COSMOS LESSONS

Chemistry

Atoms: A look inside

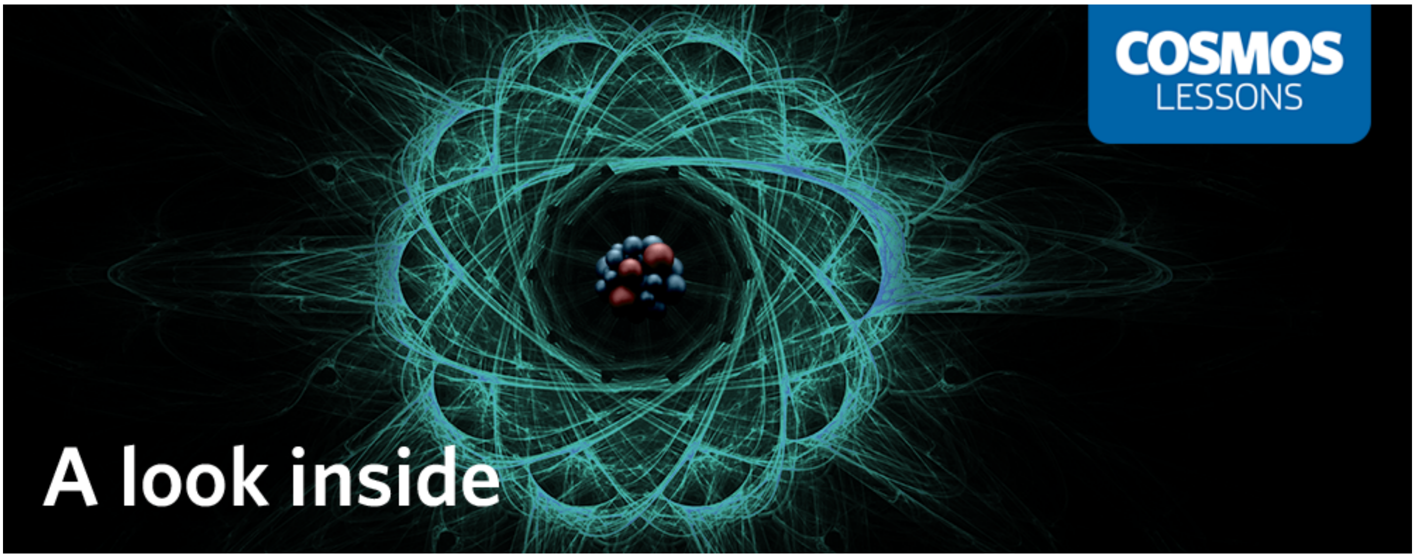
Atoms are the building blocks of all matter – but what are the building blocks of atoms? The surprising answer to this question has led to both deep scientific insights and cutting-edge technologies. For example, a new scanner allows us to look inside rocks, cameras and car engines like never before.

- In this lesson you will investigate the following:
- What are atoms made of and how are their parts arranged?
- What are isotopes?
- How can we use subatomic particles to create revealing new images of objects?

Are you ready to discover what lies deep below the surface of things?

This is a print version of an interactive online lesson.
To sign up for the real thing or for curriculum details about the lesson go to **www.cosmosforschools.com**

Introduction: Atoms



One day you're walking along a beach lined by towering cliffs when a strange-looking rock catches your eye. You pick it up and take a closer look. One side is pale and curved like a skull and on the other you can see a row of sharp teeth jutting out.

Your heart is suddenly thumping as you realize you've discovered a fossil! Maybe it's a completely new type of animal, unknown to science. But how do you see what the whole skull looks like? If you try to tap the extra rock away with a hammer you might crack the fossil in two.

Luckily, scientists have ways of seeing what's inside a lump of rock without damaging it. It's not exactly X-ray vision – X-rays are too weak to get through. Instead they use neutrons, subatomic particles that are found in nearly all atoms.

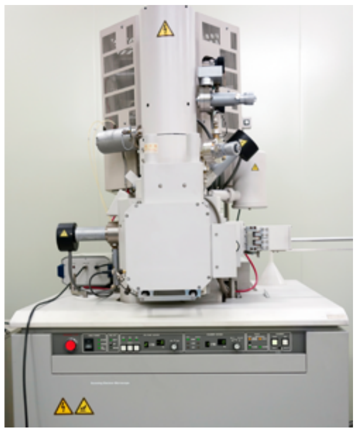
You can build up a wonderfully detailed image of an object's internal structure by directing a beam of neutrons at it and detecting how they're absorbed or scattered. The latest technology is so powerful that it might even allow you to see the faint impression left by a creature's brain on the inside of its skull!

Fossils aren't the only things being investigated by neutron imaging. It can also be used to test the quality of metal parts used in cars, aeroplanes and medical implants. Or give you a video of the inner workings of a car engine or an alarm clock.

Funnily enough, we only discovered neutrons by directing beams of *other* types of particles at atoms. So the same basic idea allows us to investigate the internal structure of just about anything – from strange rocks picked up on a beach to the tiny building blocks of all matter.

Read the full *Cosmos Magazine* article here.





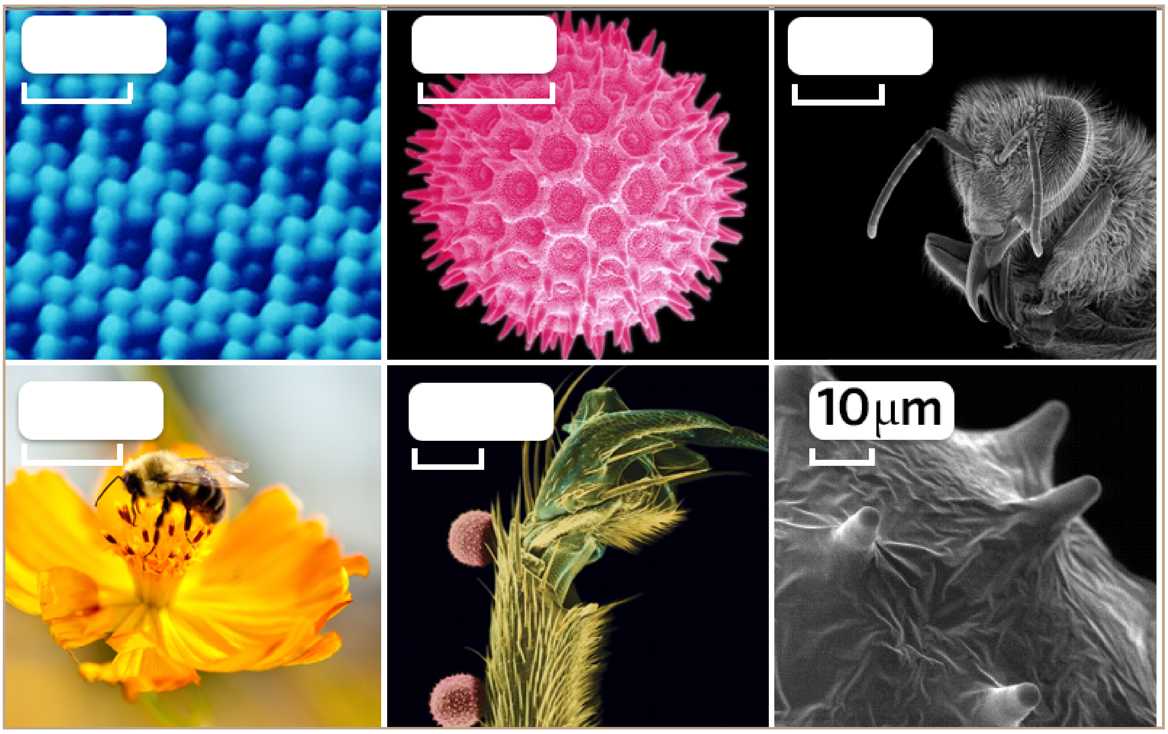
Question 1

Label: Everything you can see and touch is made up of atoms. Everyone knows that atoms are incredibly small – but how small are they exactly?

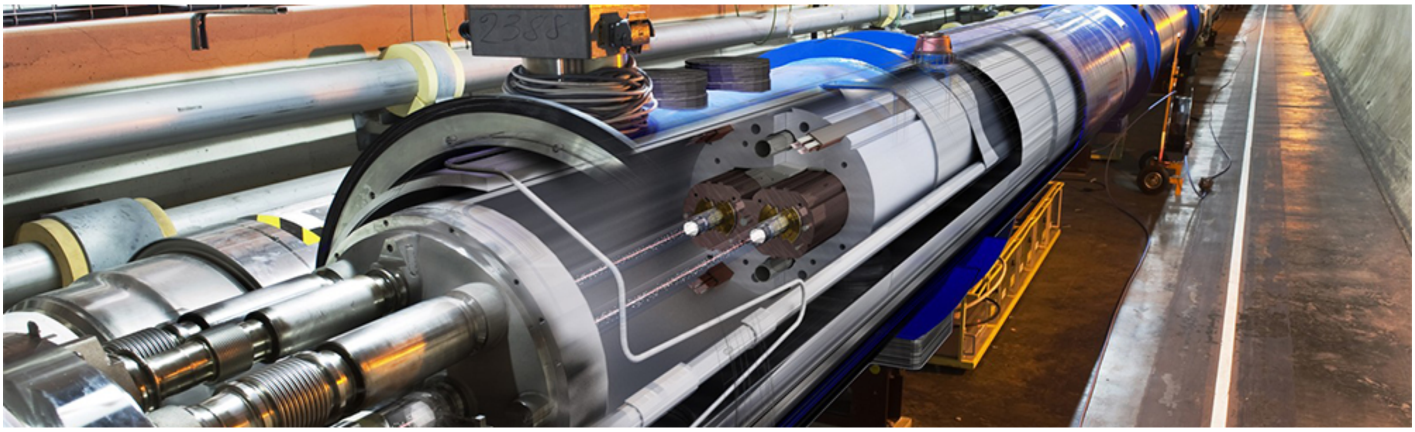
Suppose you see a bee buzzing around a flower. To see the tiny pollen grains attached to the bee's legs you'd need to zoom in about 50 times. But to see the atoms that the pollen is made out of you'd need to zoom in about 500,000 times!

Given that 1 mm is equal to 1000 µm (microns) and 1 µm is equal to 1000 nm (nanometres), label each of the images below with the proper scale:

1 cm | 1 mm | 0.1 mm | 0.05 mm | **10 µm** | 1 nm



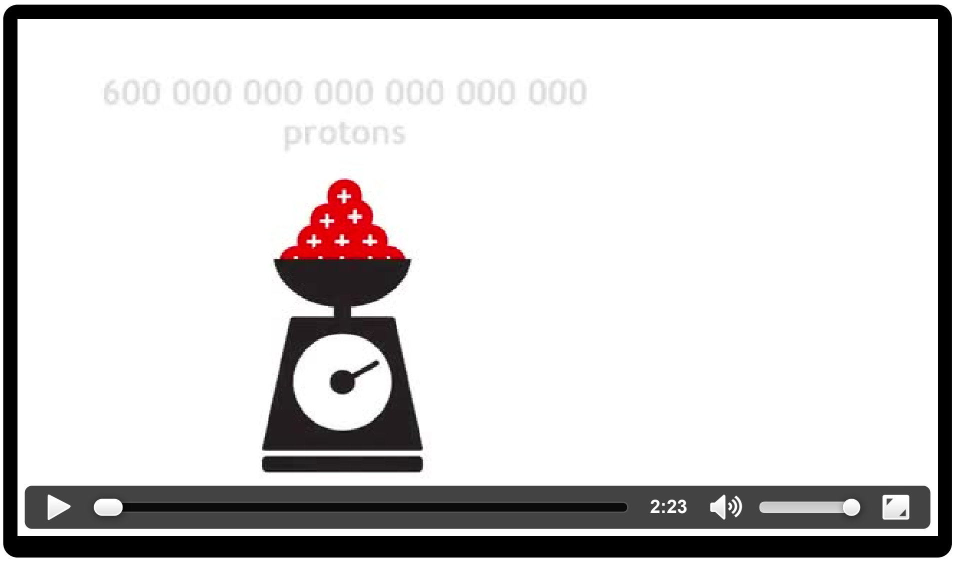
Gather: Atoms



The Large Hadron Collider, located beneath the French-Swiss border, is used to investigate the subatomic world by smashing particles together at close to the speed of light.

Inside atoms

The idea that all matter is made up of tiny indivisible particles – *atoms* – has a very long history but it only became widely accepted by scientists around the beginning of the 20th century. At the same time a series of discoveries revealed that atoms are not indivisible after all. As new technologies developed we gradually learned how to look inside atoms and explore the *subatomic* world.



Question 1

Recall: The subatomic particle that is not found in the nucleus is the:

- [ ] electron
- [ ] neutron
- [ ] proton

Question 2

Identify: The subatomic particle that has no electric charge is the:

- [ ] neutron
- [ ] electron
- [ ] proton

Question 3

Recollect: The mass of the neutron is approximately equal to the mass of the:

- [ ] nucleus
- [ ] electron
- [ ] proton

Question 4

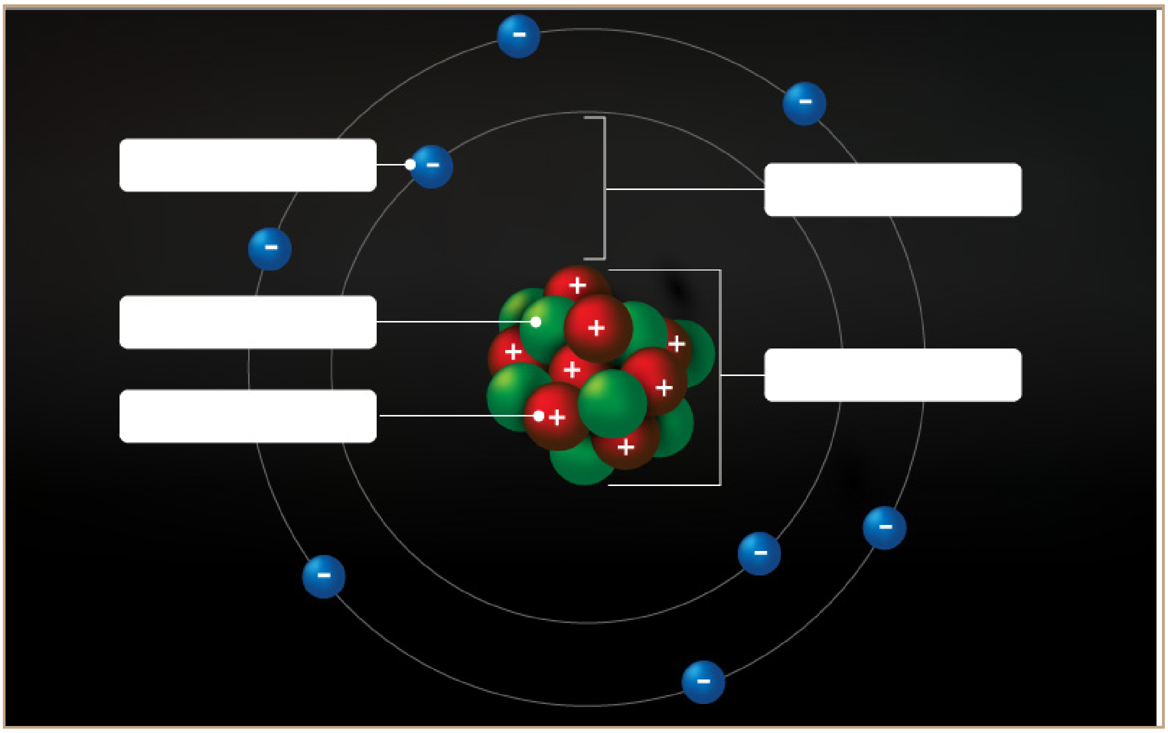
Remember: Most of an atom's volume is made up of:

- [ ] electrons
- [ ] protons
- [ ] empty space
- [ ] its nucleus

Question 5

Label: Identify the parts of an atom by adding the following labels:

proton | nucleus | electron | empty space | neutron

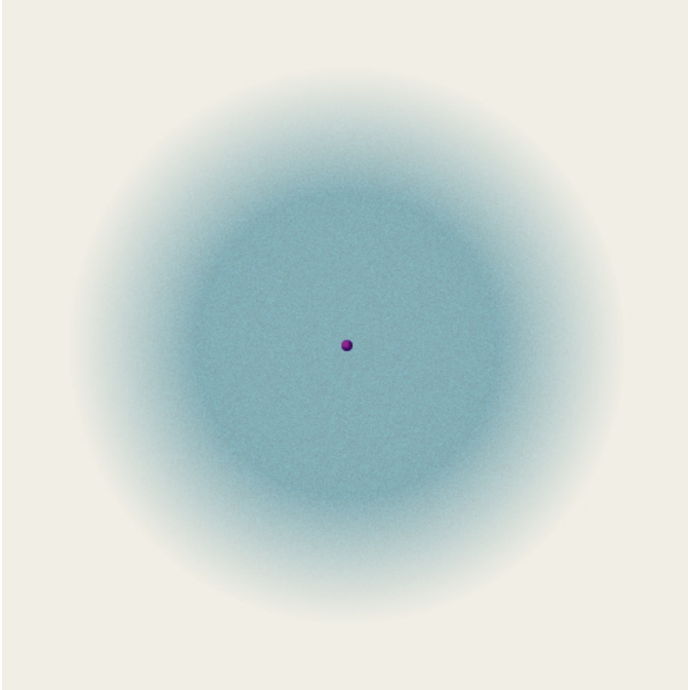


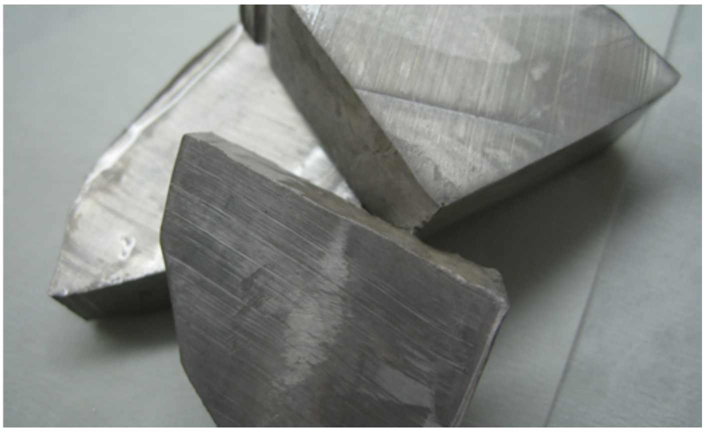
Models

Atoms are too small for us to see their internal structure, even with the most powerful microscopes. To overcome this problem, scientists develop *models* – different ways of picturing and thinking about what we can't observe directly.

The diagram in the sketchpad above shows the planetary model of the atom. We think of the atom as a miniature Solar System with the electrons orbiting the nucleus at different distances. Unlike the actual Solar System, the paths in these diagrams are meant to represent three-dimensional spheres known as *shells*.

A different way of thinking about the structure of atoms is to picture the nucleus as being surrounded by an electron *cloud*. In this model it's impossible to say exactly where the electrons are but they *might* be anywhere in the atom's cloud.





Left: The element neon is a colourless gas but it can be made to glow when supplied with electricity, as in this neon sign.
Right: The element sodium is a silvery metal so soft that it can be cut with a knife.

Building an atom

All atoms of the same element have the same number of protons, also known as the *atomic number* of that element.

For example, the atomic number of the element neon is 10, so each neon atom has 10 protons in its nucleus. Adding one more proton to a neon atom turns it into a completely different element: sodium, with the atomic number 11. Whereas neon is a colourless, odourless and chemically unreactive gas, sodium is a soft, silvery metal that is extremely reactive. That's the difference a single proton can make!

We can investigate the differences between atoms more closely using a simple simulator.

1. Open the simulator here and select **Atom** in the main menu.
2. Start building an atom by dragging a proton to the spot marked 'X'. The name of the element – hydrogen – will appear above the nucleus.

Question 6

Complete: Continue adding protons until there are six protons in the nucleus and use the information provided at each step to complete the following table. Don't worry about adding neutrons and electrons yet.

Element	Number of protons in nucleus	Atomic number
hydrogen	1	
	2	
lithium		3
	4	4
boron		
	6	

Open the panel marked **Net Charge** on the right hand side. Notice that the carbon atom you've created has an overall charge of +6 because it has six protons and each proton has a charge of +1. Most atoms are electrically neutral – that is, have an overall charge of zero – because the positive charge of their protons is balanced by the negative charge of the same number of electrons.

Question 7

Decide: An atom is electrically neutral when:

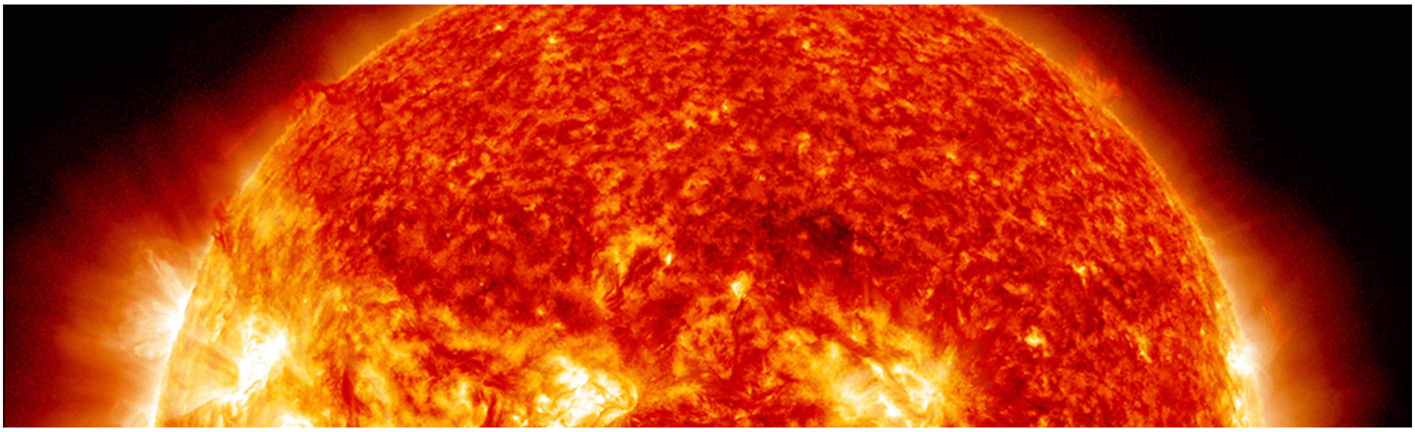
- [ ] the number of protons equals the number of electrons.
- [ ] it has more neutrons than protons.
- [ ] the number of positively charged subatomic particles equals the number of negatively charged subatomic particles.
- [ ] it has no charged subatomic particles.

Question 8

Describe: Gradually add electrons to your carbon atom until its overall charge is neutral. Now add one more electron and describe what happens to the net charge.

Note: We'll add neutrons to your atom in the next section of the lesson.

Process: Atoms



Over 98% of the atoms in the universe – including those in our own Sun – belong to the two lightest elements: hydrogen and helium. Most of the heavier elements are created when large stars "die" in massive supernova explosions.

Mass number

We'll now continue using the simulator (here) to build the same carbon atom from the last section. It has 6 protons and 6 electrons, but there's still one ingredient missing: neutrons! Because neutrons have about the same mass as protons, adding them to the nucleus will make a big difference to the atom's mass. Electrons, in contrast, make very little difference to an atom's mass.

The total number of protons and neutrons in the nucleus of an atom is known as its *mass number*.

1. Open the panel marked **Mass Number** on the right hand side of the simulator. It should read 6 because at this stage your atom has 6 protons and 0 neutrons.
2. Check the box marked **Stable/Unstable** on the lower right and notice that your atom is marked "Unstable".

Question 1

Propose: Suggest a reason why a nucleus with 6 protons and no neutrons would be unstable.

Hint: Remember that all protons are positively charged.

Question 2

Investigate: Start adding neutrons to the nucleus of your atom.

1. What happens to the mass number each time you add a neutron?
2. How many neutrons do you need to add to make a stable carbon atom?

Question 3

Test: Once you've made a stable carbon atom, add one more neutron. Is the nucleus stable or unstable?

- [ ] Stable
- [ ] Unstable

Question 4

Test: What if you add yet another neutron to the nucleus so that the mass number is 14?

- [ ] Stable
- [ ] Unstable

Isotopes

You should have found that your carbon atom was stable when it had a mass number of 12 or 13 but became unstable when its mass number increased to 14. In fact, carbon atoms with all three of these mass numbers exist in nature.

Atoms of the same element with different mass numbers are known as *isotopes*. They are identified by their mass numbers – for example, as carbon-12 or carbon-14. The heavier isotopes of an element are often unstable and break down into simpler atoms.

Carbon dating relies on the unstable nature of the carbon-14 isotope. It can be used to determine the age of organic matter, including a 1,000-year-old Viking (left), a 20,000-year-old charcoal cave painting found in France (centre), and the "Ice Man" discovered in a glacier in the European Alps in 1991 (right), who lived 5,200 years ago.

As well as drawing diagrams, scientists often use a shorthand notation to represent isotopes. Each element has its own symbol – for example, O for oxygen and Li for lithium. By adding the mass number and the atomic number different isotopes can be uniquely identified.

The standard symbol for an isotope of an element consists of the element symbol and two numbers: the mass number and atomic number. This is illustrated by two of the isotopes of carbon (symbol: C).

Question 5

Summarize: Complete the following table to summarize the three main isotopes of oxygen and use the simulator to find out whether they are stable or unstable.

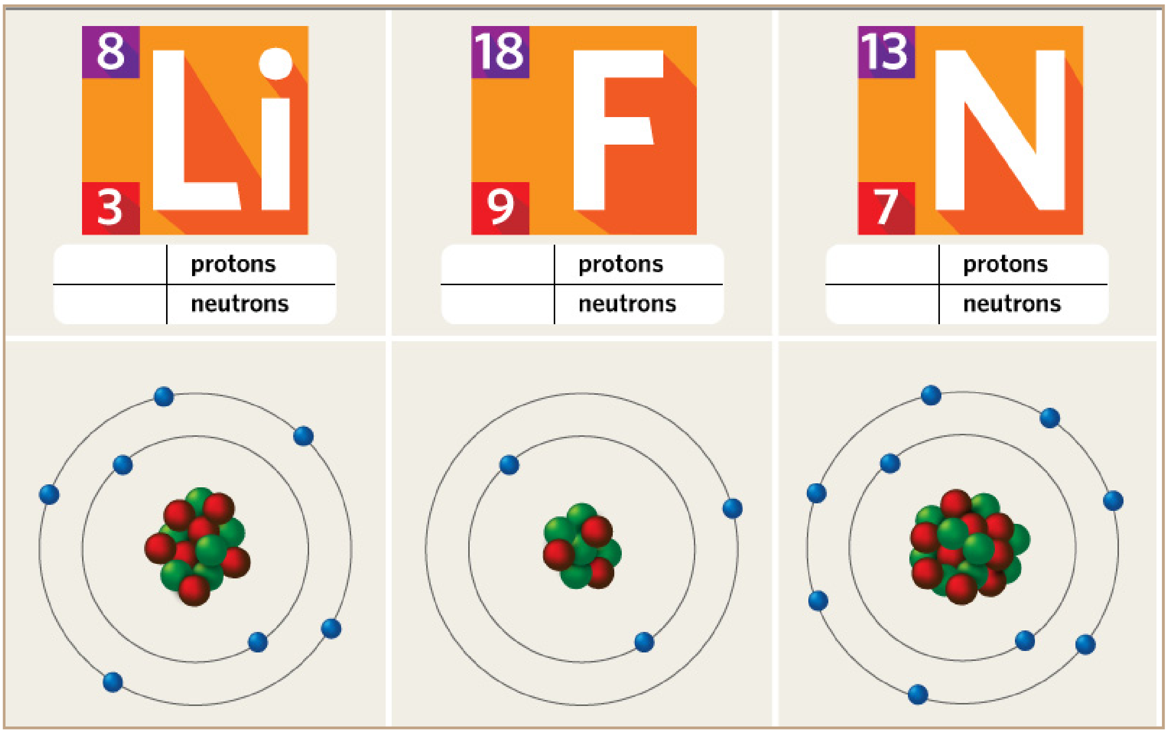
Isotope	Atomic number	Number of protons	Mass number	Number of neutrons	Stable/Unstable
oxygen-16: $^{16}_{8}O$					
oxygen-17: $^{17}_{8}O$					
oxygen-18: $^{18}_{8}O$					

Question 6

Analyze: Describe in your own words how you calculated the number of neutrons in these oxygen isotopes. Then sum up your answer by writing an equation that begins: "number of neutrons = ..."

Question 7

Match: Determine the number of protons and neutrons for each of the isotopes below – lithium-8, fluorine-18 and nitrogen-13 – and then draw lines to match the symbols to their diagrams.



Question 8

Apply: An electrically neutral atom of lithium has an atomic number of 3 and a mass number of 7. The number of protons, neutrons and electrons, respectively, is:

- [ ] 3, 4, 3
- [ ] 4, 4, 3
- [ ] 4, 3, 3
- [ ] 3, 3, 3

Question 9

Infer: If you remove one neutron from an atom of nitrogen then:

Hint: Select more than one answer.

- [ ] it will become a different isotope of nitrogen.
- [ ] its mass number will decrease by one.
- [ ] it will become positively charged.
- [ ] its atomic number will decrease by one.

Two examples of imaging using subatomic particles: the head of a fly, magnified 292 times (left); the inner mechanism of an old-fashioned camera (right).

Imaging

It turns out that electrons and neutrons can be used to create extraordinary images of the objects around us.

Because they have very different properties they create very different types of image. One allows us to see the hidden mechanism inside an object like a camera while the other allows us to see fine details on the surface of an object such as a fly. But which is which?

Question 10

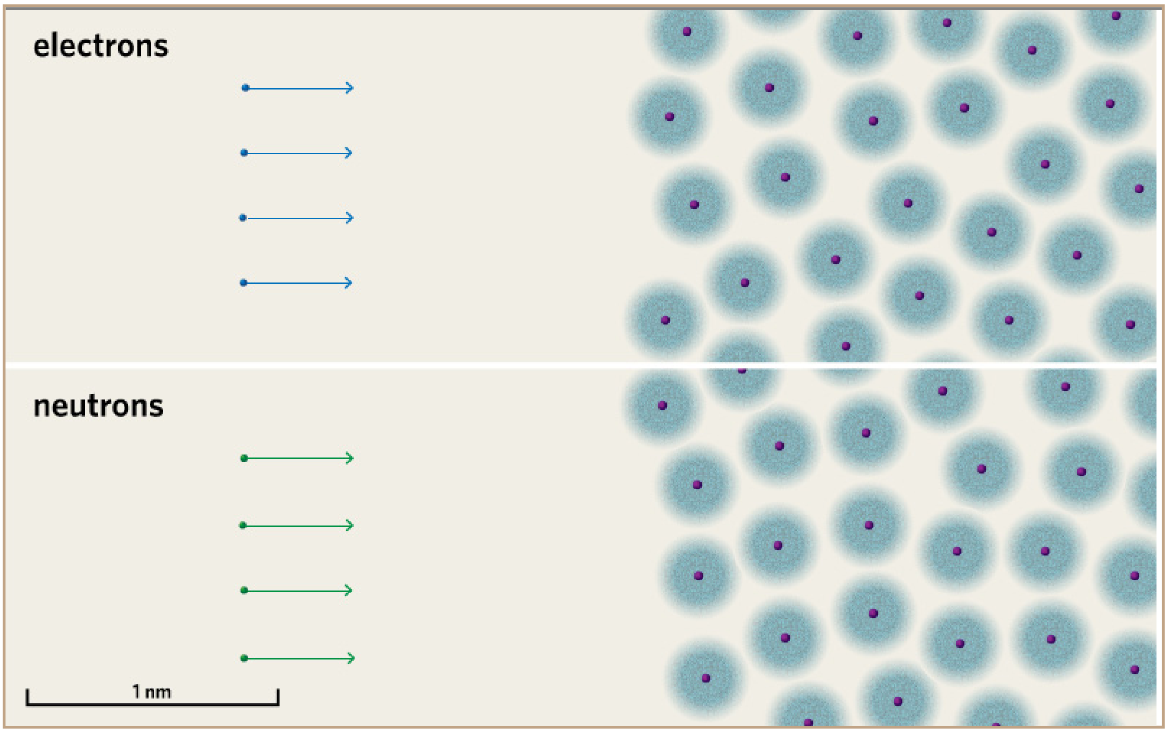
Compare: Use the table to compare the mass and charge of electrons and neutrons. Based on this information, infer which type of particle can penetrate matter to depths of several centimetres (cm) and which can only penetrate to depths of a few nanometres (nm).

Property	*Terms to choose from:*	**Electron**	**Neutron**
Relative mass	heavy | light		
Electrically charged?	yes | no		
Penetration into matter	deep (cm) | shallow (nm)		

Question 11

Draw: When you direct beams of electrons or neutrons at an object they can interact with its atoms in complicated ways, but we'll focus just on simple collisions and electrical repulsion.

In the sketchpad below the atoms at the surface of an object are shown on the right, using the electron cloud model. The small dots represent their nuclei (not to scale). Draw blue arrows to show the likely paths of electrons and green arrows for the neutrons.

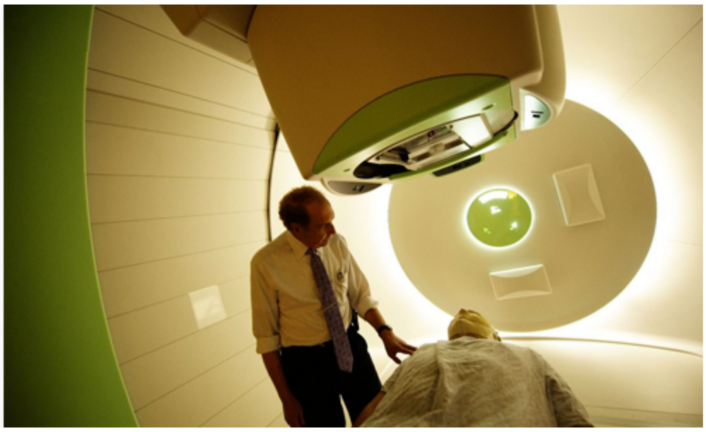


Did you know?

Neutron imaging is used by engineers to test the strength of machines. The slow motion video on the right shows a chainsaw engine as its piston pumps up and down 8000 times per minute. And because neutrons interact with the nucleus of an atom rather than its electron cloud they are also used to identify the different isotopes of elements in a sample.

Electrons are used in the most powerful microscopes we have. For example, scanning electron microscopes produce beautifully detailed images with magnifications of up to 500,000 times! The hydrothermal worm pictured below is a deep sea creature not much bigger than a bacterium and has been magnified a mere 525 times.

Protons have both charge and relatively high mass so are usually too destructive to be used for imaging – but this makes them very useful for destroying cancer cells. Proton therapy is now becoming the preferred way of treating a wide variety of cancers.



Question 12

Super-sight!

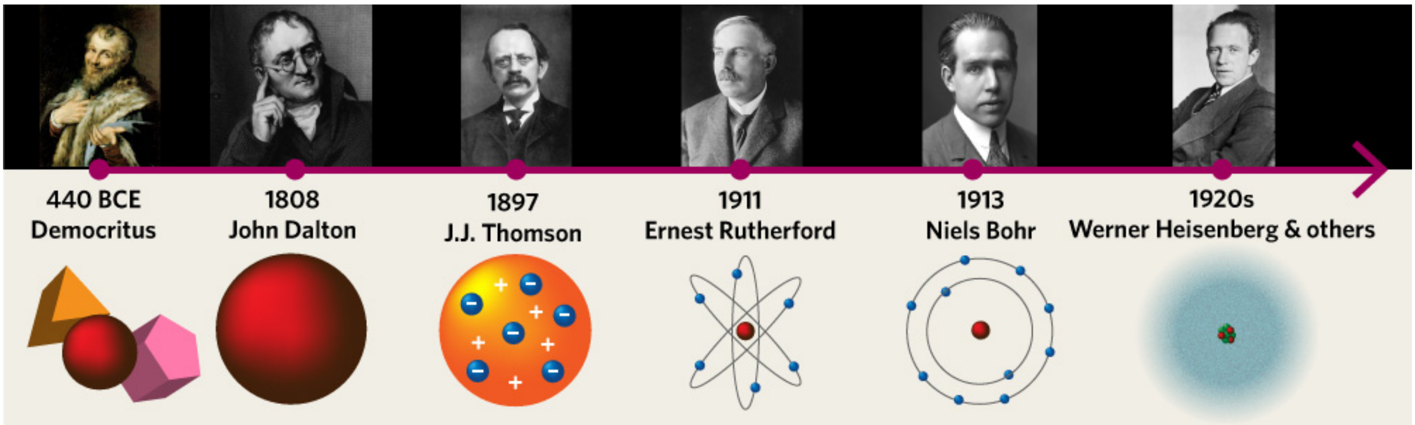
Imagine: You're walking home from school one day past the old nuclear research laboratory when a tremendous storm breaks out. Pounding rain, a flash of lightning, and flash – you're blown off your feet in a shower of subatomic particles! When you wake up in the hospital you're groggy, but slowly realize over the following days that you've developed superhero powers: neutron-vision that allows you to see inside solid objects and electron-vision that allows you to zoom in on the tiniest surface details.

How do you use your new powers – for good or evil? Write a short story to describe what happens next.

Apply: Atoms

COSMOS LESSONS

Modelling atoms



You've already seen two different ways of representing the structure of atoms – the planetary model and the electron cloud model. As the above diagram shows, these are just two of the models of atoms that scientists have developed over time.

One reason that models change is that new evidence becomes available. Sometimes a new technology or experiment shows that the current model is inaccurate and needs to be replaced. Scientists spend a great deal of time building, testing and revising models to improve their understanding of nature and this is why progress is usually slow and difficult.

Question 1

Write: Imagine that you're either J. J. Thomson or Ernest Rutherford and that you've just come up with your new model.

Draw two diagrams on a plain sheet of paper:

- one of the model that yours is designed to replace, and
- one of your own model.

Label both diagrams and upload photos of your drawings into the project space.

Write a 1-2 page personal diary entry about your theory and the impact you imagine it will have. Make sure your response addresses the following questions:

- How is your model similar to and yet different from the previous one?
- What new evidence does your model help to explain?
- How do you think other scientists will respond to it? How *should* they respond?

Career: Atoms

Brought to you by Edith Cowan University

Growing up in Bacau, a vibrant town in northeastern Romania, Dr Genoveva Burca's bedroom was cluttered with more scientific instruments and rock samples than dolls. It almost looked like a little laboratory, she says. When her dad gave her a kaleidoscope for her fifth birthday she became captivated with the beauty of light and the way it shapes our lives. She still has that kaleidoscope today.

Genoveva's fascination with light drew her to mathematics as well – maths is needed to study the way light interacts with different materials. She gradually realized how powerful numbers are. They are abstract yet real, and we can hardly imagine our lives without them. For Genoveva, maths and physics are the two keys to understanding the mystery of existence so she decided to study them at university.

During her PhD studies in the UK, Genoveva was on the team that began developing the first neutron imaging instrument in the world. After graduating, she stayed in the UK to continue working on the same project at the Rutherford Appleton Laboratory, where she still works as an instrument scientist.

All of Genoveva's work investigates the atomic and subatomic structures of materials. Her responsibilities include setting up experiments, analyzing data and carrying out research. She says she loves trying to make visible what is usually invisible. And because neutron imaging doesn't damage objects it can also be used to authenticate paintings or study the valuable artefacts collected by archaeologists.

When she isn't trying to unlock the mysteries of the world, Genoveva enjoys travelling, classical music and cooking. She also loves reading – particularly about the history of science and the lives of women scientists.

Question 1

Investigate: Genoveva mentions some of the fascinating applications of neutron imaging, and you've seen how it can also be used to look inside machines such as engines. If you were a nuclear scientist with access to this technology what would *you* use it to study? Look up the two nuclear research centres that are closest to where you live and write down their names and locations. Which of them would you rather work at, and why?

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