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

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| **Key concept (age 14-16)** |
| **PMA5.3: Ionising radiation** |

**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 properties of ionising radiation and by comparing ionising radiation to radioactive particles and radioactive material.

The conceptual progression starts by checking understanding of radioactive particles and radiation. It then supports the development of an understanding of what ionising radiation can and cannot do to atoms, or groups of atoms, and of the reasons for the different ionising powers of alpha, beta and gamma radiation. The concepts of irradiation and contamination are used in the conceptual progression to provide new contexts in which to apply understanding about ionising radiation, in order to help consolidate learning.

**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: Ionising radiation**

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| **Learning focus** | Some forms of radiation can ionise atoms or groups of atoms. Several properties of each form of ionising radiation are determined by its ionising power. | | | | |
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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 difference between radioactive particles and radiation.  **P** | Describe what happens when radiation causes ionisation. | Explain why ionising radiation does not make objects radioactive\*. | Explain how the ionising power of each ionising radiation affects its properties. | Explain radioactive contamination and how it differs from irradiation. |
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| **Diagnostic questions** | Radioactive sources | Alpha ionisation | Radiation remains | Getting through stuff | Radioactive contamination |
| Alpha particles | Ionising power |
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| **Response**  **activities** |  | Beta ionisation | Irradiation | Blocking paper | Fukushima |

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

*\*An exception to this rule is the example of high-energy gamma photons that may excite atomic nuclei.*

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| **Radioactive sources** | **Alpha particles** | **Alpha ionisation** | **Radiation remains** | **Getting through stuff** |
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| Focused cloze | Simple multiple choice | Confidence grid | Two-tier multiple choice | Linking ideas |
| **Ionising power** | **Radioactive contamination** | **Beta ionisation** | **Irradiation** | **Blocking paper** |
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| Simple multiple choice | Two tier multiple choice | Explanation story | Talking heads | PEOE |

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| **Fukushima** |  |  |  |  |
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| Talking heads |  |  |  |  |
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**What’s the science story?**

An ion is an atom or group of atoms that has a different number of electrons to protons. With excess electron, an ion has a negative electric charge and with too few electrons it has a positive charge.

A fast-moving alpha- or beta-particle, or a gamma photon, can knock one or more electrons off an atom (or group of atoms) to form an ion. Each is a form of ionising radiation. Alpha-particles are more powerfully ionising than beta-particles and beta-particles are more powerfully ionising than gamma photons.

* Alpha-particles are stopped by a few centimetres of air or by a thin piece of paper, because each one can cause multiple interactions (and ionisations) within a very small distance.
* Beta-particles have fewer interactions than alpha-particles, because their smaller electric charge and faster speed reduce their influence on the electrons around atoms they move past. In air beta-particles have a range in the order of one metre and are stopped by 3mm of aluminium (the thickness of twelve sheets of kitchen foil).
* Gamma photons have no electrical charge and are only weakly ionising. They can travel several kilometres through air and need the equivalent to a thick piece of a dense metal, such as lead, to stop them.

Ionising radiation does not cause objects or materials to become radioactive.

**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?**

When discussing radiation, it is important to make a clear distinction between radioactive material and radiation. These two terms are commonly mixed up and this can lead to the forming of misunderstanding (Eijkelhof, 1990; Millar, 1994; Millar and Gill, 1996; Plotz, 2017). Students can also have the misunderstanding that radioactive materials contain ‘radiation’ (Millar, 1994) in much the same way as a wet sponge contains water.

Radioactive materials contain radioactive particles that are unstable and may undergo radioactive decay, and emit radiation. Alpha and beta particles are types of radiation, but it is common for students to describe them as ‘radioactive particles’ (Millar and Gill, 1996). This is wrong because they are both stable particles and do not undergo radioactive decay. Similarly, gamma radiation, which comprises of high energy photons, (which, at this stage, can be thought of as short bursts of electromagnetic wave) does not undergo radioactive decay.

Students often think that all radiation is harmful for living beings (Millar and Gill, 1996) and as a result, there is a widespread fear to any type of radiation and in any situation (Morales Lopez and Tuzon Marco, 2021). Some students think radiation is something artificial and man-made (Neumann and Hopf, 2012) and some think that living matter is more vulnerable to radioactivity than inert matter (Klaassen, Eijkelhof and Lijnse, 1990).

Radiation can be harmful if it causes ionisation. Ionising radiation can cause outer electrons to be forced out of atoms, in turn affecting bonds and interactions between atoms. Often, discussion about ionising radiation is limited to a description of the relative likelihood of alpha, beta or gamma radiation to cause ionisation and to be ‘absorbed’. Alpha particles are typically described as the most likely to ‘collide’ with and ‘knock out’ an atom’s outer electrons, because they are the biggest radiation particle with the most electrical charge. This description is also used to explain that alpha particles are the most easily absorbed, because they are slowed down or stopped by each collision. However, this description can lead to a misunderstanding that direct collisions with electrons are necessary to dislodge them. In fact, it is the attraction or repulsion between the electric field of an electron and that of alpha, beta or gamma radiation that is responsible.

Classroom discussions about ionisation often do not include opportunity for students to consider what happens to radiation particles after they have caused an ionisation (Eijkelhof, 1990). It is common for students to think that an object exposed to radiation becomes radioactive as a consequence\* (Prather, 2005), perhaps because they think that radiation is conserved (Morales Lopez and Tuzon Marco, 2021) and can transfer from one material to another.

In a series of lesson observations of a class of 14 students, age 16-17, Eijkelhof (1990) found that although the teacher consistently referred to the ‘absorption of radiation’, students typically described it as being stopped by a material. This suggests some students may have a mental model of radiation bouncing off of a material.

The relative penetrating powers of alpha, beta and gamma radiation are connected to the probability of each interacting with electrons around the nucleus of an atom. Each interaction is the mechanism by which energy is transferred from alpha, beta or gamma radiation to a material. With each interaction, alpha and beta particles lose some momentum and after many interactions become unable to cause further ionisations. Gamma photons are fully absorbed in a single interaction. Beta particles are more likely than alpha particles to penetrate further into a material, before they lose most of their momentum and become a part of the material, because they are less likely to interact with electrons around atoms’ nuclei.

These ideas can be used to explain the relative dangers of different types of ionising radiation in different situations and to challenge the common misunderstanding that the danger of radiation depends only on the dose and not also on ionising power (Plotz, 2017).

A combination of some of the misunderstandings described above often lead students to form misunderstandings about contamination and irradiation (Millar, 1994; Millar and Gill, 1996; Plotz, 2017). Students need to consider: whether objects have had radioactive material transferred to them (contamination); or whether they have been exposed to radiation, and possibly damaged, without becoming radioactive (irradiation).

\*It should be noted that high energy gamma radiation can in some instances can excite nuclei and cause a material to become radioactive.

**Guidance notes**

This key concept focuses on understanding ionising radiation and does not explore the uses and dangers of each sort of ionising radiation. Immediately after this key concept would be an appropriate time to do so, in order to apply understanding in a range of new contexts.

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