Fragmentation Box

Step 1

Acceleration

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This is part of the Marble Nuclei Project, downloadable from: https://www.jinaweb.org/educational-outreach/marble-nuclei-lessons

For maximum student attention, you may want to have them play with the marbles and fragmentation box for a few minutes before starting!

This works best with teams of no more than 4. Have at least one teammate take the responsibility of reading the instructions, and tell the teams to make sure that everyone gets a turn smashing marbles.

Often, when we want to study a particle in physics, we make it go fast using an accelerator. Usually accelerators are big and expensive. Your marbles, however, can use a gravity-based accelerator like the one in Figure 5... *set up your accelerator and box as shown, but don't attach a target nucleus in the box yet.*

You'll first test your accelerator with a proton (single yellow marble). *What will be different if you drop that proton in the lowest or highest openings in the tube? Why? Try it.*

For the rest of this experiment, particles dropped in the lowest opening will be called "low energy", while those dropped in the opening on top are "high energy." Accelerated particles are called "beam".

Figure 5. Your marble accelerator.

Step 2

Collision

Directions for building a simple, inexpensive, and portable fragmentation box as shown in the pictures is included in the "Fragmentation Box building instructions" document included with these Marble Nuclei Project documents.

There is a longer version of this activity in the marble nuclei activities document, part of the marble nuclei downloads.

You've just tried out your accelerator by giving the proton different energies (depending on which opening you dropped it in). Let's see how those energies can be important by smashing the proton into a target.

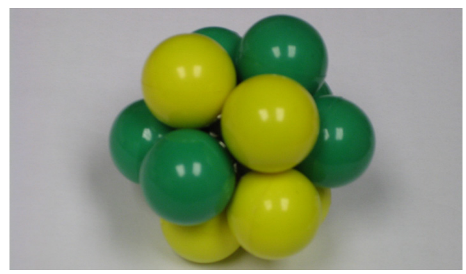


Figure 6. A carbon-12 nucleus.

Build a carbon-12 nucleus (6 yellow protons, 6 green neutrons). *Hang your nucleus* in the plastic fragmentation box (the silver magnet should stick to the nail hanging through the metal mesh). ***You may need to place your target closer to the pipe than shown in Figure 7!*** C-12 is now your "target" nucleus into which the proton "beam" will smash.

Figure 7. The carbon-12 nucleus set up as the "target" in the plastic fragmentation box, beam tube on left.

What will happen if you hit the "target" with a low-energy "beam" proton? Try it, and describe the result. (NOTE: if your beam misses, *you might need to reposition the target.*)

The beam will probably scatter off, doing no damage to the target.

What will be different if you use a high-energy proton? Try it (reset your C-12 nucleus if necessary) and describe the results.

The beam will probably still scatter, but it might "fuse" to the target

Breaking real nuclei is difficult, because they are tightly-bound (tough) and both beam and target nuclei are positively-charged, repelling each other. **You can solve those problems by smashing with an accelerator!**

Step 3
Fragmenting the beam

Now you're going to try beam fragmentation - crashing nuclei into a target to break them into something smaller. This is how the National Superconducting Cyclotron Laboratory at Michigan State University creates rare isotopes!

Figure 13. (top) C-12 "beam" leaving the accelerator, (bottom) beam hits target nucleus, knocking off protons and neutrons and making a new isotope.

In the activity below, you will fragment your beam nucleus on a target. Afterwards, ***collect the remains of the beam nucleus (whatever is still attached to the silver magnet core) from the floor of the box, ignoring the target***. If the two nuclei have fused together, *pull the bottom silver magnet off and count it (and any marbles that come with it) as the beam. Identify your new beam nucleus with a Chart of Nuclides.*

This is usually the most confusing part... students want to examine and quantify the target. Make sure they understand that the beam is key!

Build a carbon-12 beam nucleus. Now the beam is as big as the target. *How will smashing this beam into the target be different than when the beam was a smaller nucleus? Try it at low energy and describe the results. Were you right? What isotope is the beam nucleus now?*

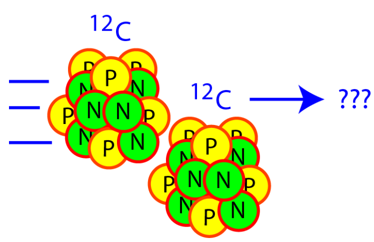
There will likely be more damage to beam and target nuclei.

Rebuild your C-12 beam and target nuclei and try that collision again at high energy. Was the collision different? What isotope is the beam nucleus now?

Again, more particles will likely break off of their nuclei: "fragmentation"

Step 4
Creating rare isotopes

Rebuild a C-12 beam and target. You are going to try fragmenting C-12 on C-12 at high energy several times and see what you produce. *Do you think you will get the same result each time? Why or why not?*



Statistically, students are likely to produce a variety of final isotopes in their beam. It might be interesting to have all teams put their results together and chart a distribution.

Resetting your beam and target each time, ***drop your C-12 in the high energy opening three times*** *and find out what it has become after each fragmentation.* ***Record the three resulting isotopes wherever your leader indicates*** *(your whole class may be combining results). Compare your three results with each other and those of other people. Are the resulting fragmented beam nuclei all the same? Can you think of one or more reasons for that result?*

While beam, target and energy were the same, many other variables weren't controlled.

Check your Reference Chart of the Nuclides. *Are the beam isotopes you made all stable (white boxes)? Did all the isotopes in your beam change into a nucleus that is lighter (fewer protons and/or neutrons) than C-12?*

The beam isotopes will usually be lighter after fragmentation, having lost some particles. To generate rare isotopes, NSCL scientists nearly always fragment a heavier stable isotope.

Now you will do what NSCL operators do: try to make a specific isotope through fragmentation. Specifically, you will attempt to fragment carbon-12 and make carbon-11. *What do you need to knock off your beam to do that? Try it, using any beam energy, target nucleus and target position you like. Were you successful? If not, why? Try again if you like - if you have the time, change what you need to and see how few tries it takes you.*

This is a difficult task - it may require a LOT of tries! That's why NSCL fragments a billion nuclei per second.