Inside the Atom: Hidden Shape – Teacher Notes

Overview

Students identify the shape and size of a hidden object (without looking!) by bouncing projectiles off the object and recording their tracks. This activity is analogous to accelerator experiments that use the results of collisions to deduce properties of unseen objects.

Ages 11-16, extensions available for 16+.
Time to make up the hidden shape trays: 30 minutes.
Time to set up the classroom: 30 minutes.
Time for activity: 1 hour

Outcomes

This activity is a great way to introduce students to the scientific process – how scientific methods and theories are updated and develop as new evidence and information is collected. Students will experience for themselves gathering data, forming scientific theories and communicating with peers. By the end of this activity they will:

- Understand that through indirect methods they can determine the characteristics of objects they cannot see.
- Apply their knowledge of reflection of light from mirrors to identify the characteristics of plane shapes.
- Understand the analogy between their experiment and those carried out by particle and nuclear physicists.
- Learn how our understanding of fundamental particles has changed over the last 100 years.

Introduction

The idea of the indivisible atom, held since the time of the ancient Greeks, was smashed just over 100 years ago. Ernest Rutherford and his team of scientists at Manchester University discovered that atoms have a very dense and extremely small central nucleus that contains more that 99.9% of the mass of an atom and is ten thousand times smaller than an atom.

We now know that the atomic nucleus is made up of nucleons: protons and neutrons, and that nucleons are composite particles made up of quarks – but how did scientists find out what is at the heart of an atom? How did they observe what cannot be seen?

Giant Microscopes

Unfortunately no instrument allows the atomic nucleus to be observed directly, so scientists have to be creative and use indirect methods. Our eyes use the light that bounces off objects to see, but in order to see things smaller than a millimetre or so our eyes need assistance. Optical microscopes allow us to observe the cells in our bodies, but even the best microscope in the world shows the atoms that make up those cells as fuzzy blobs. To really 'see' inside the atom and detect fundamental particles we need to go beyond visible light…

Particle Accelerators

Instead of shining a beam of light on something, particle accelerators work by smashing particles into a target, or colliding them with other particles. Detectors then measure the bits that bounce off these collisions. The faster the particles are going, the more energy they have and the smaller the things we can study. To give particles enough energy to study fundamental particles like quarks you need a really big accelerator. The world's largest particle accelerator is the Large Hadron collider (LHC) at CERN on the French-Swiss border. The LHC is 27km long, 100m underground and accelerates particles to 99.999999% the speed of light!

Classroom activity: Just how big is the LHC?

Using the powerpoint slide as a guide ask the students to calculate the radius of the LHC and think about that distance from your school. Get them to put their hand up if they think their house would be inside the circle of the LHC if it was centred on your school. Use the website http://natronics.github.io/science-hack-day-2014/lhc-map/ to check.

Reflection

In this activity students will use their own mini-particle accelerator to identify a hidden shape. Using their knowledge of angles of incidence and reflection they will use particle tracks to infer where the edges of the hidden object are and determine its shape – without looking at it.

Classroom activity: On the edge?

Using the powerpoint presentation work through the series of slides getting students to come up to the board and show where they thing the edge of the shape is.

This process simulates the experiments pioneered by Ernest Rutherford and his team, which are still used by nuclear and particle physics today.

Rutherford's alpha scattering experiment

In the early 1900s, physicists Ernest Marsden and Hans Geiger (of Geiger counter fame) under the direction of Ernest Rutherford, carried out experiments measuring how beams of positively charged alpha particles were scattered when they hit an extremely thin metal target. They observed that the majority of alpha particles passed straight through, but some were reflected back towards the source!

Experiment details:
- An alpha particle is a helium nucleus containing two protons and two neutrons.
- The alpha particle source was the radioactive element radium, which continually emits alpha particles.
- The target was a thin foil of gold just a few thousand atoms thick.
- Around the experiment a florescent screen was set up which flashed when struck by an alpha particle.
- The physicists had to sit in shifts to watch for flashes, there was no way to automatically record the events!

From these experiments Rutherford concluded that:

1) The atom must consist mainly of empty space – which was why the majority of the alpha particles passed straight through the target.
2) Most of an atom's mass and all its positive charge is concentrated in a very small central core – which enables some alpha particles to be reflected back.

The tiny central core that Rutherford proposed is now called the atomic nucleus – this discovery gave birth to a whole new field of science: nuclear physics.

> *It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.*
> *—Ernest Rutherford*

Rutherford and others continued these experiments and went on to deduce that the nucleus is made up of protons and neutrons that are surrounded by a cloud of electrons.

Beyond the nucleus

In the early 1960s two physicists Murray Gell-Mann and Geroge Zweig proposed that protons and neutrons were not fundamental particles, but were instead composed of a combinations of particles Gell-Mann called quarks. A few years later three physicists: Jerome Friedman, Henry Kendall and Richard Taylor started doing experiments at a particle accelerator in America to find out what protons and neutrons were made of.

Experiment details:

- The experiment was carried out at the Stanford Linear Accelerator Center (SLAC) in California.
- Electrons were accelerated along the 2km accelerator to speeds close to the speed of light.
- The target was hydrogen nuclei or protons.
- They used detectors called spectrometers to observe the collisions.
- They saw that the electrons were not striking solid protons, but a cluster of quarks.

Experiments at SLAC led to the discovery of four different types of quarks now called: up, down, charm and strange between 1968 and 1974. Two more quarks called: top and bottom, were found at another American Laboratory called Fermilab in 1977 and 1995 respectively. We now know that protons and neutrons are composed of three quarks…

> *Three quarks for Muster Mark!*
> *Sure he has not got much of a bark*
> *And sure any he has it's all beside the mark.*
> *—James Joyce, Finnegans Wake*

Protons are made of two up quarks and one down quark, while neutrons are composed of one up quark and two down quarks.

Classroom activity

In groups of 2-4 students should be given a student activity sheet.

Optional: Give each group the hidden shape diagrams showing all the possible different shapes.

Students will be asked to identify at least one hidden shape without looking at it. For this each group will require…

Equipment list

Target – *The hidden shape made of Lego hidden beneath…*

Concealing sheet – *Must be a large flat sheet of cardboard of similar, large enough to completely hide the shape, high enough that the balls don't get stuck and low enough not to reveal the shape.*

Particles – *Rubber balls, marbles or similar.*

Flat surface – *A large tray approximately 60cmx60cm with sides or you can use a desk or the floor.*

Detector – *White paper stuck to the concealing sheet.*

Blu tack, pencil, ruler, sellotape

Preparation

Construct your hidden shape – try to do a different shape for each group. Using the blu tack stick the hidden shape in the middle of the flat surface, with the concealing sheet stuck on top of the shape. <u>Make sure your students do not peek at the hidden shape!!</u>

To make this activity easier you can cover the concealing sheet with paper held down with sellotape and allow the students to draw on this paper. You can also give the students the hidden shape diagrams.

To make this activity harder do not put any paper on the equipment and allow the students to infer the shape of the object on a separate piece of paper.

If there is enough time you can rotate the groups. If you have stuck paper on the concealing sheet get the students to carefully remove it and replace it with a fresh one. At the end of the lesson groups who examined the same shape can compare their answers to see if they match.

You can find the Student Activity Sheet at the end of this document, which can be printed multiple times for groups of students.

Safety
Students should use care when handling the balls/marbles and not throw them.
If the balls/marbles are dropped students should be careful not to step on them.
You may want to wait to hand out the balls/marbles until you are ready to begin.

Extensions

Progress to more complicated shapes and smaller balls – this is analogous to how this field of research has progresses to higher and higher energies to look at smaller and smaller objects.

Use a ruler and a pair of compasses to bisect the angle of the particle track. Use this to more accurately determine the wall the ball bounced off of by drawing the perpendicular line to the tracks bisector.

Simulate inelastic collisions using magnetic marbles. Construct a hidden shape from a cluster of magnetic marbles. Give the students magnetic marbles and then ordinary marbles to use as particles and have them discuss the differences between elastic and inelastic collisions.

For homework/discussion/ideas for research topics:

The history of Rutherford's alpha scattering experiment and the subsequent research that led to the modern idea of the nucleus.

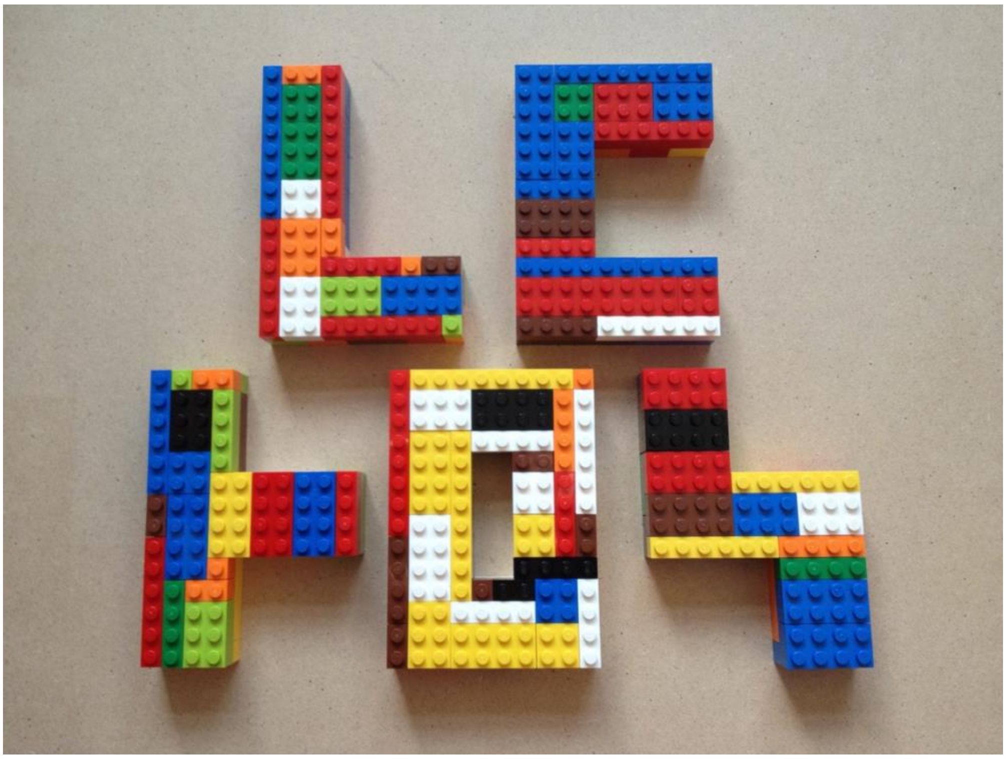
How the quark structure of nucleons was proposed and confirmed by experiment.

The impact of nuclear physics on the Second World War.

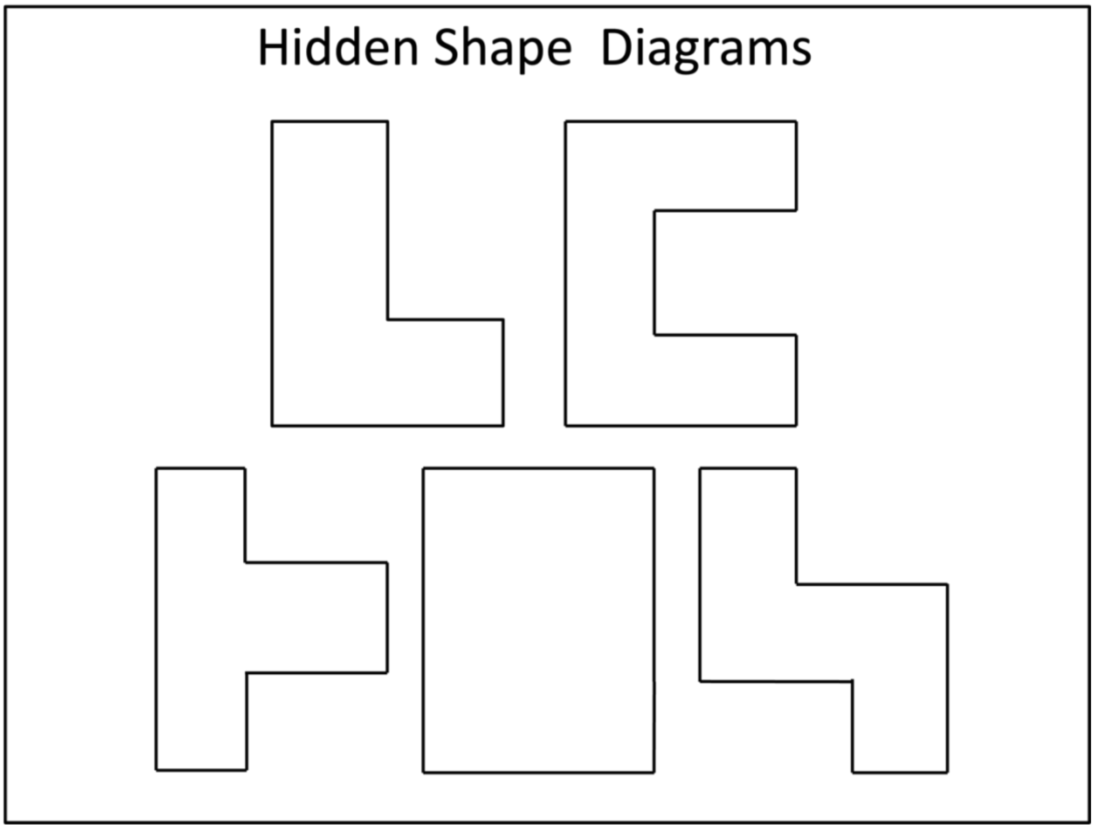
How many particle accelerators are there in the UK and where is the nearest particle accelerator to your school?

How many countries in the world collaborate at CERN?

Example Hidden Shapes using LEGO



Example Hidden Shape Designs/Diagrams



Inside the Atom: Hidden Shape – Student Activity Sheet

Your goal is to identify the shape and size of a hidden object (without looking or feeling!).

1) In groups roll your particles at the hidden object underneath the sheet of cardboard. Draw the path of the particles, even those that do not hit the shape. Make sure you roll your particles hard enough that they bounce back cleanly.

2) Repeat step 1 as many times as needed to identify the shape.

3) Once you know the shape of your hidden object, draw it out below.

4) If there's time, move on to another shapes and repeat the process.

5) At the end of the lesson each group should compare their results for each shape and see if they agree.

Inside the Atom: Hidden Shape – Student Data Collection Sheet

Name:____

Date: ____

Shape Number:

Shape Number:

Shape Number:

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