Radioactive Nuclei: Decay and Half-Life Demonstration

Objectives

Students will:

- Understand the concepts of radioactive decay and half-life using a model.
- Demonstrate that radioactive decay is a random process.
- An optional extension activity is available where the students can explore the concept of different nuclides having different half-lives.

Fast facts

Subject: Physics

Age range: 11+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 15 minutes

Location: Science Fair

Overview

Radioactive decay is the process by which an unstable nucleus releases energy in the form of particles or waves, to become more stable. This process happens over time and nuclei have a certain probability of decaying, but it is random as to which individual nucleus will decay. **The time taken for half of the radioactive nuclei in a sample to have decayed is known as the half-life.**

The students will take part in a practical activity to demonstrate the random decay of radioactive nuclides, modelled as skittles, and calculate the half-life in terms of box shakes.

Equipment

- Skittles
- Paper cups
- Cardboard boxes
- Pens
- Charts to measure half-life (Chart Template document)

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

Procedure

1. Prior to the science fair, assemble the cardboard boxes and draw a circle roughly in the centre of the base of each box. This is best done using a marker pen, but a biro can be used if a marker pen is not available. Either the template circle (Circle Template document) can be cut out or the rim of a reasonably sized mug can be used as a template to aid circle drawing, if beneficial.

2. Begin by briefly discussing some of the information in the discussion section below with the students, so they understand the basics about unstable nuclei and radioactive decay and how this links to the model they are about to use.

3. Give each student a cup of skittles, each of which has a similar number of skittles in it (approximately 40–80, there are about 135 skittles per 150 g bag), a box, a chart, and a pen.

4. Ask the students to count the number of skittles in their cups and record the number in the first box in the chart. Then they must empty their cups into the boxes they have been given.

5. Next, get the students to shake their boxes and take out the skittles which are inside the circle. Ask them to count the number they have taken out, record the number in the chart, and then replace them in the cup. Finally, get the students to subtract the number of skittles they have just removed from the number remaining in the box from the previous shake and record this in the chart.

6. Repeat step 4 several times, until the students have at least less than half the skittles left in the box.

7. You can now discuss radioactive decay and half-life further with the students and get them to calculate the half-lives of their 'nuclides' in terms of the number of shakes of the box.

8. At the end of the activity the students can take their skittles with them, if they so wish. Collect all the boxes back in and re-use as many cups as possible to save resources the next time this activity is run.

Discussion

Atoms all have a nucleus at their centre, made up of protons and neutrons. Isotopes of an element are atoms which have the same number of protons in their nuclei but a different number of neutrons. In some isotopes, the forces in the nucleus are unbalanced because there are too many protons or neutrons. Nuclei with balanced forces are stable and have much less energy, whereas those with unbalanced forces are unstable and have lots of energy.

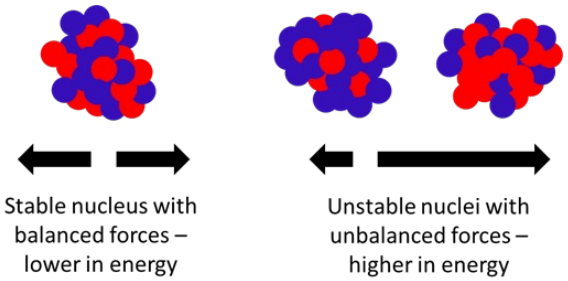

Figure 1 Stable and unstable nuclei

Unstable nuclei can release some of their excess energy by emitting particles or waves. This process is called radioactive decay and the particles or waves released are types of radiation. There are three types of radioactive decay processes. These are known as alpha decay, beta decay and gamma decay. In alpha and beta decay, a particle is emitted from the unstable nucleus, but in gamma decay a wave is emitted. Unstable nuclei undergo radioactive decay until they release enough energy to become stable.

Radioactive decay happens over time. For a given sample of unstable nuclei, over a certain period of time all of the nuclei will eventually decay, but they do not all decay at once. Ask the students to think about their starting number of skittles and imagine that these are the unstable nuclei before they have decayed. Explain that the skittles from the box which land in the circle and they take away after shaking are the nuclei that decay. This shows that it is completely random which individual nucleus will decay at any given time, as it is completely random which skittle lands in the circle after the box is shaken. However, it also shows that the nuclei decay over time, as there are fewer skittles left in the box each time it is shaken.

The time taken for half the number of nuclei in the sample to decay is known as the half-life. Get the students to calculate half of the number of skittles that they started with in the box. Then ask them to count how many times they shook the box before the number of skittles that was left in the box was less than half the starting number. This is the half-life of their sample in terms of box shakes. If the students compare between themselves, their half-lives should all be fairly similar.

$$half\ life = \frac{half\ no.\ of\ skittles\ you\ started\ with}{no.\ of\ box\ shakes}$$

Equation 1: half life in terms of box shakes

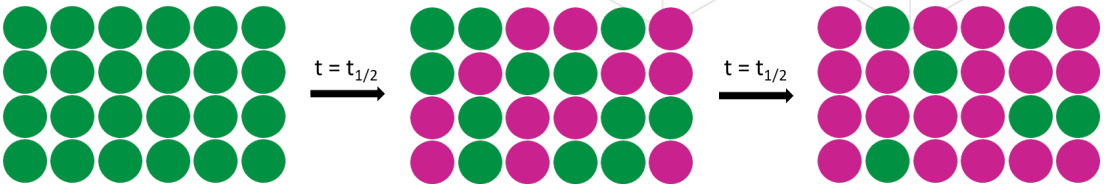

Figure 2 Sample of green nuclei decaying randomly to form pink nuclei with a half-life of $t_{1/2}$

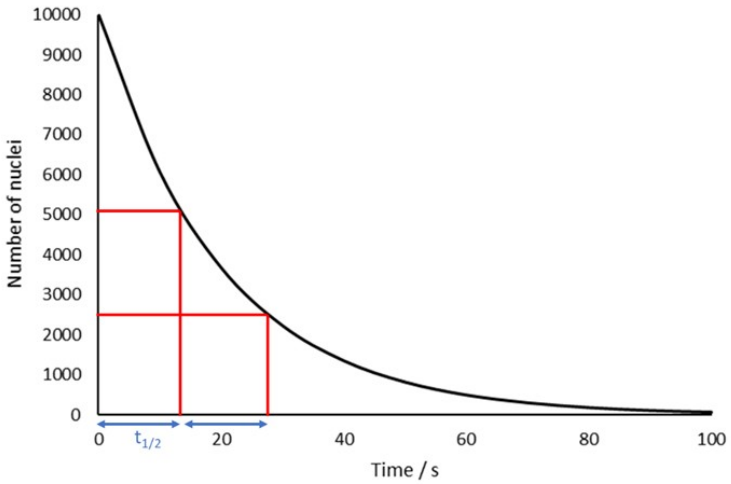

Figure 3 Decay curve for a sample of nuclei with half-life of $t_{1/2}$

Real-World Application

The understanding of radioactive decay and the half-lives of different nuclei is very important to radiation workers. This is because knowing how much energy unstable nuclei emit and how quickly ensures that radiation workers can properly protect themselves against the damage that the waves or particles released in radioactive decay can cause to the body. As well as this, the types of decay and the half-lives of nuclei are used to work out which isotopes will be present in spent nuclear fuel after it has been used and in the future. This means that nuclear waste can be handled, stored and disposed of safely, so we can protect both people and the environment.

Optional Extension

The half-lives of nuclei are different for different isotopes. Some isotopes can have very long half-lives, like uranium-238 which has a half-life of 4.468 billion years, whereas others can have very, very short ones, like astatine-215 which has a half-life of 0.1 milliseconds.

Get the students to repeat the above procedure, but this time using boxes which are lined with a bigger/smaller circle template, or get them all to draw differently sized circles in the boxes. Using a different coloured pen will make this easier.

Decay and Half-Life Demonstration

This time around, they should find that if they are using a bigger circle the decay is faster and the half-life they calculate is shorter, and the reverse if using a smaller circle. Explain that these differences in half-life are due to the differences in stability of the nuclei, as some have much more energy than others.

Equipment Purchase Links

• Skittles:

https://www.amazon.co.uk/Skittles-Sweets-Fruit-Chewy/dp/B08G9Z14PT/ref=sr_1_5?keywords=skittles&qid=1683195034&sr=8-5&th=1

• Paper cups:

https://www.amazon.co.uk/dp/B08WC4412D/ref=pe_27063361_485629781_TE_item

• Cardboard boxes:

https://www.amazon.co.uk/SHIPPING-CARDBOARD-POSTAL-MAILING-PACKET/dp/B07TDMDVBH/ref=pd_lpo_2?pd_rd_w=f5DQF&content-id=amzn1.sym.2d229339-2f42-4596-a90d-b81a4f52d6d3&pf_rd_p=2d229339-2f42-4596-a90d-b81a4f52d6d3&pf_rd_r=Y8KCNY91XEYV5CZDG6A7&pd_rd_wg=teh5e&pd_rd_r=fdf2cd16-6315-471d-9ed0-8afb46b3e985&pd_rd_i=B07T9FHWNM&th=1

• Pens:

https://www.amazon.co.uk/Medium-Fluent-Smooth-Writing-Ballpoint/dp/B07L8L33P1/ref=asc_df_B07L8L33P1?tag=bingshoppinga-21&linkCode=df0&hvadid=80539318951110&hvnetw=o&hvqmt=e&hvbmt=be&hvdev=c&hvlocint=&hvlocphy=&hvtargid=pla-4584138864844426&psc=1