Student's document

TEMPERATURE COLOURS: Making and testing liquid crystal thermometers

Did you know that coloured plastic strips can be used to measure your temperature? They are sometimes called liquid crystal thermometers. Place them on your forehead. Wait about 15 seconds. Look at the colour and that gives your temperature. They are easy to use and safer than mercury-in-glass thermometers, but do not give very accurate values. Nonetheless they are very useful.
Liquid crystal thermometers have thermochromic liquid crystals in them that change colour with temperature. This is usually over a range of about 0.1 ^{O}C. Different liquid crystals change colour at different temperatures. As well as measuring body temperature, liquid crystal thermometers can also be used to monitor the temperature of a room, refrigerator, freezer and even a fish tank. How do scientists find the right liquid crystals for a particular application?

Your brief
Imagine you work in a research and development (R&D) team of a company that manufactures liquid crystals. You have been asked to investigate the usefulness of the liquid crystals in liquid crystal thermometers.

A number of companies produce liquid crystal thermometers. Begin your investigation by finding out what is available. The next stage is to make some liquid crystals in the laboratory and study their potential use in liquid crystal thermometers.
Research already carried out has shown that cholesteryl esters behave as liquid crystals. Further, mixing them together produces a range of liquid crystals that change colour at different temperatures.

You will be given a budget for materials. You will need to ensure that you can carry out all the practical work necessary within this budget. You also have a limited amount of time (about six hours) to complete the activity. Managing the workload within this time is essential.

Finally you should find out about the properties of liquid crystals and write a brief explanation of why these thermochromic liquid crystals change colour when heated and cooled.

Plan and prepare
To meet your brief, there are several tasks to carry out. You need to show that, working in a team, you can (a) manage resources and budgets, (b) manage time and workload. How you set about the work depends on the size of the team you have been assigned to for this project.

- Before starting, each member of the team should read through the tasks and supporting information carefully.
- The team should come together to plan what needs to be done and to share the workload.
- Your teacher will tell you how much time you have and when you can use the laboratory. Write an outline plan and check with your teacher. Remember,

once you start work, unexpected things can happen. You will need to be flexible and prepared to adjust your plan if necessary.
- Standard laboratory equipment is available. However, you must order the materials you need from the chemistry storeroom and pay for them. Remember, you must work within budget.

Your investigation
Here are the tasks the team must carry out.

Practical work
Task 1: Investigate some commercial liquid crystal thermometers
There are two data sheets that illustrate the types of liquid crystal thermometers available:
- **Datasheet***: Liquid crystal thermometers*
- **Datasheet***: Liquid crystal thermometer plastic strips*.

Select some liquid crystal thermometer plastic strips from **Datasheet***: Liquid crystal thermometer plastic strips*. Working in pairs within your team, use the **procedure** *Liquid crystal thermometers - checking performance* to observe how they work and to check how closely they meet their published specifications for *Measuring Range*, *Display Accuracy*, *Display Resolution*, *Dimensions*.

Estimate the cost of carrying out these investigations (assume the cost of a chemist's time is £40 per hour, which includes salary and associated costs, building, environmental and other overheads).
Note: If you do not live in the UK, find the exchange rate and convert the prices given into Euros.

Task 2: Prepare liquid crystals
Prepare a series of liquid crystal sandwiches from cholesteryl oleyl carbonate and cholesteryl pelargonate (see the **procedure** *Liquid crystal sandwiches – Making a liquid crystal sandwich*). You might, for example, make liquid crystal sandwiches from
- cholesteryl oleyl carbonate
- cholesteryl pelargonate
- mixtures of cholesteryl oleyl carbonate and cholesteryl pelargonate.

How many you are able to investigate will depend on how many are in your group and, of course, the budget.

You can buy cholesteryl oleyl carbonate and cholesteryl pelargonate from your technical suppliers. Your teacher will explain what this entails.
November 2007 prices are:
Cholesteryl oleyl carbonate (from Aldrich Chemicals): £37.40 for 25 g
http://www.sigmaaldrich.com/catalog/search/ProductDetail/ALDRICH/151157

Cholesteryl pelargonate (from Aldrich Chemicals): £40.70 for 100 g
http://www.sigmaaldrich.com/catalog/search/ProductDetail/ALDRICH/C78801

Mixtures may be ordered from the company's technical store, but you must give them at least 24 hours notice. There is a labour charge of 50p to make a mixture regardless of quantity.

Cholesteryl oleyl carbonate / % by mass	90	80	70	60	50	40	30	20	10
Cholesteryl pelargonate / % by mass	10	20	30	40	50	60	70	80	90
£ / 100 g	139	128	117	106	96	85	74	63	51

Task 3: Check the performance
Investigate the characteristics of the liquid crystal sandwiches that have been made, using the **procedure** *Liquid crystal sandwiches – Checking performance*.

Collect the results from all team members and plot a graph of percentage composition by mass against the temperature range over which the liquid crystal sandwich changed colour.

Task 4: Make a liquid crystal thermometer
Decide what temperature range you think can be measured with reasonable confidence using liquid crystal sandwiches made from cholesteryl oleyl carbonate and cholesteryl pelargonate.

Now make a suitable liquid crystal thermometer using the **procedure** *Liquid crystal sandwiches – Making a thermometer*.

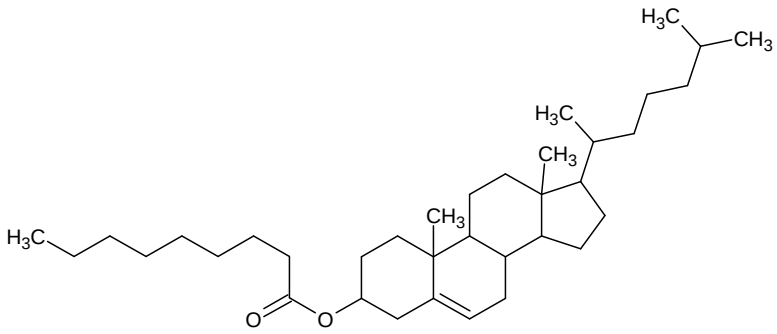
Test its effectiveness.

A research activity
Task 5: About liquid crystals
Find out about the nature of liquid crystals, including the meaning of the terms mesophase, smectic phase and nematic phase. Use these terms to describe the changes you observed when liquid crystals were heated and cooled.

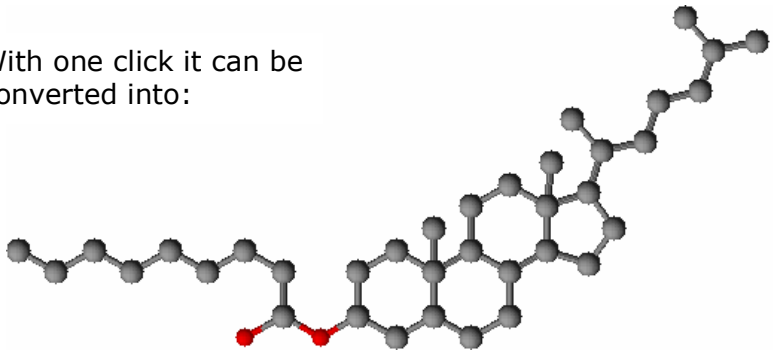
Find the molecular structures of cholesteryl oleyl carbonate and cholesteryl pelargonate and draw them in your notebook. Make molecular models and describe the relationship between the temperature at which your liquid crystals changed colour and their composition.

Note: You might draw the chemical structures and make models using *Molymod* or similar construction kits. If you have the time, you might also try building up three dimensional images on the computer that can be rotated and explored from different angles. A free software package is:
http://www.acdlabs.com/download/

Here is the structure of cholesteryl pelargonate drawn with the package.



With one click it can be converted into:



Student sheets
The information you need is on the four sheets:
- **Datasheet***: Liquid crystal thermometers*
- **Datasheet***: Liquid crystal thermometer plastic strips*
- **Student sheet:** *Liquid crystal thermometers - checking performance*
- **Student sheet:** *Liquid crystal sandwiches*

Your findings
Record:
- your initial plan for the activity, including allocation of workload
- the results of your investigation into commercially available liquid crystal thermometers
- the cost of the materials bought by your team for the activity
- the behaviour of a range of liquid crystal sandwiches made from cholesteryl oleyl carbonate and cholesteryl pelargonate
- the design, construction and performance of a liquid crystal thermometer.

Finally, find out more about liquid crystals and why their properties (e.g. colour) change with temperature. Make sure you list your sources of information and be sure to check what you find in one source against at least two others. Write a summary, with illustrations, in your file or notebook.

Evaluating results
Summarise the results of your practical investigations. Compare the properties of commercial liquid crystal thermometers with the manufacturer's specifications. Also, comment on the potential use of the liquid crystal sandwiches you made in liquid crystal thermometers.

Summarise the effectiveness of your plan to manage time and workloads. Note any changes you made, with reasons, during the course of the activity.

Say whether or not you were able to complete your plan within budget.

Student self assessment
This activity was about using scientific knowledge and understanding to solve problems, working in teams to solve problems, managing resources and budgets and managing time and workload. For each case, write about 50-100 words explaining:

- what scientific skills and knowledge you used and how effectively you used them
- how you worked as a pair, giving examples of how you supported one another and, if appropriate, worked with another pair
- what you learned about managing resources and budgets
- what you learned about managing time and workload

Student Datasheet: Liquid crystal thermometers

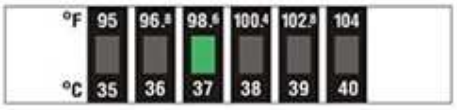
General purpose liquid crystal strips

Source: http://www.liquid-crystal.com/
"This thermometer is available in various temperature ranges and suitable for numerous applications."
Size: 12.5 mm x 45 mm.
Available in five temperature ranges:
-30 to 0 ^{O}C, 0 to 30 ^{O}C, 30 to 60 ^{O}C, 60 to 90 ^{O}C, 90 to 120 ^{O}C

Liquid crystal forehead thermometer

There are many commercially available, inexpensive liquid crystal forehead thermometers. Here are two examples:

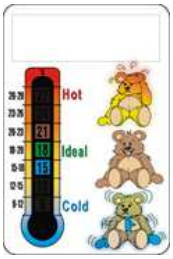
1. "Mercury-free thermometer that is placed directly on the forehead to accurately show temperature trends."
Source: http://www.liquid-crystal.com/
Size: 89 mm x 19 mm.
Temperature range: 35 to 40 ^{O}C



2. *FeverScan* forehead thermometer is a fast and reliable way to check for changes in temperature and is ideal for babies and small children."

Liquid crystal fish tank thermometer

Source: http://www.thermometersdirect.co.uk/
The liquid crystal vertical temperature strip pictured on the left may be obtained from Thermometers Direct, Ref: 100127 D6
The manufacturers say it "*can stick to most items, like glass ideal for fish tanks*".
Temperature Range: 10 to + 36 ^{O}C
Display Accuracy: ±1 ^{O}C
Display Resolution: 2 ^{O}C
Size: 130 mm x 20 mm



Liquid crystal nursery thermometer

Source: http://www.liquid-crystal.com/
"Comfort, control and safety in one. Large, easy to read display monitors the temperature in a child's room."
Size: 54 mm x 85 mm.
Temperature range: 9 to 27 ^{O}C

Student Datasheet: Liquid crystal thermometer plastic strips

http://www.thermometersdirect.co.uk/acatalog/Thermometers_Direct__Liquid_Crystal_Thermometers__LCD__17.html

Horizontal Thermometer strip Ref: 102562 D11
"This can stick to most items, like glass ideal for fish tanks."
Measuring Range: 16 °C to 40 °C
Display Accuracy: ±1 °C; Display Resolution: 2 °C
Dimensions: 103 mm x 13 mm
Price: £1.99 (Including VAT at 17.5%)

Tempstrip -3 ~ +13 °C Ref: 100020 D10
"This can stick to most items, like glass ideal for fish tanks."
Measuring Range: -3 to +13 °C
Display Accuracy: ±1 °C; Display Resolution: 1°C
Dimensions: 120 mm x 13 mm
Price: £1.99 (Including VAT at 17.5%)

Tempstrip 14 °C ~ 31 °C Ref: 102426 D12
"This can stick to most items, like glass ideal for fish tanks."
Measuring Range: 14 to 31 °C
Display Accuracy: ±1 °C; Display Resolution: 1 °C
Dimensions: 120 mm x 13 mm
Price: £1.99 (Including VAT at 17.5%)

Tempstrip 32 °C ~ 49 °C Ref: 802 304 D13
"This can stick to most items, like glass ideal for fish tanks."
Measuring Range: 32 to 49 °C
Display Accuracy: ±1 °C; Display Resolution: 1 °C
Dimensions: 120 mm x 13 mm
Price: £1.99 (Including VAT at 17.5%)

LCD Freezer Thermometer Ref: 102457 D7
"LCD strip is on a strip of plastic which has a pad to allow you to fix to a wall etc"
Measuring Range: -21 °C to -1 °C
Display Accuracy: ±1 °C; Display Resolution: 2 °C
Dimensions: 125 mm x 25 mm
Price: £2.19 (Including VAT at 17.5%)

LCD Refrigerator Thermometer Ref: 102458 D9
"LCD strip is on a strip of plastic which has a pad to allow you to fix to a wall etc"
Range: -2 °C to +12 °C
Display Accuracy: ±1 °C; Display Resolution: 2 °C
Dimensions: 125 mm x 25 mm
Price: £2.19 (Including VAT at 17.5%)

LCD Room Thermometer Ref: 102459 D8
"LCD strip is on a strip of plastic which has a pad to allow you to fix to a wall etc"
Range: 14 °C to 34 °C
Display Accuracy: ±1 °C; Display Resolution: 2 °C
Dimensions: 125 mm x 25 mm
Price: £2.19 (Including VAT at 17.5%)

Student sheet: Liquid crystal thermometers - checking performance

There is no European standard for liquid crystal thermometers at the moment. However, the following procedure might be used for liquid crystal thermometers.

Equipment and materials

- liquid crystal thermometer plastic strip
- stiff polymethylacrylate sheet (e.g. Perspex), 20 cm x 5 cm
- electric hotplate
- 250 cm^3 beaker
- glass thermometer (temperature range appropriate for the liquid crystal thermometer being checked)

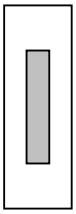
Note: Ideally, use thermometers of low heat capacity (rapid response), e.g. digital thermometers with Pt-resistance or thermocouple or thermistor sensors.

Health and safety

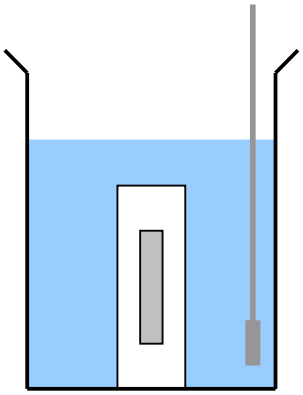
Take care when using a hotplate. Wear protective clothing and eye protection. A risk assessment must be carried out before starting work.

Procedure

1. Stick the liquid crystal thermometer in the middle of the Perspex sheet.
Record the temperature range specified for the liquid crystal thermometer being tested.



2. Lean the Perspex sheet against the inside of the beaker. Pour water into the beaker until it covers the liquid crystal thermometer by 2-3 cm. Place a thermometer in the beaker.



3. The temperature of the water should be at least 5 ^{O}C below that of the lowest temperature shown on the liquid crystal thermometer. If need be, add some crushed ice to lower the temperature.

4. Heat the beaker gently so that the temperature rises very slowly. Use the thermometer to stir the water to ensure it warms up evenly.

5. Measure and record the temperatures at which the different squares on the liquid crystal thermometer start to change colour.

6. When all squares have changed colour, cool the water and repeat steps 3 to 5.

Results

Compare your results (measuring range; display accuracy; display resolution) with the specifications of the liquid crystal thermometer being examined (see **Datasheet***: Liquid crystal thermometer plastic strips*).

Note: To extend this test, stick the liquid crystal thermometer on the outside of the beaker, imitating situations where the thermometers are used in this way.

Student sheet: Liquid crystal sandwiches

Making a liquid crystal sandwich

Equipment and materials

- mixture (about 0.1 g) of cholesteryl oleyl carbonate (CAS number 17110-51-9) and cholesteryl pelargonate (CAS number 1182-66-7)
- small test tube
- small glass stirring rod
- test tube holder or tongs
- 2 cm x 2 cm piece of black acetate transparency
- 2 cm x 2 cm piece of colourless acetate transparency
- 250 cm^3 beaker
- hotplate
- stiff Perspex sheet, 20 cm x 5 cm
- roll of waterproof tape and scissors

Health and safety

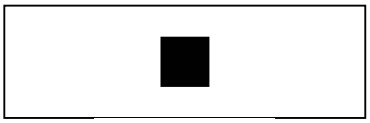
Avoid direct contact with the cholesteryl esters. Wear protective clothing and eye protection. A risk assessment must be carried out before starting work.

Procedure

1. Pour 150 cm^3 of water into the beaker and bring it to a boil on the hot plate.

2. Meanwhile, collect the required mixture of cholesteryl oleyl carbonate and cholesteryl pelargonate in a small test tube.

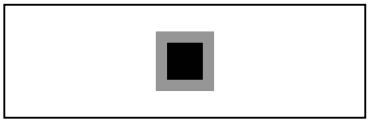
3. Using a test tube holder or tongs, hold the test tube in the boiling water. Stir to mix thoroughly. Record any changes as the mixture is heated.



picture a

4. Lay the black acetate sheet in the middle of the Perspex sheet, shiny side towards the Perspex (**picture a**).

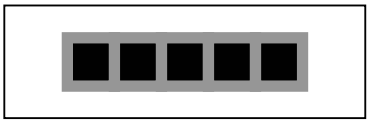
5. Use the glass stirring rod to transfer a small drop of the liquid mixture to the centre of the black acetate.



picture b

6. Quickly, place the colourless acetate over the drop. Squash it so that the liquid spreads evenly across the sheets. Try to remove all of the air bubbles and keep the solution away from the edges (wear gloves and avoid any contact between the chemicals and your skin).

7. Finally tape the acetate sandwich to the Perspex sheet (**picture b**).



picture c

8. To check reproducibility, make some other acetate sandwiches in the same way and stick them to the acetate sheet (**picture c**).

9. The liquid crystal sandwiches are now ready for performance checking.

Checking performance

Equipment and materials

- liquid crystal sandwiches
- electric hotplate
- 250 cm^3 beaker
- glass thermometer (temperature range appropriate for the liquid crystal thermometer being checked)

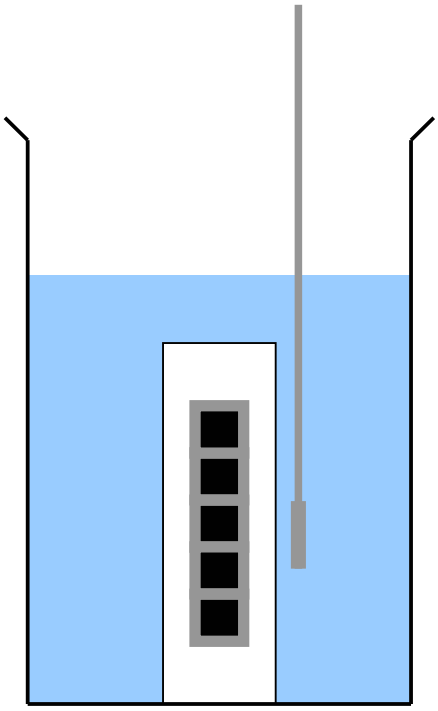
Note: Ideally, use thermometers of low heat capacity (rapid response), e.g. digital thermometers with Pt-resistance or thermocouple or thermistor sensors.

Health and safety

Take care when using the hotplate. Wear protective clothing and eye protection. A risk assessment must be carried out before starting work.

Procedure

1. Lean the liquid crystal thermometer against the inside of the beaker. Pour water into the beaker until it covers the liquid crystal thermometer by 2-3 cm. Place a thermometer in the beaker.



2. The temperature of the water should be at least 5 ^{O}C below that of the lowest temperature shown on the liquid crystal thermometer. If need be, add some crushed ice to lower the temperature.

3. Heat the beaker gently so that the temperature rises very slowly. Keep stirring the water to ensure it warms up evenly.

4. Measure and record the temperatures at which the squares on the liquid crystal thermometer start to change colour. Use a stopwatch to time the colour changes.

5. When all the squares have changed colour, cool the water and repeat steps 3 to 5 to check measurement repeatability.

Results

Tabulate your results and evaluate the quality of the liquid crystal thermometer.

Making a liquid crystal thermometer

Prepare the series of liquid crystal sandwiches needed to cover the temperature range of the liquid crystal thermometer. Tape them side by side on the Perspex sheet.

The performance of the liquid crystal thermometer may now be checked using the method above.