Top of the Bench 2019 Practical Challenge

RECYCLING PLASTICS

275 000 tonnes of plastic are used each year in the UK. That's the equivalent of 15 million bottles per day.

Plastic waste has recently been in the news extensively, owing to the large quantities which find their way into the world's oceans. Once in the ocean the plastic can enter the food web and have dramatic effects on marine ecology.

The UK has a plastic packaging recycling target of 57% by 2020. However before plastic can be recycled the many different types must be sorted. **In the first part of this practical challenge you will be asked to identify the type of plastic used to make a variety of everyday items ready for recycling**.

One of the useful properties of plastics is that they are unreactive, so they are suitable for storing food and chemicals safely. However this property makes them difficult to dispose of, with the majority of polymers being non-biodegradable. It is estimated that it may take as long as 450 years for a plastic bottle to fully decompose. In order to help tackle the problem of plastic waste, researchers have developed a number of biodegradable plastics. These are plastics that will slowly decompose naturally in the environment. **In the second part of this challenge you will identify the type of plastic used to make a biodegradable plastic cup**.

ROYAL SOCIETY OF CHEMISTRY

Equipment and chemical list

Part 1

6 × 250 cm^3 beaker

6 × boiling tube

Spatula

Access to a balance (max 1 per 4 teams)

100 cm^3 measuring cylinder

50 cm^3 measuring cylinder

Mechanical stirrer + stirrer bar

Boiling tube rack (to hold 6 boiling tubes)

Glass stirring rod

Marker pen

Paper towel

Scissors

Distilled water

Ethanol (IDA)

Potassium carbonate

Plastic samples labelled **A - I**

Part 2

250 cm^3 volumetric flask

Small funnel

Stirring rod

250 cm^3 beaker × 2

50 cm^3 burette

Burette clamp

50 cm^3 measuring cylinder

25 cm^3 pipette and filler

pH meter

30 cm ruler

Access to a balance

0.1 mol dm^{-3} NaOH

Distilled water bottle

Biodegradable plastic cup – **Sample X**

Monomer X sample in 100 cm^3 beaker

Part 1 – Identifying polymers based on their density

Different types of polymer have different densities. This means they can be identified by placing a sample of the polymer in a solution of known density and observing if it floats or sinks. If a sample floats it is less dense than the liquid. If a sample sinks it is more dense than the liquid.

You are provided with 9 different plastic samples made from different polymers labelled **A** – **I**.

Method

1. Make up solutions with different densities as described below;

Density in g / cm^3	Solution
0.79	Ethanol (IDA)
0.91	47.1 g of ethanol in 43.9 cm^3 of distilled water. This concentration is still **flammable**. Keep away from any sources of ignition. **Harmful** if swallowed; can cause **damage to organs.**
0.94	35.4 g of ethanol in 58.6 cm^3 of distilled water. **Harmful** if swallowed; can cause **damage to organs.**
1.00	Distilled water
1.15	18.4 g of K_2CO_3 in 96.5 cm^3 of distilled water. **IRRITANT** at this concentration.
1.38	51.3 g of K_2CO_3 in 86.6 cm^3 of distilled water. It will be necessary to place this on a mechanical stirrer to speed up dissolving all the K_2CO_3. **IRRITANT** at this concentration.

Table 1. Details for preparing solutions of different densities.

2. Prepare samples of each of the plastics to be identified. Each sample should be a square of about 4 mm × 4 mm. Choose sections of the plastic without any writing on which may affect the density.

3. Add samples of each plastic to be tested to samples of each of the six solutions held in a boiling tube. Air bubbles adhering to the samples can affect the results of the experiment. Use a glass rod to stir the contents of each tube and dislodge any air bubbles that may affect the end result. Wash and dry the glass rod between tubes to prevent cross contamination.

4. Observe whether the plastics float or sink and **record your observations in a suitable table on the results sheet**.

   A sample will sink if its density is greater than the density of the solution.

5. Use your results, and the densities of the seven polymers given in Table 2, to identify the polymer from which each plastic sample is made.

Record your final conclusions on the results table.

Give the recycling symbol with identification number and code with which the sample should be labelled for recycling.

Table 2. Densities of different polymer types

Polymer	**Density range in g / cm^3**
EPS – expanded polystyrene	0.02 – 0.06
PP - polypropene	0.89 – 0.91
LDPE – low density polyethene	0.91 – 0.93
HDPE – high density polyethene	0.94 – 0.96
PS - polystyrene	1.04 – 1.11
PVC – polyvinylchloride	1.20 – 1.55
PET – polyethylene terephthalate	1.38 – 1.40

Table 3. Recycling symbol with identification number and code for different polymer types.

Polymer type	**Recycling symbol, identification number and code**
polyethylene terephthalate	1 PET
high density polyethene	2 HDPE
polyvinylchloride	3 PVC
low density polyethene	4 LDPE
polypropene	5 PP

polystyrene	

Part 1 - Extension task

An alternative way to identify a polymer is using infra-red spectroscopy.

Certain groups in a covalent molecule are able to absorb certain frequencies of infra-red light.

In infra-red spectroscopy, a range of infra-red frequencies is shone through a sample one at a time. A detector on the other side of the sample then detects which frequencies have passed through unaffected (100% transmittance) and which have been absorbed (less than 100% transmittance).

Table 4 shows you the wavenumber (essentially the same as the frequency) at which some groups absorb.

Table 4. Infra-red absorption data

Group	Wavenumber / cm^{-1}
N-H	3300-3500
O-H	3230-3550 or 2500-2000 (strong broad absorption)
C-H	2850-3300
C=O	1680-1750
C=C	1620-1680

Method

1. Record the infra-red spectrum of a sample made from **PS – polystyrene** and a sample made from **PET – polyethylene terephthalate**.

   THE DEMONSTRATORS WILL SHOW YOU WHERE TO GO TO DO THIS.

2. Use the table to identify the main groups present in each of these polymers. Record these in the table on the results sheet.

3. Use this information to identify the correct structures for PS – polystyrene and PET – polyethylene terephthalate from the options provided on the results sheet.

Part 2 – Identifying the monomer used to make a biodegradable plastic cup

You are provided with a plastic cup (labelled **Sample X**) which is made from a biodegradable polymer. This means that it can be broken down relatively easily after use.

The polymer used to make the plastic cup provided can be broken down to the monomer from which it is made by a process called hydrolysis.

$$\text{polymer} \xrightarrow{\textit{hydrolysis}} \text{monomer}$$

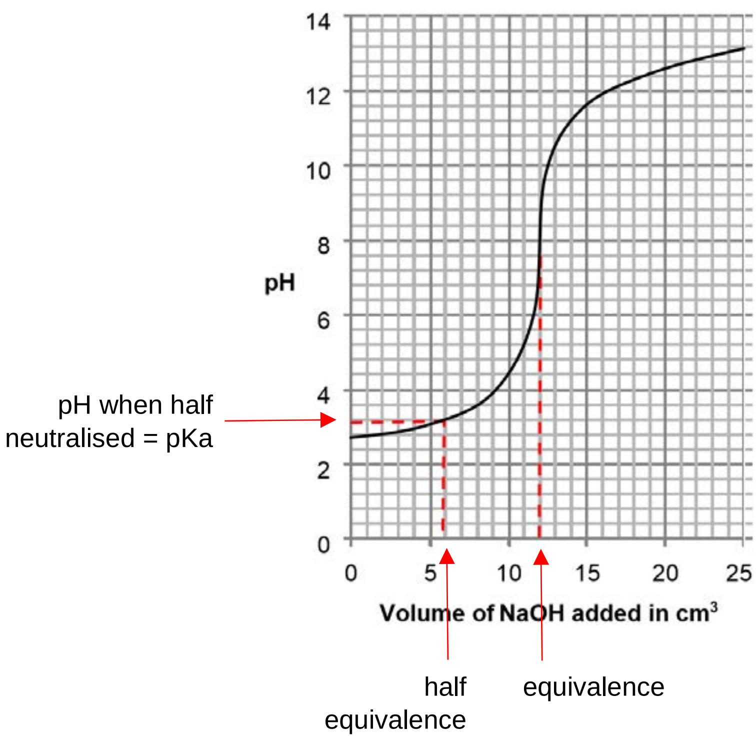
You are provided with a sample of the monomer obtained from the hydrolysis of a 2.0 g sample of the polymer used to make the plastic cup (labelled **monomer X**).

The monomer is a weak acid. In this practical you will identify the monomer used to make the plastic cup by determining its pK_a value – a measure of how strong an acid it is. You will then go on to calculate the mass of the monomer present in each plastic cup.

Method

The pKa of a weak acid can be determined by finding the pH of a solution of the acid when it is half neutralised. This value can be found by plotting a pH curve for the addition of a strong alkali such as NaOH to a solution of the weak acid. The point of neutralisation can be determined by the point at which there is a steep change in pH. The half neutralisation point is therefore the point when half the volume of NaOH needed for neutralisation is added.

For example, for the pH curve below, the pH of the solution when it was half neutralised is 3.2 and so the pKa of the acid is 3.2.



To determine the pK_a of the monomer you must first produce a pH curve to show how the pH changes when the acidic monomer is neutralised by the addition of a solution of NaOH from a burette.

1. Make up 250 cm^3 of a solution containing all of the sample of **monomer X** in the 250 cm^3 volumetric flask provided.

2. Clean a burette first with water followed by a small amount of 0.1 mol dm^{-3} NaOH solution, before filling the burette to 0.0 cm^3 with 0.1 mol dm^{-3} NaOH.

3. Clean the 25.0 cm^3 pipette first with water and then with the solution of **monomer X**.

4. Using the pipette, transfer exactly 25.0 cm^3 of the solution of monomer X made in step 1 into a 250 cm^3 beaker and add approximately 25 cm^3 of water. **Record the pH of the solution using the pH meter**.

5. Slowly add small amounts of NaOH from the burette to the solution of the monomer. **Record the pH after each addition in a suitable table on the results sheet.** Continue the addition until the pH stops changing.

6. Sketch a graph of pH (y-axis) against volume of NaOH added in cm^3 (x-axis).

7. Use the pH curve obtained to determine the pKa of the weak acid monomer. **Record the pK_a of the weak acid monomer on the results sheet.**

8. Using the table of pK_a values shown below, identify the acid from which the biodegradable polymer is made. **Write the name of the weak acid monomer on the results sheet**.

Acid	**Molar mass in g / mol**	**pKa value**
ascorbic acid	176	4.10
lactic acid	90	3.86
citric acid	192	3.08
2-aminobutanoic acid	103	2.29

Table 5. Acid pK_a values.

Part 2 - Extension

Assuming that 1 mole of the monomer reacts with 1 mole of NaOH determine the mass of monomer in the plastic cup **Sample X.**

Show all your working in your results booklet.

If you require help with this section of the task, a hint sheet is available from the demonstrators. 2 marks (out of the 5 allocated for this section) will be deducted for use of the hint sheet.

TOP OF THE BENCH 2019 PRACTICAL CHALLENGE

Recycling plastics - Results

School name: .... **Overall score** **/ 30**

Demonstrator comments:

Part 1 – Identifying polymers based on their density

Record the results of the experiment (i.e. whether the samples float or sink in each of the different solutions) in a neat table below;

1

Conclusion

Complete the table to identify the polymer used to make each plastic sample. Add the recycling symbol with identification number and code with which the plastic sample should be labelled.

Plastic sample	Polymer from which it is made	Recycling symbol, identification number and code
A – Margarine tub		
B – Water bottle		
C – Shampoo bottle		
D – Cosmetics tube		
E – Bowl		
F – White plastic cup		
G – Milk bottle		
H – Transparent plastic cup		
I – Black plastic chips		

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Part 1 – Extension challenge

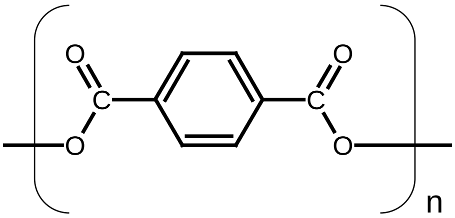
Absorbances observed in the infra-red spectra:

PET – polyethylene terephthalate	
Wavenumber / cm^{-1}	**Group present**

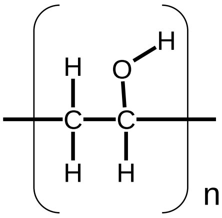
PS – polystyrene	
Wavenumber / cm^{-1}	**Group present**

3

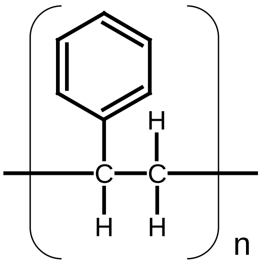
Structure A



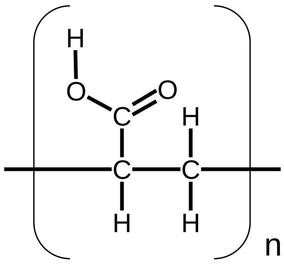
Structure B



Structure C



Structure D



Conclusion:

Circle the correct structure in each case.

PET - polyethylene terephthalate has structure A B C D

PS – polystyrene has structure A B C D

2

Part 2 – Identifying the monomer used to make a biodegradable plastic cup

Record how the pH changes on addition of NaOH to the solution of **monomer X** in a suitable table in the space below.

pK_a of acid present in the solution of monomer = ... (to 1 dp)

Identity of acid in the solution of monomer = ...

5

Free resources from www.mathsphere.co.uk

5

Part 2 - Extension task **Hint sheet given** ☐

Mass of monomer in a single biodegradable plastic cup = ... g

/5