*Physics > Big idea PMA: Matter > Topic PMA3: Energy of moving particles*

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| **Key concept (age 14-16)** |
| **PMA3.1: Transfer of energy by conduction** |

**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 developing an understanding of two mechanisms of thermal conduction through materials, in order to prepare students for thinking qualitatively and quantitatively about energy in a thermal store.

****The conceptual progression starts by checking understanding of thermal conduction by the transmission of vibrations between atoms or ions in a material. It then supports the development of understanding the role of free electrons in thermal conduction in order to explain why materials of different types have differing thermal conductivities and how this makes them feel warmer or cooler to the touch.

**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: Transfer of energy by conduction**

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| **Learning focus** | Energy is transferred through a solid away from regions of higher temperature as its particles are caused to vibrate more vigorously. | | | | |
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| **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** | | | | |
| Describe how the sensation of hotness is caused by vibrating particles.  **P** | Describe the mechanism of thermal conduction that can occur in all solids.  **P** | Explain why metals are good thermal conductors. | Explain why different objects in thermal equilibrium feel hotter or cooler to touch. | Explain why some non-metals are better thermal conductors than metals.  **B** |
|  |  |  |  |  |  |
| **Diagnostic questions** | Hot blocks | Heating spoons | Fast conduction | Warm and cold | Diamond conductor |
| Hot iron | Handlebars |
| Cold spoons |
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| **Response**  **activities** | Feel the heat | | Free electron model | Thermal equilibrium |  |
|  | Along the line | | Melting ice |

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| Key: | | | |
| **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning |
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| **Hot blocks** | **Hot iron** | **Heating spoons** | **Fast conduction** | **Warm and cold** |
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| Two tier multiple choice | Two tier multiple choice | Confidence grid | Confidence grid | Confidence grid |
| **Handlebars** | **Cold spoons** | **Diamond conductor** | **Feel the heat** | **Free electron model** |
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| Simple multiple choice | Confidence grid | Two-tier multiple choice | Talking heads | Explanation story |

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| **Along the line** | **Thermal equilibrium** | **Melting ice** |  |  |
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| Critique a representation | Predict, explain; observe, explain  (PEOE) | Predict, explain; observe, explain  (PEOE) |  |  |
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**What’s the science story?**

All matter is made of very tiny particles – very, very much smaller than anything that can be seen under a microscope. 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.

If different parts of a metal object are at different temperatures, energy moves spontaneously (and quite rapidly) from the region at higher temperature to the region at lower temperature. This process is called thermal conduction. Non-metals are, in general, less good thermal conductors.

In non-metals, thermal conduction occurs as particles with larger vibrations interact with adjacent particles causing them to vibrate more vigorously in turn. Thermal conduction in metals is rapid because in addition to this process, outer electrons from metal atoms that move freely in-between metal ions can be accelerated by heating and move quickly through the metal to cause non-adjacent particles (ions) to vibrate more vigorously. In some non-metals, such as diamond, the bonds holding the particles together are so rigid that thermal conduction through the structure is faster than it is in a metal.

At room temperature, thermal insulators feel warmer to the touch than conductors (such as metals, glass, stone and ceramics), because they do not allow energy to be transferred as quickly from our body (which is at 37oC – well above room temperature).

Heating a system will change the energy stored within the system and raise its temperature or produce changes of state.

**Earlier development of understanding (BEST 11-14)**

When applying their understanding to novel situations, students of all ages often revert to earlier misunderstandings. Before moving forward it is worthwhile using diagnostic questions to check that students do not have any persistent blocks on their learning. Time spent consolidating the scientific understanding of earlier concepts before moving forward can accelerate progression later.

**Key concept: PMA1.1 Temperature**

Learning focus: temperature is a measure of the average speed at which the particles in a substance or material are moving.

This key concept:

* Consolidates understanding that the temperature of different materials are the same when they are in thermal equilibrium.
* Uses understanding of the kinetic theory of particles to describe changes to the particles of a substance as it is heated.

**Key concept: PMA1.2 Heating and cooling**

Learning focus: if two objects at different temperatures are in contact, energy will move spontaneously from the object at the higher temperature to the object at the lower temperature.

This key concept:

* Consolidates understanding of how temperature changes when hot and cold water are mixed.
* Distinguishes the difference between temperature and energy.
* Develops this understanding to explain how and why hotter objects cool down.

**Key concept: PMA1.3 Thermal conduction**

Learning focus: heating makes the particles in a material move more quickly. Heating raises the temperature quickly throughout a good thermal conductor, and very slowly through a good thermal insulator.

This key concept:

* Compares the properties of thermal conductors and insulators.
* Uses the idea of vibrating particles to explain heating by thermal conduction.
* Introduces outer electrons from metal atoms as the cause for more rapid conduction in metals.

**What does the research say?**

It is common for students to *not accept* that different objects are at the same temperature as each other if they are left in contact with the same surroundings for a long time (Thomaz et al., 1995; Hatzikraniotis et al., 2010). Hatzikraniotis et al. (2010) found that just over 40% of 13- to 14-year-olds (n=24) did not understand that objects in thermal equilibrium all have the same temperature. Understanding the concept of thermal equilibrium is central to understanding other heat and temperature concepts (Thomaz et al., 1995).

The notion that heat and cold are material substances that can flow from one place to another seem to be both common and persistent (Engel Clough and Driver, 1985; Hatzikraniotis et al., 2010; Thomaz et al., 1995). Engel Clough and Driver (1985) found that almost all 12- to 16-year-olds understood that ‘heat’ travelled through metals, but often described heat flowing rather than the actual mechanism. Hatzikraniotis et al. (2010) reported that the majority of 13- to 14-year-olds (n=24) described thermal conduction as the flow of hot particles. In their study in Portugal, Thomaz et al. (1995) similarly found that before teaching, 42% of 14- to 15-year-olds (n=79) wrongly thought of ‘heat’ (or ‘cold’) as a substance.

Students may link their perceived temperature of an object to whether it feels warm or cold to the touch, for example that metal is colder than plastic when both are at room temperature (Engel Clough and Driver, 1985; Thomaz et al., 1995). In a study of 12- to 16-year-olds (n=84), Engel Clough and Driver (1985) found just 6% were able to explain correctly why metal spoons felt colder to the touch than plastic spoons at the same temperature. 25% said it was because metals let ‘heat’ in or out more easily and 5% that they attracted or absorbed coldness. Pathare and Pradhan (2010) found that this idea persisted even amongst a few undergraduate physics students.

When asked to explain why the metal parts of handlebars felt colder than plastic parts in cold, frosty weather, Engle Clough and Driver (1985) found that 23% of 12- to 16-year-olds (n=84) explained this using the misunderstanding that metals attract or absorb cold more easily. ‘The direction of conduction of heat in relation to the human body appears to influence thinking; quite simply students find it difficult to think of conduction of heat when they feel cold’ (Engel Clough and Driver, 1985).

McLure, Won and Treagust (2020) found that a thinking frames approach to understanding the concept of why conduction away from the body caused object to feel cold was particularly successful, and significantly improved students understanding both immediately and in the longer term. The thinking frames approach used predict, explain; observe, explain activities to engage students in focussed small group discussions, in order to support the construction of a scientific understanding.

Metals are good thermal conductors because the outer electrons of metal atoms can move freely in-between metal ions. In thinking about how these outer electrons make metals good thermal conductors Pathare and Pradhan (2010) found some second year undergraduate physics students wrongly thought the heating of one end of a metal rod *released* more electrons from atoms to flow along it.

**Guidance notes**

This key concept describes the *mechanisms* by which energy that particles have because of their movement can be transferred by thermal conduction. These mechanisms are used to explain everyday observations in order to give students insights into *how* energy can be transferred.

The BEST key concept: PMA3.2 Specific heat capacity builds on this understanding, describing how the properties of an object or material can be *measured*, in order to *quantify* the energy transferred to it by heating.

**References**

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