Science in School
The European journal for science teachers

ISSUE 70 – November 2024 **Topics** Chemistry | Engineering | General science | Physics

Image Nik/Unsplash

Science in a toilet-paper roll

Nasko Stamenov

On a roll: a humble roll of toilet paper can be used in science experiments explore diverse topics in materials science, chemistry, and physics.

One of the most common hurdles in science education is the lack of proper facilities and enough materials, but don't despair! As Peter Borrows says: "chemistry doesn't just happen in test tubes", and we can extend this motto even further. If we ask ourselves what the minimum required materials for a science class are, we can start with something as plain as a humble roll of toilet paper and not a lot more. In the following activities, we are going to see experiments with toilet paper and ideas for discussions on materials science, chemistry, and physics.

Activity 1: Anisotropy

In this simple activity, students investigate the material property of anisotropy by tearing toilet paper in different directions. It can be adapted for different ages by tailoring the level of the discussion.

Materials

- Toilet paper (a few sheets per student)

Procedure

1. Ask students to consider the materials around them. Consider what material characteristics engineers must consider when designing materials and products. What properties of materials can they name? Perhaps they know the states of matter (e.g., solid, liquid, gas), or properties like viscosity, ductility, brittleness, and elasticity. Have any of them heard of anisotropy? No? That's ok because we're going to learn about it now.
2. Grab a piece of toilet paper and hold it tightly between the thumb and pointer finger of both hands along the smooth edge. Then, with a single motion (one hand pulling towards you and the other pulling away) try to rip

the piece. You can make a fairly straight tear where your fingers are, but the moment the tear goes beyond them, it changes direction along the fibres' length.

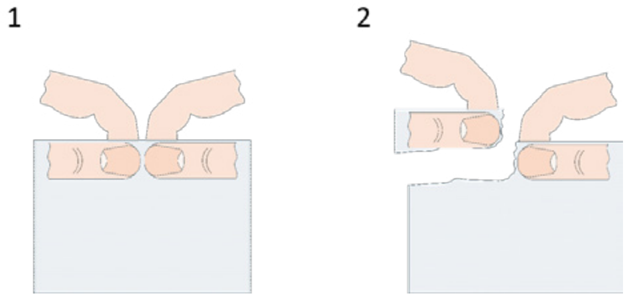


Image courtesy of the author

3. Let's now try the same thing again, but we are going to hold the paper on the perforated edge. The tear should go straight down. You can repeat this several times with the same result; with a number of ribbons, you can make a pompom with an up-and-down motion.

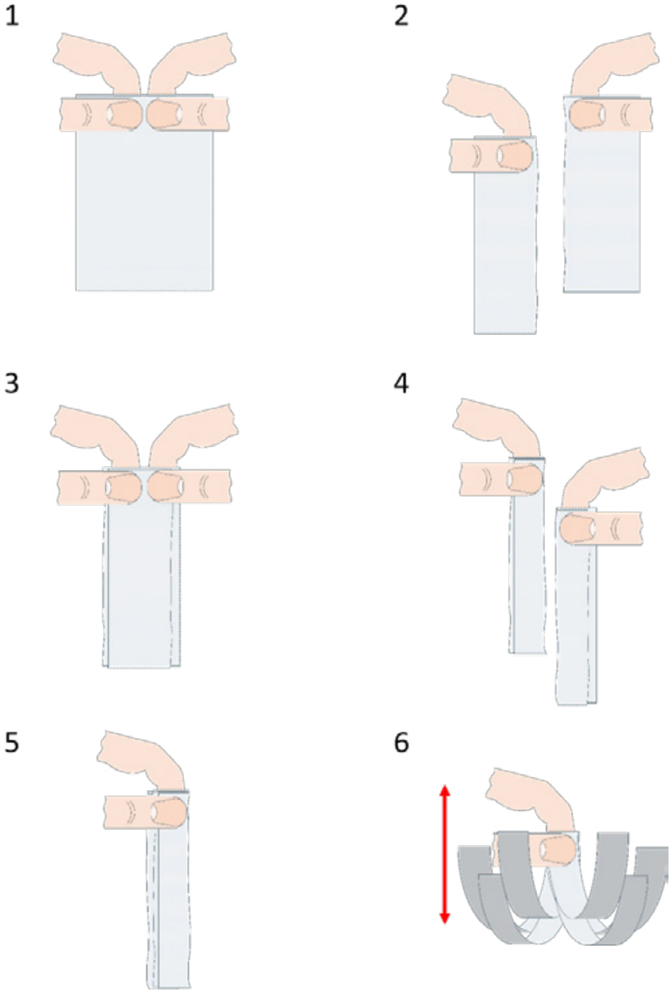


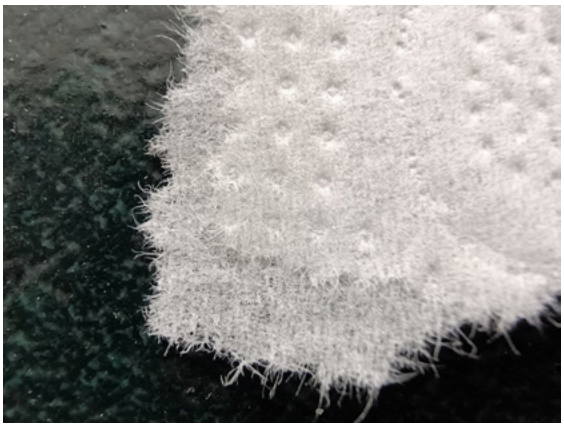
Image courtesy of the author

4. Note how the material behaves so differently in the different directions. This is an example of anisotropy!
5. Discuss the results using the questions and discussion points below. The level of discussion can be tailored to different levels to suit different ages.

Discussion

Some leading questions that can help to form the basis for a discussion:

- Why do you think the toilet paper behaves in different ways, depending on how you hold it?
- What is toilet paper made of? Look at a torn end with a magnifying glass; the students should observe fibres. What are these fibres? Are they found in other materials? Younger students may just note that it's the same fibres found in wood, which toilet paper is made of, and older students might consider the molecular structure of cellulose.



Observing torn toilet paper under a magnifying glass reveals the fibres.
Image courtesy of the author

- Do these fibres help explain the properties observed? Do they seem to be oriented more in one or the other direction?
- Do you think this is deliberate design? Is it useful that toilet paper behaves like this? Can you think of potential problems if it didn't have this property? What about the cellulose fibres in wood? What are the functional consequences of their being aligned?

Anisotropy is a big word, but it means nothing more than the ability of a material to behave differently depending on direction; this dependency is usually because of the internal structure of the material. The closest-to-us example is how some materials can split easily in given directions but are quite tough (or brittle) in others, for example, wood is made out of fibres, so it splits along their length (one good whack with an axe does the trick), but we need power tools to easily cut it perpendicular to them (e.g., a chainsaw for tree felling). Similarly, diamonds can be split nicely along their crystal-lattice borders, but a cut in a slightly off angle can reduce them to a pile of worthless dust (diamond dust can be used as an abrasive, but it costs much less than a good-quality gem). Other places in which we can encounter anisotropic materials are our bodies, in which we have muscle fibres in bundles, and the Eiffel Tower, which is made of wrought iron, an interesting pre-steel material filled with silicate fibres.

What does any of this have to do with toilet paper you ask? Well toilet paper is made of fibres (cellulose from wood), and those fibres are arranged parallel to each other because of the way the paper was made – the moist-fibre pulp was squished between two metal rolling drums, and that motion rotated the fibres in the direction of rolling.

Activity 2: Friction and intermolecular forces

We have seen in the first activity that toilet paper is a fibrous anisotropic material, but the same can be said about string or rope. What is the difference between them and toilet paper? In this activity, students investigate friction and intermolecular forces in toilet paper.

Materials

- Toilet paper (a few sheets per student)
- Water

Procedure

1. So, we figured out that paper is a fibrous anisotropic material, but the same can be said about string or rope. What is the difference between them and toilet paper? Let's find out!
2. Grab another piece of toilet paper and fold it lengthwise, then once more, and you will have a thick ribbon. Pull on it hard and it will tear at some place, forming jagged edges.

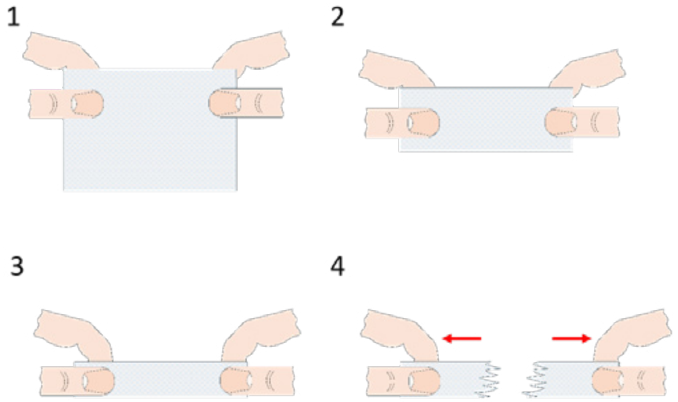


Image courtesy of the author

3. Can you guess what the problem is? The fibres are too widely spread, and they are in contact with each other only in a few places, so the friction force between them is miniscule. We can alleviate that, but there is a twist – we need to twist the ribbon.
4. Grab another piece of toilet paper, fold it once, start twisting to make a tight wick, and then pull again.

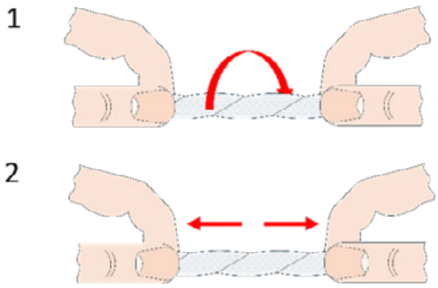


Image courtesy of the author

If the wick is tight enough, this will prove to be a difficult task, as we've just made a nice toilet-paper rope.

5. Now try adding a drop of water to the centre of the toilet-paper rope and pull again. What happens? Can you guess why?

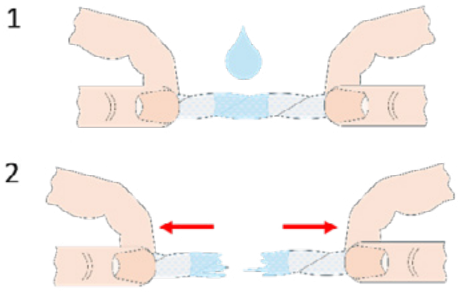


Image courtesy of the author

Discussion

Some leading questions that can guide the discussion. These can be used during the experiment or as part of a discussion at the end:

- How long do you think the fibres are in toilet paper?
- When you pull on the ends of the toilet paper, do you think you are breaking the fibres or just pulling them apart?
- Does adding water usually increase or decrease the friction between surfaces? This could be a much longer discussion on the effect of water in different settings.

The fibres in toilet paper are typically rather short. In the folded toilet paper, these fibres are fairly widely spread and they are in contact with each other only in a few places (loosely entangled), so the friction force between them is minuscule and they easily pull apart. When you twist the toilet paper, the fibres are brought close together, and we have multiplied the friction force between them to create a rope! The twist also makes it so that more threads are in contact, for example, compare the position of the threads that are on opposite edges in the folded piece with the same when twisted. There is more: in the previous case, when a thread is broken, the force is colinear with it; the thread can no longer hold, and from that breakage, the whole paper snaps. In the second case, the broken thread is not colinear with the force and the two pieces are in contact with more threads, which prevents propagation of the breakage.

However, there is a reason we don't usually make rope out of paper. Paper is mostly short-fibre cellulose, and cellulose is a type of polycarbohydrate with many –OH groups sticking out of the chain. If we introduce water, it will interact with those groups and form hydrogen bonds; the paper will absorb the water and it will swell. That swelling is not a problem with normal long-fibre rope, but with our toilet-paper one, the short fibres will move further apart and the friction force will lessen; the water will act as a lubricant between the fibres and they will just slide past each other.

Activity 3: Capillary action and chromatography

In this activity, we use capillary action to divide mixtures and gather information on the components of a felt-tip marker.

Materials

- Toilet paper
- Water
- Shallow dish
- Black, water-washable felt-tip marker*

* You also can check other markers – some will be pure dye, some will be mixtures, and grey usually gives an interesting result.

Procedure

1. Firstly, take half a piece of toilet paper (you already know the easier direction to tear it in), and dip the end in some water. What happens? The water 'climbs' up the toilet paper.
2. Do the students know why this is? If necessary, explain capillary action. What do they think will happen if we draw a mark on the toilet paper first?
3. Next draw a thick point with the marker at about 1–2 finger widths from the bottom edge. Dip the edge of the paper in the water, and observe how the water climbs up and, at a given point, carries some of the marker dye with it.

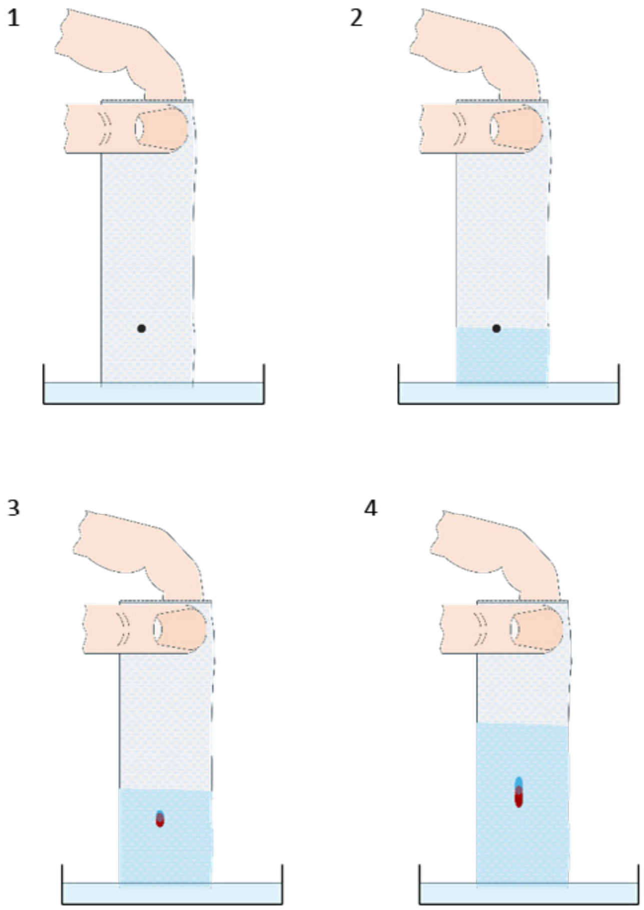


Image courtesy of the author

- Can you explain what you see?
- Why are there different colours?
- Why can you see them at different positions on the toilet paper?

Discussion

Molecules tend to stick to each other, and the more similarities they share, the stronger the bonds they form. The ability of identical molecules to stick to each other is called cohesion, and their ability to stick to another material is called adhesion. Water molecules are great at cohesion, and they are good at adhesion to cellulose. These two qualities make capillary action – an upward flow of liquid through a narrow space – possible. Water can climb up to 10 m due to capillary action, and this plays an important role in water transfer in plants (although this is not the only trick that trees use). In the lab, we use capillary action to divide mixtures and gather information in a process called thin-layer chromatography (TLC).

Activity 4: Refractive index

In this experiment, students discover some of the common real-world effects of refractive indices by revealing a hidden image with oil.

Materials

- Toilet paper
- Printed image
- Drop of glycerol or oil (mineral oil like baby oil or most edible oils, e.g., sunflower seed oil, cooking oil, olive oil)

Procedure

1. What colour is the toilet paper? Or similarly, what colour is snow? If the students say white, then ask what snow is made of. Answer: ice particles and air. What colours are ice and air? Answer: transparent. So why does snow look white? What happens if you wet a snowball; does the colour change?
2. Toilet paper is made of cellulose fibres; what colour are they? Answer: like water, they are transparent. Optional: look at the torn edge of a piece of toilet paper using a microscope or even a microscope lens on a smartphone. So, why does toilet paper look white?
3. Take a sheet of toilet paper and place it on the printed image. Is the image still clearly visible?

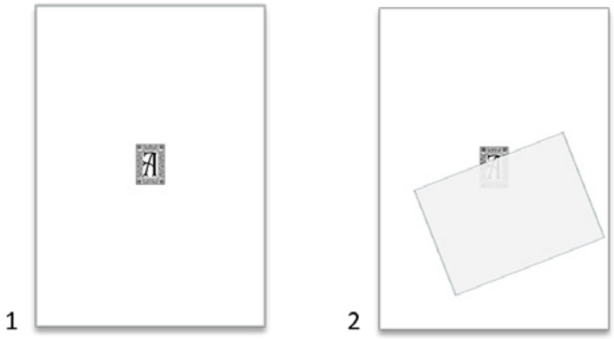


Image courtesy of the author

4. On the illustration, you can barely see the print. Why is this? If necessary, explain refraction. Older students have probably drawn ray diagrams for when light hits water at an angle or travels along optical fibres. They can do the same for a light ray passing from air into a cellulose fibre at different angles.
5. Now, what if we exchange the air that's between the cellulose fibres with something else, such as oil? Put a drop of oil on the piece of toilet paper, then put the piece on the paper with the printed image; there should be a vast improvement in visibility.

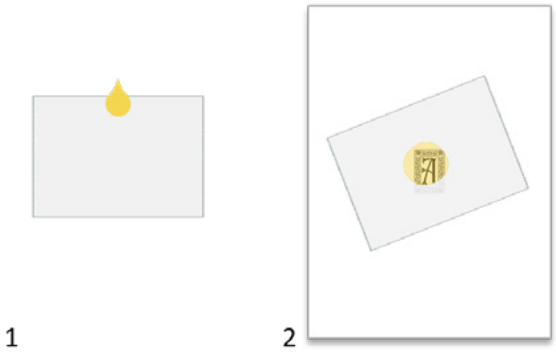


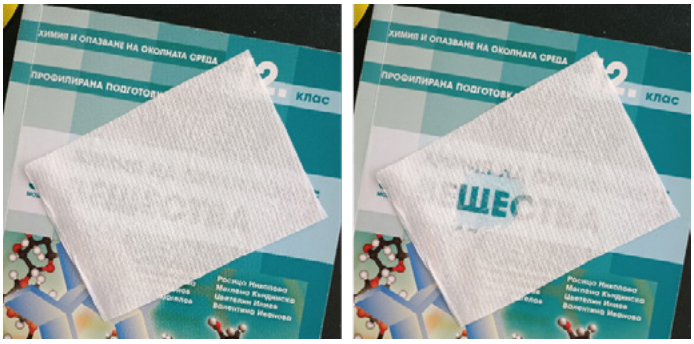
Image courtesy of the author

6. What is happening in this case? There seems to be less refraction. Why? Older students can look up the refractive indices of air, oil, and cellulose.

Discussion

Though we perceive snow as white, it is composed of tiny ice particles and air, both of which are transparent. So, why does snow appear white? Two phenomena come into play here: one is refraction – light bends when it passes from one material to another if its speed is different in the two materials; the other is scattering – all that bent light gets reflected at random angles. In the end, most of the light gets back to our eyes but is scrambled, so snow (and toilet paper) appears neither transparent nor mirrorlike but white.

Now, what if we exchange the air that's between the cellulose fibres with something else? Cellulose has a refractive index of about 1.47. Glycerol and most edible oils (sunflower seed oil, cooking oil, olive oil, etc.) have similar refractive indices, which means that, if oil fills the spaces between the fibres, there will be no refraction and the toilet paper will become transparent.



With the addition of oil (right), the toilet paper becomes transparent and the image beneath can be clearly seen.
Image courtesy of the author

Optional additional questions, which can act as a basis for further discussion on optics:

- What happens if you move the toilet paper slightly away from the paper?
- Does the oil spot look brighter or dimmer than the rest of the paper? Does this depend on the light (e.g., direction, intensity)? This can be extended in another lesson by building an oil-spot photometer.[1]

«

References

[1] Compare the brightness of two light sources using an oil spot on a white card: https://www.exploratorium.edu/snacks/oil-spot-photometer

Resources

- Compare the brightness of two light sources using an oil spot on a white card.
- Learn how to make indicators from butterfly tea: Prolongo M, Pinto G (2021) Tea-time chemistry. *Science in School* **52**.
- Engage your students and demonstrate fundamental physics with everyday objects: de Winter J (2022) Physics with everyday objects: springy sweets, a universe in your pocket, and drawing circuits. *Science in School* **56**.
- Perform quantitative chemistry experiments using microscale techniques with bottle tops and spirit burners: Worley B, Allan A (2024) Simple gravimetric chemical analysis – weighing molecules the microscale way. *Science in School* **69**.
- Discover some low-cost physics experiments to try out in your own classroom: Gregory M, Varnica G, Lazos PT (2022) My favourite experiments – connecting teachers and ideas. *Science in School* **58**.
- Discover the science of limonene: Butturini F, Fernández JJ (2022) Citrus science: learn with limonene. *Science in School* **58**.
- Explore how colours arise through reflection, absorption, and transmission: Félix RC, Paleček D, Correia TM (2024) Colour science with lasers, gummy bears, and rainbows. *Science in School* **66**.
- Explore viscoelasticity by making slime: Ospina V, Ospina C (2024) Beyond solids and liquids: the science of slime. *Science in School* **67**.
- Read about the colour blue in nature and the chemistry behind it: Bettucci O (2022) Colour in nature: true blue. *Science in School* **60**.
- Discover how to spot fake images in astrophotography: Muñoz Mateos JC (2024) CSI Astronomy: learn how to spot fake astrophotography images. *Science in School* **69**.
- Share the wonder of particle physics with the Particle Detectives science show: Gregory M and Kranjc Horvat A (2024) Particle Detectives: boldly bringing particle physics outreach to new frontiers. *Science in School* **68**.
- Discover simple adaptations of experiments to make chemistry accessible to students with vision impairment: Chataway-Green R, Schnepp Z (2023) Making chemistry accessible for students with vision impairment. *Science in School* **64**.

AUTHOR BIOGRAPHY

Nasko Stamenov is a chemistry teacher and science communicator. He teaches at the National High School of Science and Mathematics, Sofia, Bulgaria, as well at Sofia University, and he does shows and lectures on materials science and chemistry. He also trains teachers in the ways of low-cost experiments and microscale chemistry.