*Physics > Big idea PMA: Matter > Topic PMA5: Nuclear physics*

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| **Key concept (age 14-16)** |
| **PMA5.1: Atomic nuclei** |

**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 the nature and structure of an atom’s nucleus to explain isotopes and the properties of stable and unstable nuclei.

****The conceptual progression starts by checking understanding of the structure and scale of an atom. It then supports the development of understanding the structure of a nucleus and how elements are determined by the number of protons in their nuclei, in order to enable understanding of isotopes. The effects of too few or too many neutrons are considered to support understanding of why some nuclei are stable others are not.

**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: Atomic nuclei**

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| **Learning focus** | There is a fixed number of positively charged protons in the nucleus of each atom of an element, but the number of neutrons can vary to make isotopes that are either stable or unstable. | | | | |
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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 the structure and scale of an atom.  **P** | Describe the properties of protons and neutrons in a nucleus. | Determine the structure of an atom from its mass number and atomic number. | Explain what isotopes of an element are. | Explain why some nuclei are stable and others are not.  **B** |
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| **Diagnostic questions** | Building blocks | Protons and neutrons | Numbering nucleons | Different, but the same | A stable relationship |
| A stable partnership |
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| **Response**  **activities** | Striking gold | Holding it together | Accounting for atoms | | Pushing apart |

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

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| **Building blocks** | **Protons and neutrons** | **Numbering nucleons** | **Different but the same** | **A stable relationship** |
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| Confidence grid | Confidence grid | Simple multiple choice | Simple multiple choice | Two-tier multiple choice |
| **A stable partnership** | **Striking gold** | **Holding it together** | **Accounting for atoms** | **Pushing apart** |
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| Confidence grid | Talking heads | Focused cloze | Application and practice | Explanation story |

**What’s the science story?**

An atom comprises of a positively charged nucleus surrounded by negatively charged electrons.

An atom’s nucleus contains most of its mass in the form of protons, that are positively charged, and neutrons that have no charge. Protons and neutrons each have a mass of about 1 atomic mass unit, which is almost 2000 times the mass of an electron.

The radius of an atom is in the order of 10 000 times that of its nucleus and most of an atom is empty space.

Atoms are too small to see with a microscope. The images produced by electron microscopes show computer generated representations of atoms.

Atoms of each element have a fixed number of protons in their nuclei. Electrons are attracted to a nucleus (and vice-versa) because the electric charge of an electron is equal in size and opposite to the electric charge of a proton. The number of electrons in an atom is the same as the number of protons in its nucleus, and the total charge of protons and electrons in an atom adds to zero.

The number of neutrons in atoms of an element can sometimes vary. Isotopes of an element contain the same number of protons and electrons as each other, but differ in the number of neutrons in their nuclei.

An atom can be represented as , where: X is the symbol of the element; Z is the atomic number, equal to the number of protons (and equal to the number of electrons); and A is the mass number, equal to the total number of protons *and* neutrons in a nucleus of the atom. The mass number is also called the nucleon number.

In a nuclear equation, sub-atomic particles can be represented in a very similar way as , where: X is the atomic symbol of a nucleus *or* the symbol of a particle; Z is the charge number, equal to the charge relative to that of a proton (-1 for an electron); and A is the mass number that is equal to the total number of protons *and* neutrons.

**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 from earlier topics to check that students do not have any persistent misunderstandings that can form barriers to learning. Time spent consolidating the scientific understanding of earlier key concepts before moving forward can accelerate progression later.

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| **Key concept CPS6.1: Atomic model**  **Learning focus:** The structure of an atom may be represented by an atomic model.  This key concept:   * Introduces subatomic structure of a basic atomic model. * Develops an understanding of the properties of key parts, and the scale, of the atom. * Compares two models of atom used in chemistry. |

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| **Key concept CPS7.1: Metallic bonding**  **Learning focus:** A model of metallic structure, made up of positive metal ions surrounded by ‘free’ outer electrons, can explain some properties of metals.  This key concept:   * Consolidates understanding of the electron shell model of an atom. * Develops an understanding that an electron shell diagram is a model and not a copy of reality. * Develops this understanding to explain metallic structure and bonding. |

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| **Key concept PEM4.1: Moving charge**  **Learning focus:** Around every particle or object with an electric charge there is a region of space called an electric field, with which every other particle or object with an electric charge will interact and cause both to experience a force.  This key concept:   * Consolidates understanding that electrostatic forces act at a distance around an electric charge. * Develops an understanding of an electric field and the effect it has on charged particles. * Develops this understanding to explain how a battery causes current to flow around a complete circuit. |

**What does the research say?**

Students’ reasoning difficulties about radioactive decay and half-life often stem from their inaccurate mental models about the atom (Prather, 2005) .

Five categories of increasingly sophisticated atomic model emerge from science education research (Zarkadis, Papageorgiou and Stamovlasis, 2017):

* Particle model – the atom is simply a particle
* Atom-cell model – the atom is a living organism (like a biological cell)
* Nuclear model – the atom is made of electrons around a nucleus of protons and neutrons
* Bohr model – the atom has electrons in levels or orbits around a central nucleus
* Quantum mechanical model – the atom with electrons in probabilistic clouds or orbitals.

In science education the four simpler models tend to be described as versions of the Bohr model, and this is the dominant model of an atom used by secondary school students: one of electrons moving in paths around the nucleus.

Research into students’ mental models of atoms (Harrison and Treagust, 1996) produced some unexpected responses during student interviews, most notably that the majority of respondents thought that atoms are visible under a powerful microscope. This has implications on students understanding that atomic structure is a model and not a representation of reality. If students believe that scientists have seen atoms then, the researchers suggest, students may be more likely to consider a model to be a realistic representation of the structure of an atom.

Another, much less frequent but surprising response, was that small, but significant, numbers of students thought that an atom was alive. This appeared to arise due to a confusion that atoms behaved like biological cells (possibly due to the presence of something called a nucleus in both).

The way in which a few students conflate the nucleus of an atom to the nucleus of a cell illustrates how sometimes students can make wrong connections between different pieces of information. Using metaphors to develop understanding of atomic structure can be very helpful, but as Harrison and Treagust (1996) found, can also lead to confusion: electron shells can misconstrued as protective enclosures around atoms; and electron clouds as loose structures in which electrons are embedded.

Metaphors or analogies used to explain atomic structure need to be made explicit in teaching; and characteristics of models used should be overtly connected to students’ understanding of the real-world atom (Harrison and Treagust, 1996; Tabor, 2013; Zarkadis et al., 2017).

In Harrison and Treagust’s study (1996), the large majority of students (age 13-16, n=42) pictured electrons much closer to a nucleus than in a real atom. They found students’ ideas of scale were usually similar to the (necessarily) out of scale illustrations of atoms drawn in text books.

The level of awareness is low amongst students, age 13-18, that an electrostatic force attracts electrons to a nucleus and causes electrons around a nucleus (or protons within a nucleus) to repel each other (Harrison and Treagust, 1996; Tabor, 2013). In his study, Taber (2013) found that it was more common for students aged 15-18 (N=105) to think instead, that gravity or magnetism attracts electrons towards a nucleus.

To develop a deeper understanding of the structure of nuclei, Brock, Manning and Walsh (2021) suggest starting by reinforcing understanding of the structure and scale of an atom by modelling Rutherford’s scattering experiment. Their next step is to introduce the proton and neutron, and to use nomenclature to give students opportunity to explore the numbers of protons, neutrons and electrons in different atoms. This introduces students to ideas about isotopes and about what makes some nuclei stable and others unstable (radioactive).

**Guidance notes**

An atom can be represented as , where: X is the atomic symbol; Z is the atomic number, equal to the number of protons (and equal to the number of electrons); and A is the mass number, equal to the total number of protons *and* neutrons in a nucleus of the atom. The mass number is also called the nucleon number.

N.B. ***The mass number of an atom is not the same as atomic mass.***

The atomic mass of an element is the average mass of all the different isotopes of the element when their relative abundances are accounted for. The atomic mass of each element is given on a periodic table, and mass numbers are not.

In a nuclear equation, sub-atomic particles can be represented in a very similar way as , where: X is the atomic symbol of a nucleus *or* the symbol of a particle; Z is the charge number, equal to the charge relative to that of a proton (-1 for an electron); and A is the mass number that is equal to the total number of protons *and* neutrons.

**References**

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