Specific heat capacity

* define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods.
* define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods.

Social and human context

The specific thermal capacity is an essential quantity to consider for any change of temperature. When materials are used for cooling purposes, for example, it is crucial to remove energy quickly and economically without the coolant changing its temperature too greatly. Water is, of course, ideal in this respect. But other materials are used too. In nuclear reactor technology, a variety of coolants are used to remove thermal energy from the reactor core, including liquid sodium. An additional property for reactor coolants is that they should not disturb the running of the reactor by absorbing neutrons. Hot water, close to boiling, when dropped on to the skin can cause great harm. It releases large quantities of energy into the tissues and, as every first-aider knows, the correct remedial treatment is to cool the affected part (i.e. to remove thermal energy from it) for a time of at least 500 s. This removes thermal energy from the underlying tissue as well. Storage heaters rely on the large mass and the high specific thermal capacity of the hot materials; the heater needs to retain the energy for a significant time for release into a room late into the day.

Finding The specific heat capacity of water and aluminium

This experiment is designed to measure the specific heat capacities of water and aluminium.

Before starting the experiment read through the instructions carefully.

You will need:

* 12 V immersion heater 60 W
* aluminium saucepan
* block of aluminium
* thermometer
* 12 V power supply (6 A)
* stop clock
* balance
* 2 digital multimeters
* Electronic balance

What to do

1. Water

Put 1 kg of water in the saucepan and measure its temperature. Now hold the heater in your hand and switch on the power supply. When you feel the heater getting warm put it in the water and start the stop clock. After 10 minutes switch off the power supply, stir the water and take its temperature. Allow the heater to cool in air.

2. Aluminium

Put the thermometer in the small hole in the aluminium block. Switch on the heater and when it is warm put it in the large hole in the block and start the stop clock, having recorded the initial temperature of the block. After 10 minutes switch off the power supply and take the temperature of the block.

Safety

Check the seals on the immersion heaters before use. Reject any that are obviously defective. In doubtful cases, any water which has entered during a precious activity can be removed by placing the heater in an oven for an hour at about 80 °C.

Measurements to make

Mass of water (m) = kg

Temperature of water before heating = oC

Temperature of water after heating = oC

Rise in temperature of water () = oC

Voltage applied to heater (V) = V

Current through heater (I) = A

Electrical energy converted to heat energy in 10 minutes = J

Heat energy required to heat m kg by oC = J

Specific heat capacity of water = J / (kg oC)

Make up a similar set of results for aluminium.

Questions

1. Why do you think that you allowed the heater to warm up before putting it in the water?
2. Why will your result for either experiment not be very accurate?
3. Why should you stir the water at the end?
4. Why would it not be a good idea to get the water or aluminium too hot?

Follow up topic

Devise an experiment to measure the specific heat capacity of soil.

External reference

This activity is taken from Resourceful Physics

Information more accurate measurement of specific heat capacities

There are several simple methods for measuring the specific heat capacities of both solids and liquids, such as ***the method of mixtures***, but we will consider here only electrical methods. Since the specific heat capacity varies with temperature, we have seen it is important to record the mean temperature at which the measurement is made.

Electrical calorimeters

Figure 1(a) and 1(b) show possible arrangements for electrical calorimeters for a solid and a liquid specimen.

solid block

lagging

immersion heater

thermometer

immersion heater

thermometer

calorimeter

stirrer

shield

lid

Figure 1(a)

Figure 1(b)

The material under investigation is heated by an electrical immersion heater and the input energy (Q) and the rise in temperature that this produces are measured. If the mass of the specimen (solid or liquid) is m and its specific heat capacity C, then:

Q = m C (1 - o) + q

where θ0 and θ1 are the initial and final temperatures of the specimen and q is the heat loss. Using the cooling correction, the value of q may be found. This simple method can be used for liquids or solids, although in the case of a liquid, allowance has to be made for the thermal capacity of the container, and the liquid should also be stirred to allow an even distribution of the heat energy throughout its volume. This is necessary since liquids are such poor thermal conductors

The continuous-flow calorimeter

This was first developed by Callender and Barnes in 1902 for the measurement of the specific heat capacity of a liquid, and is shown in diagram below. Its main advantage is that the thermal capacity of the apparatus itself need not be known.

Continuous-flow calorimeter

**V**

V

## A

platinum resistance thermometer

liquid in

liquid out

platinum resistance thermometer

heater

Liquid flows in from a constant-head apparatus at a constant rate past a thermometer (θ 0). It then flows around the heater coil and out past a second thermometer where the outlet temperature (θ1) may be measured. When steady-state conditions have been reached (a temperature difference between inlet and outlet points of 50C is reasonable) the temperatures and the flow rate of the liquid (m) are measured. A vacuum jacket round the heater coil reduces heat losses.

The electrical energy supplied to the heater coil (E = V I t) may be found readily with a joulemeter or with an ammeter and voltmeter.

Two sets of measurements are carried out.

For a first experiment we have:

Electrical energy supplied (E1) = V1 I1 t1 = m1 C (θ1 – θ0) + q

C is the specific heat capacity of the liquid and q the heat loss to the surroundings and to the apparatus.

The flow rate and rate of energy input are now altered to give a second set of results. However, if the inlet and outlet temperatures are the same as in the first experiment the heat loss will also be the same. Therefore:

Electrical energy supplied (E2) = = V2 I2 t2 = m2 C (θ1 - θO) + q

Eliminating the heat loss (q) gives

Specific heat capacity of the liquid (C) = [E2 – E1]/ (m2 – m1)(1 – o)

Practical advice

A smaller amount of water could be heated in a polystyrene cup than in a calorimeter; this reduces the heating time needed and provides insulation. *The heater must be covered by the water*. The heat absorbed by the polystyrene is also small compared to that absorbed by the calorimeter. However take care that the heater does not touch the cup or it will melt. Thermometers can also overbalance the cup. Always stir liquids before taking a temperature.

It is better to choose an immersion heater that fits all the way into the solid material rather than having part of it in the air. The top of the block should also be lagged. Take the highest temperature reached by the block after the heater has been switched off.

External reference

This activity is taken from Resourceful Physics

Specific heat capacity: some questions

What to do

Three of these questions ask you to consider areas in which specific heat capacity is important: one domestic, one transport-based and one industrial. The remaining questions are calculations that involve the use of specific heat capacity.

The specific heat capacity of water is 4200 J kg–1 K–1; the specific heat capacity of air is about 1000 J kg–1 K–1.

Why does heat capacity matter?

1. Some cooks make toffee. Essentially, this is a process of boiling down a sugar solution to concentrate it and then allowing the liquid to cool until it sets. Small children are usually warned not to touch the cooling toffee for a very long time – much longer than the cooling for the same volume of pure water in the same vessel. Why is the cooling period so long?

2. Why is water commonly used in the cooling system of a motor car? Why is the system pressurised?

3. Find out which materials are used as coolants in nuclear reactors. What do these materials have in common?

Calculations

4. The Sun delivers about 1 kW of power to a square metre of the Earth when overhead at the equator. A parabolic mirror of radius 1m is used to focus this energy onto a container of water. Estimate the time taken by the mirror to raise 1 litre of water to 100 oC. Comment on whether your answer is likely to be an over or an underestimate.

5. Estimate how much energy is required to heat the air in your physics laboratory from a chilly 10 °C to a more comfortable 20 °C. Comment on the answer.

Practical advice

Students may find it more difficult to answer the qualitative questions than the quantitative questions. Answering qualitative questions provides essential practice in using the language (and concepts) of physics correctly.

Thermal changes

Use these data to answer the questions below, showing how thermal changes apply to a wide range of phenomena:

| Material | Specific heat capacity /  J kg–1 K–1 |
| --- | --- |
| Aluminium | 900 |
| Copper | 385 |
| Expanded polystyrene | 1300 |
| Iron and steel | 450 |
| Ice | 2100 |
| Air | 1000 |
| Water | 4200 |

A set of varied questions Answer in detail in your copy books

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For each of the following, find the internal energy difference for a 10 K change in temperature:

1. 5.0 kg of water.

2. The bit of a soldering iron, made from 3.5 g of copper.

3. An expanded polystyrene cup of mass 5.0 g.

4. A steel brake disc of mass 1.5 kg.

5. If you eat a fruit pastry fresh from a hot oven, the pastry may be harmless while the fruit filling scalds your tongue.

Use your ideas about specific heat capacity to explain why.

6. You can put your hand in an oven at 200 C and even touch a baking cake, without serious harm. But you must avoid touching anything in the oven made from metal.

Why is it not so harmful unless you touch metal?

7. In Fiji, some people will walk barefoot over a bed of white-hot pumice coals as part of a religious ritual. It is meant to demonstrate supernatural powers over pain and heat. Their feet are generally not hurt.

Pumice has a low specific heat capacity, low density and is a poor conductor of heat. Explain how each of these properties helps to make a bed of white-hot pumice coals safe to walk (quickly) over.

8. In the middle of the nineteenth century, James Joule performed a great series of experiments, which was part of the work leading to the law of conservation of energy. One of them was on his honeymoon, when he measured the temperature difference between water at the top and bottom of a waterfall.

If the waterfall was 100 m high, what maximum temperature difference could Joule expect?

Two holes are made in a 1.0 kg block of aluminium. A 48 W electric immersion heater is placed in one hole, and a thermometer in the other. Both objects make good thermal contact with the block. The heater is switched on for exactly 3 minutes and the temperature rises from 20 C to 29 C.

9. Calculate the specific heat capacity of aluminium.

10. Is this likely to overestimate or underestimate the true value?

In some supermarkets the freezer compartments are upright, with front-opening doors, while in other supermarkets there are chest-type freezers, with access from the top and no lids. Some people consider the upright design wasteful, because the cold air escapes when the door is opened. The temperature inside such freezers might be – 20 C, and the specific heat capacity of air (at constant pressure) is about 1000 J kg–1 K–1.

11. Consider a freezer of volume 1.5 m3 and discuss whether you agree or disagree.

A power station needs to get rid of energy at a rate of 800 MW and does so by warming up a river that flows past it.

12. If the river flow rate is 1100 m3 s–1, how much warmer is the river downstream of the power station?

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