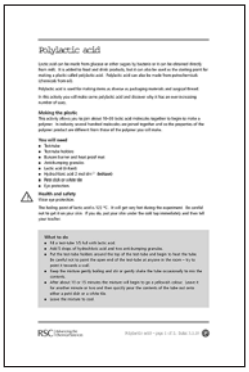
Polylactic acid



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This experiment is aimed only at more able and more sensible students as an introduction to other studies on polylactic acid. It is not recommended for students who would find it difficult to be calm and concentrated while heating a liquid to a high temperature for at least 10 minutes.

The student sheet **Using polylactic acid** covers some of the environmental issues surrounding the industrial production of this plastic and its disposal.

Background information

Lactic acid (2-hydroxypropanoic acid) can be obtained by fermenting glucose or maltose or can be extracted from milk. It is used as the starting point for the production of polylactic acid, also known as poly (2-hydroxypropanoic acid), which can also be made from petrochemicals.

Polylactic acid is a condensation polymer – a molecule of water is produced for every link made in the chain. This is not specified in the students' notes, but you might wish to draw their attention to it. When the water is removed, an oligomer made of 10–30 lactic acid units is formed. An oligomer is essentially a short length of polymer. The production of true polylactic acid involves catalytic depolymerisation of the oligomer to a lactide intermediate followed by polymerisation of the lactide to high molecular weight polylactic acid. In the experiment described here only the oligomer is made. The product therefore has different properties from the polylactic acid used in packaging. It may be useful to discuss with students how the different properties are related to the chain length of the polymer molecules.

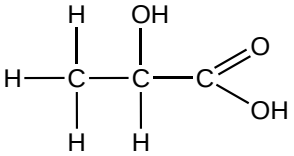

Figure 1 Lactic acid or 2-hydroxypropanoic acid

During polymerisation, the OH on the acid group (CO_2H) group of the monomer reacts with the OH group on the second carbon atom of another monomer. This is an esterification reaction and involves the loss of water. The resulting polymer is shown in Figure 2.

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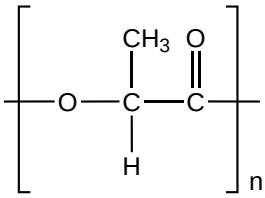

Figure 2 Polylactic acid or poly (2-hydroxypropanoic acid)

Equipment required

For each group of students:

- Test-tube
- Test-tube holders
- Bunsen burner and heat proof mat
- Anti-bumping granules
- Lactic acid (2-hydroxypropanoic acid) (**Irritant**)
- Hydrochloric acid 2 mol dm^{-3} (**Irritant**)
- Petri dish or white tile
- Eye protection.

Health and safety

The boiling point of lactic acid is 122 °C so when students pour it out it will be very hot. Warn students to take care.

Notes

Lactic acid is very viscous so do not attempt to get students to use measuring cylinders. A $^1/_5$ full test-tube works fine and measuring the lactic acid in this way saves making several measuring cylinders very sticky.

The product is very sticky, so discourage students from touching it. They should use a glass rod or a wooden splint instead of their fingers.

Answers – making polylactic acid

1. The molecules will have got bigger because during polymerisation, the small molecules join together in chains.
2. The lactic acid is quite viscous, but the product is a solid (or a very viscous liquid). The product does not run off a petri dish or fall off if you turn it upside down. Note: You can also test for water solubility – the starting material is water soluble but the product is not.
3. As the molecules get larger, the intermolecular forces holding them together also get larger. This causes the material to become stickier and more viscous. (Larger molecules also tend to move around less so materials with large molecules are often solids.)

Answers – using polylactic acid

1. Most plastics are made from petrochemicals/oil.
2. The raw material for polylactic acid is corn.
3. Energy is required for harvesting the corn, transporting it and processing it. All this energy comes from fossil fuels.
4. Production of polylactic acid releases more carbon dioxide into the environment than production of polyethene because a greater amount of fossil fuels is burnt to release energy.
5. Polylactic acid is made from biodegradable material (corn), whereas polyethene is made from fossil fuels, which will release carbon dioxide if the plastic is burnt as waste. (Note: polylactic acid releases carbon dioxide and methane when it degrades.) Also can trap carbon dioxide during photosynthesis.
6. The procedure for producing polylactic acid uses a lot of fossil fuel energy, which is expensive. It is also a complex procedure and involves a lot of steps. For example, the bacteria used to ferment the sugar in the raw material must then be separated from the lactic acid produced.
7. Production of polylactic acid uses less oil.
8. Mark by impression. Students should produce a reasoned argument to support their opinion.
9. Most British rubbish is dumped in landfill sites (where only some of it will biodegrade over hundreds of years) or is incinerated (which can produce toxic fumes). Students could be directed to **http://www.foe.co.uk/resource/factsheets/plastics.pdf**) (accessed November 2005) for more information on the disposal of plastics.
10. Mark by impression. Students might be expected to suggest disposable products because of the biodegradable nature of polylactic acid and a marketing campaign that emphasises the 'green' aspect of the plastic.

Making polylactic acid

Lactic acid can be made from glucose or other sugars by bacteria or it can be obtained directly from milk. It is added to food and drink products, but it can also be used as the starting point for making a plastic called polylactic acid. Polylactic acid can also be made from petrochemicals (chemicals from oil).

Polylactic acid is used for making items as diverse as packaging materials and surgical thread.

In this activity you will make some polylactic acid and discover why it has an ever-increasing number of uses.

Making the plastic

This activity allows you to join about 10–30 lactic acid molecules together to begin to make a polymer. In industry several hundred molecules are joined together and so the properties of the polymer product are different from those of the polymer you will make.

You will need

- Test-tube
- Test-tube holders
- Bunsen burner and heat proof mat
- Anti-bumping granules
- Lactic acid (**Irritant**)
- Hydrochloric acid 2 mol dm^{-3} (**Irritant**)
- Petri dish or white tile
- Eye protection.

Health and safety

Wear eye protection.

The boiling point of lactic acid is 122 °C. It will get very hot during the experiment. Be careful not to get it on your skin. If you do, put your skin under the cold tap immediately and then tell your teacher.

What to do

- Fill a test-tube 1/5 full with lactic acid.
- Add 5 drops of hydrochloric acid and two anti-bumping granules.
- Put the test-tube holders around the top of the test-tube and begin to heat the tube. Be careful not to point the open end of the test-tube at anyone in the room – try to point it towards a wall.
- Keep the mixture gently boiling and stir or gently shake the tube occasionally to mix the contents.
- After about 10 or 15 minutes the mixture will begin to go a yellowish colour. Leave it for another minute or two and then quickly pour the contents of the tube out onto either a petri dish or a white tile.
- Leave the mixture to cool.

Questions

1. If you have successfully polymerised the lactic acid, what will have happened to the size of the molecules?

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2. Look at the lactic acid you started with and your product. Describe the differences in properties between them (be careful – your product will be very sticky).

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3. Try to explain the change in properties in terms of the size of the molecules in the materials.

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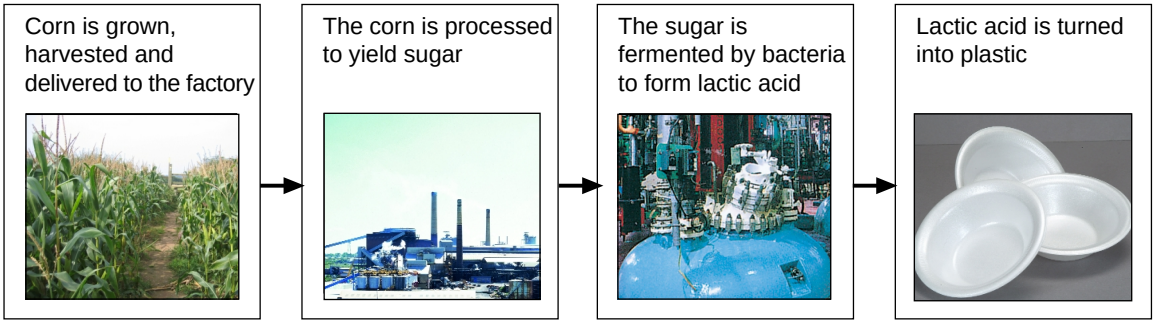
Using polylactic acid

Polylactic acid is commercially manufactured in the USA and in Japan. It can be made into consumer items as diverse as disposable plates and cups, packaging and clothing. The lactic acid used to make it is derived from corn. The process used to make it involves both biotechnology and chemistry.



1. What are most plastics are made from? (What is the raw material?)

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2. What is the raw material for making polylactic acid?

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When the plastic polyethene is made, energy is used to make the ethene and to turn the ethene into polyethene. As ethene is a gas, it is usually piped from place to place.

When polylactic acid is made, the corn has to be transported from the field to the factory and the distances involved can be vast. The PLA (polylactic acid) plant in Nebraska is in the middle of a huge corn field to minimise transportation costs.

3. Look at the stages of the process for making polylactic acid shown above. Which of the stages uses energy? Where is this energy likely to come from?

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To make a kilogram of polyethene, 81 MJ worth of fossil fuels is required. This includes 29 MJ worth of raw materials and 52 MJ of fuels that are burnt to release the energy needed for the manufacturing process. To make a kilogram of polylactic acid, 56 MJ of fossil fuels is required. All of this is burnt to release energy.

When fossil fuels are burnt, carbon dioxide is released into the environment. When a fossil fuel is turned into plastic, the carbon dioxide is not released but is locked in the plastic and only released into the environment if that plastic is burnt or decomposes.

4. When polylactic acid and polyethene are made, which results in the most carbon dioxide being released to the environment?

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5. Why is this less of a problem than it might seem at first? (Hint: think about what the polylactic acid is made from).

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6. Polylactic acid is about five times as expensive as polyethene. Why do you think this is?

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The chemical industry is trying to make itself 'greener.' There are three main ways it is likely to do this:

- Use less oil
- Develop cleaner chemical processes
- Avoid damaging ecosystems.

It is also important to reduce any risk to employees working in the chemical industry and to the users of its products.

7. Which of the two products (polyethene and polylactic acid) uses less oil?

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Although the oil saving is not much at the moment, it is hoped that in time the process for making polylactic acid will become more efficient and use less oil. This could be achieved by burning leftover parts of the corn to produce energy or by scientists spending a lot of time doing research to find a better way to make the product. Improvements have already been made that have significantly reduced the cost of polylactic acid.

However, businesses have to make money and there is no advantage for a manufacturer who develops an environmentally friendly product that is very expensive to produce. A manufacturer could spend a lot of money on research and not manage to find a way of using less energy. Consumers are not normally willing to pay more for an item just because it is 'environmentally friendly.'

8. Do you think the government should do something to help companies who make 'greener' packaging? Packaging that is not degradable could be taxed, for example, or the government could pay for some of the research needed. Remember – this means that you will end up paying for it eventually! Things wrapped in plastic may become more expensive or taxes may go up, which could lead to your parents having less money to spend on you. Explain your answer.

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One of the main benefits of polylactic acid is that it is biodegradable. Polyethene is too, but it will probably take hundreds of years to biodegrade. Polylactic acid can be put into a compost heap and will degrade within a few months.

9. Where does most rubbish in Britain end up? What happens to it there?

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10. Which products would it be best to make out of polylactic acid. How would you market those products?