TEMPERATURE COLOURS
Making and testing liquid crystal thermometers

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Languages available
English, Slovenian

Summary
Coloured plastic strips containing liquid crystals can be used to measure temperature. The thermochromic liquid crystals change colour with temperature. This is usually over a range of about 0.1 ^{O}C. Different liquid crystals change colour at different temperatures. They have been used to measure, for example, the temperature of a person, a room, a refrigerator, a freezer and even a fish tank. But how do scientists find the right liquid crystals for a particular application?
Students imagine they are working in a research and development (R&D) team of a company that manufactures liquid crystals. Being asked to investigate the usefulness of the liquid crystals in liquid crystal thermometers, they begin by investigating commercial products. This is followed by making some liquid crystals in the laboratory and studying their potential use in liquid crystal thermometers.

Activity type **F**
Use of scientific knowledge and understanding to solve problems
Working in teams to solve problems
Resource/budget management
Time and workload management

Techniques
Temperature measurement

Field
Nanotechnology
Liquid crystals
Thermochromic

Time
Practical lessons: 360 minutes
Theory lessons: 60 minutes
Out of class time: 180 minutes

StandardBase procedures
None

StandardBase techniques
None

Other resources
Boddingtons Thermometers; http://www.boddingtonsthermometers.co.uk/
Other resources are listed in the activity.

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 L40 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): L37.40 for 25 g
http://www.sigmaaldrich.com/catalog/search/ProductDetail/ALDRICH/151157

Cholesteryl pelargonate (from Aldrich Chemicals): L40.70 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
L / 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*.

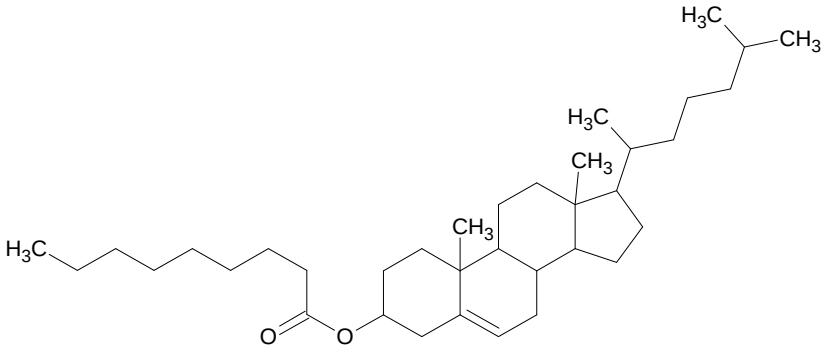
Test its effectiveness.

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.

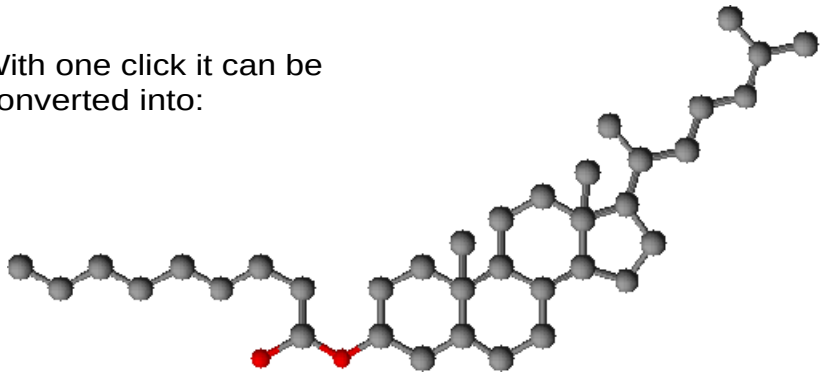
Find the molecular structures of cholesteryl oleyl carbonate and cholesteryl pelargonate and draw them in your notebook. Make molecular models and describe the relationship between the temperature at which your liquid crystals changed colour and their composition.

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

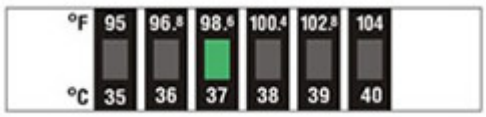
General purpose liquid crystal strips

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:

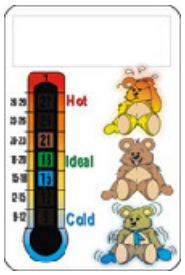
1. "Mercury-free thermometer that is placed directly on the forehead to accurately show temperature trends."
Source: http://www.liquid-crystal.com/
Size: 89 mm x 19 mm.
Temperature range: 35 to 40 ^{O}C



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: L1.99 (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: L1.99 (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: L1.99 (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: L1.99 (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: L2.19 (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: L2.19 (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: L2.19 (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)

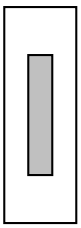
Note: Ideally, use thermometers of low heat capacity (rapid response), e.g. digital thermometers with Pt-resistance or thermocouple or thermistor sensors.

Health and safety

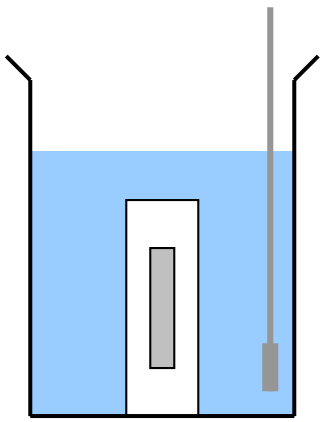
Take care when using a hotplate. Wear protective clothing and eye protection. A risk assessment must be carried out before starting work.

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

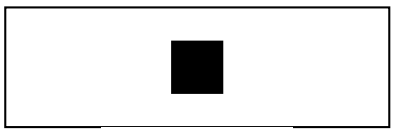
Avoid direct contact with the cholesteryl esters. Wear protective clothing and eye protection. A risk assessment must be carried out before starting work.

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.

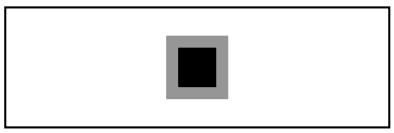
3. Using a test tube holder or tongs, hold the test tube in the boiling water. Stir to mix thoroughly. Record any changes as the mixture is heated.



picture a

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

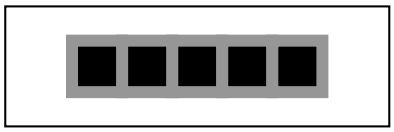
5. Use the glass stirring rod to transfer a small drop of the liquid mixture to the centre of the black acetate.



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)

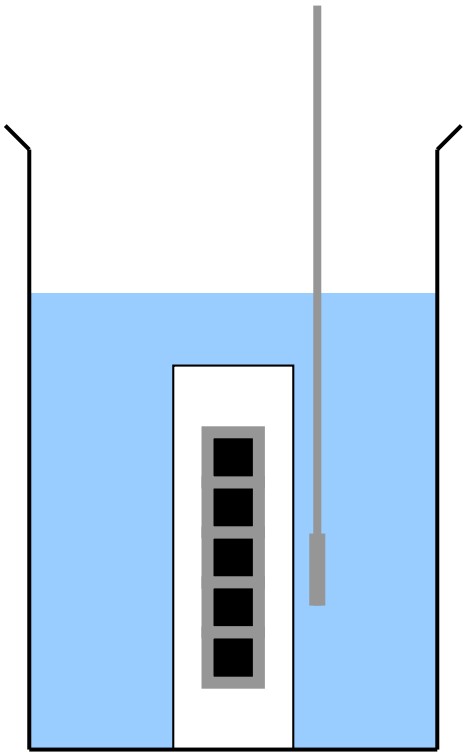
Note: Ideally, use thermometers of low heat capacity (rapid response), e.g. digital thermometers with Pt-resistance or thermocouple or thermistor sensors.

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.

Teacher's document

Overview

Students 'work' in a research and development (R&D) team of a company manufacturing liquid crystals. They are asked to investigate the usefulness of the liquid crystals in liquid crystal thermometers. They begin by finding out what is available, then make some liquid crystals in the laboratory and, finally, study their potential use in liquid crystal thermometers. To be effective they need to have appropriate scientific skills and knowledge, be able to work together as a team and understand the importance of resource and budget management and be able to manage time and workloads.

Developing students' skills

Learning objectives

Students learn to:

- tackle scientific problems by applying their practical skills and their knowledge
- observe, measure and analyse data collected and to evaluate these
- work with others
- manage resources and budgets
- manage time and workloads.

in the context of a team of chemists investigating the potential of liquid crystals in a R&D laboratory.

Guidance and help

Students need to recognise the importance of taking care and pride in their work. They need to be gently reminded of this while they are working. They may need three types of help.

- Help with technical details, including manipulative skills and correct handling of chemicals and equipment.
- Help with, and vigilance over, health and safety issues.
- Help with working relationships in their group.

Learning

The "assessment for learning" approach aims to help students identify their weaknesses and work to improve them. It is not intended to be used to 'give students marks'. See: http://www.presentingscience.com/aflchem/

When using questioning, do not intervene too soon with 'the answer'. Give students thinking time. Use questions as prompts for students to think about what they are doing. They need to be aware of the consequences to themselves and others of actions they take. Use relevant unambiguous questions. Allow plenty of time for students to respond. Involve all members of the group.

An effective series of questions might start with a closed question, followed by open questions. For example: *What was your result? How did you arrive at that result? Where else can you use this method? How can you improve the method?*

Organising and managing the class

Students should work in small team; 4-6 would be suitable.

Most of the work in this activity is practical. It does not require a great deal of equipment, but it does require access to a laboratory. How this is arranged depends on lesson time.

Each team will need to be allocated a budget. Calculate the budget based on how much you feel a team can manage in the time allowed. It might be worked out based on each pair within a team needing to 'buy' from the school or college chemistry storeroom:

A L2.00 for a commercial liquid crystal strip thermometer;
each pair might investigate 1 or 2
B 15p for 0.1 g cholesteryl oleyl carbonate; each pair may have 0.1 g
C 5p for 0.1 g cholesteryl pelargonate; each pair may have 0.1 g
D 60p for 0.1 g ester mixture (this includes the mixing cost);
each pair may investigate 2-4 mixtures

Notes

- 0.1 g liquid crystal is ample to make several sandwiches.
- The "company's technical stores" means the chemistry prep room in your school or college.

A reasonable budget for a team of six might be L15. Of course, this is not what it will cost the school or college since the commercial thermometer (L2) may be reused, the total includes L4.50 'mixing' charges and the quantities of cholesteryl esters can be less than 0.1 g (it is simply that they are 'sold' in these quantities).

Notes on the tasks

Task 1: Investigate some commercial liquid crystal thermometers

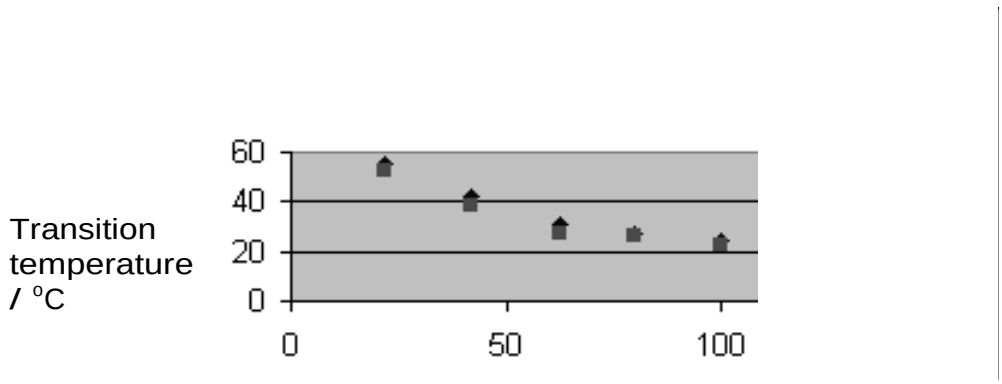
You may limit the choice of commercial thermometers available to students, but they are inexpensive and a wide range would be useful.

It may be helpful to spend a short while discussing the terms used in the specifications for thermometers: Measuring Range, Display Accuracy, Display Resolution, Dimensions.

Task 2: Prepare liquid crystals

Students should start with six mixtures of composition 0, 20, 40, 60, 80, and 100% by mass cholesteryl oleyl carbonate.
Source: http://www.hofstra.edu/pdf/tec_nyscate_liquid_crystals.pdf

They will find that the curve looks like this (see reference above):



Higher proportions of cholesteryl oleyl carbonate (>80% by mass) cause only small changes in the transition temperature. Additional mixtures could be used.

Further, students might choose to 'mix two mixtures'. For example, mixing equal masses of 9:1 and 8:2 mixtures would give a resulting mixture that is 8.5:1.5.

The mixtures provided for students will probably not be homogeneous because of the difficulty of mixing them. Therefore, students should be warned that the whole of the mixture must be melted to make the liquid crystal. It is essential that students stir the mixture thoroughly while melting it.

An alternative approach would be to use a three component system:
- Cholesteryl oleyl carbonate
- Cholesteryl pelargonate (Cholesteryl nonanoate)
- Cholesteryl benzoate

However, this will make the investigation a little more expensive.

More information may be found at the two references given below.
Preparation of liquid crystals:
http://mrsec.wisc.edu/Edetc/nanolab/LC_prep/
Preparation of liquid crystal thermometer:
http://mrsec.wisc.edu/Edetc/nanolab/LC_prep/index2.html

Here are the transition temperatures of the mixtures.

Cholesteryl oleyl carbonate	Cholesteryl pelargonate	Cholesteryl benzoate	Transition range, ^{o}C
0.65 g	0.25 g	0.10 g	17-23
0.70 g	0.10 g	0.20 g	20-25
0.45 g	0.45 g	0.10 g	26.5-30.5
0.43 g	0.47 g	0.10 g	29-32
0.44 g	0.46 g	0.10 g	30-33
0.42 g	0.48 g	0.10 g	31-34
0.40 g	0.50 g	0.10 g	32-35
0.38 g	0.52 g	0.10 g	33-36
0.36 g	0.54 g	0.10 g	34-37
0.34 g	0.56 g	0.10 g	35-38
0.32 g	0.58 g	0.10 g	36-39
0.30 g	0.60 g	0.10 g	37-40

Task 3: Check the performance
Make sure students carry out sufficient tests to be able to judge the repeatability and reproducibility of data.
- repeatability: consistency of results obtained by one member of the group
- reproducibility: consistency of results obtained by different members of the group

Task 4: Make a liquid crystal thermometer
Same comments as task 3.

Task 5: About liquid crystals
This is a straightforward Internet search exercise.

Session plan for teachers

A suggested approach is:

- Introduction to the activity and checking prior knowledge (about 30 minutes)
- Students, arranged in their teams, discuss, consider the budget, plan and allocate the work (about 30 minutes)
- Carry out the investigation of commercial liquid crystal thermometers (about 80 minutes)
- Make and investigate the performance of a number of liquid crystal sandwiches (about 170 minutes)
- Make and investigate a liquid crystal thermometer (about 110 minutes)
- Find out about liquid crystals (about 180 minutes)

Technical notes

- **Preparation**

Working environment and conditions

Students need to work in a laboratory for about 360 minutes. Other work may be done outside the laboratory. Although not part of the activity, if students are asked also find out about liquid crystals they will need access to high speed Internet connection.

- **Equipment and Materials**

Materials and their CAS numbers

Prices at from Sigma Aldrich, February 2008

	Aldrich ref	CAS number	price
Cholesteryl oleyl carbonate	151157	17110-51-9	L37.40 for 25 g
http://www.sigmaaldrich.com/catalog/search/ProductDetail/ALDRICH/151157			
Cholesteryl pelargonate (Cholesteryl nonanoate)	C7,880-1	1182-66-7	L40.70 for 100 g
http://www.sigmaaldrich.com/catalog/search/ProductDetail/ALDRICH/C78801			
Cholesteryl benzoate	C7,580-2	604-32-0	L41.40 for 100 g
http://www.sigmaaldrich.com/catalog/search/SearchResultsPage/PricingAvailability/ALDRICH;C75802			

Mixtures should be made by weighing the appropriate quantities into small, stoppered sample bottles. It is not necessary to ensure complete mixing, but students must be reminded that this is the case and that the whole sample must be melted to get liquid crystals of the correct proportions.

Equipment

Liquid crystal thermometers - checking performance

- 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.

Making a liquid crystal sandwich

- mixture (about 0.1 g) of cholesteryl oleyl carbonate and cholesteryl pelargonate
- 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

Checking performance
- 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.

Testing prior knowledge

Mercury-in-glass thermometers come in various sizes.

1. Which thermometer should you not use in boiling water?
   a. 155 mm -10 °C to 50 °C x 1°C
   b. 305 mm -10 °C to 110 °C x 0.5 °C
   c. 155 mm -10 °C to 360 °C x 5 °C
   d. 155 mm -10 °C to 250 °C x 2 °C

2. Which thermometer has the greatest range?
   a. 155 mm -10 °C to 50 °C x 1°C
   b. 305 mm -10 °C to 110 °C x 0.5 °C
   c. 155 mm -10 °C to 360 °C x 5 °C
   d. 155 mm -10 °C to 250 °C x 2 °C

3. Which thermometer has the highest precision?
   a. 155 mm -10 °C to 50 °C x 1°C
   b. 305 mm -10 °C to 110 °C x 0.5 °C
   c. 155 mm -10 °C to 360 °C x 5 °C
   d. 155 mm -10 °C to 250 °C x 2 °C

4. Which thermometer would be best for evaluating the effectiveness of a liquid crystal thermometer that is claimed to have a temperature range of 36 °C to 42 °C?
   a. 155 mm -10 °C to 50 °C x 1°C
   b. 305 mm -10 °C to 110 °C x 0.5 °C
   c. 155 mm -10 °C to 360 °C x 5 °C
   d. 155 mm -10 °C to 250 °C x 2 °C

5. Which of the following statements is true?
A measurement is reproducible...
   a. if you repeat the measurement and get the same value
   b. if the measurement has a percentage uncertainty of better than 0.5%
   c. if a colleague repeats the measurement and gets the same value
   d. if you repeat the measurement and get almost the same value

6. Liquid crystals have properties somewhere between those of solids and liquids. Which of the following statements is false?
   a. particles in a solid are tightly packed, usually in a regular pattern
   b. particles in a solid vibrate, but do not move from place to place
   c. particles in a liquid are close together with a regular arrangement
   d. particles in a liquid vibrate, move about, and slide past each other

Note: answers are given in red. These need to be changed before the test is used.

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