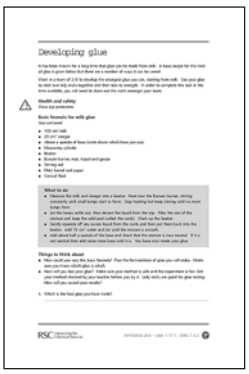
Epoxy glues and the ATLAS project: the biggest experiment ever?


The biggest experiment ever? – Video question sheet


Developing glue


The biggest experiment ever?

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ATLAS is a particle physics experiment that will explore the fundamental nature of matter and the basic forces that shape our universe. The ATLAS detector will search for new discoveries by colliding extraordinarily high-energy protons head on with each other. ATLAS is the largest collaborative effort ever attempted in the physical sciences. Over 1800 scientists from more than 150 universities and laboratories in 34 countries (including the UK) are participating.

The protons will be accelerated in the Large Hadron Collider, an underground accelerator ring 27 kilometres in circumference at the CERN Laboratory in Geneva, Switzerland. The particle beams will be steered to collide in the middle of the ATLAS detector. It is hoped that the debris of the collisions will reveal fundamental particle processes and may help in the discovery of new particles. The energy density in these high-energy collisions is similar to the particle collision energy of the early universe less than a billionth of a second after the Big Bang.

The amount of information generated by this experiment will be huge. There will be four experiments and each will generate about one petabyte (10^{15}) of data (one thousand million million bytes, equivalent to a billion copies of the Sunday Times newspaper) every year. This information will need to be sent to researchers in various institutions around the world. Current information technology cannot handle this quantity of data and so new computing systems will be needed. The world wide web was originally developed to handle the data produced in an earlier experiment at CERN and a new generation of the internet is likely to result from the ATLAS project. Much of the development of the new technology is taking place in the UK – for further details see the PPARC (Particle Physics and Astronomy Research Council) website at the address given below.

The idea of colliding particles to find out more about matter is not new. Ernest Rutherford discovered that the majority of the mass of an atom is in a tiny region in the centre (which we now call the nucleus) by bombarding gold leaf with alpha particles. This is described in the RSC publication *Chemists in a Social and Historical Context* by Dorothy Warren. Many other discoveries have since been made by studying collisions.

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The ATLAS project will seek to accelerate protons to greater speeds than ever before in the hope that the exceptionally high energy of their collisions will lead to new discoveries and either confirm or help to develop current theories about the make-up of matter.

Aim

The aim of this activity is to give students some idea of the scale of the projects undertaken in science and to make them aware of how scientists from dozens of different countries can work collaboratively to enhance our understanding of the universe.

The activity focusses on one aspect of the ATLAS accelerator/detector – that of the superconducting magnets and, more specifically, the glue which is used to hold them together.

Students will develop their own glue to solve a specific problem and then look at how the issue was tackled by the research team at CCLRC (Council for the Central Laboratory of the Research Councils) in Didcot, Oxfordshire.

Background knowledge required

Developing glue is accessible to the majority of students; the rest of the activity may not be. This activity could be carried out as an enhancement activity or as a science club activity.

Students will need to have some understanding of the structure of the atom. The video (see Resources available below) goes way beyond what students will need at this stage. However, with a little background knowledge and interest they will be able to understand enough to grasp the point of the ATLAS experiment.

Students will need some knowledge of organic chemistry, acids and bases.

Resources available

- **http://atlas.ch/** (accessed November 2005) – The ATLAS website is an excellent source of information with diagrams, graphics and well presented information. Interested students could be directed to it for further details. In particular, the video is superb: **http://atlas.ch/movie/index.html** (accessed November 2005). It is 18 minutes long and very well worth watching as an introduction to the experiment as it gives the background and the scale of the project. Note that there are two English language versions – the USA server version is different from the Swiss server one. The USA version is far more accessible and the question sheet provided in this resource is based on this version of the movie. The ATLAS website provides details of how to obtain a CD copy of the movie if you prefer not to work online. Some suggested questions to accompany the video are provided with the student sheets (see below).
- **http://www.pparc.ac.uk/frontiers/archive/feature.asp?id=18F3&style=feature** (accessed November 2005) – Information from PPARC on the UK scientists involved in ATLAS.
- **http://www.pparc.ac.uk/frontiers/archive/feature.asp?id=8F2&style=feature** (accessed November 2005) – Information from PPARC on the computing power required for ATLAS.
- **http://www.pslc.ws/macrog/eposyn.htm** (accessed November 2005) – Information on epoxy resins and glues.

In this resource

- Questions for use with the video provided on the ATLAS website – **The biggest experiment ever? – video question sheet**.
- Glue development worksheet – **Developing glue**
- Information sheet for students (includes questions) – **The biggest experiment ever?**

Developing glue – equipment needed

For making the glue:

- Milk – full fat, semi-skimmmed and skimmed – 100 cm^3 of each per group
- Vinegar
- Bases, *eg* sodium hydrogencarbonate, magnesium carbonate, calcium carbonate, milk of magnesia
- Spatulas
- Stirring rods
- Measuring cylinders (100 cm^3 and 25 cm^3)
- Beakers (100 cm^3 and 250 cm^3)
- Bunsen burner, mat, tripod, gauze
- Filter funnel and paper
- Conical flask (100 cm^3 or above)
- Universal Indicator paper (some students may request it).
- Lolly sticks

For testing the glue:

- Weights (the ones on a hook are ideal) to be added aprox. 100 g at a time
- Sand tray.

Health and safety

Eye protection should be worn whilst making the glue.

To avoid the danger of weights landing on students' feet, make sure a sand tray is placed underneath the sticks as they are tested.

If the sticks snap then there is a risk of splinters. Students should wear eye protection during testing.

Check students' proposals for testing before they are carried out – pay particular attention to their plans for safety.

Notes on the method

Factors that could be varied in the glue making include: the type of milk – ordinary full fat, semi-skimmed, skimmed milk; the base (*eg* sodium hydrogencarbonate, magnesium carbonate, calcium carbonate) – carbonates are good as the mixture bubbles when they are added so it is easy to tell when the glue has been neutralised without using an indicator; the pH of the glue (*ie* vary the amount of base added, from not enough for neutralisation to excess); the acid used to curdle the milk.

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Students can make one 'batch' with one type of milk and then divide the curd and water mixture into portions and add a different base to each portion. A large number of different glues can then be made without too much effort.

Testing the glue can be awkward as it is so strong that if paper is used, the paper will almost certainly break before the glue does, which would not allow relative strengths of glue to be tested. One alternative is to use two lolly sticks overlapped by about 2 cm and glued down at the overlap. Once the glue is dry, balance the sticks over the gap between two tables separated by a suitable distance. Place a sand tray underneath and hang weights on the lower of the two sticks until the glue breaks and the sticks come apart. Quite a significant amount of force is required for this – if you are short of weights, make the overlap between the sticks smaller to reduce the force needed. As the results vary, each glue should be tested at least twice.

Table 1 gives some sample results. Two variables were tested – type of milk and base used.

Type of milk	**Mass required to break the glue (g)**	
	Magnesium carbonate	**Sodium hydrogencarbonate**
Full fat	2500	1200
	3000	2100
Semi-skimmed	2900	2100
	3000	2400
Skimmed	3100	2400
	3000 – stick broke	2300

Table 1 Sample glue test results

The results in the table show that skimmed milk tends to be the best type for this purpose, and magnesium carbonate the best base, although there is some variability within these results.

The glue consists of molecules of the protein casein which are precipitated from the milk by the addition of acid. Polymerisation of these protein molecules forms the glue. The fat in the milk can get in the way of these polymer chains – lubricating them like oil on a bicycle chain – and prevent them from sticking together as effectively as in the absence of fat.

Answers

Video Question sheet

1. Copernicus and Gallileo questioned the geocentric model. They lived in the 16th century.
2. Satellites, mobile phones and broadcasting rely on Newton's equations.
3. The current model of matter is the Standard Model.
4. The four forces in nature are gravity, electrostatic force, the weak and the strong forces.
5. ATLAS will try to find out if the Higgs particle exists, what it is like, what causes particles to have mass, why different particles have different masses, how mass was obtained from energy, why there are only 12 basic particles and why there are three families of particles. It will also try to find evidence of supersymmetry.

6. 34 countries are involved in building ATLAS.

7. High speed protons will be made to collide.

8. The accelerator will contain supermagnets made of superconductors.

9. These will be the biggest supermagnets ever built.

10. The ATLAS accelerator/detector is 45 m x 22 m (as big as a five storey building).

11. The equipment is precise to 1/100 mm (in some cases it can be even more precise than this).

The biggest experiment ever?

Note: The full structures of the molecules used to make the epoxy glues described in the student sheet are given at the end of this section.

1. The aim of the ATLAS experiment is to find out what protons are made of and to discover new particles.

2. During the experiment, protons will be accelerated to very high speeds and made to collide. (Detectors then look at what is produced.)

3. The accelerator is to speed up the protons.

4. The epoxy resin will be used to hold the coil of the superconductor together and prevent individual loops of the coil from touching each other.

5. The glue will need to be an insulator and must not break when exposed to very low temperatures.

6. The glue will need low viscosity so that it can be put in between the coils of the electromagnet without difficulty. It will need to be a good insulator to prevent short circuiting, which would make the temperature of the magnet rise. It will need a long working time so that the coils can be made before the glue dries. It will need to be flexible rather than brittle so that it does not snap when it undergoes extreme temperature changes.

7. The brackets and the number five mean that the group of atoms within the brackets is repeated five times in a chain.

8. Resin B has hydrogen atoms attached to the carbon atom in the middle (between the two carbon chains), whereas resin A has methyl (or CH_3) groups in this position.

9. The resins all contain a group of three atoms in a ring – two carbon atoms and an oxygen atom:

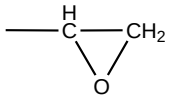

Figure 1 The epoxy group

10. Resin C and hardener 2 both contain long chains in their molecules. These long chains are what gives the glue its flexibility.

11. The two hardeners share an $–NH_2$ group.

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The full structures of the molecules used for the epoxy glues are:

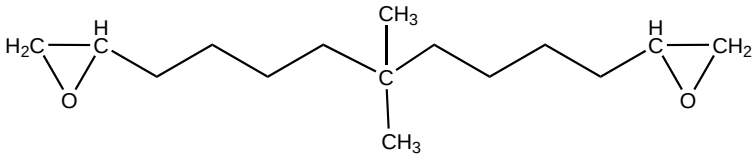

Figure 2 Resin A

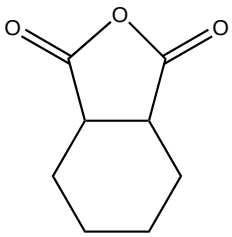

Figure 3 Hardener 1

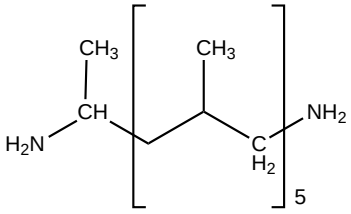

Figure 4 Hardener 2

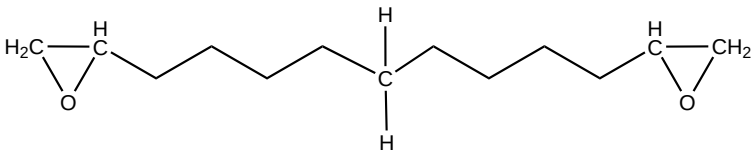

Figure 5 Resin B

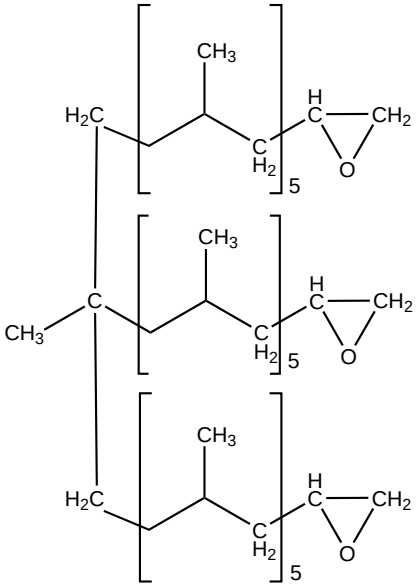

Figure 6 Resin C

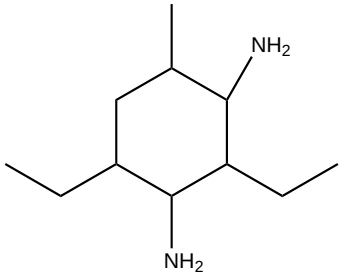

Figure 7 Hardener 3

The structures used in the student sheets are simplified representations only and not the full correct structures. The pictures given enable the students to answer all the questions and understand the key ideas in this topic.

The biggest experiment ever? – video question sheet

The video is available online at **http://atlas.ch/movie/index.html** (accessed November 2005). The USA version is more accessible than the Swiss one and these questions relate to the USA version.

1. People used to think that the Earth was the centre of the universe. Which scientists questioned this model? When were they working?

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2. Name some modern technologies that rely on Newton's equations.

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3. What is the name of the current model of matter?

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4. What are the four forces in nature?

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5. What are some of the questions that ATLAS will try to answer?

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6. How many countries are involved in building ATLAS?

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7. What will be colliding in the ATLAS experiment?

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8. What type of magnet will the accelerator contain?

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9. What is special about the magnets that will be in ATLAS?

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10. How big is the ATLAS accelerator/detector?

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11. How precise is the equipment?

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Developing glue

It has been known for a long time that glue can be made from milk. A basic recipe for this kind of glue is given below but there are a number of ways it can be varied.

Work in a team of 2–5 to develop the strongest glue you can, starting from milk. Use your glue to stick two lolly sticks together and then test its strength. In order to complete this task in the time available, you will need to share out the work amongst your team.

Health and safety

Wear eye protection.

Basic formula for milk glue

You will need:

- 100 cm^3 milk
- 20 cm^3 vinegar
- About a spatula of base (write down which base you use)
- Measuring cylinder
- Beaker
- Bunsen burner, mat, tripod and gauze
- Stirring rod
- Filter funnel and paper
- Conical flask.

What to do

- Measure the milk and vinegar into a beaker. Heat over the Bunsen burner, stirring constantly until small lumps start to form. Stop heating but keep stirring until no more lumps form.
- Let the lumps settle out, then decant the liquid from the top. Filter the rest of the mixture and keep the solid part (called the curds). Wash up the beaker.
- Gently squeeze off any excess liquid from the curds and then put them back into the beaker. Add 15 cm^3 water and stir until the mixture is smooth.
- Add about half a spatula of the base and check that the mixture is now neutral. If it is not neutral then add some more base until it is. You have now made your glue.

Things to think about

- How could you vary this basic formula? Plan the formulations of glue you will make. Make sure you know which glue is which.
- How will you test your glue? Make sure your method is safe and the experiment is fair. Get your method checked by your teacher before you try it. Lolly sticks are good for glue testing. How will you record your results?

1. Which is the best glue you have made?

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The biggest experiment ever?

What is the biggest experiment ever undertaken in the world?

One contender is the ATLAS experiment, which is due to begin in 2007. Scientists began planning it in 1995 and thousands of researchers from dozens of countries are involved. It will take place partly in Switzerland and partly in France in a circular tunnel 100 m underground with a diameter of 27 km. The main piece of equipment being built for the experiment will be the height of a five story building, but each component will be engineered to within a fraction of a millimetre of the desired size. Each part has to work perfectly or the whole thing may fail.

The aim of the experiment is to find out more about the structure of matter. We know now that everything is made of protons, neutrons and electrons (although this was confirmed less than 100 years ago). Particle physicists have been trying to discover what these particles are themselves made of. They have some answers, but many more questions remain and ATLAS is an attempt to answer some of the them.

Ever since Ernest Rutherford bombarded gold atoms with alpha particles and discovered that every atom has a nucleus, physicists have collided different particles with each other at varying speeds to try to find out more about what matter is made of. The ATLAS project is no exception. Protons will be made to collide with other protons at exceptionally high speeds. The hope is that this will cause the protons to fall apart and reveal what they are made of.

Scientists from the UK have contributed to many parts of ATLAS, including the development of the accelerator needed for the experiment. The accelerator will speed up the protons to ensure that they are travelling at very high speeds when they collide. As the protons are charged, they can be accelerated by a magnetic field – the larger the magnetic field, the faster the protons will go. To create a very large magnetic field, superconducting magnets will be used. These are electromagnets made of superconductors. Superconductors are alloys with no resistance and they are extremely efficient conductors, but they only work at extremely low temperatures – about -268 °C. To make a superconducting magnet, a superconducting alloy is made into a coil. The loops of the coil must not touch. To keep them apart and to hold the coil together, a type of glue made from epoxy resin is used. The glue must have very particular properties to work in this extreme environment and a team of chemists at the RAL (Rutherford Appleton laboratory) in Didcot, Oxfordshire have been working on developing a glue with the properties required.

1. What is the aim of the ATLAS experiment? What are scientists trying to find out?

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2. What will happen during the experiment?

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3. What is the accelerator for?

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4. What will the epoxy resin (glue) be used for?

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5. What properties might the glue require?

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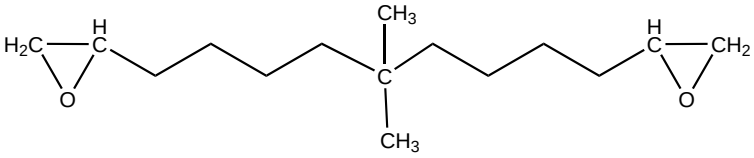
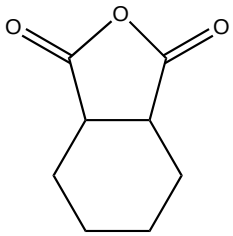
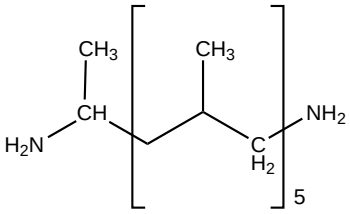
The epoxy glue consists of two parts – the epoxy resin and a hardener. The team at RAL started with two glues that are available commercially. Resin A was in both glues but each contained a different hardener. The structures of the resin and the hardeners are shown below. They look at bit complicated but you do not need to understand every single part of the diagrams. The zig-zag lines represent the bonds between the carbon atoms but you do not need to worry about how they are arranged.



Resin A



Hardener 1



Hardener 2

The hardener reacts with the epoxy resin to make a cross-linked polymer. This is the glue.

The properties required for the glue are:

- Low viscosity (not too sticky)
- Good insulator
- Long working time (does not set too quickly) – at least 10 hours
- Not brittle.

Remember that this glue will be used between the coils of the electromagnet. It will be at about 100 °C when the coil is put together and will be working at about -268 °C.

6. Explain why the glue will need each of the four properties above.

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7. What do the brackets with the number five outside in the structure of hardener 2 represent? (Hint: Think about polymers.)

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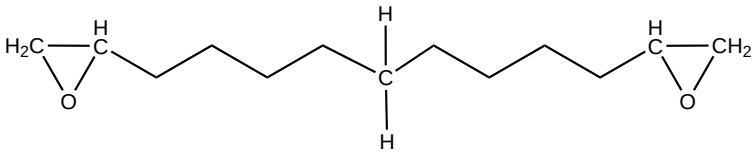
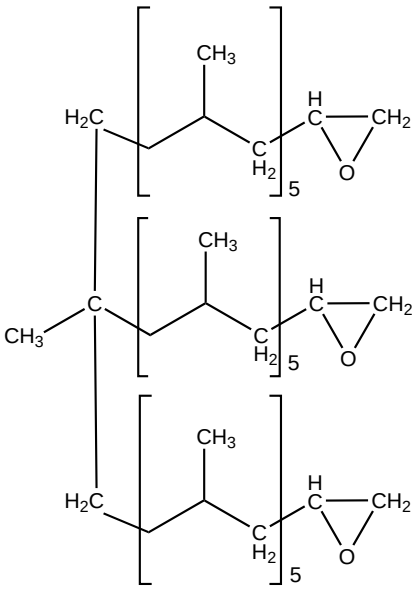
Resin A and Hardener 1 give a glue with three of the right properties, but it is too brittle. If it cracks, the coils of the electromagnet may touch each other. This would result in a short circuit which would heat up the magnet. If the magnet rises above -268 °C then it stops being a superconductor and can no longer produce the magnetic force required to accelerate the protons. The whole ATLAS experiment could fail if the glue cracks so this is not acceptable.

A glue made of resin A and Hardener 2 has the required flexibility. However, its working time is only about 30 minutes. This is not long enough to finish making the coils of the electromagnet.

A new glue system is needed. The team at RAL tried many different glue systems. Eventually they found one with the properties they want. They used a mixture of Resin B and Resin C. This gave the level of flexibility they required.



Resin B



Resin C

8. How is Resin B different from Resin A?

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9. What unusal group of three atoms do all three resins share? Draw it.

This group is called the epoxy group. It gives the glues their name (epoxy resins). As it is very reactive, it helps the glues to set. This is the part of the resins that reacts with the hardener to make a polymer.

10. Either Hardener 2 or Resin C can be used to give the finished glue more flexibility. What group of atoms do they share and why might this group give flexibility?

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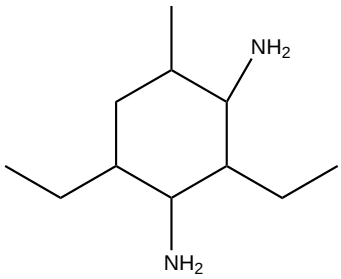

Hardener 3

11. What unusual group of atoms do Hardeners 2 and 3 share?

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