Teaching ideas for Topic 3: Thermal physics

This topic is a very good way to get students to consider the large-scale (macroscopic) aspects of thermal physics, such as pressure, temperature, volume and bulk thermal properties such as specific heat capacity, and to link these with the small-scale (microscopic) behaviour of atoms and molecules.

Some useful points to consider are:

- Much of the knowledge and understanding that forms this topic has come from experimentation that was done over 200 years ago. Although modern equipment has made repeating some of the classical experiments much easier to do, it is worthwhile remembering that at the time of the original experiments, the micro-scale physics was not understood. This makes the findings seem much more reliable, as they have stood the test of time.
- This topic is very good for experimentation and will allow students to feel that they are really seeing for themselves the relevance of their experimental work and how important empirical evidence has been in the gathering together of scientific knowledge. Two of the required experiments, as given in the 'Applications and skills' sections of the IB Physics guide, should be done by students in this topic: using a calorimetric technique for finding the specific heat capacity (or specific latent heat) of a substance and investigating at least one of the gas laws. (Boyle's law and the pressure law are the two of the easiest for students to do.)
- Some good investigations and ideas for extended essays and internal assessment work can also come from this topic. The effect of temperature on the 'bounciness' of a ball, for example, is a popular investigation for students to do.
- It is important, from the start of this topic, that students understand that the total internal energy of a system is the total of its intermolecular potential energy plus the total random kinetic energy of its molecules. This is an idea worth getting across to students early on.

Ideas for teaching the topic

- A good way to start this topic is to consider what we mean when we say we warm something up. A good discussion should follow, which will bring out ideas of change of state and what is meant by terms such as 'solid', 'liquid', 'gas', 'vapour', 'temperature' and 'thermal energy'. This is a good time to ensure that students understand correctly what these terms mean. This links well with aim 3 in the group 4 aims in the IB Physics guide.
- At this point, it may be very helpful for students to consider the use of models to describe atomic arrangement and behaviour in various states. This is very good practice for students because a lot of physics relies on the use of models to help describe and explain how things work. There is good scope for theory of knowledge (TOK) discussions here on how effective (and necessary) the use of models is in physics.
- Once students have experimented with heat capacity and latent heat, it will be sensible to move on to investigating the behaviour of gases. This may be a good time for students to review what assumptions physicists make in their ways of analysing molecular behaviour, what the assumptions/conditions are for a gas to be described as 'ideal' and how a real gas can approximate to an ideal gas under certain conditions. This links directly with aim 3 in the group 4 aims in the IB Physics guide.
- It is also a good idea for students to begin to understand the basic aspects of statistical mechanics and how they play their part in our understanding of this topic: at the very least, an appreciation of how the kinetic energy spectrum for a sample of atoms varies with its temperature and how this can lead to an understanding of why evaporation causes cooling.

Practical activities

- Getting students experimenting again is easy to do with this topic. A good way to begin their investigative work is to measure the specific heat capacity of aluminium (or other suitable metal, such as steel). There are many different ways to do this, but one is to use a block of metal with two holes drilled part way into them, into which are inserted a cylindrical electrical heater (12 V, 4 A is ideal) and a thermometer. Students can then plot a graph of temperature against time and, using the idea that the heater supplies a constant amount of energy to the metal block each second, the gradient of the graph (where it is linear) will lead to the specific heat capacity of the metal. This experiment could be done with a beaker of water, but it will take more time (because the specific heat capacity of water is so much larger and there will be significant energy loss from the warming beaker during this time) and will not be quite so accurate. This will fulfil the requirement of the first of the two required experiments (see 'Applications and skills' section of the IB Physics guide) for this topic.
- A test tube partly filled with solid paraffin (or similar waxy substance) will provide an excellent way for students to spot how to detect when a substance begins to change state. If you warm up the test tube (perhaps by putting it in a beaker of water and warming up the water) then students can plot a graph of temperature of the paraffin/wax (use a thermometer in the paraffin/wax) against time. Where the temperature remains constant is where the paraffin/wax is changing state (it will melt at somewhere around 50–55 °C).
- The second of the required experiments can be fulfilled by getting the students to repeat Boyle's law. A simple way to do this is to use a plastic syringe, with a volume scale drawn, or fixed, on its side, attached to one end of a piece of rubber tubing. Put a pressure gauge on the other end of rubber tubing. Students can then vary the volume of air inside the syringe by pushing on the plunger of the syringe, measure the value of the volume with the scale on the side of the syringe and the value of the pressure of the air inside with the pressure gauge. Plotting a graph of P against V will produce a reliable inverse curve, which students can then process to give a linear graph in the IB way.
- Another really good experiment to do is the pressure law. A rigid spherical container (copper is ideal) with air inside is heated by being immersed in a large beaker of water. With a pressure gauge fixed to the spherical container and able to measure the pressure of the air inside it, students can change the temperature of the water (by any means, electrical or with a Bunsen burner) and measure the temperature of the water with a thermometer immersed in it. Plotting a graph of pressure against temperature and then extrapolating it backwards to where the pressure becomes zero will lead to a very close value for absolute zero. For schools with the added bonus of having a supply of liquid nitrogen, immersing the copper sphere into a beaker of liquid nitrogen will provide a very helpful extra data point. This experiment, or the previous one, Boyle's law, will fulfil the second of the required experiments for this topic. This also links directly with aim 6 in the group 4 aims in the IB Physics guide.
- Please see the available practical notes for further ideas.

ICT

- The experimental work in this topic is very suitable for students to use in order to become highly competent with software packages intended to graph and analyse data. Any of the commercially available software packages can be used for this.
- Temperature probes attached to data loggers can be used to good effect in these experiments. Where available, students might like to use these because they will reduce the work they have to do! Nonetheless, they are helpful in allowing students to complete an experiment accurately and in good time.
- The university of Colorado website (http://phet.colorado.edu) is a useful site for simulations that students can follow if equipment or time is short.

Common problems

- Although the conversion of temperatures between Celsius and kelvin is not itself a difficult calculation for students to do, this is a common problem when students come to solving problems with gas laws. It is important that students understand the need to use kelvin temperatures in the equations of state for ideal gases. Regular reviewing and constant practice should help students to do this correctly.
- Students frequently get their language wrong and use terms that are incorrect or inappropriate in this topic. For example, students frequently confuse the terms ‘heat’ and ‘temperature’; it is important to teach students that ‘heat’ is energy being transferred because of a difference in temperature between two bodies and that ‘temperature’ is a measure of the average (or typical) kinetic energy of the atoms and molecules of a body.

Theory of knowledge (TOK)

- The ideal gas is a model used to help describe the behaviour of gases. This is a good starting point for a discussion about how important models are to physics. Why are models necessary and what is it that makes a good model? Why do we keep models that are seen to be flawed – and what does this tell us about the nature of science?
- The scientists that formulated the early knowledge about gases did not need any confirmation from other areas of physics; they were confident that what they had measured must be correct. To what extent does this way of knowing relate to how modern scientists work and their growing knowledge? Take, for example, the Higgs boson and how a theoretical idea has encouraged a multibillion dollar research project at CERN; or 80 years ago, how the realisation of the conservation of lepton number and the kinetic energy spectrum of a beta particle encouraged scientists to search for the electron antineutrino.
- Another interesting point worthy of debate is why it is that, internationally, the scientific community agree on the use of the kelvin temperature scale, whereas non-scientists continue to use a variety of temperature scales in different countries.

International-mindedness

- It is by international agreement and collaboration that scientists use ways of measuring that are the same. As mentioned before in other topics, it is a part of ‘following the rules’ that scientists do. Without this, research and peer review would be much more difficult.

