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

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| **Key concept (age 14-16)** |
| **PMA5.4: Radioactive half-life** |

**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 ideas of how the random nature of radioactive decay results in the predictability of radioactive half-life and of the properties of radioactive materials over time.

The conceptual progression starts by checking understanding of randomness. It then supports the development of an understanding of the random decay of a radioactive material and the effect that radioactive decay has on its properties. Radioactive half-life graphs are introduced in order to describe and to quantify patterns in the radioactivity of a material over time. Understanding of radioactive half-life is further developed to include half-life calculations in different contexts.

**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: Radioactive half-life**

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| **Learning focus** | Radioactive half-life is the predicted time it takes for half of a large sample of radioactive nuclei to decay randomly. | | | | |
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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** | | | | |
| Identify events that are random. | Explain how randomness can lead to predictable outcomes. | Describe the decay of a radioactive material. | Describe patterns in the random nature of radioactive decay and interpret radioactive half-life graphs. | Make calculations using values of half-life. |
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| **Diagnostic questions** | A random question | Heads or tails? | Radioactive material | Radioactive half-life | Predicting radioactivity |
| Tossing coins | Radioactive half-life graph | Carbon dating |
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| **Response**  **activities** |  |  | Half-life of clay dice | |  |
| Half-life of pizza | | |

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

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| **A random question** | **Heads or tails?** | **Tossing coins** | **Radioactive material** | **Radioactive half-life** |
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| Simple multiple choice | Simple multiple choice | Simple multiple choice | Confidence grid | Simple multiple choice |
| **Radioactive half-life graph** | **Predicting radioactivity** | **Carbon dating** | **Half-life of clay dice** | **Half-life of pizza** |
|  |  |  |  |  |
| Confidence grid | Simple multiple choice | Linking ideas | Clarifying - modelling | Critiquing a representation |

**What’s the science story?**

Over time the nuclei of a radioactive isotope decay randomly into other more stable nuclei. It is impossible to predict when any specific nucleus will decay, but it is possible to predict the half-life of a radioactive isotope.

The half-life of a radioactive isotope is the time it takes for half of its nuclei to decay into other more stable nuclei. The half-life of a radioactive isotope remains constant over time.

After a second half-life, half of the remaining half of the radioactive isotope’s nuclei will have decayed into more stable nuclei; after a third half-life, half of the remaining quarter; and so on.

Different radioactive isotopes have different half-lives.

**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.

This key concept does not build directly on key concepts in BEST 11-14, but rather on the earlier key concepts in the BEST topic: Nuclear physics, of which this key concept is a part.

**What does the research say?**

Students often have difficulty in understanding what randomness is, and they find it even harder to understand how something predictable, like radioactive half-life, can emerge from a set of random events (Hull and Hopf, 2020). In a review, of the research about how students are able to understand and use probability-related ideas in science topics, Hull, Janksky and Hopf (2021) explore why these ideas are so challenging.

A common misunderstanding about randomness is known as the gambler’s fallacy. This states that if a roulette ball has landed on black several times in a row, then next time it is more likely to land on red (Hull et al., 2021). Instead, because it is a random event, the next roulette ball is equally likely to land on either red or black. An explanation for this misunderstanding is that people may be imposing their idea of what they think a random pattern should look like, in order to predict what they expect to happen. Another misunderstanding is to think that an event is *random* only because there is *insufficient information* to know for sure what will happen. In this case, the term ‘randomness’ is being used to describe unpredictability, which is not the same thing.

Students often think that random events are ones for which outcomes are unpredictable and that equations and other models are not useful for describing them. Conversely, when events lead to predictable outcomes, students typically expect to see a pattern in the outcomes that is determined by a set of rules and perhaps an equation. This thinking leads many students to believe that random events cannot be predictable and vice versa. (Hull et al., 2021)

Students’ belief that ‘only clearly determined events can lead to predictable outcomes’, is described by Hull et al. (2021) as a *deeply held* misunderstanding. It is a misunderstanding that can lead to students forming several other common misunderstandings about radioactive half-life. For this reason, Hull et al. (2021) strongly recommend that students are taught how random events can sometimes lead to predictable outcomes, and are given opportunity to consolidate that understanding, before learning about radioactive half-life.

The development of an understanding of randomness and prediction is challenging and analogies may be helpful. A useful one to use is that of popcorn being cooked: the order in which individual kernels pop isn’t easy to predict; but is easy to predict the rate at which they will pop as a whole, after a little experimentation. (Brock et al., 2021)

Misunderstandings that may stem from a thinking that ‘only clearly determined events can lead to predictable outcomes’ are:

* a radioactive material will be safe and no longer radioactive after one half-life (Lijnse et al., 1990);
* *all* the radioactive atoms will have decayed after one half-life (or after *two* half-lives); and
* half-life is a special time before which, or at which, a particular nucleus decays (Hull and Hopf, 2020).

In each of these examples, students appear to have used the idea that ‘half-life’ is predictable, to develop a misunderstanding that the decay of particular radioactive atoms is also predictable. The last example additionally shows how some students (about a third of a sample of 55 students age 13-14) ascribe the predictive nature of a whole sample to a single radioactive nucleus (Hull and Hopf, 2020). In fact, an individual radioactive nucleus does not have a half-life and its decay is random. Half-life is instead, a *good predictor* of the time it takes for half of a sample of *very many* radioactive nuclei to decay.

Another misunderstanding students have is that atoms disappear during radioactive decay (Prather, 2005). Prather (2005) found that the majority (59%) of (n=258) undergraduate students believed that the mass or volume of a radioactive substance would reduce by half during one half-life. Expressed differently, this means that a radioactive object disappears as it decays. This misunderstanding is likely to stem from the fact that is not clear to a lot of students that radioactive materials contain both stable and unstable atoms.

**Guidance notes**

This key concept does not make much reference to background radiation, or to the uses and dangers of radioactivity. These aspects of radioactivity commonly appear in science curriculums for students aged 14-16 and fit well with the ideas covered here.

**References**

Hull, M. M. and Hopf, M. (2020). Student Understanding of Emergent Aspects of Radioactivity. *International Journal of Physics and Chemistry Education,* 12(2).

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