An Experiment On Elasticity Using Balloons

In this article Dr Francisca Wheeler, IOP Teacher Network Co-ordinator for Greater Manchester and Dr Russell Goodall, Lecturer in Metallurgy in the Department of Materials Science and Engineering at the University of Sheffield describe a simple and interesting experiment that you can do with your class that relates to the behaviour of blood vessels

This article appeared in Issue 38 of the SAS newsletter in Summer 2011.

Rubber balloons are always fun things to have at celebrations for children and adults alike, but you can also use them in the classroom to demonstrate a variety of scientific concepts.

The party balloon has an interesting history with the first rubber balloons being made by Michael Faraday in 1824 for use in his experiments with hydrogen at the Royal Institution in London. They were named “caoutchouc” (raw rubber) after the material from which they were made. “The caoutchouc is exceedingly elastic” wrote Faraday in the Quarterly Journal of Science, the same year. Faraday made his balloons by cutting around two sheets of rubber laid on top of each other and gluing the edges together.

Inflated rubber balloons rely on a delicate balance between the elasticity of the rubber skin and the difference between the pressure of the air on the inside and on the outside of the balloon, with the pressure inside being higher than the atmospheric pressure outside. When air is forced into the balloon the pressure inside increases and the balloon expands. The expansion stops when the forces inside and outside balance. The force inside, pushing the walls of the balloon outward, is due to air pressure, while outside are the combined forces due to atmospheric pressure and elasticity of the continuously stretching rubber, which try to contract the balloon.

The elasticty of rubber varies throughout the streching process. At first the balloon expands as air is blown into it until the internal pressure increases to a maximum, typically when the balloon is 40 per cent larger in diameter than when it is unstretched. Anyone who has tried to blow up a balloon by mouth will have found how difficult a task it is at first but afterwards the balloon stretches easily.

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Two-balloon experiment

The two-balloon experiment is a demonstration that can be used in the classroom to illustrate the effect that the non-linearity of the stress-strain function has on the air pressure inside it.

The set-up

The simple experiment involves two identical balloons connected by a tube with a tap which controls the flow of air between them. The balloons have both been inflated but to different sizes, as shown in Figure 1. When the tap is opened, air is free to flow between the balloons. The result is surprising because most people watching the demonstration expect both balloons to end up the same size. Instead, the smaller balloon gets smaller and the balloon with the larger diameter inflates even more!

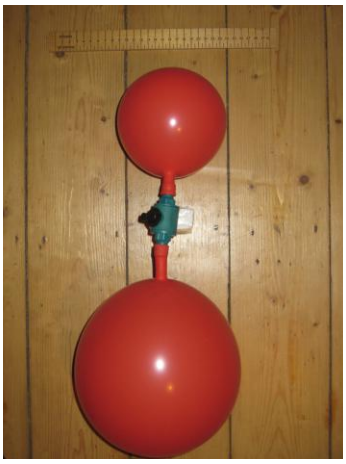

Figure 1 – The set up with the tap closed.

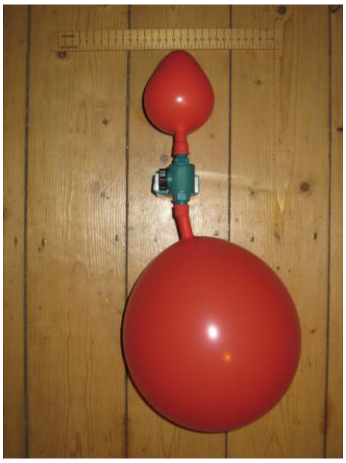

Figure 2 – The small balloon gets even smaller when the tap is opened.

The key to understanding the behaviour of the balloons is in the difference in the pressure of the air inside each balloon which is related to the amount of stretching undertaken by each balloon. When the tap is opened air flows from the balloon at higher pressure to the balloon at lower pressure. The smaller balloon has the higher pressure because its rubber exerts a greater elastic force and it pushes the air into the larger balloon, whose rubber exerts a lower elastic force. The air flow ceases when the pressure in the two balloons is the same.

The Elasticity of Rubber

Rubber is a polymer, made up of long chains of mostly carbon and hydrogen. In the normal state, these chains are, like many polymers, tangled around each other in random shapes. Unlike other polymers, the chains are linked together (referred to as cross linked) with chemical bonds, which are much stronger than the intermolecular forces.

When we deform rubber elastically, the molecules uncoil. When the rubber is released, the molecules recoil and it returns to the original shape. In most materials, elastic behaviour is due to the stretching of interatomic bonds under load, and them contracting to pull the material back into shape. Rubber is elastic because of entropy; as a coiled up molecule is stretched out, the number of different ways of arranging the links decreases, thus increasing the order in the system (lower entropy). When unloaded, the entropy can be increased (the direction for a spontaneous change) by the system becoming more disordered as the molecules coil up

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This leads to unusual behaviour of rubber, see Figure 3. We describe this as an S-shaped stress strain curve. As the molecules untangle and stretch out, the entropy change with additional stretching is less, and further stretching becomes easier (compare the slope – the local “elastic modulus” - at the red and blue points). Eventually, as the molecules become fully extended, the force starts to pull against the cross links, and further stretching becomes more difficult again.

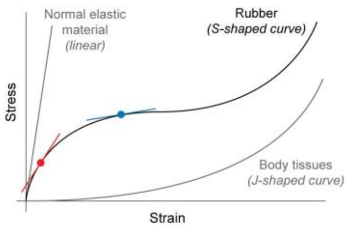

Figure 3 - A schematic stress-strain curve for rubber and some other elastic materials.

This is why balloons are hard to blow up at first, then easier. When we look at the effect this behaviour of rubber has on a balloon, we find that it means that the pressure is not linearly related to the inflation (just as the stress-strain curve in Figure 3 is not linear) and different inflations can be stable at the same pressure as a result. Therefore, what we are seeing in the two-balloon experiment described above is the system stabilising at two different inflations under the same pressure.

Interestingly, natural tissues, like blood vessels, do not show this type of behaviour. If they did, there would be the risk of a slight bulge developing into a dangerous swelling; an aneurism. They have J-shaped, rather than S-shaped curves, which tend to resist swelling. As these materials are stretched they become more resistant to further extension.

More on rubber, balloons and the elastic properties of biological tissues can be found in the Teaching and Learning Packages on http://www.doitpoms.ac.uk/tlplib/stiffness-of-rubber/index.php and http://www.doitpoms.ac.uk/tlplib/bioelasticity/index.php.

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