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Introduction

Chemistry has a human face. The aim of this book is to present chemists as real people and not stereotypical 'mad scientists' whose lives are completely dominated by science. It may only take a couple of minutes of a lesson to present the class with a bit of personal background information which could, for some students, add interest to the lesson. The history of chemistry is full of serendipitous tales. The influence of World War II played a major role in the development of plastics, which otherwise may not have been produced on a commercial scale. In other parts of the world science was held back, simply because the scientists were coloured and this was socially unacceptable. In the early days of chemistry, there were few woman chemists as this too was deemed to be unacceptable. The womans' place was in the home and certainly not in the laboratory carrying out experiments. The social context of the time must be understood to explain why the majority of the early chemists appear to be white middle-class or upper-class gentlemen. Many of the scientific projects had to be funded by the chemists themselves, so they already had to be wealthy or have a very good income. At times science was just the hobby, before it took over. This is not to say that there were no scholarships available. In fact, there are a number of very distinguished scientists such as Ernest Rutherford and John Jacob Berzelius who came from very humble backgrounds.

Today we live in a very different world, where people should be accepted regardless of race or gender. Science is taught in all schools and young people of today are encouraged to develop an interest in the subject. There is more money available to carry out research, although some would say not enough, as we go on living in the scientific and technological age.

Running throughout this series of books written by Dorothy Warren, there are many references to different scientists. The scientists are always introduced within the context of their work at the most appropriate place; for example John Lind is found in **The nature of science** book, Alice Hamilton in the **Health, safety and risk** book, Mario Molina in the **Climate change** book and the aluminium pioneers in the **Green Chemistry** book. In this resource, the focus is twofold, namely providing strategies for teaching about people in chemistry and an introduction to some of the chemists who played a role in the development of major ideas in chemistry, *eg* theories about the atom and burning. Roy Plunkett and the discovery of Teflon has been included as an example of serendipity, Harry Kroto and buckminsterfullerene as an example of a living chemist and Norbert Rillieux as an example of a successful chemical engineer, despite being an African-American living in the 19th century.

One of the problems for busy teachers is having a readily available source of background information about different scientists. There are many Internet sites that will provide a wealth of biographical information, photographs and scientific information. The three web sites listed here are worth a visit.

1. The British Society for the History of Science (BSHS) website **http://www.bshs.org.uk/index.php** (accessed September 2005). This site links into several other useful sites. It also provides a discussion forum for teachers as well as useful contacts such as actors willing to do scientific performances in schools.

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2. The Nobel Foundation site at **http://www.nobelprize.org** (accessed September 2005) lists all the Nobel Laureates with photographs, biographical and scientific background information.
3. This week in the history of chemistry **http://webserver.lemoyne.edu/faculty/giunta/week.html** (accessed September 2005) can be accessed to provide information for any week of the year.
4. European Network for Chemistry, Millennium Project, has a site listing 100 distinguished European chemists from the chemical revolution to the 21st century. **http://www.euchems.org/Distinguished/index.asp** (accessed September 2005).
5. Chemsoc timeline is a linear based exploration of key events in the history of science with a particular emphasis on chemistry. **http://www.chemsoc.org/timeline** (accessed September 2005).

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The atom detectives

Teachers' notes

Objectives

- To understand how the model of the atom has developed over time.
- To learn about some of the chemists involved in developing the model of the atom.
- To be able to apply today's accepted model of the atom and draw diagrams to represent the atoms of the first 40 elements of the periodic table.

Outline

This section looks at how the model of the atom has developed over the last 200 years. It explores how scientists work together to develop new ideas and how new theories may, at first, give rise to controversy. It shows how technological advances can lead to the development of new theories and ideas.

Teaching topics

This material is intended to be used with more able students between the ages of 14 and 16 or post-16 students, when teaching about atomic structure and the Periodic Table. Understanding the arrangements of subatomic particles in the atom is a high level concept. In this activity, you can see how the ideas developed as scientific method and instrumentation developed and other areas of science unfolded. Look at the student worksheets before reading the detailed notes below.

Background information

Since 5 BC, people have been curious to find out more about different materials and substances. The theory of Democritus said 'Substances are different because homogenous particles have different sizes and shapes and cannot be cut'. This was just the start of many more theories that would be put forward and then rejected over the next 2000 years. Many of the early theories of matter were not based upon experiments. As scientists began to study the relationship between physical phenomena such as electricity and magnetism they began to develop different models about atomic structure.

Sources of information

The atomic structure timeline at
http://www.watertown.k12.wi.us/hs/teachers/buescher/atomtime.asp
(accessed September 2005).

The timeline has twenty-two entries, starting in the Greek era and finishing in 1932 with James Chadwick. By clicking on the scientist's name, personal background information and portraits can be accessed. A short summary of their contribution to atomic structure is included with some hot links leading to further information.

Teaching tips

This section is ideal for group work leading to a wall display featuring the history of the atom. There are five student worksheets each featuring a scientist who made a significant contribution to the development atomic theory.

- Dalton
- Berzelius
- Thomson

- Rutherford
- Bohr.

The sixth student worksheet is an information sheet, bringing the theory up-to-date.

Following an introduction to the lesson, the class could be divided into groups of 4 or 5 students. Each group could work through one of the worksheets. To make the sheets more durable, they could be photocopied onto card and laminated. The activities at the bottom of the sheet could be carried out and presented as a poster, on a large piece of paper. The group should also include some background information about the scientists and what they did.

You will need to tell the class whether you expect models or diagrams of the atoms, or if they have a free choice. In order to answer all the questions some groups will have to communicate with others.

At the start of the next lesson, each group could present their posters, in chronological order, to the rest of the class, highlighting the major aspects of the theory, which could be summarised.
Eg 1 Berzelius' relative atomic masses are used today. Berzelius introduced chemical symbols.
Eg 2 Thomson discovered that the negatively charged electron was part of the atom. It was 1/1840 the mass of the positively charged particles.

The rest of the lesson could be spent with everyone working on the sheet **Modelling the atom today**. You should go through the lithium example with the class and maybe do one of the other examples with the class. The information for completing question 1 will have been covered in the poster presentations and may already be available. The rest of the sheet could be completed as homework.

Note: Throughout this material, the term mass has been used unless the accepted terminology of weigh or weight is more appropriate. Teachers may wish to draw attention to the difference between mass and weight.

Resources

- Student worksheets
  – John Dalton
  – John Jacob Berzelius
  – Joseph John Thomson
  – Ernest Rutherford
  – Niels Bohr
  – Present day models of the atom
  – Modelling the atom today

Timing

2 hours plus homework

Opportunities for using ICT

- Using the Internet to find out more about the atom detectives.
- Word processing and drawing packages to make posters.

Opportunities for using key skills

- Working together in groups.
- Communication between groups.
- Presentation of work to the class.

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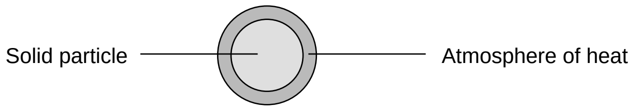
Answers

John Dalton

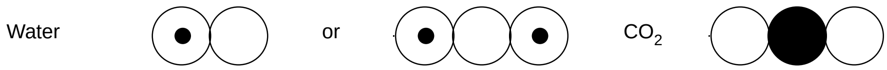
1.



2. A molecule of ice had less heat surrounding the particle than a molecule of water.

3. He guessed!

4.



Dalton thought that the water molecule only consisted of one O and one H atom, so either molecule may be accepted.

John Jacob Berzelius

1.

Element	Symbol	Relative atomic mass
Chlorine	Cl	35.5
Copper	Cu	63.5
Hydrogen	H	1.0
Lead	Pb	207.2
Nitrogen	N	14.0
Oxygen	O	16.0
Potassium	K	39.1
Silver	Ag	107.9
Sulfur	S	32.1

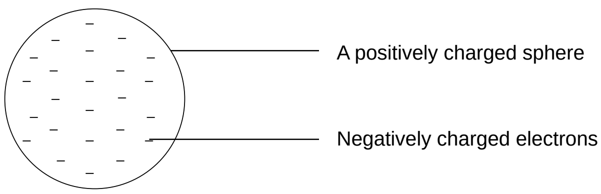
2. Berzelius because his 1826 values are very close to the ones that are used today.

3. He was able to work out the number of atoms in each molecule.

4. Berzelius believed that atoms were held together by electrostatic attraction. He thought that some atoms were positively charged and others were negatively charged.

Joseph John Thomson

1.



The plum pudding model

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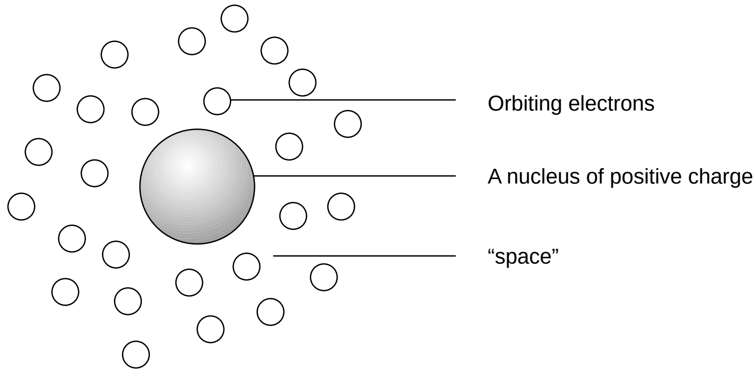
2. Thomson's model of the atom contained negative particles of electricity (which he called electrons) embedded in a solid sphere of positive charge. Daltons' atom was a solid particle, surrounded by an atmosphere of heat.

3. A very sensitive camera.

Ernest Rutherford

1.



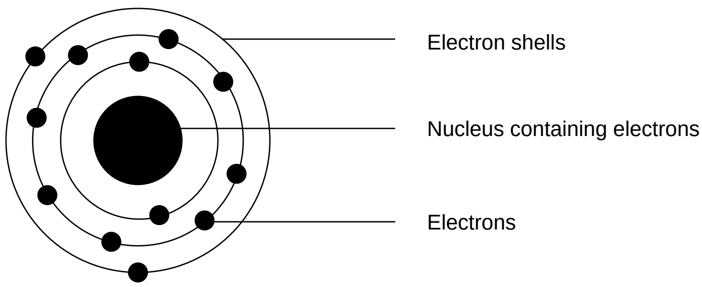
2. The main difference between the two models is that the Thomson model has a solid sphere with negative charges whereas the Rutherford model has a small solid nucleus, some 'space' and then orbiting electrons, which are separate particles.

3. Rutherford carried out his experiments in the dark so that he could observe the glow left behind by the radiation and see where the particles went.

4. Rutherford noticed that some of the positively charged radiation bounced back from the atom in the same direction. Rutherford concluded that this must be due to another positive force repelling the positive radiation. This large positive force must come from the centre of the atom.

Niels Bohr

1.



2. In the Bohr atom the electrons are arranged in definite shells whereas in the Rutherford model, the electrons just orbit the nucleus. They are free to go wherever they like.

3. Bohr's model of the atom was based on theoretical calculations and a good imagination. Although his model could explain atomic spectra, it was based on incomplete data. It was thought that the model could not be used to explain the reactivity of the elements. Many chemists preferred Lewis' model because it was based on real experimental chemical data. The Lewis model could be used to explain the reactivity of the elements. However, it could not be used to explain the hydrogen spectrum.

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Modelling the atom today

1.

Particles	**Charge**	**Relative Mass**
Protons	**positive** (+)	1
Neutrons	neutral	**1**
Electrons	**negative** (–)	**1/1840**

2.

Element	**Mass No.**	**Atomic No.**	**No. of protons**	**No. of neutrons**	**No. of electrons**
Hydrogen	1	1	**1**	**0**	**1**
Carbon	**12**	**6**	6	6	**6**
Neon	20	**10**	10	**10**	10
Aluminium	**27**	13	**13**	14	**13**
Potassium	39	19	**19**	**20**	**19**

3. Nucleus containing correct number of protons and neutrons (see table), electrons arranged in shells 2,8,8,18 *etc*.

John Dalton

John Dalton
(Reproduced courtesy of the Library & Information Centre, Royal Society of Chemistry.)

John Dalton (1766–1844)

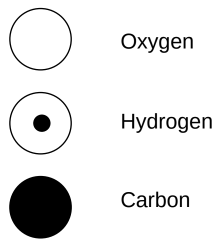
He was the son of an English weaver from Eaglesfield in Cumbria. When he wasn't carrying out investigations, he was probably teaching at the Presbyterian college in Manchester. In 1807, John Dalton was the first person to use the word **atom** to describe the smallest particle of any element.

What did Dalton do?

Dalton studied gases and discovered that elements combine with other elements to make compounds. He had to guess how many atoms joined together to make the compound. He was able to calculate the relative weights of particles using data from his own observations and measurements. Individual particles were too small to weigh. He had to make some assumptions to explain his observations *eg* the atmosphere of heat surrounding the solid particle was used to explain why some elements were solids and some gases. Solid compounds had less heat than gaseous ones.

Dalton's atomic theory of matter, 1807

1. All matter is made up of tiny particles called atoms.
2. Each atom is a solid particle with no spaces, surrounded by an atmosphere of heat.
3. Atoms cannot be made or destroyed.
4. Atoms of the same elements are alike with the same mass, colour *etc*.
5. Atoms of different elements have different masses, colours *etc*.
6. Atoms can join to form larger particles in compounds.



Dalton's symbols

Things to do

1. Make a model or draw a diagram of Dalton's atom.
2. How did Dalton explain the different between a molecule of ice and a molecule of water?
3. How did Dalton known how many atoms were in a molecule?
4. Using Dalton's symbols, write down the formulae of water and carbon dioxide.

John Jacob Berzelius

John Jacob Berzelius
(Reproduced courtesy of the Nobel Foundation.)

John Jacob Berzelius (1779–1848)

Berzelius was an orphan from Sweden, brought up by a mean stepfather. He worked on his farm and lived in a room which was also the potato store. His stepfather made sure that the potatoes did not freeze during winter, so at least this meant that Berzelius kept warm too. From high school, he went on to university where he became interested in experimental chemistry.

What did Berzelius do?

Berzelius heard about Dalton's theory and set about making his own relative atomic weight measurements. But, from previous experiments carried out by Humphrey Davy, he knew how many atoms were in the compounds. He knew that when electricity was passed through water, twice as much hydrogen was collected at the negative terminal than oxygen at the positive terminal. So he concluded that water was made from two atoms of hydrogen and one of oxygen.

Berzelius' atomic theory

1. All atoms are spherical.
2. All atoms are the same size.
3. Atoms have different weights.
4. Atoms joined together in fixed proportions, by an electrochemical reaction. Some atoms are positive and others are negative.

Dalton could not accept Berzelius' electrochemical combination, but at the same time could not explain why atoms joined together in fixed proportions.

Elements	Dalton's atomic weights 1808	Berzelius' atomic weights 1826
Chlorine	unknown	35.41
Copper	56	63.00
Hydrogen	1	1.00
Lead	95	207.12
Nitrogen	5	14.05
Oxygen	7	16.00
Potassium	unknown	39.19
Silver	100	108.12
Sulfur	13	32.18

Chemical symbols

Berzelius thought that chemical symbols should be letters. He took the first letter of the Latin name of each element. When the letters were the same, he used both the first letter and the next different letter. Berzelius' symbols are used in today's Periodic Table.

Things to do

1. Look up, in a modern data book, the relative atomic masses and the symbols of the elements listed in the above table. Put your answers in a table.
2. Who do you think had the best method for calculating the relative weights of atoms, Dalton or Berzelius?
3. What do you think was the key to the successful calculations?
4. How did Berzelius think that atoms joined together to make compounds?

Joseph John (JJ) Thomson

Joseph John Thomson
(Reproduced courtesy of the Nobel Foundation.)

Joseph John Thomson 1856–1940

Thomson was born near Manchester. His ambition was to be an engineer but instead he was awarded a scholarship in chemistry. The scholarship was in memory of John Dalton. At the age of 28, Thomson became professor at the Cavendish Laboratory, Cambridge University.

What did Thomson do?

In 1897 Thomson discovered the electron, while he was investigating the conductivity of electricity by gases at very low pressures. After collecting data for twenty years, Thomson was convinced that electrons were negative particles of electricity. He even measured the mass of the electron.

However, he still needed more evidence to convince the scientific world, so he asked Wilson to try and take a photograph of an electron. It took him until 1911 to build a suitable camera, which was sealed in a glass chamber in which electrons could be produced. The experiment was successfully carried out and the electron was photographed.

JJ Thomson was worried about telling the world his new theory of the atom, because until now the atom was thought of as a single solid particle.

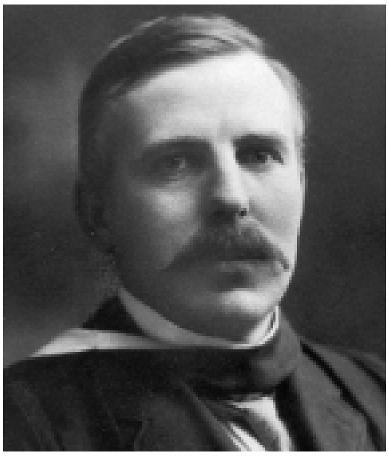
Thomson's model of atomic structure – 1899

- Atoms consisted of rings of negative electrons embedded in a sphere of positive charge (the plum pudding model).
- The positive and negative charges balance to make the atom neutral.
- The mass of the atom was due to the nucleus.
- The mass of an electron was 1/1840 of the mass of hydrogen, the lightest atom.
- There were 1840 electrons in an atom of hydrogen.

Things to do

1. Make a model or draw a diagram of JJ Thomson's model of the atom.
2. What is the main difference between this new model and Dalton's model?
3. What advances in technology made it possible for Thomson to successfully complete his investigations?

Ernest Rutherford



Ernest Rutherford
(Reproduced courtesy of the Nobel Foundation.)

Ernest Rutherford (1871–1937)

Rutherford was born near the village of Nelson, New Zealand. His father was an odd-job man and simple farmer. Rutherford obtained an honours degree in mathematics and science from the University of New Zealand before gaining a scholarship that took him to work with JJ Thomson at the Cavandish laboratory in Cambridge.

What did Rutherford do?

Rutherford studied radioactive atoms and found that they were not stable. By this time a lot was understood about radiation. Rutherford carried out his investigation in the dark. He used positively charged radiation to bombard the atom and watched to see where the radiation particle went. The radiation always left a glow. The glow showed that most particles went straight through the atom, some were slightly deflected, while others bounced back in the same direction.

After doing many calculations, Rutherford concluded that the radiation could only come back if that atom had a hard positively charged core at the centre of the atom. He called this the nucleus. If the atom was 100 m, the size of a football pitch, the nucleus would be the size of a pea placed in the centre of the pitch.

Rutherford's model of atomic theory

1. The atom consists mainly of space.
2. The mass of the atom is concentrated in the nucleus, which is a small core at the centre of the atom.
3. The nucleus has positive charges.
4. Electrons move around the nucleus like planets orbiting the sun.
5. The atom is neutral as it has the same number of positive charges and negatively charged electrons.

Things to do

1. Make a model or draw a diagram of Rutherford's atom.
2. What was the main difference between Rutherford's model of the atom and Thomson's model?
3. Why did Rutherford carry out his experiments in the dark?
4. What evidence do you think lead Rutherford to conclude that the atom had a positively charged nucleus?

Niels Bohr

Niels Bohr
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Niels Bohr (1885–1962)

Niels Bohr was born into a scientific family. His father was a professor of physiology and his brother a distinguished mathematician. After obtaining his Ph.D. from the University of Copenhagen, Denmark, he accepted an invitation to work with Rutherford, at Cambridge.

Bohr was very intelligent and had an amazing imagination. He was not afraid to build on the idea of Max Plank, that energy came in little packets called quanta, and apply this to Rutherford's model of the atom.

What helped Bohr?

Bohr based his investigation on Max Plank's idea. He imagined the electron orbiting the nucleus unless it was disturbed by some outside force, when it jumped to a different energy level. A packet of energy was either gained or lost.

Bohr's model of the atom (1922)

1. Most of the mass of an atom is in the central nucleus that contains protons.
2. The electrons are arranged in definite shells or energy levels and orbit the nucleus.
3. The electron shells are a long way from the nucleus.
4. When one shell is full a new shell is started. This is called the electronic configuration.
5. Atoms with full shells are not very reactive.
6. Electrons determine the reactivity of the atom.

Chemists not happy

While Bohr's model of the atom could explain the spectrum of the hydrogen atom, chemists didn't think it would explain the reactivity of the other chemical elements. His theory was based on incomplete physical data and mathematical calculations. Many chemists favoured Lewis' theory. The American's octet theory was based on real chemical data. Lewis proposed that the fixed nucleus was surrounded by cubic shaped electron shells. The electrons were fixed in the corner positions.

Things to do

1. Make a model or draw a diagram of Bohr's atom.
2. What is the main difference between Bohr's model of the atom and Rutherford's model?
3. Suggest why some chemists preferred Lewis' model of the atom to Bohr's.

Present day models of the atom

The up-to-date model of the atom is much more complicated than the ones we have met so far. It is based on what is known as quantum mechanics and the atom is described by a complicated equation called the Schrodinger equation. It helps to know a lot of maths, understand probability and have a good imagination to picture Schrodinger's model of the atom. However, you don't need to worry about that until you go on to further studies of chemistry or physics. Of course, if you are interested to find out more you can go and look it up yourself.

Today, most people are happy to accept a slightly modified model of Bohr's atom, because it can be used to explain the spectra and the reactivity of the elements. The modified model of the Bohr atom includes neutrons, which were discovered by Sir James Chadwick in 1932.

Figure 6 James Chadwick
(Reproduced courtesy of the Nobel Foundation.)

The neutron is a neutral particle with the same mass as a proton. It is also found in the nucleus.

Thanks to the work of many other chemists, we can now use the Periodic Table to find out the number of protons, neutrons, and electrons in the atom of any element.

Modelling the atom today

Study the following example

Mass number
Number of protons + neutrons

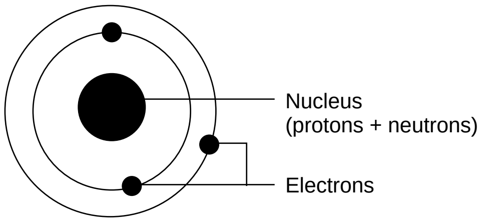
$^{7}_{3}Li$

Atomic number
Number of protons

No. of electrons = No. of protons
No. of neutrons = Mass No. – Atomic No.

Lithium has:

3 protons
3 electrons
4 neutrons



The lithium atom

Where the electrons go

- The first shell can hold up to 2 electrons.
- The second and third shells can each hold up to 8 electrons.
- The fourth shell can hold up to 18 electrons.

The arrangement of electrons in the atom is known as the electronic configuration. The electronic configuration for Li is 2.1. This means Li has 2 electrons in the first shell and one in the second shell.

Things to do

1. Complete the following table

Particles	**Charge**	**Relative Mass**
Protons		1
Neutrons	neutral	
Electrons		

2. Complete the following table.

Element	**Mass No.**	**Atomic No.**	**No. of protons**	**No. of neutrons**	**No. of electrons**
Hydrogen	1	1			
Carbon			6	6	
Neon	20		10		10
Aluminium		13		14	
Potassium	39	19			

3. For each of the elements in the table above, draw a diagram to show how the protons, neutrons and electrons are arranged in each atom.