*Physics > Big idea PMA: Matter > Topic PMA4: Particle explanations*

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| **Key concept (age 14-16)** |
| **PMA4.1: Density** |

**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 exploring what is really meant by density and by using the particle model to explain fundamentally why different substances and materials have different densities.

The conceptual progression starts by checking the qualitative understanding of mass, volume and density. This understanding is developed into a formal definition and equation for density and is used to interpret results of calculations. The particle model is used to develop understanding of why different substances and materials have different densities in order to explain the anomaly of why ice has a smaller density than water.

**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: Density**

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| **Learning focus** | Density, the mass of material in 1m3 or in 1cm3, is dependent on both the mass of its particles and their spatial arrangement. | | | | |
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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 characteristics of objects or substances with high (or low) densities.  **P** | Compare the density of objects that differ in both mass and volume.  **P** | Explain the equation ρ=m/V and use it to make calculations. | Use the particle model to explain differences in density. | Explain why the density of water in its solid state is less than the density of water in its liquid state. |
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| **Diagnostic questions** | Comparing density | Density by numbers | Defining density | Particle characteristics | Cold water |
| Railway sleepers |
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| **Response**  **activities** |  |  | Measuring density | Modelling density | Particle anomaly |

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| Key: | | | |
| **P** | Prior understanding from earlier stages of learning |  |  |

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| **Comparing density** | **Railway sleepers** | **Density by numbers** | **Defining density** | **Particle characteristics** |
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| Simple multiple choice | Focused cloze | Simple multiple choice | Simple multiple choice | Confidence grid |
| **Cold water** | **Measuring density** | **Modelling density** | **Particle anomaly** |  |
|  |  |  |  |  |
| Two-tier multiple choice | Talking heads | Critiquing a representation | Application and practice |  |

**What’s the science story?**

Density is a measure of the mass of material in one cubic metre or in one cubic centimetre. It is dependent on both the mass of the constituent particles and their spatial arrangement. It is calculated by dividing mass by the volume of an object or a material. The volume of an object can be measured using a ruler or Vernier calliper and then calculated, or the object can be submerged with the volume of water that it displaces measured.

**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: CPS1.1 Particles model for the solid, liquid and gas states**

Learning focus: The particle model of matter can explain the properties of substances in the solid, liquid and gas states.

This key concept:

* Consolidates understanding of the solid, liquid and gas states through observable properties.
* Develops understanding of the arrangement and movement of particles in each state of matter.
* Uses understanding of the particle model to explain the properties of substances in the solid, liquid and gas states and to explain changes of state.

**Key concept: PMA2.1 Floating, sinking and density**

Learning focus: An object that is surrounded by a fluid (liquid and/or gas) floats if its overall density is less than the density of the fluid.

This key concept:

* Consolidates understanding of floating.
* Develops understanding of how mass and volume determine *together* how well an object floats.
* Introduces the concept of density as a measure of whether an object is heavy (or light) for its size.

**What does the research say?**

**Density is hard to understand**

It is generally recognised that density is hard to understand for two reasons. First, density involves a complex proportional relationship between mass and volume (Smith et al., 1997) and proportional understanding is not fully developed in many children aged 14-15 (Smith, Snir and Grosslight, 1992).

Second, density can only be perceived through calculation and not directly with the senses (Smith et al., 1997). It is a very common for students to be unable to distinguish weight from density (Smith et al., 1992).

**Teaching density from definitions and equations is not usually the best approach.**

Teaching density from definitions and equations has consistently being shown to be less effective than methods that focus first on developing a qualitative understanding of density (Smith et al., 1997; Fassoulopoulos, Kariotoglou and Koumaras, 2003; Almuntasheri, Gillies and Wright, 2016; Hashweh, 2016).

The successful completion of practical work to measure density should not necessarily be taken as evidence that students understand the concept of density (Xu and Clarke, 2012). Practical work in which mass and volume are measured accurately and an equation used to calculate density does not either require or develop an understanding of density. Instead students can complete such practical work using only measurement skills and the application of mathematical operations.

**It is effective to develop a qualitative understanding of density before introducing quantitative calculations.**

A common misunderstanding amongst students is that weight and density are the same thing. This is perhaps linked to a tendency to define matter (including density) in terms of tangible properties that can be sensed. Mass (weight) and volume can both be sensed and directly measured. Mass and volume can also be defined as extensive quantities because they change with the amount of material. Density, by contrast, is an intensive quantity because it does not change with the amount of material (Smith et al., 1992). Intensive properties cannot be measured directly and are therefore harder to understand.

In a study of (n=296) 12- to 15-year-olds Fassoulopoulos et al. (2003) found that 54% were able to describe density using the correct scientific understanding. These students used phrases like ‘it is heavy for its size’, or ‘it has more mass for the same volume’. By contrast 24% of students in the study sometimes applied an understanding of density that showed they thought it changed in proportion to the amount of a substance.

Seah, Clarke and Hart (2015) suggest that when volume is not mentioned in an explanation of density, it is not necessarily true that a student has not understand what density is. They may instead have not realised that in a scientific definition there is a need to include the condition about comparable volumes in their answer. Definitions of density need to include: per unit volume; if the volume of the objects is equal; or similar.

Modelling clear explanations for density can raise awareness in students of the need to be explicit about volume (Seah et al., 2015). Students need to be actively engaged in thinking about how volume plays a role in determining density and given opportunity to explain density in their own words. Asking students to elaborate on answers in class or in small-group discussions allows them to rehearse their use of the language of scientific explanation, as well as indicating their ability to do so.

A focus on developing qualitative reasoning can help students to bridge the gap between their starting conceptions and more formal quantitative reasoning. This might start with an understanding that if one of two objects of equal size is heavier, it is made of a heavier kind of material. Second, that if two objects have the same weight but are each a different size, the smaller one is made of a heavier kind of material. Third, if two objects are made of the same kind of material, they have the same density because equal-sized pieces would have the same weight. (Smith et al., 1997)

**Particle model of density**

An understanding of particles is not necessary to understand density, but to understand *why* the density of one material is different to the density of another, students need to use the particle model. They also need to understand that even sub-microscopic particles have a mass and volume (Smith et al., 1992). Smith et al. (1997) found that although these concepts are often assumed when density is taught, 27% of 12- to 13-year-olds (n=30) do not hold them. In their study they found that giving students opportunity to address these concepts directly led to a more robust understanding of density.

The particle model of matter can represent how closely particles are packed together, which together with the mass of each particle explains the density of a material. Density is a joint function of mass of particles and their spatial arrangement, which is affected by temperature and pressure. An understanding of particles provides students with powerful tools for thinking about changes of density. (Smith et al., 1992)

**Applying a particle model of density**

Students need opportunity to test out and consolidate their understanding of density in a range of different situations. When a class of (n=36) 15- to 16-year-olds were shown a block of ice floating on water and asked to draw diagrams to represent particles in the ice and the water, their drawings showed particles closer together in ice than in water (Mortimer and Machado, 2000). Only when asked whether ice was more or less dense than water did some realise their error. This example illustrates the truism that in solving a physics problem it is always good practice to consider whether or not the final answer is reasonable.

**Guidance notes**

In this key concept, the term particle describes an atom, an ion or a molecule.

The BEST topic: *Particle explanations*, of which this key concept is a part, uses the particle model to develop a deeper qualitative understanding of both density and pressure, in order to develop insights that are useful for solving quantitative calculations.

Density can be explained in terms of the mass of particles and their spatial arrangement. Pressure in a gas can be explained in terms of the spacing (density) of particles and their motion. The particle model also explains changes to the pressure of a gas if it is: compressed or allowed to expand; or if it is heated or allowed to cool. In their later studies, some students will build on these explanations in order to understand the gas laws and the equations of an ideal gas.

**References**

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