B1: HEAT ENERGY AND TEMPERATURE

Overview

The energy within a system **cannot be created or destroyed**. It can only be **changed from one form to another**. This principle is known as the **Conservation of Energy**.

The **chemical energy** in a battery, for example, can be transferred into **light energy**, or into **kinetic energy** when used to make a mechanical toy move.

Heat is a transfer of energy between two bodies due to temperature difference. The temperature of a body is an indication of the direction of the flow of energy when two bodies come in contact with one another. When one body is at a higher temperature, then energy will flow from the region of higher temperature to the region of lower temperature until both bodies attain the same energy level. All of the activities in this section should provide students with opportunities to examine their understandings of heat, temperature, and the role of thermometers.

The purpose of these activities is to provide students with an introduction to heat energy and temperature. The calibration process of the thermometer in **B1 ACTIVITY 3 (II): CALIBRATING THERMOFILM** is not a rigorous one, as the purpose of the activity is only to relate measuring temperature to a visible physical change – a thermometric property. Two physical changes are used – the expansion and contraction of liquid, and colour change.

Using the smart material thermofilm (also known as thermochromatic film) shows the students that not all thermometers need to be accurate. In **B1 ACTIVITY 1: DESIGNING, CONSTRUCTING AND USING A THERMOMETER** students use the expansion and contraction of liquids resulting from the transfer of heat energy to construct a simple liquid-in-glass thermometer. In **B1 ACTIVITY 2: THE DIFFERENCE BETWEEN HEAT AND TEMPERATURE** the students examine the difference between heat energy and temperature.

B1 ACTIVITY 3: HOT VERSUS COLD introduces the students to thermofilm as another form of thermometer. Using a standard alcohol-in-glass thermometer, students calibrate the thermofilm and draw up a scale of temperature. They can then use the thermofilm to distinguish between hot and cold, and to explore the relationship between these terms and temperature.

In **B1 ACTIVITY 3 (III) VISUALISING ENERGY FLOW** the students use this film to observe the direction of heat flow with the aid of the scale they have drawn up in **B1 ACTIVITY 3 (II): CALIBRATING THERMOFILM**.

NOTE:

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Suggested approaches:

- Start with a short brainstorming session to discover what the students think 'temperature' is:
  - ? ***Can they name the units it is measured in?***
  - ? ***Can they name different types of thermometers, e.g. a meat thermometer, a fridge thermometer, a clinical thermometer, a strip thermometer (i.e. temperature strip held on forehead)?***
  - ? ***Can they give some reasons we might need to measure temperature?***
- Another approach might be to see if students can relate physical changes to temperature change, e.g. relating the colour of a gas flame to hotness.
  - ? ***Can they give you a number of examples?***
  - ? ***What do they understand by the term physical changes?***
- Introduce the term 'thermometric property' and challenge the students to explain it without looking it up.
  - ? ***Suggest that they 'dissect' the word, i.e. what about 'therm'? What does it suggest? The second part, 'metric' – when might the word 'meter' be used?***
  - ? ***Check the spellings of 'meter' and 'metre' – do they represent the same concept?***
- Another approach might be to focus on finding out what ideas the students have about the direction of heat energy.
  - ? ***Why might a table feel initially cold when I put my hand on it?***
  - ? ***How long will it continue to feel cold?***
  - ? ***What about walking on carpet?***
  - ? ***What about walking on a tiled floor?***
  - ? ***What are our five senses?***
  - ? ***Could any of our senses be responsible for our responses to heat and cold?***
- Before the investigations, the following questions could be put to the students to provoke a short discussion:
  - ? ***Must all thermometers be accurate?***
  - ? ***What is the function of a thermometer?***
  - ? ***What information are we looking for when using a thermometer?***
  - ? ***Is accuracy an important feature of all thermometers?***

If the students are arranged in groups for this, have each group draw up their conclusions for reference at the end of the investigations.

B1 ACTIVITY 1: DESIGNING, CONSTRUCTING AND USING A THERMOMETER

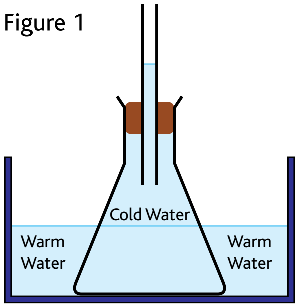
Background

This investigation is not a rigorous calibration of a thermometer (using fixed points of freezing water and boiling water and then dividing the length interval between these points into equal parts). The purpose of the activity is only to show that the physical changes of the expansion and contraction of liquids can be used as a means of constructing a thermometer.

Equipment required – per group:

- Lab flask or colourless medicine bottle
- Glass tube or straw
- Rubber stopper with hole to fit flask or medicine bottle
- Food colouring or ink
- Container of cold water
- Container of hot water
- Container of hand-hot water
- Tea light
- Matches
- Marker suitable for writing on glass

Figure 1



What to do:

1. Fit the lab flask or small medicine bottle with a cork and clear tube or glass straw.
2. Fill the lab flask to the brim with very cold water coloured with a drop or two of ink or food colouring, and cap it securely.

   ? ***Why are we using food colouring?***
3. Mark the water level on the glass tube.
4. Using a tongs lower the lab flask into a beaker of hot water.
5. Mark the water level in the tube.

   ? ***Describe and record what you observe happening to the water in the flask and glass tube.***
6. Remove the flask and put it into the container of cold water.
7. Again mark the water level in the tube.

   ? ***Describe and record what happens to the water level.***

   ? ***Is there a difference in the water level?***

   ? ***What conclusion could you arrive at?***
8. Lower the flask into hand-hot water and mark the water level on the tube.

   ? ***From the data you have collected what is your conclusion?***

   ? ***Consider what other things could increase the sensitivity of the thermometer.***

   ? ***What does 'sensitivity' mean?***

What next:

- Having constructed and used the thermometer, students can now investigate why mercury or alcohol is used in thermometers rather than water, despite water being freely available.
- Galileo is often credited with inventing the thermometer, but his invention is not, in fact, a thermometer. Can you explain?
- Ask the students to research Galileo in groups and present their results to the class. To discourage them from carrying out a cut-and-paste exercise and just reading from the text, do not allow them to use notes.

Figure 2: Familiar item labelled and sold as 'Galileo's thermometer'

Resources:

- The Galileo Project is an accessible and informative site that might serve as a useful source for students starting their research.
- The Brannan thermometer manufacturers website gives an overview of thermometer types and the different scales used.

B1 ACTIVITY 2: THE DIFFERENCE BETWEEN HEAT AND TEMPERATURE

Background

We do not measure temperature directly. Instead, we **read the changes** that heating and cooling produce.

Liquids **expand when heated** and **contract when cooled**. The **mercury thermometer** uses these facts to show temperature. The mercury in the thermometer absorbs heat and expands when it comes in contact with anything warmer than itself. It grows smaller when in contact with something cooler than itself. **Temperature is a measure of whether one object will give heat to, or absorb heat from, another object**.

This activity allows students to observe the **difference** between two bodies that both have the same temperature but contain different quantities of **heat energy**.

Equipment required:

- Test tube with support stand
- Beaker with tripod and gauze mat, or support stand
- Two candles (ideally tea lights)
- Matches
- Two mercury/spirit thermometers (best for this experiment)
- Stopwatch
- Access to water

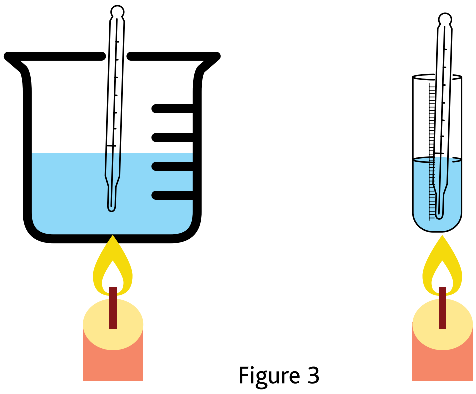


Figure 3

What to do:

1. Fill the beaker up halfway with water.
2. Add a small amount of water to the test tube.
3. Check the temperature of the water in both containers and make a note of it.
4. As indicated in Figure 3, position each container over the flame of a candle or a Bunsen burner. Use support stands, or tripod and gauze.
5. Heat both amounts of water for the same length of time and no more than five minutes.
6. Check and record the temperature of the water in each container.

   ? ***Are the temperatures the same?***

   ? ***If not can you explain why not?***

   ? ***Which container contains the most heat energy?***

   ? ***What are the variables in this activity?***

   ? ***Which one did you keep constant?***

B1 ACTIVITY 3: HOT VERSUS COLD

Background

This activity aims at clarifying students' understanding of the distinction between the terms 'hot', 'cold', 'heat energy' and 'temperature' using thermofilm – a liquid crystal film that changes colour as it heats up. Using the thermofilm introduces students to another thermometric property suitable for measuring temperature – colour change. The colours that appear as the film reacts to heat energy are referenced against the standard glass-in-liquid thermometer.

Before using the thermofilm the students need to calibrate the film and draw up a reference chart to use.

Suggested approaches:

- Let the students brainstorm about their ideas of hot versus cold, and temperature versus heat. They should record their ideas for future reference. They can then carry out the first activity, **B1 ACTIVITY 3 (I): IT'S ALL RELATIVE (TEACHER-LED)**, in groups of four. After completing this activity they can revisit their original ideas and see if they should change their minds.
- Alternatively the students can carry out the activity first, and then have a brief discussion on hot versus cold and temperature versus heat.
- Keeping any questions on hold, the students can then use the thermofilm. They can learn how to calibrate it and then use it to demonstrate energy flow.

B1 ACTIVITY 3 (I): IT'S ALL RELATIVE (TEACHER-LED)

Equipment required:

- Four beakers to be used as follows:
  - Beaker A containing hot water (from the tap)
  - Beaker B containing a mixture of cold water and ice cubes/crushed ice
  - Beakers C and D both containing body-temperature water (approx. 37°C)
- Thermometer

What to do:

1. Select two volunteers from the class: **Volunteer 1** and **Volunteer 2**.
2. Without disclosing the temperatures of the beakers, ask **Volunteer 1** to hold **Beaker A** in one hand and **Beaker B** in the other.
3. Ask **Volunteer 2** to measure the temperature of **Beaker A** and **Beaker B**.
4. Ask **Volunteer 1** to confirm which of the beakers is hot and which is cold.
5. Now ask **Volunteer 1** to put one hand into **Beaker C** and one hand into **Beaker D**, and ask them to tell you which contains hot water, and which contains cold water.
6. Ask **Volunteer 2** to measure the temperatures of **Beakers C** and **D** and announce them to the class.
   - Discuss the students' original ideas about hot and cold and see if this demonstration has changed those ideas. Do not press too much for answers at this stage.
7. After the students have completed the activities **B1 ACTIVITY 3 (II): CALIBRATING THERMOFILM** and **B1 ACTIVITY 3 (III) VISUALISING ENERGY FLOW**, revisit what they learned from this demonstration.

   At this point, explain that our skins have temperature sensors able to detect the direction of energy flow along the surface of our bodies. There are two different messages sent along the nerves: that heat energy is flowing into the skin (hot); and that heat energy is flowing out of the skin (cold).

B1 ACTIVITY 3 (II): CALIBRATING THERMOFILM

Before using the **thermofilm** the students need to calibrate the film and draw up a reference chart to use. The different colours that occur as a result of heat energy should be referenced against the standard glass-in-liquid thermometer as follows: black corresponds to approximately 25°C; brown to approximately 26°C; green to between 29°C and 30°C; and blue to above 30°C.

Equipment required:

- Hot plate or Bunsen burner with tripod and wire gauze
- Heatproof mat
- 250 cm3 beaker
- Thermometer
- Test tube
- Piece of thermofilm (3 cm x 1 cm)
- **B1.3 printout: Thermofilm calibration chart**

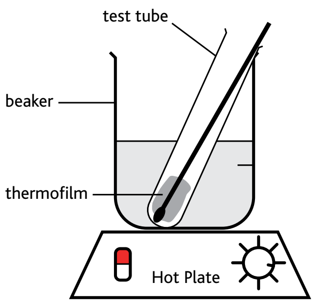


Figure 4

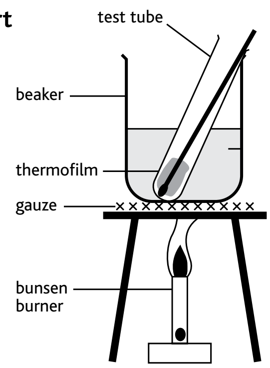


Figure 5

What to do:

1. Set up the hot plate or the Bunsen burner tripod and gauze as shown in Figure 4 and Figure 5.
2. Half fill the beaker with cold water and place it on the hot plate or the gauze.
3. Drop the thermofilm into the clean, dry test tube.
4. Place the thermometer into the test tube.
5. Place the test tube in the beaker of water.
   - ✔ Note the initial temperature of the water and the colour of the thermofilm.
6. Switch on the hot plate or light the Bunsen burner and slowly heat the water.
7. As the water heats up, the thermofilm changes colour.
   - ✔ Note the temperature readings for each of the colour changes.
   - ? ***What do you notice about the colour bands?***
   - ? ***What temperature range does each band cover?***
8. When the water temperature reaches 40°C switch off the heat.
   - ? ***Why do you think you should do this?***

B1.3 printout: Thermofilm calibration chart

TEMPERATURE RANGE	CORRESPONDING COLOUR

B1 ACTIVITY 3 (III) VISUALISING ENERGY FLOW

Equipment required:

- Two small empty aluminium cans (150 g tomato puree can is ideal)
- An aluminium sheet (3 x diameter of can)

  [Alternatively take two sheets of kitchen foil, put them together and laminate them as one. Gently peel the laminate cover apart giving two sheets which can then be cut to size. The laminated side can be stuck to the polystyrene.]
- Strip of thermofilm (5 cm x 2 cm)
- Thermometer
- Ice cubes
- Access to hot water
- Expanded polystyrene slab (approx. 25 cm x 10 cm)
- Calibration chart from previous experiment **B1 ACTIVITY 3 (II): CALIBRATING THERMOFILM**
- Insulating covers to fit cans (optional)
- Stopwatch

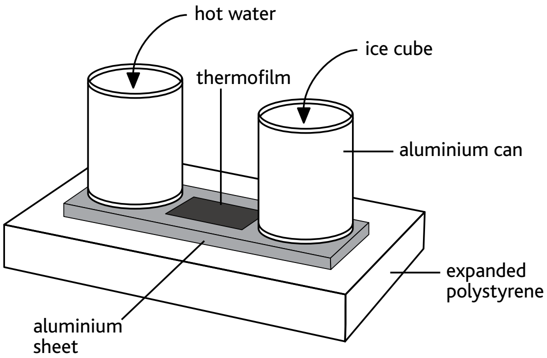


Figure 6

What to do:

1. Affix the thermofilm to the aluminium sheet as shown in Figure 6.
2. Place the aluminium sheet on the expanded polystyrene slab as shown in Figure 6.
3. Place the aluminium cans on either side as shown in Figure 6.
4. Put a cube or two of ice into one of the cans.
5. Fill the other can halfway with hot water.
6. Place the thermometer in the hot water and note the temperature.

   Observe what happens to the thermofilm, referencing the calibration chart from the previous experiment.
7. Repeat the experiment.

   This time, note the time it takes for the thermofilm to stop changing colour.

   ? ***What is this colour?***

   ? ***What has happened?***
8. Repeat again, this time placing lids on the cans.

   Compare time results.

   ? ***If using laminated kitchen foil, is it important which side is facing upwards?***

   ? ***Why?***

B1.3 Discussion points: Colour and Temperature

1. Students are familiar with mood rings, bracelets, etc. These come with a chart relating colours to emotions.
   - ? ***Is the colour-temperature range the same as that of the thermofilm used in* B1 ACTIVITY 3 (II): CALIBRATING THERMOFILM*?***
   - ? ***If the body temperature is 37°C when it is worn, why does the ring colour at lower temperatures?***
   - ? ***Is the colour-temperature range the same as the thermofilm?***
   - ? ***If the body temperature is 37°C, how can the ring change colour when it is worn?***

Figure 7: One of the many charts used with mood jewellery

- Stressed
- Fear
- Nervous
- Mixed Emotions
- Normal
- Relaxed
- Calm
- Cool
- Lovable
- Romance
- Passion
- Very Happy

RESOURCES:

- Search the National Stem Centre, UK for some great ideas on teaching heat and temperature.

B1.4 HISTORY NOTE A: CELSIUS AND THE REVERSE SCALE

The **Celsius temperature scale** dates back to 1742, when the Swedish astronomer **Anders Celsius** published a paper entitled 'Observations on two persistent degrees on a thermometer'.

After providing background on the various ways that temperature could be expressed at that time, the paper presents an account of Celsius' experiments with two fixed points for a temperature scale:

- The temperature of thawing snow or ice
- The temperature of boiling water

The idea of using the **freezing point of water** as a temperature calibration point had already been suggested by **Reaumur** and **Newton**. Celsius' approach was different. He wanted to use the point at which snow or ice thaw, rather than the point at which water freezes; the **melting point** of water, rather than the **freezing point**. In his paper, Celsius described an experiment which involved placing a thermometer in thawing snow. 'I have repeated this experiment many times over two years in all winter months...' he wrote, 'through different barometric changes, and always found precisely the same point on the thermometer... When it was strong winter I took the cold snow into my room and put it in front of the fire until it began to thaw...'

The second calibration point was more complicated. 'As far as the second fixed point is concerned,' Celsius wrote, 'it is well known that once water has begun to boil, it will not take up any considerable degree of heat even if one continues the boiling for long; thus the mercury in the thermometer will end at the same point.'

The intensity of the boiling might, however, affect the calibration point to a certain degree. Celsius proposed a standardised method for determination. He noted that when the thermometer is taken out of the boiling water the mercury level rises somewhat before it retracts. The explanation, Celsius suggests, is that the glass tube contracts before the mercury starts to cool off.

The second factor that affects the boiling point of water is the air pressure. This was already observed by Fahrenheit, and Celsius reports a series of experiments confirming this observation. His conclusion is that 'the height of the thermometer in boiling water is always proportional to the height of the barometer, thus eight "points" on the thermometer I use correspond to a change of one inch in the barometer reading; a thermometer which is somewhat more sensitive or has large degrees can be used as a barometer when put into boiling water, and would be easier to bring along when travelling at sea or land, especially on high mountains.'

Celsius proposed a standardised procedure for the calibration of a thermometer:

1. Put the cylinder AB of the thermometer (i.e. the bulb) in thawing snow. Mark the freezing point of water C. This should be at such a height over the cylinder at A that the distance AC is half the distance between C and the water boiling point marked D.
2. Mark the boiling point of water D at a pressure of approximately 755 mm.
3. Divide the distance in 100 equal parts or degrees; so that 0 degree corresponds to the boiling point of water, D, and 100 to the freezing point of water, C. When the same degrees have been continued below C all the way down to A the thermometer is ready.

Celsius thus put the boiling point at 0 degrees and the freezing point at 100. This is, of course, the reverse of the Celsius scale as we now know it.

It is often claimed that Carl von Linné (Carolus Linnaeus) instigated the reversal, but it appears more likely that the responsible person was Daniel Ekström, who manufactured most of the scientific instruments, including thermometers, used by both Celsius and Linné.

B1.4 HISTORY NOTE B: LORD KELVIN; THE IRISH CONNECTION

In 1848 the Irish-born scientist, **William Thomson**, formulated a temperature scale that was **independent of all thermometric properties**.

He proposed that the temperature at which all movement ceases (no heat energy available) should be called **'the absolute'** temperature. While the existence of a very low temperature was acknowledged, at the time it was Thomson who actually determined its value of approximately **minus 237.15°C**. He called the value the 'absolute zero' to distinguish it from zero degrees on the Celsius scale, which by then referred to the freezing point of water. Because minuses have a habit of getting lost, the Kelvin scale replaces −273.15°C with zero. The divisions on the **Kelvin scale** are the same as those of the Celsius scale.

Figure 8: William Thomson

According to the Kelvin scale:

− 273.15°C = 0 K

0°C = 273.15 K

This makes it easier to convert readings on the Celsius scale to the equivalent on the Kelvin scale.

The Kelvin is one of the seven basic units used in the International System of Units (SI).

The development of the Kelvin is only one of Thomson's great achievements. Born in Belfast in 1824 and raised for the most part in Glasgow, he was an avid **geologist** and **mariner** as well as a **scientist**. His list of achievements includes establishing the basic **laws of thermodynamics**, investigating the relationship between cable thickness and data flow (present day **bandwidth**), developing **submarine communication** systems, introducing accurate methods for **measuring electricity**, and inventing the **adjustable compass**. A great believer in the practical application of science, he was deeply involved in laying the **transatlantic telegraphic cables** for which he was knighted in 1866 and became known as **Lord Kelvin**. He died in 1907.