Radioactivity Module
Student Guide

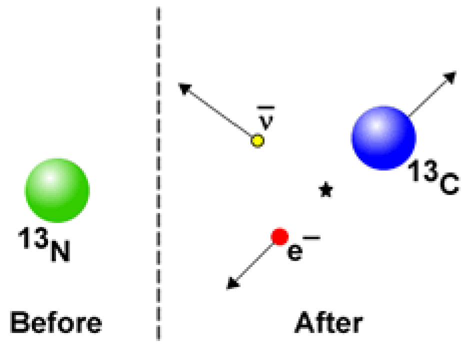
<u>Please Bring Your Clicker to this Practical</u>

Concepts of this Module

- Radioactivity, half-life
- Probability, randomness
- The meaning of Quantum Mechanics

Activity 1

Some elements are unstable, decaying via the weak interaction into other elements. Such substances are called *radioactive*. For example, ^{13}N decays into ^{13}C plus an electron e^- plus an anti-neutrino $\overline{\upsilon}$.



There are two factors that determine the rate at which a sample of radioactive atoms decays:

1. How many atoms are there? Twice as many atoms will have a total decay rate that is double.
2. What is the tendency of a particular atom to decay?

The tendency of an element to decay is expressed by its *half-life*.

The half-life of ^{13}N is almost exactly 10 minutes. What this number means is that if we have a large "pot" of ^{13}N and wait 10 minutes one half of the ^{13}N atoms will have decayed and one half will not have decayed. If we wait a further 10 minutes one half of the remaining sample of atoms will have decayed and one half will not. After a further 10 minutes one half of that remaining sample will have decayed. So, after one-half life there is a 50% probability that a particular atom will decay.

A Flash animation of radioactive decay of 500 atoms of the fictitious element Balonium is available. Balonium’s half-life is 2 seconds. The animation is available at:

http://www.upscale.utoronto.ca/PVB/Harrison/Flash/Nuclear/Decay/NuclearDecay.html

A full-screen version for browsers that can display "raw" Flash animations is at:

http://www.upscale.utoronto.ca/PVB/Harrison/Flash/Nuclear/Decay/NuclearDecay.swf

In this Activity we will simulate radioactive decay of ^{13}N by a coin flip. We imagine that each student is an atom of ^{13}N, and flipping a coin corresponds to waiting one-half life, ten minutes. The Instructors will lead the data collection for a few half-lives, with the clicker assignments:

> A. **Heads**: you have decayed and will not be available for the next half-life.
> B. **Tails**: you did not decay.
> C. You decayed in a previous trial. This choice is in case you want to click something and not be left out.

A. It is probable that at each trial the number of decays was not exactly one-half of the number of atoms. Why is this? Is the situation different for the 500 Balonium atoms in the Flash animation linked to above? What do you predict would happen if we did this Activity in Con Hall with the entire class? What about if we did it with the entire population of Canada?

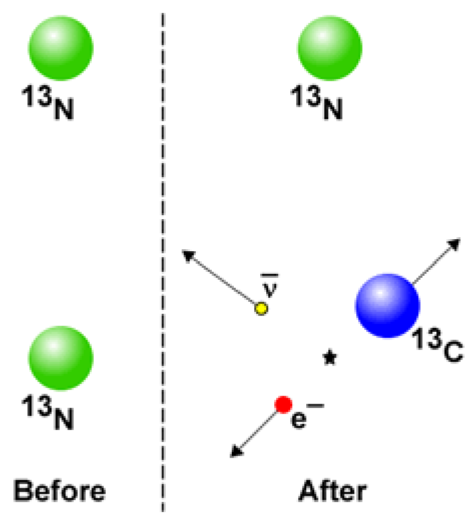
B. A reasonable definition of *random* is: **a process whose outcome follows no describable deterministic pattern**. Is flipping a coin truly random?

C. Imagine that you flip a coin and it comes up heads. What is the probability that on the next flip it will come up tails?

D. Imagine that you flip a coin 10 times and it comes up heads each time. What is the probability that on the next flip it will come up tails?

Course Concepts *Activity 2*

Imagine that we have exactly two ^{13}N atoms and wait one half-life. It is possible that both atoms will have decayed, and it is possible that both atoms did not decay. But perhaps one atom decayed and the other one did not: this would correspond to flipping two coins and have one come up heads the other come up tails.



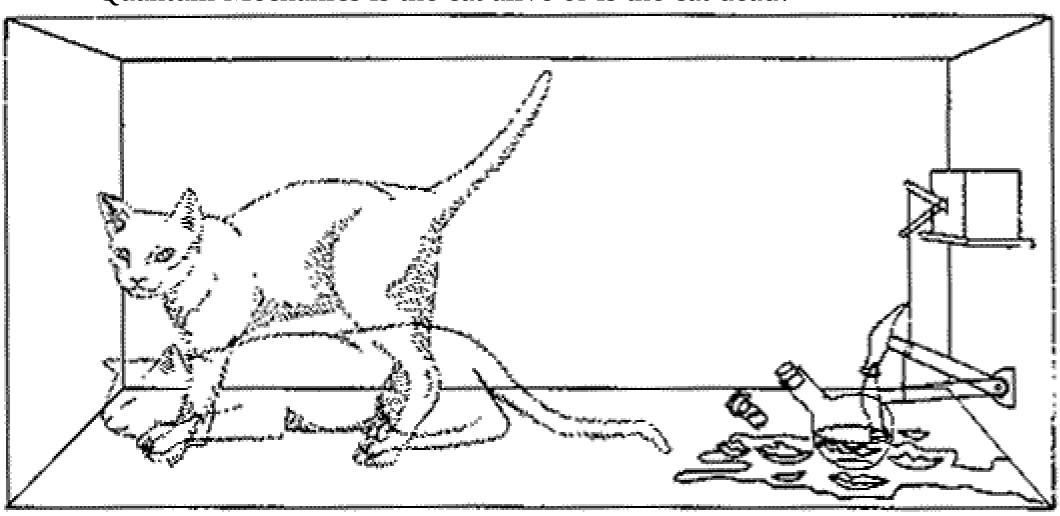
What is the difference between the two atoms? What *was* the difference between the two atoms before we waited one half-life?

Activity 3

A. A philosopher once said: “It is necessary for the very existence of science that the same conditions always produce the same results.” Do you agree? Why?

B. Assume for now that Quantum Mechanics is correct and complete. This means that the two ^{13}N atoms in Activity 2 were completely identical before: there is no “hidden variable” inside the atom that influences when it will decay. Is radioactive decay truly random? Is Quantum Mechanics a science under the rules of the philosopher in Part A?

C. We continue to assume that Quantum Mechanics is correct and complete. Here is a “thought experiment” published by Schrödinger in 1935. We imagine an apparatus containing just one ^{13}N atom and a detector that will respond when the atom decays. Connected to the detector is a relay connected to a hammer, and when the atom decays the relay releases the hammer which then falls on a glass vial containing poison gas. We take the entire apparatus and put it in a box. We also place a cat in the box, close the lid, and wait 10 minutes. According to Quantum Mechanics is the cat alive or is the cat dead?



D. When we open the box, we see a hopefully live cat. Is this consistent with your answer to Part C? Can you explain?

Activity 4

Imagine that the Facilitator at Pod 1 flips a coin, and at the same instant the Facilitator at Pod 5 also flips a coin. Can the result at Pod 1 influence the result at Pod 5? Why?

Further Information

The Instructors may have introduced Bell's Theorem. Here are some links for further information:

- A document written by the author of this Guide: http://www.upscale.utoronto.ca/PVB/Harrison/BellsTheorem/BellsTheorem.html
- A Flash animation illustrating the strangeness inherent in Quantum Mechanics: http://faraday.physics.utoronto.ca/PVB/Harrison/BellsTheorem/Flash/Mermin/Mermin.html
- Caroline H. Thompson, *The Chaotic Ball: An Intuitive Analogy for EPR Experiments*, Found. Phys. Lett. **9**, 357 (1996).

This guide sheet was written by David M. Harrison, Dept. of Physics, Univ. of Toronto, in February 2008.

The unnamed philosopher in Activity 3 Part A is from R.P. Feynman, **The Character of Physical Law** (MIT, 1965), pg. 147. The figure of the cat in Activity 3 is from B.S. DeWitt, "Quantum mechanics and reality," Physics Today **23**(9), (September 1970).

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