

# MYP Physics

A concept-based approach

Years

**4&5**

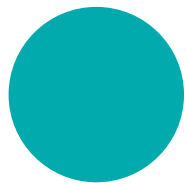
William Heathcote

OXFORD



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# Introduction

The MYP Physics course, like all MYP Sciences, is inquiry based. To promote conceptual understanding, the MYP uses key concepts and related concepts. Key concepts represent big ideas that are relevant across disciplines. The key concepts used in MYP Sciences are change, relationships and systems. Related concepts are more specific to each subject and help to promote more detailed exploration. Each chapter is focused on one of the twelve related concepts and one key concept.

Each chapter opens with ways in which the related concept is explored in other disciplines. This structure will help to develop interdisciplinary understanding of the concepts. After the interdisciplinary opening pages, the concepts are introduced more deeply in relation to the specific content of the chapter.

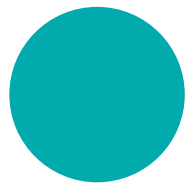
The objectives of MYP Science are categorized into four criteria, which contain descriptions of specific targets that are accomplished as a result of studying MYP Science:

- A. Knowing and understanding
- B. Inquiring and designing
- C. Processing and evaluating
- D. Reflecting on the impacts of science

Within each chapter, we have included activities designed to promote achievement of these objectives, such as experiments and data-based questions. We also included factual, conceptual and debatable questions, and activities designed to promote development of approaches to learning skills. The summative assessment found at the end of each chapter is framed by a statement of inquiry relating the concepts addressed to one of the six global contexts, and so is structured similarly to the MYP eAssessment.

For those students taking the eAssessment at the end of the MYP programme, the International Baccalaureate Organization provides a subject-specific topic list. Great care has been taken to ensure all of topics from the list are covered within this book.

Overall, this book is meant to guide a student's exploration of Physics and aid development specific skills that are essential for academic success and getting the most out of this educational experience.



# How to use this book

To help you get the most of your book, here's an overview of its features.

## Concepts, global context and statement of inquiry

The key and related concepts, the global context and the statement of inquiry used in each chapter are clearly listed on the introduction page.

## Activities

A range of activities that encourage you to think further about the topics you studied, research these topics and build connections between physics and other disciplines.

## Worked examples

Worked examples take a step-by-step approach to help you translate theory into practice.



## Experiments

Practical activities that help you prepare for assessment criteria B & C.

## Data-based questions

These questions allow you to test your factual understanding of physics, as well as study and analyse data. Data-based questions help you prepare for assessment criteria A, B & C.

## ATL Skills

These approaches to learning sections introduce new skills or give you the opportunity to reflect on skills you might already have. They are mapped to the MYP skills clusters and are aimed at supporting you become an independent learner.

1 A conceptual question

2 A debatable question

## Summative assessment

There is a summative assessment at the end of each chapter; this is structured in the same way as the eAssessment and covers all four MYP assessment criteria.

## Glossary

The glossary contains definitions for all the subject-specific terms emboldened in the index.

# Mapping grid

The MYP eAssessment subject list for Physics consists of six broad topics:

Forces and energy

Electromagnetism

Astrophysics

Heat, light and sound

Waves

Atomic physics

These topics are further broken down into sub-topics and the mapping grid below gives you an overview of where these are covered within this book. It also shows you which key concept, global context and statement of inquiry guide the learning in each chapter.

Chapter	Topics covered	Key concept	Global context	Statement of inquiry	ATL skills
1 Models	Atomic structure, particles, charges and masses Longitudinal and transverse waves Wave equation	Relationships	Scientific and technical innovation	A good model can simplify and illuminate our understanding of complex phenomena.	<b>Communication skills:</b> Understanding and using standard form <b>Affective skills:</b> Practicing resilience
2 Interaction	Gravity and gravitational fields Electric fields Static electricity	Relationships	Identities and relationships	The way in which the universe changes is governed by fundamental interactions of matter.	<b>Thinking in context:</b> How does weight shape our identity?
3 Evidence	Measurement in science The Big Bang theory	Relationships	Identities and relationships	Experiments and measurements provide evidence to support or disprove scientific claims.	<b>Communication skills:</b> Presenting data in a graph <b>Communication skills:</b> Using and interpreting a range of discipline-specific terms and symbols <b>Transfer skills:</b> What constitutes evidence?
4 Movement	Speed, motion graphs Magnetism, magnetic fields	Change	Orientation in space and time	Movement enables humans and animals to change their surroundings for the better.	<b>Thinking in context:</b> How can magnetism help us to navigate?
5 Environment	States and properties of matter, kinetic theory Condensation and evaporation Density	Systems	Globalization and sustainability	Changes in our environment require all living things to adapt in order to survive.	<b>Thinking in context:</b> Why is rain important?
6 Function	Forces and effects of forces Forces and motion, newton's laws Current, voltage, power Electric circuits	Systems	Fairness and development	The development of machines and systems has changed the way in which human beings function.	<b>Communication skills:</b> Using subject-specific terminology <b>Thinking in context:</b> What happens to the Earth when you jump up in the air? <b>Creative thinking skills:</b> Proposing metaphors and analogies <b>Thinking in context:</b> How can we use electricity to drive machines?

Chapter	Topics covered	Key concept	Global context	Statement of inquiry	ATL skills
7 Form	The solar system Planets and satellites	Systems	Identities and relationships	Determining the form of objects can help us to understand how they behave.	<b>Communication skills:</b> Understanding and using units <b>Thinking in context:</b> How have our identities been shaped by the stars? <b>Thinking in context:</b> What happens when science challenges our identity? <b>Collaboration skills:</b> Encouraging others to contribute
8 Consequences	Electric and magnetic fields Electromagnetic forces and induction AC & DC Generation and transmission of electricity Sound waves	Change	Personal and cultural expression	The consequences of actions are predicted by the laws of physics.	<b>Thinking in context:</b> What are the consequences of personal expression
9 Development	Measurement in science Wave phenomena including reflection, refraction, diffraction	Systems	Fairness and development	The development of science and technology gives us the possibility of changing the world for the better.	<b>Critical thinking skills:</b> Considering ideas from multiple perspectives <b>Information literacy skills:</b> Publishing a scientific paper <b>Communication skills:</b> Plotting graphs
10 Transformation	Pressure Thermal physics Heat transfer	Change	Scientific and technical innovation	Scientific innovation can transform our human existence.	<b>Communication skills:</b> Organising and depicting information logically <b>Critical thinking skills:</b> Formulating counterarguments
11 Energy	Work and power, efficiency Transfer and transformation of energy, conservation of energy Energy sources and resources, fuels and environmental impact	Change	Globalization and sustainability	The need for sustainability is changing the way in which we produce and use energy.	<b>Communication skills:</b> Interpreting discipline-specific terms <b>Media literacy skills:</b> Seeking a range of perspectives from multiple sources
12 Patterns	Electromagnetic spectrum, imaging and applications Radioactivity and decay, forms of radiation, uses and dangers	Relationships	Identities and relationships	Patterns can demonstrate relationships between events and shed light on how they are caused.	<b>Information literacy skills:</b> Using mnemonics to remember sequences <b>Thinking in context:</b> Color and identity <b>Collaboration skills:</b> Building consensus <b>Media literacy:</b> Demonstrating awareness of media interpretations of events <b>Reflection skills:</b> Considering ethical implications

# 1 Models

Models are simplified representations of more complex systems.



- ◀ Modeling the many different processes in the economy is complicated. Economists use models to help predict the consequences of changes in government policy, foreign trade and domestic expenditure. In this machine, developed by Bill Phillips in 1949, water flows between different tanks representing financial transactions. Changing factors such as taxes, interest rates or the amount of government lending, are modeled by opening and closing different valves. The amount of water held in different tanks represents the amount held in banks or by the government. Are there any other processes which can be modeled with water?

- ▶ Understanding the development of the brains of babies is complicated by the fact that they cannot tell you what they are thinking. Developmental psychologists use models to simplify infants' development into stages. The baby's brain also uses progressively improved models to understand the world around it. This baby's brain is just learning about object permanence – the idea that hidden objects still exist. What would this baby think about a game of hide and seek?





- ▲ Astronomers use models to explain how the solar system might have formed. One such model is the solar nebular model which depicts how planets were formed from the same collapsing gas cloud that formed the Sun. It successfully explains why the planets all orbit in the same direction and in nearly circular orbits. If the solar nebular model suggests that the process which forms stars also forms planets, what does that say about the likelihood of finding life on another planet?

“

**All models are wrong but some are useful.**

**George Box**

”



- ▲ Chemists use models to build up visual pictures of complicated molecules. This model shows a part of DNA. If a full DNA chain were modeled, how big might it end up being?



**Key concept:** Relationships

**Related concept:** Models

**Global context:** Scientific and technical innovation

## Introduction

The human brain is highly sophisticated but we struggle to envisage the sheer size of the universe. We find it difficult to conceive the vast distances of space in our heads without using scale models to help us to visualize them.

One of the greatest skills of the human brain is that of intuition. Through experience and perception, we build up patterns and we learn what to expect. If we see something balanced precariously, then we know that it is likely to fall over without having to calculate the forces on it.

- ▼ Our intuition tells us that the tightrope walker is unstable without us having to calculate the forces involved

### Statement of inquiry:

A good model can simplify and illuminate our understanding of complex phenomena.

We can employ our intuition to help with complicated physics by using models. A good model can take something that we do not understand, simplify it and liken it to a more familiar concept. It can enable us to make predictions about how something will behave, which we can then test. A good model may make predictions which agree with experimental results, or it might highlight shortcomings in our understanding.

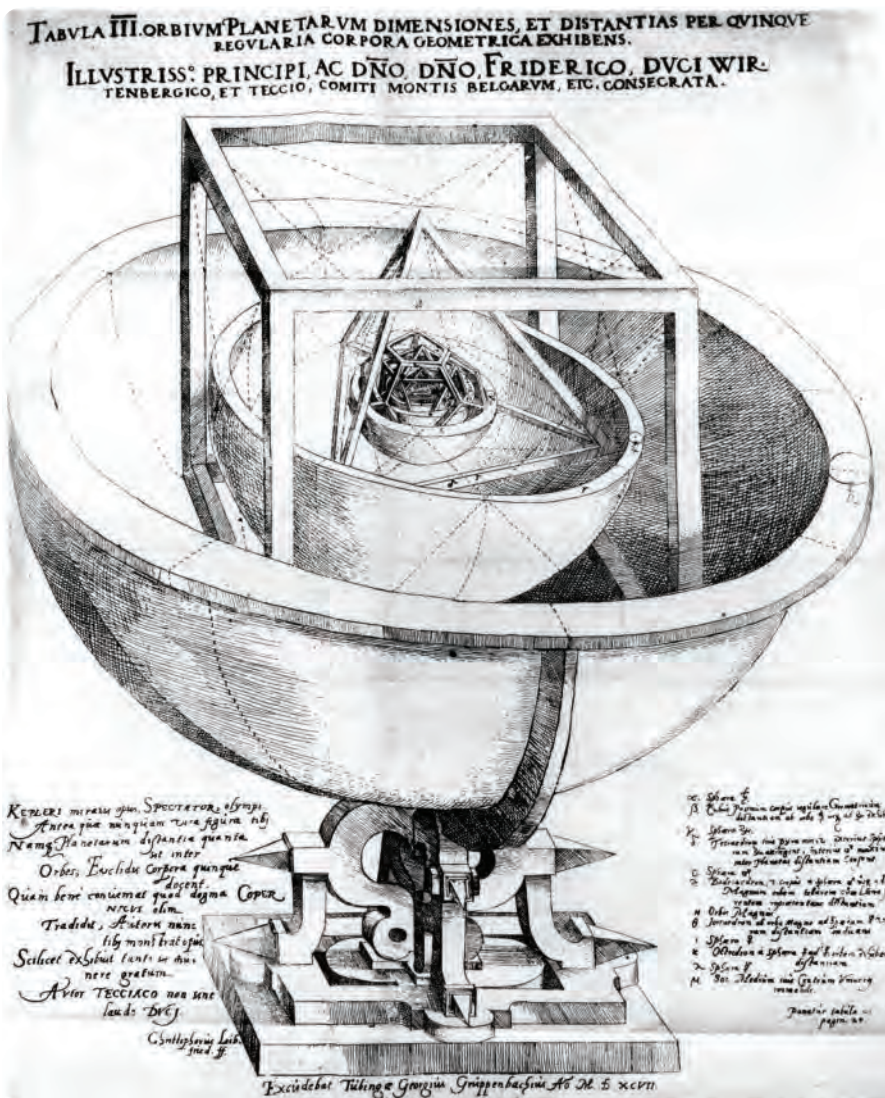
This chapter investigates how models of atoms and waves can simplify our understanding of what matter in the universe is made from and how it interacts. The key concept of this chapter is relationships.

Knowledge of the fundamental nature of matter fueled a technological revolution in the 20th century and today many scientific innovations arise from our better understanding of the nature of matter and its interactions and so the global context of this chapter is scientific and technical innovation.



▲ The way air flows around the wing of an airplane is a complex system. Testing a model wing in a wind tunnel can help engineers to understand how well the wing is working

◀ Early models of the solar system allowed astronomers to predict and explain how the planets move in the sky. In this model, Kepler (1571–1630) attempted to explain the size of the gaps between the orbits of the six planets known at the time using the five regular polyhedra (cube, tetrahedron, dodecahedron, icosahedron and octahedron). Kepler abandoned this model because it was not sufficiently precise to match his measurements. Since there are only five regular polyhedra, this model explained why there were only six planets. What would have happened to this model after the discovery of Uranus in 1781?



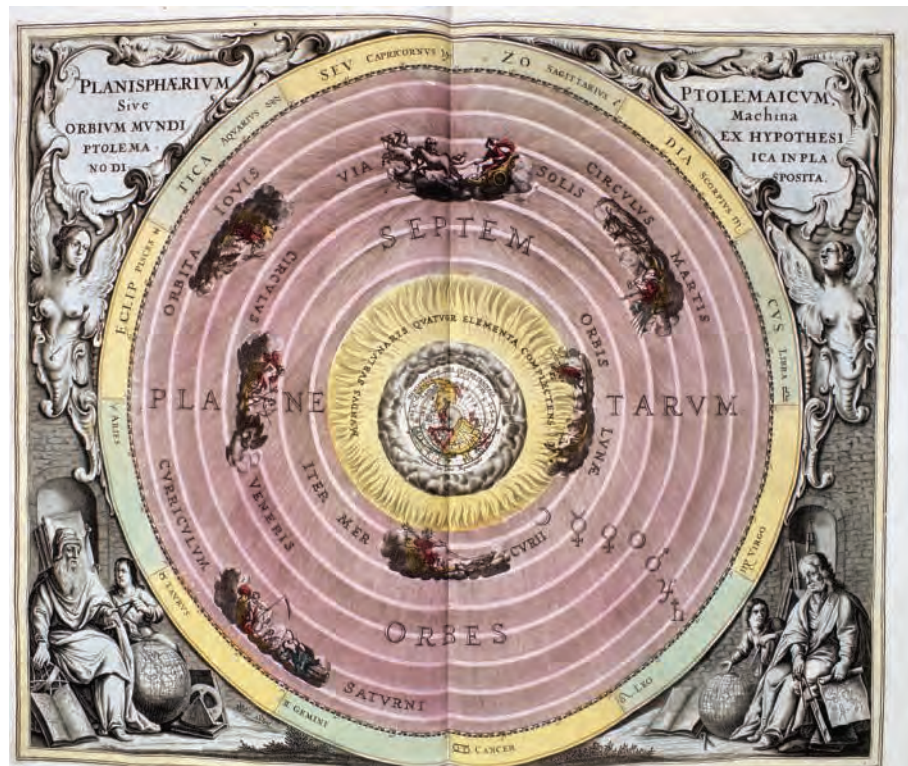
## What is an atom?

In one of his famous physics lectures in the 1960s, the Nobel Prize-winning physicist Richard Feynman considered a conundrum: if there were to be some cataclysmic event and all scientific knowledge were to be destroyed, what single sentence would contain the most information? His sentence described atomic theory: “That all things are made of atoms”.

The ancient Greeks first developed the idea of atomic theory and thought of atoms as being the smallest building blocks of matter. They considered the idea of taking an amount of a substance, such as water, and dividing it into smaller portions. They knew that when a cup of water was poured into two smaller cups, the two smaller portions of water would have the same properties as the initial cup – it would still be the same substance. However, they thought that there would be a limit to how many times you could go on dividing the water. Eventually, they concluded, you would have the smallest amount of water possible that could not be divided any further while still having the properties of water.

They called this smallest amount an atom. The word atom itself derives from the Greek meaning “indivisible”. We still use the word atom and their ideas of atoms today, however, the ancient Greeks did not know what types of atoms there could be – they thought that all matter was made from air, earth, fire and water.

- This 1660 model of the solar system shows the Earth in the center and the planets orbiting around it. Surrounding the Earth are what were thought to be the other three elements at the time: water, air and fire. What other models feature in this picture?





In the late 18th century, chemists studied the quantities of matter used in chemical reactions and realized that the relative amounts of matter involved were always in fixed ratios. This led to them drawing the conclusion that the fixed ratio of chemicals was due to the fact that the chemicals came in discrete quantities – atoms. Chemists were then able to classify substances as being either a compound, involving two or more different types of atom, or an element, matter which only had one type of atom. At the time they knew of only about 30 different elements, but over the next century, they discovered around another 50.

Chemists put the elements into an arrangement that they called the periodic table. This is a useful model: the position of an element in the table is related to its chemical properties. This means that you can predict how an element might behave in chemical reactions from where it appears in the periodic table. In the 19th century, gaps in the table were used to predict the existence of more elements: this led to the discovery of germanium and gallium.

Elements			K = 39	Rb = 85	Cs = 133	-	-
			Ca = 40	Sr = 87	Ba = 137	-	-
			-	?Yt = 88?	?Di = 138?	Er = 178?	-
			Ti = 48?	Zr = 90	Co = 140?	?La = 180?	Tb = 231
			V = 51	Nb = 94	-	Ta = 182	-
			Cr = 52	Mo = 96	-	W = 184	U = 240
			Mn = 55	-	-	-	-
			Fe = 56	Ru = 104	-	Os = 195?	-
			Co = 59	Rh = 104	-	Ir = 197	-
			Ni = 59	Pd = 106	-	Pt = 198?	-
			Cu = 63	Ag = 108	-	Au = 199?	-
			Zn = 65	Cd = 112	-	Hg = 200	-
			-	In = 113	-	Tl = 204	-
			-	Sn = 118	-	Pb = 207	-
			As = 75	Sb = 122	-	Bi = 208	-
			Se = 78	Te = 125?	-	-	-
			Br = 80	J = 127	-	-	-

Position of germanium and gallium

▲ Mendeleev's original periodic table enabled chemists to predict the existence of missing elements

Up to this time, the atom was considered to be a fundamental particle, that is it could not be split into anything smaller. However, the discovery of the electron in the late 19th century showed that this did not seem to be the case. Scientists later determined that the electron was part of the atom and was much smaller and lighter than an atom. This meant that an atom was not the smallest unit of matter possible.

## What is an electron?

An electron is a tiny particle, in fact it is so small that it behaves as if it were a point with no size. Scientists believe that it is a fundamental particle, that is, it is not made up of any smaller particles.

An electron's mass is also tiny:  $9.1 \times 10^{-31}$  kg. This is much smaller than the masses of the other particles in an atom, and so the mass of the electrons makes up a tiny proportion of the total mass of the atom. In fact, the mass of the electrons in an atom contributes less than one tenth of a percent (0.1%) to the total mass of an atom.

An electron also has a charge. Charge is a fundamental property of matter, just as mass is (this is discussed in more detail in Chapter 2, Interaction). Charge is the property which is responsible for electrostatic forces and electricity. The charge of an electron is negative and is  $-1.6 \times 10^{-19}$  C. The unit of charge is the coulomb which has the symbol C.

### ATL Communication skills

#### Understanding and using standard form

People regularly have to communicate large or small numbers and our language has words such as million or thousandth that help us to do this. The International System of Units, referred to as the SI system, also has prefixes which help communicate large or small units. For example, a kilometer is one thousand meters and a microgram is a millionth of a gram.

Some other prefixes used with SI units are shown below.

exa	E	$\times 10^{18}$	milli	m	$\times 10^{-3}$
peta	P	$\times 10^{15}$	micro	$\mu$	$\times 10^{-6}$
tera	T	$\times 10^{12}$	nano	n	$\times 10^{-9}$
giga	G	$\times 10^9$	pico	p	$\times 10^{-12}$
mega	M	$\times 10^6$	femto	f	$\times 10^{-15}$
kilo	k	$\times 10^3$	atto	a	$\times 10^{-18}$

Scientists often need to express numbers which are beyond this scale. The mass of an electron is 0.91 thousandths of a yoctogram (the prefix yocto means  $10^{-24}$  and is so small that it is rarely used) and so you would need about one million million million million million electrons to make a kilogram. Neither of these numbers is easy to communicate. Standard form makes it easier to represent large or small numbers. In standard form, we would write that the mass of an electron is  $9.1 \times 10^{-31}$  kg and so you would need just over  $1 \times 10^{30}$  electrons to make a kilogram.

1. Express these numbers in standard form:

- The probability of shuffling a pack of cards and finding that they had ended up in sequential order is one in eighty million million million million million million million million million million.
- The number of insects on the Earth is estimated to be ten million million million.
- The number of protons in the universe is thought to be about one hundred million million million million million million million million million million.

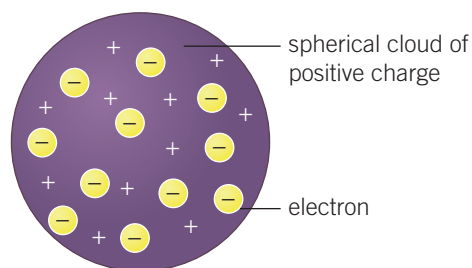


Because electrons are fundamental particles and cannot be divided into smaller parts with smaller charges, a charged object has a total charge that is a multiple of  $1.6 \times 10^{-19}$  C as it will have gained or lost a whole number of electrons. Scientists call this the elementary charge and label it  $e$ . An electron has a charge of  $-e$  and an object that has gained two electrons would gain a charge of  $-2e$ . On the other hand, a previously uncharged object which loses an electron would be left with a charge of  $+e$ .

## What else is inside an atom?

The discovery of the electron prompted scientists to rethink their ideas about the atom. If an atom had electrons which were negatively charged but the atom as a whole appeared to have no charge, then there must be a positive charge somewhere in the atom.

At first they thought that perhaps the electrons were dotted around inside the atom in a sea of positive charge. Because this resembled the fruit in a popular pudding of the time, this model was called the plum pudding model.



### ATOMS

- ◀ The plum pudding model enabled scientists to explain the idea of electrons in an atom. However, it could not explain the results of Rutherford's scattering experiment

Ernest Rutherford was a physicist working in the early 20th century. He proposed an experiment where particles were fired at a thin sheet of gold. The experiment was carried out by Hans Geiger and Ernest Marsden. The particles fired at the gold were called alpha particles; these are positively charged and although they are about 50 times lighter than an atom of gold, they are more than 7,000 times heavier than the electrons in the atoms of gold. Since the alpha particles were heavier than anything known to be inside the gold atoms and traveling at a significant speed, Rutherford expected all of them to pass straight through.

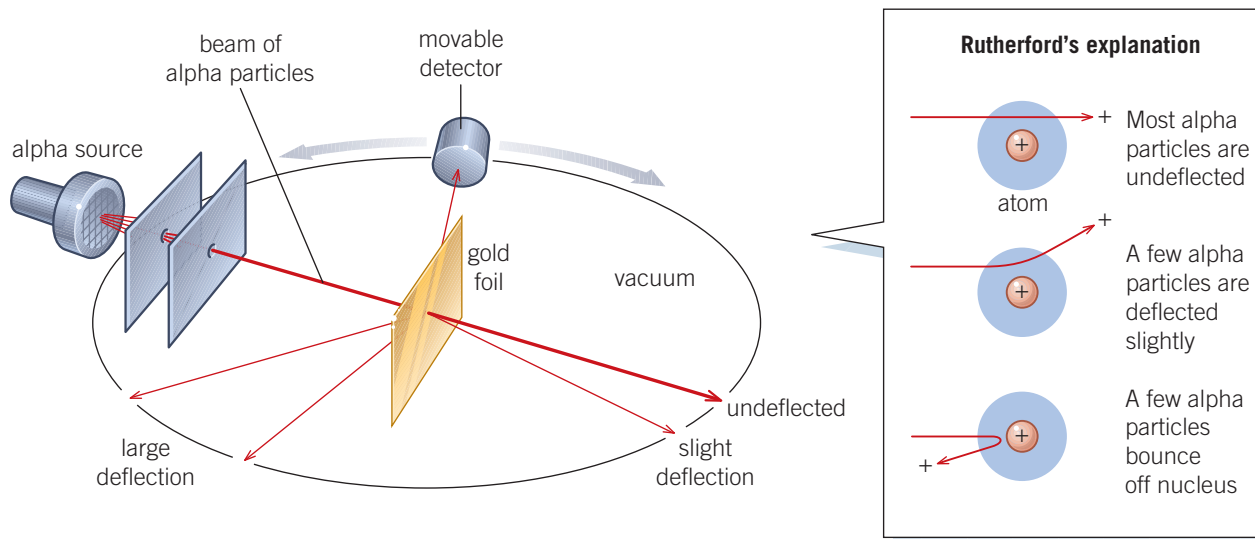
Indeed, the vast majority of them did, but Rutherford was hugely surprised at Geiger and Marsden's finding that a very small number of alpha particles bounced back, since the plum pudding model of the atom did not have any particle heavy enough to deflect the alpha particles. He deduced that the alpha particles must be bouncing off something much heavier than themselves. He also deduced that whatever the alpha particles were deflecting off must be small, since very few particles were deflected.

### Modeling the Geiger–Marsden experiment

For this activity you will need some lightweight balls such as table tennis balls, a blindfold and a football suspended from the ceiling. (You could put the football on a table if this is easier.)

From a couple of meters away, while wearing the blindfold, throw the table tennis balls towards the football. (You could have several people throwing table tennis balls at the same time.)

1. How many of them hit the football? What happens?
2. What would happen if you threw table tennis balls at a smaller object?
3. If you threw tennis balls at a balloon, how many would bounce back?
4. In the Geiger–Marsden experiment, some alpha particles bounced back but very few (about one in a million). Using your model, what does this suggest about the target that the alpha particles deflected off?



▲ The Geiger–Marsden experiment observed a small number of alpha particles were deflected through a large angle

Rutherford had discovered the nucleus of an atom. The nucleus is positively charged and contains almost all of the mass of an atom, but is also very small. If an atom were blown up to be the size of the Earth, then the nucleus would still only be about 100 meters in diameter. In later experiments, Rutherford showed that the nucleus contained positively charged particles called protons.

### Making a model atom

A gold atom has a diameter of about  $3.32 \times 10^{-10}$  m. The nucleus inside the atom is only about  $1.46 \times 10^{-14}$  m across.

Make a scale model of a gold atom. Find a field or a large room to represent the size of the atom and work out what size the nucleus should be on this scale.



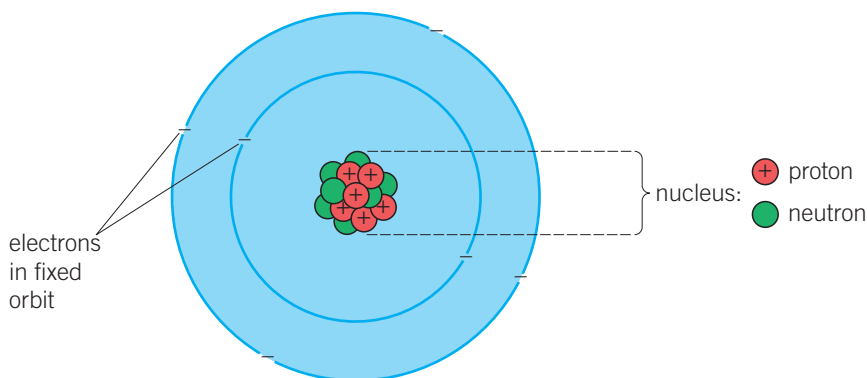
The discovery of isotopes – atoms with nearly identical chemical properties but different atomic masses – suggested that nuclei could vary not only in the number of protons but also in some other way. Since a variation in the number of protons would result in a different element altogether, Rutherford suggested that there was another particle in the nucleus with no overall charge. The discovery of the neutron in 1932 confirmed that the nucleus of an atom is composed of two different particles: protons and neutrons.

Protons and neutrons both have a similar mass: the mass of a proton is  $1.673 \times 10^{-27}$  kg and a neutron has a mass of  $1.675 \times 10^{-27}$  kg. These masses are much bigger than the mass of an electron (by about 1,830 times). Often relative masses are used where the mass of a proton or neutron is just counted as one.

Protons have a positive charge of  $+e$ , in other words they have the same sized charge as an electron, but are positive rather than negative. Neutrons have no charge.

	Electron	Proton	Neutron
Charge (relative units)	-1	+1	0
Mass (relative units)	0.00055	1	1

Rutherford's model of the atom consisted of protons and neutrons in a nucleus at the center of the atom with the electrons orbiting around the nucleus.



◀ In Rutherford's model of the atom, the nucleus consists of protons and neutrons, and the electrons are in fixed orbits around the nucleus. The overall atom has no charge, since there are the same number of electrons as protons

- 1 Why do you think that the electron was the easiest of these three particles to discover?
- 2 Why do you think the neutron might have been the hardest of these particles to discover?
3. Any given atom will have the same number of electrons as protons. For light elements it is likely to have the same number of neutrons as protons. For example, an atom of nitrogen taken from the air has seven protons and seven neutrons in its nucleus, and there are seven electrons which orbit around the nucleus. What proportion of the particles in the atom are electrons? What fraction of the mass is in the electrons?



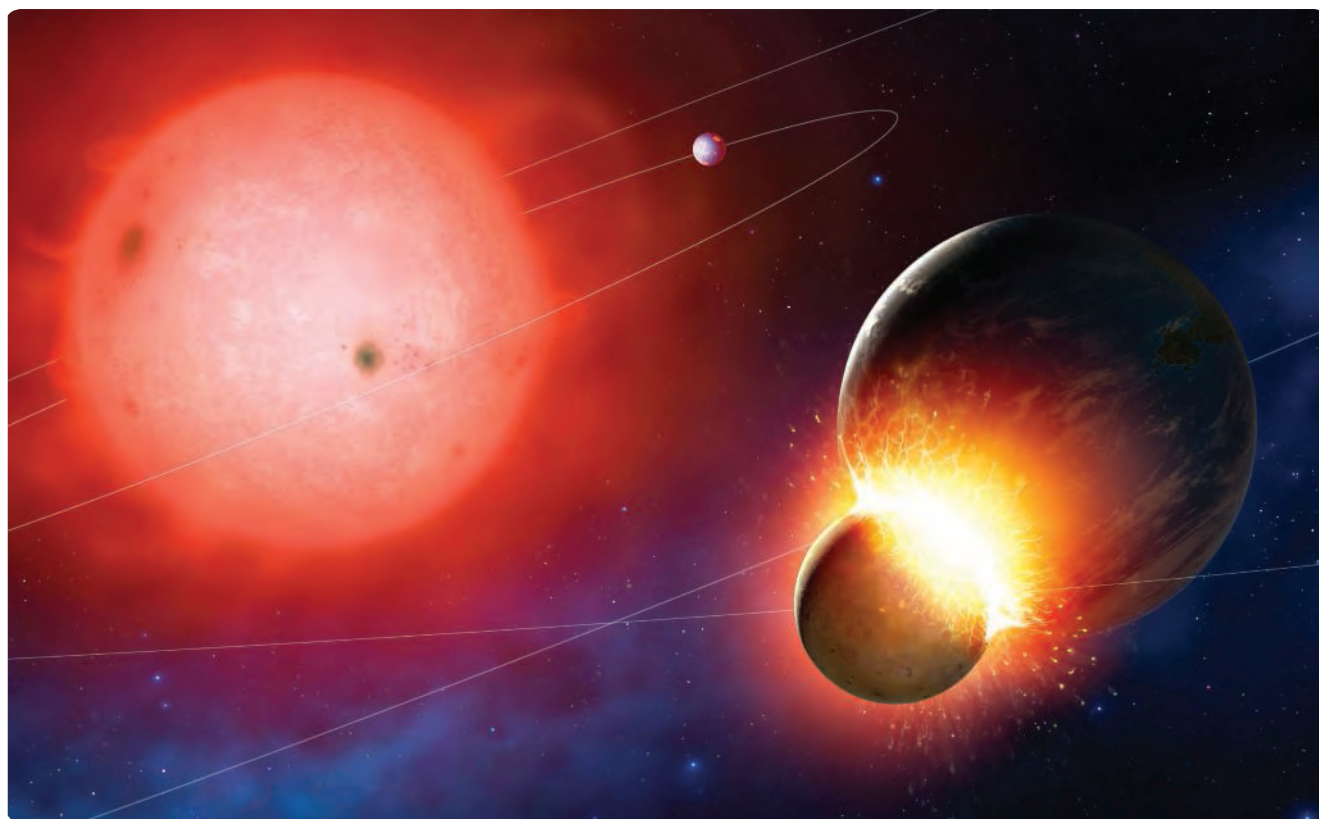
## What are isotopes?

The nucleus of the atom contains essentially all the mass of an atom, but it is about a hundred thousand times smaller than the whole atom. It is the electrons orbiting the nucleus which determine the size of the atom, and how it interacts with other atoms if they collide. This means that the electrons determine the chemical properties of an element. In fact almost all of what is studied in chemistry can be explained by the interaction of the electrons on the outside of atoms.

Atoms have an overall neutral charge, so an atom must have the same number of protons and electrons. An atom with more protons in its nucleus has more electrons, and these electrons experience a greater attractive force holding them around the nucleus. The electrons repel each other (see Chapter 2, Interaction, for why this is so) and some end up closer to the nucleus and some further away. This positioning of the electrons, their configuration, affects how atoms interact with each other. To summarize, atoms with different numbers of protons in their nucleus have different electron configurations, therefore they have different chemical properties.

The number of neutrons does not affect the number of electrons required to maintain a neutral charge, nor does it affect how the electrons interact with the nucleus. As a result, additional neutrons do not affect the configuration of the electrons and so there is no change to the chemical properties of the atom. The only difference is that the atom has a different mass on account of the additional neutrons.

- ▼ Analysis of rock from the Moon that was gathered during the Apollo missions shows that they have an almost identical mixture of the oxygen isotopes  $^{16}\text{O}$ ,  $^{17}\text{O}$  and  $^{18}\text{O}$  to rocks on Earth. Since rocks from elsewhere in the solar system, such as asteroids, have different mixtures of these isotopes, this evidence points to the Moon and the Earth having a common origin. Astronomers believe that the Earth suffered a huge collision which blasted material into space and later formed the Moon. This model of the Moon's formation is called the giant impact hypothesis





Atoms of the same element, that is, with the same number of protons in the nucleus, but with differing numbers of neutrons are called isotopes. As a result of having the same number of protons, they have the same number of electrons and therefore the same chemical properties. The different number of neutrons gives them a different mass but does not affect the chemical properties.

1. The table below shows the numbers of particles in some different atoms.

Atom	Number of electrons	Number of protons	Number of neutrons
A	1	1	0
B	3	3	3
C	6	6	6
D	6	6	8
E	6	7	6

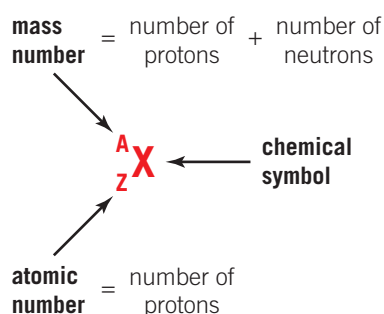
- Which two atoms are isotopes of each other?
- Which atom is charged (is an ion)?
- Which of these atoms is the most common in the universe?
- Which atom has the greatest mass?

## What is atomic notation?

Elements are classified according to their chemical properties. As we have seen, these properties are governed by the configuration and number of the electrons which in turn are determined by the number of protons in the nucleus. The number of protons in the nucleus is called the atomic number.

The number of protons and neutrons in a nucleus determines the mass of an atom (since the electrons barely contribute to the mass). The total number of protons and neutrons is called the mass number.

A useful shorthand for describing the constituents of an atom is to use atomic notation. In atomic notation, the element is abbreviated to its chemical symbol and the atomic number and mass number are given in the format  ${}^A_ZX$ .



### ATOMS

#### ◀ Atomic notation

For example, the oxygen in the air has eight protons in its atomic nuclei.

- Most of these oxygen atoms will also have eight neutrons. This gives the oxygen an atomic number of 8 and a mass number of 16. We would write this in atomic notation as  $^{16}_8\text{O}$ .
  - A very few atoms of oxygen (one in 2,700) have an extra neutron; these atoms are written as  $^{17}_8\text{O}$ . This is an isotope of oxygen since it still has eight protons and hence the eight electrons which give oxygen its chemical properties, but the number of protons (8) plus the number of neutrons (9) is now 17.
  - About one in 500 oxygen atoms have ten neutrons; this isotope is written as  $^{18}_8\text{O}$ .
1. Here are some atoms written in atomic notation:  $^{14}_7\text{N}$ ,  $^{14}_8\text{O}$ ,  $^{13}_6\text{C}$ ,  $^{14}_6\text{C}$ .
    - a) Which atom has more protons than neutrons?
    - b) Which atom has the most neutrons?
    - c) Which two atoms are isotopes of each other?
    - d) In a radioactive process,  $^{14}_6\text{C}$  changes one of the neutrons in its nucleus into a proton. Which atom has it turned into?

## ATOMS

## Is this atomic model correct?

The notion of atoms explains, among many other things, how gases exert pressure and why chemicals react in certain quantities. As a result, this model of atomic theory has been successful and scientists are happy with the idea that matter is made up of atoms. But is the Rutherford model of the atom correct?

The idea of a model being perfectly correct or not does not really matter, since the purpose of a model is to simplify a concept to make it easier to understand. Our idea of protons and neutrons in the nucleus with electrons orbiting around it helps us to explain why the electrons interact with other atoms and cause chemical reactions while the nucleus remains in the center of the atom and does not affect these. The masses of protons and neutrons enable us to explain isotopes. However, in simplifying the atom into an understandable model, it is inevitable that there will be some things which are lost in the simplification.

It turns out that electrons, and in fact all particles, can behave as waves as well as particles. The electrons in an atom act like a wave rather than a well-defined particle. Indeed, it is impossible to predict where an electron will be at any given time; we can only establish probabilities. This is quantum theory and it requires a more sophisticated model of the atom in which the electrons are waves.

The electron is a fundamental particle; that is, it cannot be split into anything smaller. Physicists have discovered that the proton and the neutron are not fundamental particles, but that they are made up of three quarks. During the 20th century, physicists discovered six different types of quarks as well as other electron-like particles. Just as chemists developed the periodic table and used this model to predict where elements were yet to be discovered, physicists developed a similar model of these fundamental particles. We call it the standard model and it has been used to predict the existence of particles such as the Higgs boson. It is the most successful theory of the universe that we have and yet it is only a model; for example, it cannot explain gravitation.

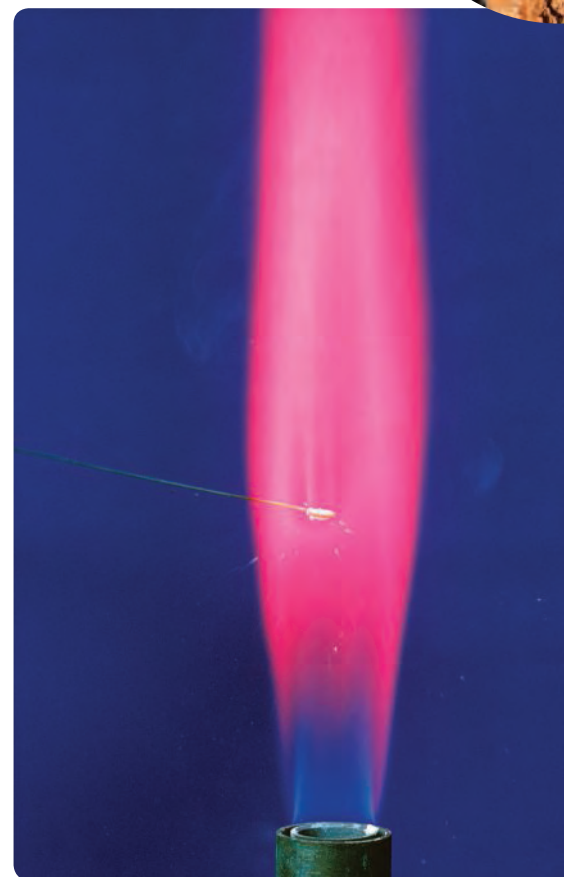
### The Higgs boson

Peter Higgs used the standard model to predict the existence of a particle which was responsible for the other particles having mass. He predicted this particle's existence in 1964, but it was not discovered until 2012. In 2013 he was awarded the Nobel Prize along with François Englert.



Some Nobel prizes in physics are awarded for developing new models (often referred to as theories or laws), while others are for discoveries or technological innovations.

1. Research the Nobel prizes that have been awarded in physics and try to find one that was awarded for developing a model. Write a brief explanation for what the model explained.
2. Can you find two Nobel prizes that were awarded for other discoveries that are mentioned in this chapter?



- ▲ More complicated models of the atom using quantum mechanics are required to explain why different metals exhibit particular colors in a flame test

## ATL Affective skills

### Practicing resilience

At many times, the existing model of the atom has been shown to be wrong. It would have been tempting to throw away the model and to start again. However, a simple model of an atom is still useful even if it is known to have limitations. A more complicated model may be harder to use but may not be necessary in many applications.

When faced with evidence which contradicts their models, scientists need resilience. Sometimes new discoveries are made when an existing model fails to explain an experimental result, therefore failure is an important process in science.

Can you think of a time when you have failed and been able to learn from the experience?

## What is a wave?

The complicated way in which electrons behave in an atom requires physicists to be able to model matter as sometimes being wave-like and sometimes particle-like. Particle-like behavior has been explained by the atomic model, but what is a wave and how do waves behave?

Sometimes in a football stadium, spectators create a Mexican wave by standing up and waving their arms at the right time. The effect is that a wave appears to move around the stadium quickly, but the spectators have not moved around the stadium, they have only moved up and down and remained in the same seat.

A Mexican wave is a good example of a wave. Waves transfer energy without transferring matter. This transfer of energy means that waves are also able to transfer information. We can see the wave move around the stadium; however, no matter has been transferred as the spectators all stay put in their original seats.

Light and sound are other examples of waves. In order to see and hear, when light and sound waves reach you, your eyes and ears need to detect the energy that is transferred. Just as with Mexican waves no matter is transferred, and so as you receive these waves, you do not get heavier.

▼ A Mexican wave





## What types of wave are there?

There are two types of wave:

- transverse waves
- longitudinal waves.

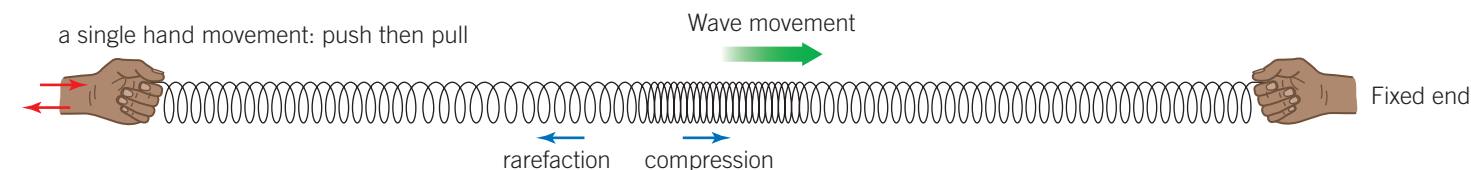
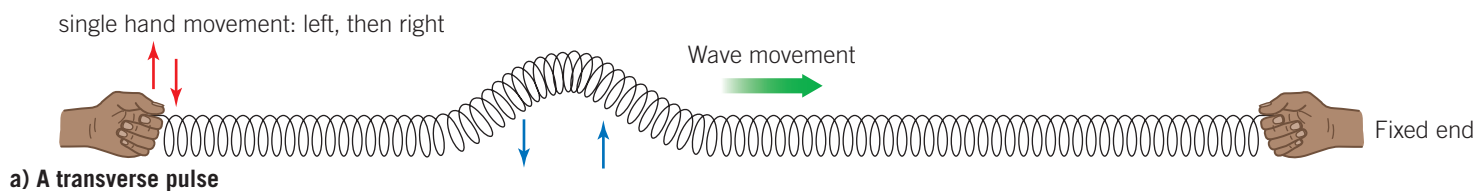
In transverse waves the matter (or whatever medium the wave is traveling in) moves at right angles to the direction in which the wave is traveling. Waves on water are a good example of this (as are the Mexican waves discussed previously). When ripples travel across a pond, the surface of the water moves up and down but the wave travels along the surface of the pond at right angles to this. Once the ripple has passed, the water is left in the same position as it was before the wave came along because the water itself is not transferred by the wave. Electromagnetic waves (which are discussed in Chapter 12, Patterns), such as radio waves, X-rays and visible light, are transverse waves, as are the S-waves from earthquakes and waves which travel along strings or other surfaces.

In a longitudinal wave the matter moves parallel to the direction in which the wave travels. Sound is an example of this type of wave. When sound travels through air, a pressure wave is created. The particles of air are moved backwards and forwards in the same direction as the sound is traveling. After the wave has passed, the air particles are left in approximately their original positions because the wave has transferred energy through the air but not the actual air itself. Other compression waves, such as P-waves from earthquakes, are also longitudinal.



- ◀ In these waves on the surface of the pond, the water moves up and down but the wave travels along the surface of the water at right angles to the direction in which the individual molecules of water move

the short arrows  $\uparrow \downarrow$  show the movement of particles (spring coils), the long arrows  $\rightarrow$  show the movement of the wave

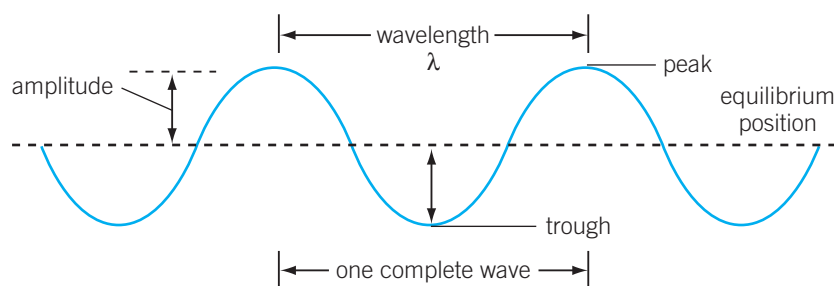


- ▲ A slinky may be used to produce transverse and longitudinal waves. Moving your hand at right angles to the slinky creates a transverse wave pulse. As the pulse travels down the slinky, the individual coils move at right angles to the direction of the pulse. A push and pull motion, on the other hand, will create a longitudinal wave where the slinky coils move parallel to the direction of the wave

WAVES

## How do we measure waves?

- The amplitude of a wave is measured from the equilibrium position to the peak while the wavelength can be measured from peak to peak or from trough to trough



A typical wave is shown in the diagram – it could be a ripple on a pond. The dashed line shows the level of the pond’s surface if there were no wave present. This is called the equilibrium position. The length of one complete wave is called the wavelength. This could be measured from the peak of one wave to the peak of the next, or from trough to trough. The maximum displacement that the wave has from the equilibrium is called the amplitude.

This picture only shows one moment in time; the wave will travel along the surface of the pond and as it does so the surface of the pond will move up and down. The time it takes a part of the pond’s surface to complete an entire cycle of its motion (upwards, downwards and back to its original position) is called the time period of the wave.

The number of waves that pass by a given point in one second is called the frequency. Frequency is measured in Hertz (Hz) where



one Hertz means one wave per second. The frequency can also be calculated using the equation:

$$f = \frac{1}{T}$$

where  $f$  is the frequency and  $T$  is the time period.

The frequency of a wave and its wavelength are also related – longer waves take longer to pass and so the frequency is lower. The equation which relates these quantities is:

$$v = f\lambda$$

where  $v$  is the speed of a wave,  $f$  is the frequency and  $\lambda$  is the wavelength.

### Observing waves on a slinky

With a partner, stretch a slinky along a long table or on the floor. Try sending these types of waves down the slinky.

- A longitudinal wave with a high frequency.
- A longitudinal wave with a small amplitude.
- A longitudinal wave with a low frequency and a high amplitude.
- A high-amplitude, low-frequency transverse wave.
- A low-amplitude, high-frequency transverse wave.
- A high-amplitude, high-frequency transverse wave.
- A low-amplitude, low-frequency transverse wave.

## Experiment

For this experiment you will need a rectangular tray or plastic box, a stopwatch and a ruler.

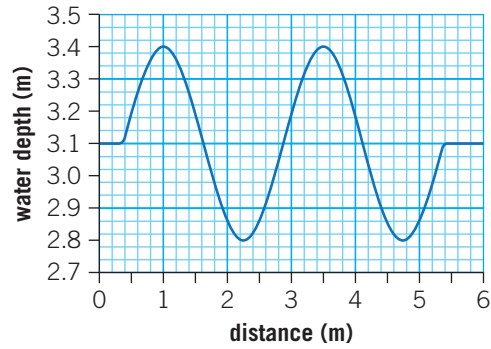
### Method

- Fill the tray with just enough water to cover its base to a depth of a couple of millimeters. Measure the depth of the water with a ruler.
- Give the side of the tray a sharp tap and observe the ripple travel across the tray. Measure the time it takes for the ripple to cross the tray. Repeat your measurements three times and take an average.
- Measure the length of the tray and use this to calculate the speed of the ripple across the tray.
- Repeat your measurements for different depths of water. Record your values of depth, time for the wave to cross the tray and wave speed in a table.
- Plot a graph of your results.

How does the speed of waves change in different depths of water?



1. The graph below shows the depth of water in a harbor as a wave passes through.
  - a. From the graph, measure the wavelength of the wave.
  - b. Determine the amplitude of the wave.
  - c. The speed of the waves is  $1.4 \text{ m s}^{-1}$ . Calculate how long it takes a wave to pass a given point.



▲ Hokusai's 'The Great Wave off Kanagawa' is one of the most iconic images of a wave



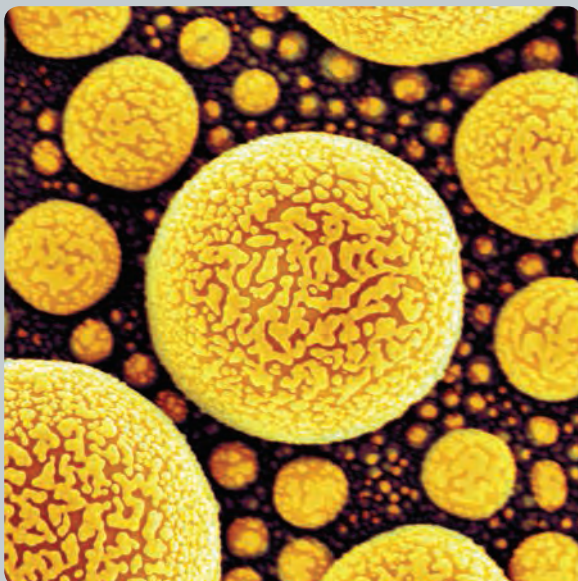
## Summative assessment

### Statement of inquiry:

A good model can simplify and illuminate our understanding of complex phenomena.

### Introduction

A nucleus is so tiny that is hard to study experimentally; it is impossible to use conventional techniques such as a microscope. This assessment is based on experiments to determine the size of the nucleus in atoms.



◀ In this image, electrons with a small wavelength have been used to see the atoms of gold with a scanning electron microscope. Electrons with a much smaller wavelength would be required to observe the nuclei of these atoms



### Probing the atom

As a general rule, waves can only be used to see objects that are larger than the wavelength of the waves. Since the wavelength of visible light is about a thousand times larger than an atom, an optical microscope cannot be used to see individual atoms.

The nuclei of atoms are much smaller still and so we require waves with very small wavelengths to probe the nucleus of atoms. Electrons demonstrate both a wave-like and a particle-like behavior and since the wavelength of high energy electrons can be very small, they can be used to probe the nuclei of atoms.

In an experiment to measure the size of the nucleus of a gold atom, the wavelength of the electrons is  $2 \times 10^{-16}$  m and they are traveling at  $3 \times 10^8$  m s<sup>-1</sup>.

1. Calculate the frequency of the electron wave. [2]
2. Calculate the time period of the electron waves. [1]

3. The target nucleus in the experiment was gold which has a mass number of 197 and an atomic number of 79.
  - a) Describe this nucleus in atomic notation. (The chemical symbol for gold is Au.) [2]
  - b) How many neutrons are in the gold nucleus? [2]
4. Another isotope of gold has a mass number of 200. Explain what is meant by an isotope and how these nuclei differ from the gold-197 nuclei. [3]
5. Explain why the two gold isotopes have similar chemical properties. [3]
6. The electron waves are transverse. Describe the difference between a transverse wave and a longitudinal wave. [2]



### Investigating the nuclear radius

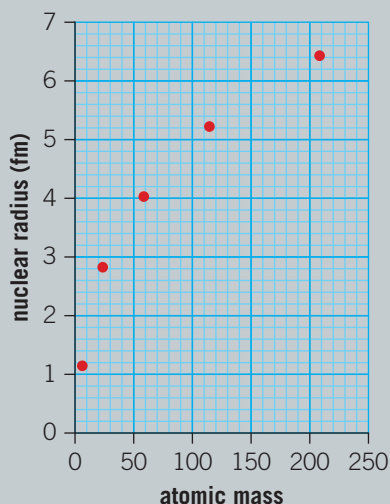
A series of experiments is designed to investigate other nuclear radii.

7. Explain which of the following you think would be the most suitable independent variable for the experiment:  
atomic number      mass number      number of electrons. [3]
8. Write a suitable hypothesis for this experiment. [4]
9. One suggestion is to investigate and measure the different radii of the isotopes of gold. Discuss whether this is a good suggestion. [5]
10. Explain why it might be important to use the same wavelength of electrons when measuring the differing nuclei. [3]



### The liquid drop model of the nucleus

11. The graph below shows the nuclear radius of some nuclei in femtometers ( $1 \text{ fm} = 1 \times 10^{-15} \text{ m}$ ).



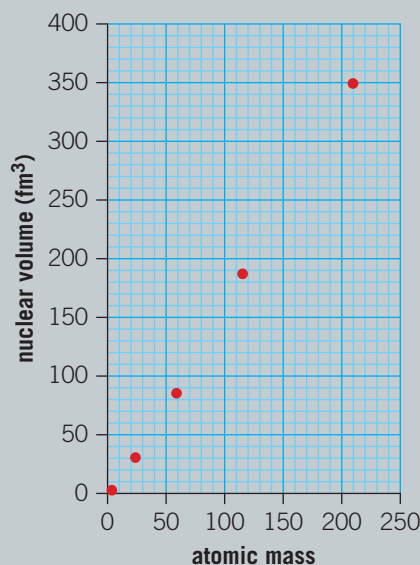
- a) Would you classify the trend of the graph as directly proportional, linear or non-linear? [1]



- b) Draw a line of best fit on a copy of the graph. [1]
- c) Use the graph to predict the radius of a nucleus of tungsten-184. [2]

12. A model of the nucleus called the liquid drop model suggests that the volume of a nucleus is directly proportional to the number of protons and neutrons in it.

A graph of the volume of nuclei against mass number is shown below.

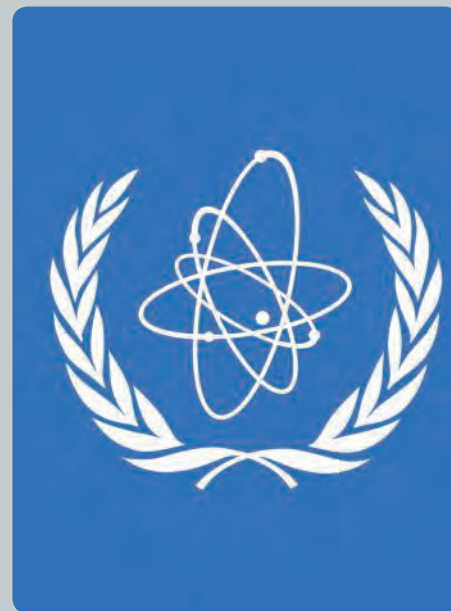


- a) Using your value of the radius of tungsten-184 from the first graph, calculate the volume of this nucleus. (Assume that the nucleus is a sphere.) [4]
- b) How would you classify the trend of this graph? [1]
- c) Add this data point to a copy of the graph. [1]
- d) Discuss whether the liquid drop model of the nucleus appears to be a good model. You should refer to the graph in your answer. [5]



## Describing the atom

- 13. The experiment described in this section can be described as nuclear physics since it is the study of the nucleus. However, the words “nuclear” and “atomic” are sometimes thought to refer to nuclear weapons and can cause fear as a result. Write a short paragraph explaining the structure of an atom without using the words “nuclear” or “atomic”. [5]
- 14. Our increased knowledge of the structure of the atom and its nucleus have been a significant advance in scientific understanding. Identify the benefits and limitations that these scientific advances have brought us and justify whether this progress has been beneficial to humankind. [10]



- ▲ The emblem of the International Atomic Energy Agency (IAEA) features a diagram of the Rutherford model of the atom. The IAEA promotes the safe, secure and peaceful use of nuclear science and technology