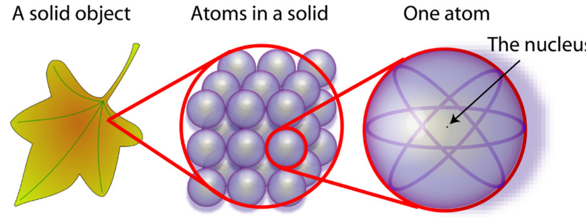
Shadow Nuclei
Seeing the Invisible

Notes to parents/teachers appear in this sidebar.

This is a quick way to explore how detectors can be used to measure something that you can't observe directly, like the nucleus! It also emphasizes the importance of theoretical models for interpreting experimental data.

It may be wise to keep the theoretical models hidden until students get to that part.



Normal matter (like you, your house, a tree, and air) is made of tiny particles called atoms. Your fingernail is about 100 million atoms across! And yet, the atom is made of even smaller things. At its core is the **nucleus**, which is 10,000 times smaller.

Scientists at the **Facility for Rare Isotope Beams (FRIB)** on the campus of Michigan State University study nuclei (plural of nucleus) every day... but how do we measure them, or even know they exist?

Materials needed (work with a partner)

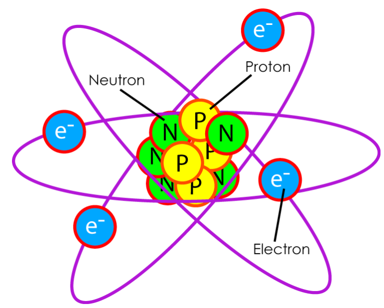
- A set of "mystery boxes" with paper covering and object inside
- A set of "theoretical models" - objects in a transparent box **(do not look inside until instructed to do so!)**
- A flashlight, sheets of paper, and pencils/pens

What's in the atom

This "Bohr model" of the atom is not accurate, but it is widely-recognized and useful in some cases.

Imagine that an atom is the size of the room you are in (that's one big atom)! The atom has a nucleus made of protons and neutrons (in the center of the room), plus some electrons around the outside.

Look at the thickness of your fingernail – that's about the right size for the nucleus in your room-sized atom. The much-smaller electrons would be somewhere near the walls.



A model atom (not to scale)

"Solid" matter is mostly empty space!

Discuss with your partner: how much space inside the atom is full of particles? How much space inside the atom is empty?

A reaction you see

But how can we know about the atom, much less the nucleus, when it's too small to see? Actually, you "see" something invisible every day: moving air!

Moving air pushes on the paper, so the paper's reaction is visible.

Partners should take turns dangling a piece of paper from their fingers. Then they can either blow on it (gently but firmly) or pretend to blow on it. The other partner guesses whether they actually did blow.

They might listen for the rush of air.

You can "see" wind when the leaves blow and trees sway.

Discuss with your partner: how can you see whether air came out of your partner's mouth? Did you use any other senses as well? Another name for moving air is "wind"… how can you "see" wind outside?

Measuring invisible things

Knowing that the nucleus is there can simply be a matter of seeing how it **affects something else** (like how moving air affects the paper). The material or equipment that reacts to a nucleus is called a "detector." Some detectors can actually measure the size and shape of a nucleus!

Students will likely think of shaking or weighing the mystery box to get some idea of the opject inside.

Pick up one of the "mystery boxes" labeled "very easy". There is an object inside, but it's invisible to you. *Try to guess what's inside.* How can you learn about the object? What things can you know about it/what evidence can you detect?

On a sheet of paper, *write your guess of what the object is and what evidence you have.*

You have probably measured the object by seeing how it interacts with gravity (weight) and when it hits the sides of the box (sound). Now, let's see how it interacts with a beam of photons (light)!

Shine your flashlight into the box. How does the object affect the light? Discuss with your partner: is the object "invisible" (like a nucleus) in both cases? How can you "see" the invisible object? Are there other ways you can think of to "see" something invisible by how it affects something else?

Draw what you see on your paper. With that evidence, write your new guess of what the object is.

The object was invisible because light bouncing off of it couldn't reach your eye. But by blocking the light and casting a shadow on the paper, the object can be detected!

Nuclear shapes

Let's see if you can use your "detector" (light shining through the mystery boxes) to measure the shapes of other invisible objects.

Shine your flashlight through three other mystery boxes: one each labeled "easy", "medium", and "hard". Try to identify the objects inside them. Write your guesses for each on your paper. Think about the shadows they cast and the shapes you have seen in your life. What makes it easy to recognize an object? What makes some of them more difficult?

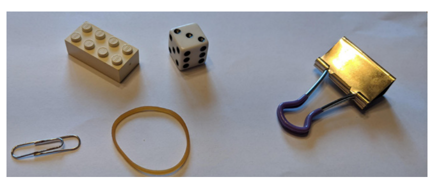
If you find an object that is hard to identify from its blurry shadow on the paper, this is the challenge that nuclear scientists have in trying to understand what a detector tells them. Just seeing how the detector reacted (in this case, a shadow) isn't necessarily enough to understand the invisible thing we're measuring.

The blurry shadows cast by some objects are a good analogy for the uncertainties that can occur in measuring a nucleus.

Models to the rescue

Models predict what data you can expect from your detector!

Nuclear theorists make "models" of a nucleus, calculating the ways a nucleus might look or act based on what we know about it. After an experiment, a researcher might compare their detector information to see if it could be explained by a model.



Pick up the boxes labeled "theoretical models" and study the objects inside. Now that you can see predicted shapes that could be in the mystery boxes, can you correctly identify which objects cast the shadow(s) you saw? Is it easier to understand the shadow's shape when you have some idea of the object casting it? This is why modeling is important!

Scientists will have a theoretical model ready before an experiment to check their results against. *Have a good look at the model objects, then shine your flashlight into a mystery box labeled "very hard".* Is it easier to tell what the object is and why it casts the shadow you see?

Experimental data are regularly compared to more than one model to find which best predicts the physics.

What's Next?

Students may like to try guessing small objects by their shadows again!

There is much more to discover about nuclear science at MSU's Facility for Rare Isotope Beams!

Lots of YouTube videos, a virtual lab tour, and the Isotopolis video game: frib.msu.edu/public