*Physics > Big idea PMA: Matter > Topic PMA1: Heating and cooling*

|  |
| --- |
| **Key concept (age 11-14)** |
| **PMA1.1: Temperature** |

**What’s the big idea?**

A big idea in physics is matter. Matter is a more formal word for ‘stuff’. Anything that can be stored in a container, or weighed, is matter. Scientific ideas can help to explain why a given material behaves as it does, and may help scientists to develop new materials with specific properties.

**How does this key concept develop understanding of the big idea?**

This key concept helps to develop the big idea by building on the understanding that heating increases the temperature of a substance or material, to establish a general understanding that as the temperature of an object increases, its particles move with increasing speed.

****The conceptual progression starts by checking understanding that different materials in thermal equilibrium with a room will all have the same temperature as the room. It then supports the development of the kinetic particle theory in order to enable understanding of why solids and liquids expand as their temperature is increased.

**Using the progression toolkit to support student learning**

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.

**Progression toolkit: Temperature**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Learning focus** | Temperature is a measure of the average speed at which the particles in a substance or material are moving. | | | | |
|  |  |  |  |  |  |
| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Predict the temperature of different materials that are all in thermal equilibrium with the room.  **P** | Predict the temperature reached by mixing samples of water that are all at the same temperature.  **P** | Describe the arrangement and movement of particles in a substance in the solid and liquid states. | Describe the changes in particles of a substance or material when its temperature is changed. | Explain the changes in volume of solids and liquids when their temperature is changed. |
|  |  |  |  |  |  |
| **Diagnostic questions** | Three balls | More water | Particle model SL | Pie tin particles | A cup of tea |
|  |  |  |  |  |  |
| **Response**  **activities** | Water and sand |  | Particle diagram of a liquid | Ouch! |  |
| Expansion model | |

|  |  |  |  |
| --- | --- | --- | --- |
| Key: | | | |
| **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Three balls** | **More water** | **Particle model SL** | **Pie tin particles** | **A cup of tea** |
|  |  |  |  |  |
| Confidence grid | Simple multiple choice | Simple multiple choice | Confidence grid | Two-tier multiple choice |
| **Water and sand** | **Particle diagram of a liquid** | **Ouch!** | **Expansion model** |  |
|  |  |  |  |  |
| Application - practical | Critique a representation | Talking heads | Critique a representation |  |

**What’s the science story?**

*A particulate model of matter*

A particulate model can explain basic properties of substances in the solid, liquid and gas states.

In this model:

* All matter is made of very tiny particles – very, very much smaller than anything that can be seen under a microscope.
* There is no other matter except these particles (in particular, no matter between them).
* The properties of matter are the properties of large collections of particles – single particles do not have the same properties as the bulk matter.
* The particles of any given substance are all the same.
* There are attractive forces between particles. These differ in strength from one substance to another.
* In the solid state, the particles are close together, arranged in a regular pattern, and unable to move away from their neighbours.
* In the liquid state, the particles are also close together, but are less regularly arranged and can slide past each other.
* In the gas state, the particles are further apart, and can move freely.
* The particles are always moving: in the solid state, they are vibrating; in the liquid state, they are vibrating and jostling around; in the gas state, they are moving freely in random directions.
* The hotter something is, the faster its particles are vibrating or moving.

*Temperature*

The temperature of an object is a measure of how hot it is. It can be measured using a thermometer (in degrees Celsius, oC). To raise the temperature of an object, energy has to be transferred to it by heating. To lower the temperature of an object, energy has to be transferred from it (lost from its thermal store of energy).

If two objects at different temperatures are in contact, energy will move spontaneously from the object at the higher temperature heating the object at the lower temperature. If several objects and materials are left for some time in contact with one another, all of them will reach the same temperature (thermal equilibrium).

**What does the research say?**

Students aged 11-12 are often able to use and read a thermometer to take temperature readings, but they often make judgements about the temperature of an object based more on the materials it is made from rather than on the temperature of its surroundings. When a piece of metal and a piece of wood are picked up, both at room temperature, the metal feels colder. This gives some students the belief that they are at different temperatures. It can also lead to the misunderstanding that some materials can be heated and others cannot, which is perhaps reinforced by ideas about thermal conductors and thermal insulators. Most teaching schemes take these ideas for granted. (Erickson and Tiberghien, 1985)

It is important for students to understand that temperature is an indication of the concentration of energy in an object. A material that is in thermal equilibrium with a room contains energy in its thermal store in proportion to its mass, but its temperature will be the same no matter what that mass is. In a study of 8- to 14-year-olds (n=324) it was found that one in six 13- to 14-year-olds, and half of 12-year-olds thought that larger ice-cubes were colder than smaller ones because they take longer to melt (Driver and Russell, 1982).

Students are usually good at predicting that when samples of hot and cold water are mixed, the temperature of the mixture is somewhere in the middle. When samples are mixed that are both at the same temperature, they need to use the idea that temperature is an intensive property in order to predict that the resulting temperature is no different. Some students are likely to get this wrong because they confuse temperature with an amount of energy and adding more water adds more energy. When a value for the temperature of each sample is given some students add or subtract the temperatures, applying a mathematical process without appearing to think about what happens. (Erickson and Tiberghien, 1985; Driver et al., 1994; Millar, 2011)

The difference between temperature and a thermal store of energy is a crucial idea in the understanding of thermal concepts. When an object is warmed up its temperature rises, the amount of energy in its thermal store increases and the particles in the object move or vibrate more. All of these changes are interconnected and happen at the same time. Heating an object makes its particles move around more; temperature is a measure of the average kinetic energy of the particles; and the extra kinetic energy of all the particles adds to the energy in the thermal store (Institute of Physics).

An understanding of what happens to particles when they are heated is necessary in order to explain the mechanisms of heating, and to understand the difference between temperature and a thermal store of energy. Earlier ideas about the arrangement and movement of particles in solids, liquids and gases (BEST key concept: *CPS1.1: Particle model for the solid, liquid and gas states*) can be used to construct models in order to help develop students’ understanding of these things.

Johnson (1998) found research evidence that showed very few students have an appreciation of the intrinsic motion of particles. Many have difficulties with the idea that there is ‘nothing’ between particles. Others think of particles with the same properties as tiny pieces of the bulk material. This may lead to students thinking that particles expand when they are heated, in the same way that a substance does.

The progression toolkit for *temperature* reminds students that all objects that are in thermal equilibrium with a room are at the same temperature as each other and that heating each object increases its temperature. Students also revise the particle model of solids and liquids in order to describe what happens to particles in a material when its temperature is increased. These ideas are used to develop the kinetic particle model, which students are challenged to use to explain why very hot objects can cause burns and why solids or liquids expand when their temperature increases.

**Guidance notes**

The BEST resources for chemistry include a big idea: *CPS Particles and structure*. This big idea includes the BEST key concept: *CPS1.1 Particle model for the solid, liquid and gas states* and the BEST topic: *CPS4 Energy and changes of state*.

**For this topic it has been assumed that the ideas in the BEST key concept: *CPS1.1 Particle model for the solid, liquid and gas states* have already been covered.**

In this key concept temperature is defined as a measure of the average speed at which the particles in a substance or a material are moving. This is true but it is not a linear relationship. Temperature is more accurately defined as a measure of the average energy the particles in a system have because of their kinetic properties. The former definition was chosen because it more clearly supports a visual model for thinking about heating and temperature and it does not contradict the more accurate definition that is often taught in post-16 physics courses.

*Problems with ‘heat’*

The use of the word ‘heat’ as a noun in colloquial speech can cause problems because it implies that ‘heat’ is a substance that can flow. For example in the phrases: ‘close the door to keep the heat in’; or ‘the kettle has gained heat’ (Erickson and Tiberghien, 1985). For this reason is good practice to avoid using the word ‘heat’ when describing heating and cooling effects. More accurately when one object is *heating* another, energy is being transferred. The BEST key concept: *PMA1.4 Thermal store of energy* describes how this energy is transferred into or out of a thermal store by heating.

**References**

Driver, R. and Russell, T. (1982). An investigation of the ideas of heat, temperature adn change of state of children aged between 8 and 14 years. Leeds: University of Leeds.

Driver, R., et al. (1994). *Making Sense of Secondary Science: Research into Children's Ideas,* London, UK: Routledge.

Erickson, G. and Tiberghien, A. (1985). Heat and Temperature. In Driver, R., Guesne, E. & Tiberghien, A. (eds.) *Children's Idease In Science.* Milton Keynes and Philadelphia: Open University Press.

Institute of Physics. *Supporting Physics Teaching (SPT): Energy* [Online]. Available at: <http://supportingphysicsteaching.net/EnHome.html> [Accessed July 2018].

Johnson, P. (1998). Progression in children's understanding of a 'basic' particle theory: a longitudinal study. *International Journal of Science Education,* 20(4)**,** 393-412.

Millar, R. (2011). Energy. In Sang, D. (ed.) *Teaching Secondary Physics.* London: Hodder Education.