3.1 What is heat?

Lesson outcomes

At the end of this activity students will be able to:

- describe how Count Rumford's observations provided evidence against the caloric theory of heat.

What ideas might your students already have?

- Students will have a general understanding that heat flows from hot objects to cold. This will be covered in **Activity 3.3**. The common use of the word flow is unfortunate, as it suggests a fluid.

Key vocabulary

Heat

Teacher content information

It is not the most desirable approach to introduce weapons of war as teaching tools, but this particular experiment was a fundamental and famous one, which transformed our understanding of heat and energy.

Cannons originated in ancient China along with the gun powder required to fire them. They were important in warfare for many centuries and modern artillery guns are simply a later modification. Only recently have powered missiles replaced modern artillery.

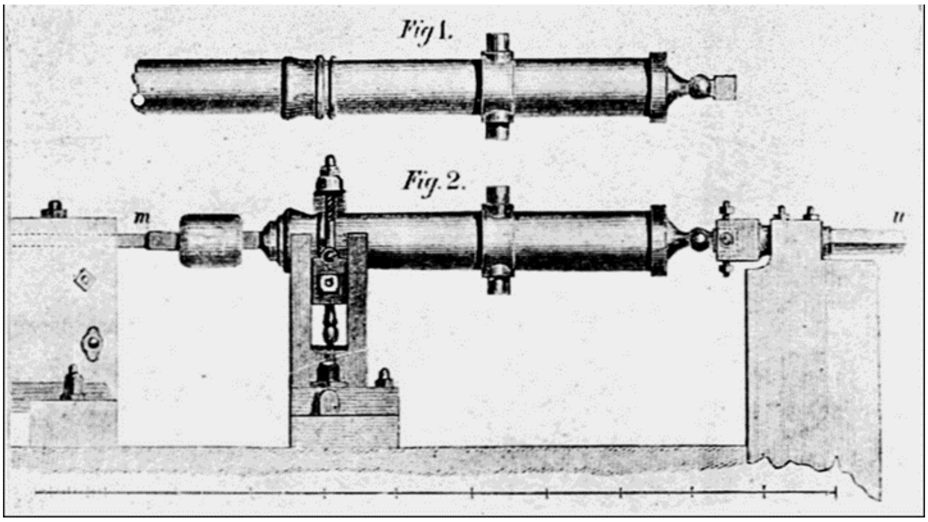
Cannons were traditionally made by casting in solid metal, usually bronze or iron. The barrel was bored out using a special grinding tool. During grinding the metal became very hot. The heat's origin was explained by the caloric theory. Caloric was believed to be a fluid-like substance that contained the heat. It was released as metal was shaved away from the barrel.

Benjamin Thompson, later known as Count Rumford, undertook a series of experiments into the heating effects of friction. His conclusions were published in an essay, *An Inquiry Concerning the Source of the Heat Which is Excited by Friction*, which were presented to the Royal Society in 1788. [Interesting historical coincidence: this was the year the First Fleet arrived in Sydney Cove].

Count Rumford measured the temperature change as a result of boring a cannon with the apparatus illustrated below.

If caloric was a fluid, it should weigh something, so if it were released, mass should be lost during the experiment. However, the total mass of metal after the experiment equalled the mass of matter before.

By surrounding the end of the cannon with a water filled box, and measuring the temperature rise during the boring process, Rumford proved that a blunt cutting tool produced a large heating effect. He collected the metal cut from the cannon and showed it could not have been the source of the caloric. Further experiments allowed him to rule out the water and the rest of the machinery as the source of the caloric.



He also found more heat was produced using a blunt boring tool, rather than a sharp one. He observed heat generated by friction seemed inexhaustible – which was at odds with the idea that caloric was a substance of limited amount. Apparently, friction could create as much of this substance as desired.

He concluded heat was a form of motion. We now know bodies have heat because of the random kinetic energy of their constituent atoms and molecules.

Lesson plan

What to do:

Step 1: Students should view the animation of Thompson's (Count Rumford) cannon boring experiment in *Student Digital* **Activity 3.1**. The video has three parts so students can answer questions provided in the *e-Notebook*.

3.2 Keeping your drink warm

Lesson outcomes

At the end of this activity students will be able to:

- describe mechanisms of heat transfer: convection, conduction and evaporation.
- apply the concepts of heat transfer through convection, conduction and evaporation to the problem of keeping a drink hot.

What ideas might your students already have?

- Students may have difficulty in appreciating the importance of movement within invisible fluids, particularly air.

Key vocabulary

Heat, temperature, conduction, convection.

Equipment list

Each GROUP will require:

- three identical beakers around 100-150 mL.
- thermometer (0 - 100 °C)
- beaker insulating material such as bubble wrap, newspaper, foam, wool
- hot water.

Things to consider

This activity is a solid introduction to convection and conduction. Radiation, as a form of heat transfer, is not introduced until **Activity 3.4**. Although heat is emitted by all surfaces above absolute zero (the phenomenon of black-body radiation) it does not contribute substantially to heat loss in this situation.

Teacher content information

It is surprising how much heat is lost from the surface of a drink. Covering with a thin piece of paper can significantly reduce this effect. Two processes occur at the surface: evaporation absorbs a large amount of energy and the warm, moist air is then carried away by convection currents. Covering the drink disrupts these currents and hence reduces the rate of evaporation at the surface.

Lesson plan

What to do:

Step 1: Students fill a beaker with hot water. Ask them to touch the sides of the beaker and to hold their hands above it.

Can they feel heat through the glass of the beaker? This is called *conduction*.

Can they feel warm air rising from above the beaker? This is called *convection*.

Step 2: Pose the research question: is most heat lost from the drink through conduction from the beaker's sides or through convection from the drink's surface?

Ask each group to devise ways to minimise each effect. These could include simply wrapping the beaker in an insulating material and covering the top with paper to prevent warmed air escaping. Students should carefully keep the volumes equal so heat loss is clearly demonstrated by temperature decline.

Step 3: Students test their different techniques to find which most effectively maintains the temperature of a hot drink. They must clearly understand how to do this. How will they know if they have seen a real effect? Introduce the idea of a suitable experimental control.

Suggested questions:

- How did the heat loss from the two experimental beakers compare with the heat loss from the control beaker?
- What was happening at the surface of the hot drink that would have contributed to the heat loss?

Help students record a concluding statement in their ***Notebook***.

3.3 Water is hard to heat

Lesson outcomes

At the end of this activity students will be able to:

- correctly apply the terms *heat* and *temperature*
- understand that not all objects of the same mass and at the same temperature have the same heat content* (refer Teacher Content Information)
- understand that heat is transferred from objects at a higher temperature to objects at a lower temperature.

What ideas might your students already have?

- Students struggle to distinguish between the concepts of heat and temperature.

Key vocabulary

Heat, temperature, thermal equilibrium.

Equipment list

Each GROUP will require:

- foam cups
- hot water and tap water
- 100 mL measuring cylinder
- thermometers (0 - 100 ^oC)
- 50 g brass metal masses from a slotted mass kit
- ice-block sticks for stirrers.

Things to consider

This activity explores the transfer of heat between substances, leading to temperature changes. The key idea explored is that objects in contact will come to the same temperature, regardless of how hot or cold they feel.

Teacher content information

It is more correct to refer to the internal energy or thermal energy of a system that has absorbed heat energy, but this terminology can be confusing at this stage, so we refer to heat content. What is important is that if a system absorbs a certain amount of heat and its temperature increases, and no other changes occur, such as a change in volume, then all this heat will be available in the reverse reaction.

This activity explores the transfer of heat between substances, leading to temperature changes. The key idea being explored is that objects in contact will come to the same temperature, regardless how hot or cold they feel. Two objects at thermal equilibrium will be at the same temperature.

Water has an enormous capacity to absorb and deliver heat without large changes in its temperature. This property is referred to as specific heat (or thermal) capacity. The specific heat capacity of brass is much lower than that of water (around 0.4 rather than 4.2 J/g/ oC). The value for water is higher than most other known substances. In the second experiment, the brass weights will have a relatively small effect on the temperature of the hot water. Theoretically it would take nearly a kilogram of brass to equalise the temperature of 100 mL of water.

This property of water leads to many of its important characteristics, such as the difficulty of heating water, large electricity bills associated with frequent and long showers, moderate climate on islands, Earth's relatively stable climate, and the stable temperatures of large animals and the use of water in extinguishing fires.

Lesson plan

What to do:

Experiment 1

Step 1: Add 100 mL of hot water to one cup and measure its temperature.

Add 100 mL of cold tap water to another cup and measure its temperature.

If you mix these two amounts of water together in one cup, what temperature will the mixture will be? Why?

Step 2: Mix the two amounts of water and test your hypothesis. Stir quickly with a stick and measure the new temperature.

What did you find? Perhaps the results were unsurprising?

Experiment 2

Now mix two different substances, one water and a metal, brass.

What will happen if you add 100 g of cold brass to 100 mL of hot water? As in the first experiment, they have the same mass, as 100 mL of water has a mass of 100 g, so you will still be mixing the same mass amounts.

Predict a result in your ***Notebook***.

Step 1: Bring the temperature of the brass masses (100 g, usually two 50 g masses) to equal that of cold water by immersing them in tap water, and measure the temperature.

Step 2: Add 100 mL of hot water to a cup and measure its temperature.

Step 3: Use tongs to quickly transfer the cold masses to the hot water. Stir with a stick and measure the new temperature.

Suggested questions:

- In **Experiment 2** did the hot water cool? Where did the heat go?
- Was there a difference in the capacity of the cold water and the cold brass to cool down the hot water?

Extension

Students could design an experiment to approximate the difference in heat capacities of brass and water. They could use a larger volume of water and test what mass of brass was required to bring its temperature to half way between the original brass and water temperatures.

A comparison with water is a standard approach to determining specific heats. Without calculations, only an approximate value will be reached, but since the specific heat of water is more than ten times that of brass, the effect should be obvious.

Help the students record a concluding statement in their ***Notebook***.

3.4 Feeling hot and cold

Lesson outcomes

At the end of this activity students will be able to:

- explain how the conduction of heat relates to whether surfaces feel hot or cold
- understand objects in contact in the same environment will come to the same temperature.

What ideas might your students already have?

- Most students will have the misconception that metal surfaces feel cold because they are at lower temperatures.

Key vocabulary

Heat, temperature, conduction, senses.

Equipment list

Each GROUP will require:

- metal plate (e.g. retort stand's base, unpainted)
- plastic of similar size (e.g. small plastic chopping board)
- ice cubes
- egg rings

Things to consider

See the video in *Student Digital* **Activity 3.4** for the best way to conduct this experiment. Students may be inspired, and able, to conduct this experiment at home on their own subjects.

The metal and plastic plates, and the rings, used in the video are available from Arbor Scientific [http://www.arborsci.com/ice-melting-blocks-thermal-conductivity].

Teacher content information

Our sense of touch, in detecting hot and cold, depends on our skin absorbing or losing heat. This may occur when we touch a surface at a very different temperature or one at only a slightly different temperature, but with high thermal conduction. Metals are good thermal conductors (as well as good electrical conductors).

The space shuttle heat tile is non-metallic and conducts heat poorly. Little heat is lost to the surrounding air (or to the hand) through conduction. It is black and therefore emits radiant energy very well. Most of its heat loss occurs through radiation, mostly in the infra-red range.

Lesson plan

What to use:

Each GROUP will require:

- large container or sink half filled with water
- large ball (hollow)
- spring balance or force measurer
- two masses tied to a string (one that would sink and one that would float).

What to do:

Step 1: Have students view the video in *Student Digital* **Activity 3.4**.

Step 2: Provide appropriate materials so students can replicate Dr Muller's experiment in the classroom. Everyday objects are best so students can repeat the experiment at home. This could be a whole class demonstration.

Suggested question/s:

Explain, using the term thermal conduction, why the person pictured in **Activity 3.4** can hold the red-hot space shuttle heat tile in his bare fingers.

3.5 Heating water with light

Lesson outcomes

At the end of this activity students will be able to:

- demonstrate heating water with light
- provide evidence that dark surfaces absorb more light energy than light-coloured surfaces.

What ideas might your students already have?

- Students may be familiar with the effect of wearing a white or black shirt on a sunny day.

Key vocabulary

Heat, temperature, light, radiation.

Equipment list

Each GROUP will require:

- black and white spray paint
- three empty aluminium drink cans: one spray painted black, one painted white, one wrapped in alfoil. You could include cans painted with shiny and matt black paint. Cans should be painted beforehand.
- thermometers (0 - 100 ^{o}C)
- tap water
- sunny day.

Things to consider

A class set of control cans will also be needed.

You will need a sunny outdoor spot where the class can settle down for half a lesson as the cans heat up.

The final step includes combining all the groups' results on the board to produce a class result. This lets you introduce the idea of replications in an experiment to improve accuracy and reliability. Several groups provide replicates, rather than each group replicating the experiment several times.

Teacher content information

By *solar energy* we mainly mean light energy, mixed with some infra-red radiation. This is the radiation absorbed by surfaces producing heat. As in other experiments in this unit, heating water is a standard way of detecting heat transfers.

The black cans will absorb most of the light that falls on them, while the white and alfoil-covered cans will reflect most light. There should be no difference between the controls if they are in complete shade.

Give some consideration to where to place the cans in the sun. Ensure they are not placed on a hot surface where they will absorb heat from conduction.

Lesson plan

Step 1: Add 250 mL cold tap water to each can and measure the temperature. It is preferable if all cans are close to the same temperature.

Step 2: Place the cans side by side in direct sunlight so all, if possible, receive the same light exposure.

The class control set, including one can of each colour, should be placed in complete shade.

Step 3: Monitor the temperature of the cans every five minutes for 30-40 minutes or until a significant temperature increase has occurred in at least one.

Step 4: Determine the temperature increase in each can. Combine the results of each group on the board and ask the class to calculate the average for each can type.

Students should report the results in their ***Notebook***, including a diagram of the setup.

3.6 Solar energy

Lesson outcomes

At the end of this activity students will be able to:

- apply an understanding of heat and light to design a solar collector to successfully heat water
- evaluate the effectiveness of a solar heater by taking appropriate measurements.

Key vocabulary

Heat, temperature, light, radiation, reflection.

Equipment list

Each GROUP will require:

- cardboard box (large enough to house your collector)
- thermometer (0 - 100 ^{o}C)
- cling wrap
- alfoil
- plastic PET bottle, around 1.25 L
- sunny day
- students may request other useful equipment.

Each STUDENT will require:

- **Activity Sheet 3.6 *Solar energy***

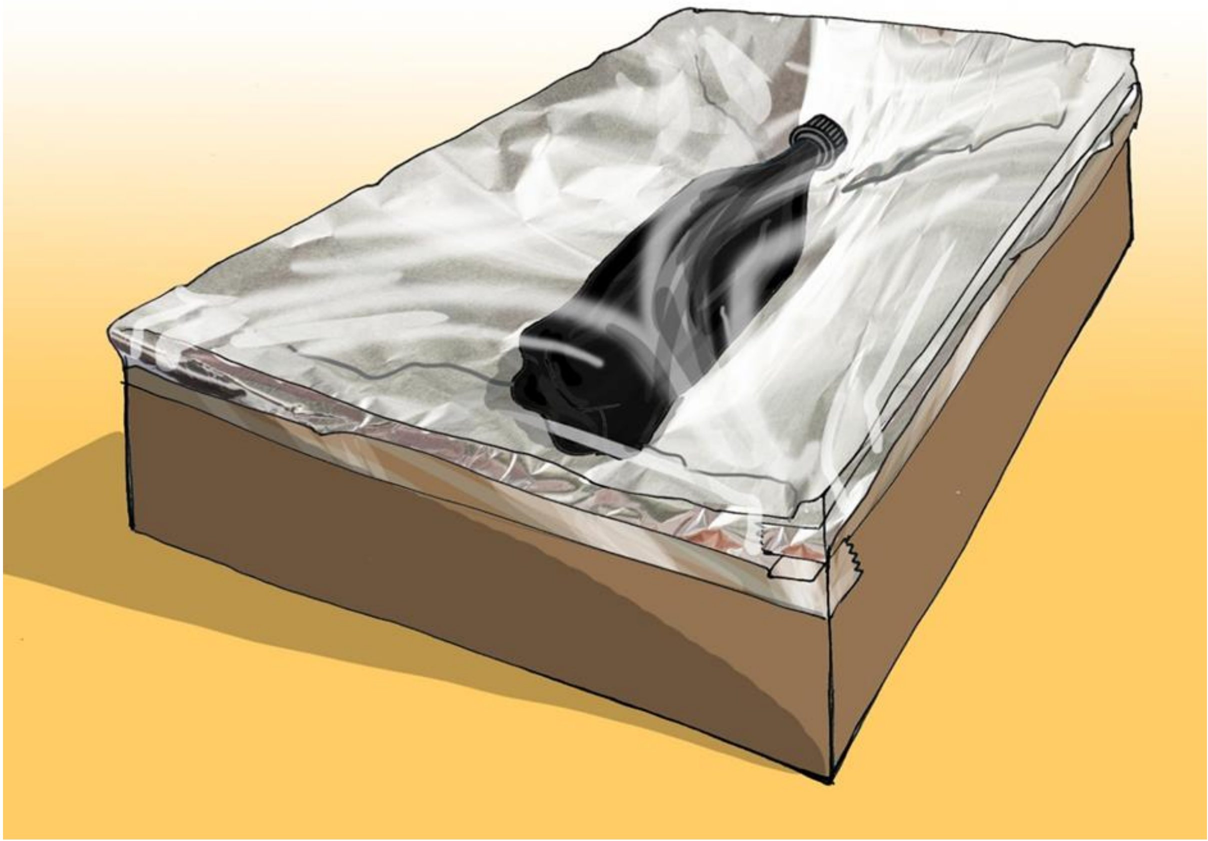
Things to consider

This activity is an opportunity for students to apply, and for you to evaluate, their understanding so far in the unit. It could be used as a summative assessment item. Students will be asked to write a report describing their design, using appropriate scientific language to explain why it was or wasn't effective.

A basic bottle-in-a-box design can be used, or the more complex circulating system shown at the following website. However, such systems are difficult to seal and may leak badly.

http://www.behance.net/gallery/SOLAR-WATER-HEATER-EXPERIMENT/2753215

A simple design is shown in this image.



Lesson plan

Distribute **Activity sheet 3.6**. It provides students with instructions and a marking scheme.

Suggested question:

Students should prepare a report describing their investigation and evaluating their design.

3.7 What is sunlight?

Lesson outcomes

At the end of this activity students will be able to:

- explain that sunlight is a mixture of visible light and invisible ultraviolet and infra-red light.
- describe the visible spectrum
- understand that light is a way energy can be transferred through the vacuum of space.

What ideas might your students already have?

- Students will know light comes from the sun, but might not know that a significant amount is infra-red light or heat rays.

Key vocabulary

Heat, light, radiation, spectrum.

Equipment list

Each GROUP will require:

- glass prism and a ray light source, such as from a standard light-box kit.

Things to consider

This activity allows students to visualise light and its spectrum. It will link to previous activities where they used sunlight to heat water. Students will understand the sun emits light, the only energy form that reaches the Earth's surface.

Teacher content information

Light has a spectrum, which is centred on visible light. Ultraviolet (UV) and infra-red are also forms of light, but invisible to human eyes.

Lesson plan

Step 1: Give access to *Student Digital* **Activity 3.7**.

Step 2: Give students a prism and suitable light source to produce their own spectrum.

Suggested questions:

Students should complete the ***Notebook*** questions.

3.8 Cyclones

Lesson outcomes

At the end of this activity students will be able to:

- describe the overall structure of a cyclone
- explain how heat is involved in its formation
- explain how the evaporation and condensation of water contribute to these heating effects.

Key vocabulary

Heat, temperature, cyclone, hurricane, evaporation, condensation.

Things to consider

This activity introduces the central importance of heat in the Earth's weather and climate systems.

Teacher content information

The evaporation of water to form water vapour absorbs large amounts of energy. This is the basis of evaporative cooling. Conversely, as water condenses back to the liquid state, it releases this heat energy in large quantities.

The most important idea is that cyclones, and much of our weather, are driven by heat. Heat exchange between the atmosphere and the oceans is the principal driver of many weather and climate systems. Oceans warm as they absorb sunlight, causing water to evaporate. As warm, humid air rises, it expands and cools. Water vapour condenses in the atmosphere and releases large amounts of heat, which drives many weather systems.

Lesson plan

Provide access to *Student Digital* **Activity 3.8**.

Suggested questions:

Students should answer the ***Notebook*** questions.