w suggest conducting activities 2 and 3 within a classroom environment or maybe a lab environment. All the rest of the activities can be done in any setting, be it outdoors or in class.

Finally, activities 4 and 5 are designed to nudge the students to reflect on the activities hitherto, and motivate them to come up with their own ideas on potential sources of error in their inference, as well as some real world applications of elasticity. You may also use activity 5 to gauge the pulse of the class and can work with colleagues and students to identify related topics for future discussion.

Overall, I hope both you and your students will enjoy this lesson. If you have any question, concern, or feedback, please feel free to email us. I look forward to hearing your experience at conducting this lesson. All the very best.

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