What happened to the cup?

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Age: Can be done at age 15-16 without going into glass transition temperatures and structures; age 17-18 with a more detailed look at polymer structure and properties
Subject-matter area: Structure and properties of polymers, recycling
Duration: 2-3 lessons

ENGAGE[1]

Scenario

I was making a cup of coffee and there were no clean cups. So I grabbed a transparent disposable plastic cup from the shelf and put in the coffee powder and then poured the hot water into the cup. It was a good job I did it over the sink because the cup 'collapsed' and shrank, spilling all the liquid. The cup had collapsed and changed its shape. That doesn't happen when I use cold water or when I use a more rigid plastic beaker. Why did that happen? What is the difference between those two plastic vessels? How hot does the water have to be to make it happen? Does it happen with all disposable plastic cups?

EXPLORE

How hot does the water have to be for this to happen? Set up an investigation using hot water from a kettle and a thermometer to test this out. Does it happen with other makes of disposable cups? Get some different transparent cups and try it out. Does it work with all or only some? Is it reversible – does cold water restore the shape or not? How can you check what sort of polymer the cups are made from?

Hint: check the symbol on the bottom and look up the name and symbol to identify the plastic. See the table of polymer symbols provided (Table 1).

- Are the cups that collapse made from particular polymers?
- Is the way they are produced of relevance?
- What about cups that don't collapse?
- The cups change shape but do they lose mass or stay the same?
- Is it to do with whether the polymer is biodegradable or not?

[1] This teaching unit was developed within the framework of the FP7 EU-project TEMI (Teaching Enquiry with Mysteries Incorporated, Grant Agreement N. 321403; see also http://teachingmysteries.eu/ [Oct 28 2015]). All units are based on the 5E model of inquiry-based learning. Details can be found in the introduction of the issue.

Preparation

You need to source some transparent, disposable plastic cups made from different plastics. Several types are available: polystyrene (PS), polyethyleneterephthalate (PET), poly-lactic acid (PLA), polypropylene (PP). There are also coloured, opaque cups available and white, expanded polystyrene cups. The initial mistake was made with PLA cups, which are also biodegradable. The cups are cheap and so after the initial teacher demonstration, the students can work in groups with a set of different cups. Each group should have access to hot water, e.g. from an electric kettle, thermometer and a plastic bowl or container to contain the cups and water. This should avoid water being spilled over the classroom.

EXPLAIN

The cups are made from polymers and are meant for one use only. They are made from very little plastic and are thin-walled and are usually used for cold drinks. Why do some cups collapse when hot water is used and others don't? What do you think is happening when hot water is added? Can you think of other examples where this sort of thing happens? You should identify the plastics used for each make of cup and look up its properties e.g. whether it is biodegradable or not (Fig. 1), its melting point (T_m) and its glass transition temperature (T_g), a property special to polymers.

Fig. 1. Recycling symbols for common polymers *http://teachers.yale.edu/curriculum/viewer/initiative_09.05.08_u [09.12.2015])*

Clarification of the subject-matter

Different polymers have different melting points (T_m), when they turn into a viscous liquid, but at a lower temperature (known as the glass transition temperature, T_g) they become plastic or rubbery and shrink back to their original size, much like a balloon when the air is let out (Fig. 2). On cooling they set solid again. A table of values for common plastics is given below (Tab. 1). Plastic cups are often made by blowing air into a blob of hot, molten polymer in a mould. It blows up to fill the mould and when it is cooled it has the shape of the mould. When the plastic is hot it can be shaped and blown like a balloon, but on cooling it sets into the new shape. (You can find some plastic bubbles in

toy shops which can be used to blow permanent bubbles.)

Fig. 2. The effect of hot water on PLA cups – T_g is the glass transition temperature, above which the polymer becomes plastic and returns to its original size.
https://publi.cz/books/180/06.html [09.12.2015]

Name	Abbreviation	Tm/°C	Tg/°C
Polylactic acid	PLA	163	60
Polystyrene	PS	240	95
Polyethyleneterephthalate	PET	260	70
Polypropylene	PP	130-171	0
Polyvinylchloride	PVC	160	87

Tab. 1: Properties of common polymers

EXTEND

Take a 500 mL or 2 L drinks bottle, used to contain fizzy drinks. If you check the bottom they may say that they are made from PET polymer (Polyethyleneterephthalate). They are transparent like glass and they are made by blowing the polymer in a bottle-shaped mould. What do you think might happen if you put a bottle into boiling water? Is this behaviour the same or different to the cup? Try filling a 500 mL bottle half full of hot water and then screwing on the top. What do you think will happen?

What do you think the effect of cold will have on a plastic cup? Plastics have two temperatures similar to melting and freezing ranges. At the lower point, the glass transition temperature, a flexible plastic becomes rigid like a glass. Check this temperature for the polymer you have identified during the exploration phase and then see if you can cool it below that temperature.

Hint: You may need to think how to get that cold – will a freezer do it? Or a salt-ice cooling mixture? Or dry ice? Or liquid nitrogen? If you have access to a suitable way of cooling the cup, try and see what effect cooling has on its physical properties. Your teacher might show you the effect of liquid nitrogen on a flexible polymer.

Make a model of a thermoplastic polymer and use this to explain why it can change its shape.

You can buy a plastic bubble kit, which can be used to blow up permanent bubbles, which don't burst like soap bubbles. What is the connection between these bubbles and a balloon on the one hand, and a plastic cup or bottle on the other?

EVALUATE

Can the students explain in terms of the structure and properties of the polymer, why some plastic cups collapse when hot water is poured into them and others don't do this? Can they explain how soft drinks bottles are made from a former (a test-tube like shape, Figure 3) and why they retain their shape when they have been produced by heat and blowing with gas? Can they then explain why the bottle will collapse back to nearly its original size if heated?

Fig. 3. PET bottle and former
https://upload.wikimedia.org/wikipedia/commons/d/d4/Plastic_bottle.jpg

Further hints:
Unbreakable bubbles
http://chemistry.about.com/od/bubbles/a/Bubbles-That-Dont-Pop.htm (access date)

Magic plastic bubbles – ar. £4 per tube (available in toy shops)
http://www.hawkin.com/magic-plastic (date)

Blow moulding
http://www.bpf.co.uk/data/iframe/injectionBlowMoulding.html (date)

Making PET bottles from a former.
https://www.youtube.com/watch?v=v89ezOA0oNE

Using PET to make bottles and its properties
http://www.kenplas.com/project/pet/

Slideshow on the development of plastic cups to make them more heat resistant:
http://www.slideshare.net/Atkinderek/innobioplast-2013-presentation-dwa-coffee-cup-development

See also:
https://en.wikipedia.org/wiki/Polyethylene_terephthalate
http://www.fpintl.com/wp_biodegradable_plastics.aspx

Name:	Subject: Chemistry	Date:	WS 1.2

The unstable cup

Transparent plastic cups are disposable and have thin walls. They are available in vending machines and are primarily used for cold drinks. Are there reasons why this type of cups are not used for hot drinks, like coffee or tea?

Engage

Task: By mistake your teacher poured a hot liquid into a transparent plastic cup and it collapsed, spilling the drink, as shown in the picture below.

before after

When the teacher repeated this with a different type of cup, the cup didn't collapse.
Why was the behaviour different?
Write down your assumptions in your exercise book.

Task 1: What is the difference between the two types of transparent cups? How could you identify what they were made from?

Hint: Think about recycling and how we know what polymer an artificial material is made from.

Task 2: Does the temperature of the liquid have an effect on the collapse of the cup? Devise an experiment using both sorts of cups to see what effect the temperature has on the shape of the cups.

Caution: You will need to use boiling liquids, which can be diluted with cold liquids to get liquid samples with different temperatures.

Task 3: Can you find any other types of transparent cups made from different polymers? See if they are affected by hot water or not.

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The unstable cup

Explain

Most solids have a definite melting point when they change from a solid to a liquid. Polymers have two characteristic temperatures: one at which they turn from a rigid, glassy state to a rubbery, plastic state (the glass transition temperature, T_g) and one at which they turn into a viscous liquid (the melting point, T_m.).

Task 1: Draw up a table for the polymers used in the cups you selected, giving the melting point and the glass transition temperature. Compare the data in the table with the behaviour of the cups during your investigation and come up with an explanation of why some polymers change their shape in hot water and others do not.

Task 2: Make models or look at pictures of polymer chains and explain why polymers can be both plastic (rubbery) and rigid (glassy), depending on the temperature. Research why they behave differently from other organic molecules, like paraffin wax or benzoic acid, which have a definite melting point?

Task 1: Look up and research how soft drink bottles are made from PET, starting with something that looks like a test-tube. Explain in terms of T_m and T_g how the test-tube can be made into a 500 mL or 2 L bottle. Will the mass change when this is done or not?
Explain also what happens when you put boiling water into the 500 mL or 2 L bottle.

Task 2: Find out how PET bottles are recycled and whether or not they can be turned back into new bottles.

Task 3: Look up the properties of the different polymers you have identified in the Explore-Phase and whether they are biodegradable or not.

Task 4: If available, investigate the properties of plastic bubbles and try to explain why they don't collapse like soap bubbles.

Task: Can you explain why polymers don't behave like other organic molecules in terms of their structure? How do the special properties of polymers allow us to make cups or bottles by blowing molten polymer inside a mould?

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