Atoms are the simplest substances. There are about 100 different elements. Each element is made up of very tiny particles called atoms, and each element is made up of just one particular type of atom, which is different to the atoms in any other element.

Gold is an element made up of only gold atoms.

Carbon is an element made up of only carbon atoms.

John Dalton had the first ideas about the existence of atoms over 200 years ago. However, it is only relatively recently that special microscopes (called electron microscopes) been invented that can actually ‘see’ atoms.

This image is highly magnified. What could it be showing?

The yellow blobs are individual gold atoms, as seen through an electron microscope.

Atoms are very small – they are about 0.00000001 cm wide.

Think about the thickness of a crisp. The number of atoms you would need to stack up to make the thickness of a crisp, is approximately the same number of crisps you would need to stack up to make the height of Mount Everest!

That’s roughly 7 million crisps!
For some time, people thought that atoms were the smallest particles and could not be broken into anything smaller. Scientists now know that atoms are actually made from even smaller particles. There are three types:

- **Proton**
- **Neutron**
- **Electron**

How are these particles arranged inside the atom?

Protons, neutrons and electrons are not evenly distributed in an atom.

The protons and neutrons exist in a dense core at the centre of the atom. This is called the **nucleus**.

The electrons are spread out around the edge of the atom. They orbit the nucleus in layers called **shells**.

**Discovery of atomic structure**

Everything on Earth is made up of atoms, and chemistry is all about the atoms and how they interact.

Click a date in the timeline below to find out who made important discoveries about the structure of the atom.

- **450 BC**
- **1803**
- **1897**
- **1907**
- **1913**
- **1932**

**J.J. Thomson discovered the electron in 1897**

**J.J. Thomson’s Cathode Ray Tubes**

Rutherford’s Gold Foil Experiment & Discovery of Neutron
Thomson proposed that cathode rays were streams of particles much smaller than atoms. An electric field or a magnetic field will deflect a beam of charged particles. Thomson’s discovery meant that the atom was divisible! He knew there had to be an equal amount of positive charge because matter is neutral.

Thomson’s Cathode Ray Tube

Rutherford proposed that cathode rays were streams of particles much smaller than atoms. An electric field or a magnetic field will deflect a beam of charged particles. Rutherford’s discovery meant that the atom was divisible!

Rutherford’s Gold Foil Experiment

Results of Rutherford’s Expt
- Most of the alpha particles went straight through – they didn’t bump into anything so most of the atom was empty space.
- Some of the alpha particles were deflected back – they must have hit something really heavy that Rutherford called the nucleus.
- Results do NOT match Thomson’s model.

Rutherford’s Gold Foil Experiment

James Chadwick (1891-1974)
- Subatomic particles with no charge but with a mass nearly equal to protons

Spring 2007
**Mass and Electrical Charge**

There are two properties of protons, neutrons, and electrons that are especially important:
- Mass
- Electrical charge.

The atoms of an element contain equal numbers of protons and electrons and so have no overall charge.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton</td>
<td>1</td>
<td>+1</td>
</tr>
<tr>
<td>neutron</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>electron</td>
<td>almost 0</td>
<td>-1</td>
</tr>
</tbody>
</table>

**How Many Protons?**

The atoms of any particular element always contain the same number of protons. For example:
- Hydrogen atoms always contain 1 proton
- Carbon atoms always contain 6 protons
- Magnesium atoms always contain 12 protons.

The number of protons in an atom is known as the atomic number or proton number.

It is the smaller of the two numbers shown in most periodic tables.

**Time Line of the Atom**

The development of atomic theory represents the work of many scientists over many years.

**What is the Atomic Number?**

What are the atomic numbers of these elements?

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>23 Na</td>
</tr>
<tr>
<td>Iron</td>
<td>56 Fe</td>
</tr>
<tr>
<td>Tin</td>
<td>119 Sn</td>
</tr>
<tr>
<td>Fluorine</td>
<td>19 F</td>
</tr>
</tbody>
</table>

Spring 2007
MORE ABOUT ATOMIC NUMBER

Each element has a definite and fixed number of protons. If the number of protons changes, then the atom becomes a different element.

Changes in the number of particles in the nucleus (protons or neutrons) are very rare. They only take place in nuclear processes such as:

- radioactive decay
- nuclear bombs
- nuclear reactors.

WHAT IS MASS NUMBER?

Electrons have a mass of almost zero, which means that the mass of each atom results almost entirely from the number of protons and neutrons in the nucleus.

The sum of the protons and neutrons in an atom's nucleus is the mass number. It is the larger of the two numbers shown in most periodic tables.

<table>
<thead>
<tr>
<th>Atoms</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Mass number</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogen</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>lithium</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>aluminium</td>
<td>13</td>
<td>14</td>
<td>27</td>
</tr>
</tbody>
</table>

WHAT’S THE MASS NUMBER?

<table>
<thead>
<tr>
<th>Atoms</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Mass number</th>
</tr>
</thead>
<tbody>
<tr>
<td>helium</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>copper</td>
<td>29</td>
<td>35</td>
<td>64</td>
</tr>
<tr>
<td>cobalt</td>
<td>27</td>
<td>32</td>
<td>59</td>
</tr>
<tr>
<td>iodine</td>
<td>53</td>
<td>74</td>
<td>127</td>
</tr>
<tr>
<td>germanium</td>
<td>32</td>
<td>41</td>
<td>73</td>
</tr>
</tbody>
</table>

How many neutrons are there in these atoms?

<table>
<thead>
<tr>
<th>Atoms</th>
<th>Mass number</th>
<th>Atomic number</th>
<th>Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>helium</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>fluorine</td>
<td>19</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>strontium</td>
<td>88</td>
<td>38</td>
<td>50</td>
</tr>
<tr>
<td>zirconium</td>
<td>91</td>
<td>40</td>
<td>51</td>
</tr>
<tr>
<td>uranium</td>
<td>238</td>
<td>92</td>
<td>146</td>
</tr>
</tbody>
</table>

HOW MANY ELECTRONS?

Atoms have no overall electrical charge and are neutral. This means atoms must have an equal number of positive protons and negative electrons. The number of electrons is therefore the same as the atomic number.

Atomic number is the number of protons rather than the number of electrons, because atoms can lose or gain electrons but do not normally lose or gain protons.

<table>
<thead>
<tr>
<th>Atoms</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>helium</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>copper</td>
<td>29</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>iodine</td>
<td>53</td>
<td>74</td>
<td>53</td>
</tr>
</tbody>
</table>
**WHAT ARE THE MISSING NUMBERS?**

<table>
<thead>
<tr>
<th>Atom</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Electrons</th>
<th>Atomic number</th>
<th>Mass number</th>
</tr>
</thead>
<tbody>
<tr>
<td>boron</td>
<td>5</td>
<td>6</td>
<td>?</td>
<td>5</td>
<td>?</td>
</tr>
<tr>
<td>potassium</td>
<td></td>
<td></td>
<td>19</td>
<td>19</td>
<td>39</td>
</tr>
<tr>
<td>chromium</td>
<td>24</td>
<td>28</td>
<td>24</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>mercury</td>
<td>?</td>
<td>121</td>
<td>80</td>
<td>?</td>
<td>201</td>
</tr>
<tr>
<td>argon</td>
<td>?</td>
<td>?</td>
<td>18</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

**ATOMS: TRUE OR FALSE?**

1. The smallest of the subatomic particles are the electrons.
2. Neutrons and protons are positively charged.
3. Atomic number is the number of protons in an atom.
4. The atomic number is the larger of the two numbers shown in the periodic table.
5. The mass number of an element is the number of protons plus the number of neutrons.
6. Each element has a fixed number of protons.

**HOW ARE ATOMS ARRANGED?**

Where are the electrons found in the atom?

Electrons are not evenly spread but exist in layers called shells. (The shells can also be called energy levels). The arrangement of electrons in these shells is often called the electron configuration.

The atomic structure is mostly empty space. If the electrons are the size shown, the nucleus would be too small to see.
**How Many Electrons Per Shell?**

Each shell has a maximum number of electrons that it can hold. Electrons will fill the shells nearest the nucleus first.

- **1st shell** holds a maximum of 2 electrons.
- **2nd shell** holds a maximum of 8 electrons.
- **3rd shell** holds a maximum of 8 electrons.

This electron arrangement is written as 2,8,8.

**IONS**

- Atoms: electrically neutral.
- \# of electrons = \# of protons.

IONS are atoms that have gained or lost electrons.

The protons and electrons don’t balance out anymore, so ions carry a charge.

- Charge of ion = \# protons - \# electrons.
- (We subtract the electrons since they’re negative.)

**IONS**

- If the atom loses electrons, it’s going to have more positive charge than negative. What kind of ion is it?
  - **Positive Cations**

- If the atom gains electrons, it’s going to have more negative charge than positive. What kind of ion is it?
  - **Negative Anion**

**CHARGE OF IONS**

- If we want to specify an ion, we write the charge as a **right superscript**.
  - Cl\(^{-1}\) a chloride ion with a charge of -1.
  - Na\(^{+1}\) a sodium ion with a charge of +1.
  - O\(^{2-}\) an oxide ion with a charge of -2.

If there’s no right superscript, it’s understood to be zero and a neutral atom.
Putting it all together

- How many protons, neutrons, & electrons in each of the following:

  - $^{23}_{11}$Na $^+$
    - 11 p, 12 n, 10 e
    - Lost 1
  - $^{25}_{12}$Mg $^2$
    - 12 p, 13 n, 10 e
  - $^{34}_{16}$S
    - 16 p, 18 n, 18 e
    - Got 2
    - 9 p, 10 n, 10 e
    - Got 1
  - $^{19}_{9}$F $^-$
    - 9 p, 10 n, 10 e
    - Got 3
    - Lost 1
    - Got 2

Summary: The atom so far

- The nucleus is:
  - made up of protons and neutrons
  - positively charged because of the protons
  - dense – it contains nearly all the mass of the atom in a tiny space.

- Electrons are:
  - very small and light, and negatively charged
  - able to be lost or gained in chemical reactions
  - found thinly spread around the outside of the nucleus, orbiting in layers called shells.

What are isotopes?

Elements are made up of one type of atom, but there can be slightly different forms of the atoms in an element. Although atoms of the same element always have the same number of protons, they may have different numbers of neutrons. Atoms that differ in this way are called isotopes.

For example, two isotopes of carbon:

- $^{12}$C
  - 6 protons
  - 6 electrons
  - 6 neutrons

- $^{13}$C
  - 6 protons
  - 6 electrons
  - 7 neutrons

Most naturally-occurring carbon exists as carbon-12, about 1% is carbon-13 and a much smaller amount is carbon-14.
**Properties of Isotopes**

The isotopes of an element are virtually identical in their chemical reactions. This is because they have the same number of protons and the same number of electrons. The uncharged neutrons make little difference to chemical properties but do affect physical properties such as melting point and density. Natural samples of elements are often a mixture of isotopes.

**What Are the Isotopes of Hydrogen?**

Hydrogen-1 makes up the vast majority of the naturally-occurring element but two other isotopes exist.

- Hydrogen
  - 1 proton
  - 0 neutrons
  - 1 electron
- Deuterium
  - 1 proton
  - 1 neutron
  - 1 electron
- Tritium
  - 1 proton
  - 2 neutrons
  - 1 electron

**What Are the Isotopes of Chlorine?**

About 75% of naturally-occurring chlorine is chlorine-35 and 25% is chlorine-37.

- Chlorine-35
  - 17 protons
  - 18 neutrons
  - 17 electrons
- Chlorine-37
  - 17 protons
  - 20 neutrons
  - 17 electrons

**What Are the Isotopes of Oxygen?**

Almost all of naturally-occurring oxygen is oxygen-16, but about 0.2% is oxygen-18.

- Oxygen-16
  - 8 protons
  - 8 neutrons
  - 8 electrons
- Oxygen-18
  - 8 protons
  - 10 neutrons
  - 8 electrons

**Isotopes – True or False?**

Are these statements about isotopes true or false?

1. Isotopes of an element have the same number of protons but different numbers of neutrons.
   - True
2. Isotopes of an element have different atomic numbers but the same mass number.
   - False
3. Isotopes have the same chemical properties but different physical properties.
   - True
4. Natural samples of elements are always made up of just one isotope.
   - False
5. There are three isotopes of carbon: carbon-12, carbon-13, and carbon-14.
   - True
6. Most hydrogen occurs as hydrogen-1, with one proton and one electron, and no neutrons.
   - True
WHAT IS AN A.M.U.?
- atomic mass unit
- amu = 1/12 the mass of the C-12 atom.
- C-12 is used as the reference for atomic masses.
- Atomic mass is relative.
- 1st H-1 was the standard. It’s the lowest. 1 atom of H was 1 amu.
- Then O-16 was the standard. O combines with lots of elements. 1 atom of O was 16 atomic mass units.
- Now C-12 is the standard. 1 atom of C-12 has a mass of exactly 12 atomic mass units.

AVERAGE ATOMIC MASS
- The atomic masses reported in the periodic table represent the weighted average of the masses of the naturally occurring isotopes of that element.
  1. Convert % to decimal format. (Divide by 100%.)
  2. Multiply each isotope’s abundance factor by its atomic mass.
  3. Sum.

ATOMIC MASSES AND ISOTOPIC ABUNDANCES
- natural atomic masses = sum[(atomic mass of isotope) * (fractional isotopic abundance)]
  Or......
- Average atomic mass = (% Isotope1)(Mass Isotope 1) + (% Isotope1)(Mass Isotope 1) + ....... 100 100

AVG. ATOMIC MASS OF Si
92.21% of Si has a mass of 28
4.70% of Si has a mass of 29
3.09% of Si has a mass of 30

AVG. ATOMIC MASS OF Si
- .9221 X 28 → 25.8188
- .0470 X 29 → 1.363
- + .0309 X 30 → 0.927
  28.1088

AVG. ATOMIC MASS OF Pb
- 1.5% Pb-204. → .015 X 204 : 3.06
- 23.6% Pb-206. → .236 X 206 : 48.62
- 22.6% Pb-207. → .226 X 207 : 46.78
- 52.3% Pb-208. → .523 X 208 : 108.78
  207.24
**Another Kind of Example:**

Chlorine has two isotopes, $^{35}\text{Cl}$ and $^{37}\text{Cl}$, which have masses of 34.96885 amu and 36.96590 amu, respectively. The natural atomic mass of chlorine is 35.453 amu. What are the percent abundances of the two isotopes?

Let $x = \text{fraction } ^{35}\text{Cl}$ and $y = \text{fraction } ^{37}\text{Cl}$.

Thus:

$$34.96885x + 36.96590y = 35.453$$

Solving for $x$ and $y$:

$$0.99705x = 1.5129$$

$$x = 0.7553$$

$$y = 1 - x = 1.0000 - 0.7553 = 0.2447$$

Thus, 75.53% $^{35}\text{Cl}$ and 24.47% $^{37}\text{Cl}$.

**Mass Spectrometer**

**Mass Spectra of Neon**

**Summary Activities**
**Glossary (1/2)**

- **atom** – The smallest particle that can exist on its own.
- **atomic number** – The number of protons in the nucleus of an atom, also known as the **proton number**.
- **electron** – Negatively charged particle that orbits the nucleus of an atom.
- **element** – A substance made up of only one type of atom.
- **isotopes** – Different atoms of the same element. They have the same number of protons and electrons, but a different number of neutrons.

**Glossary (2/2)**

- **nucleus** – The dense, positively charged centre of an atom, made up of protons and neutrons.
- **neutron** – A neutral particle, with a mass of 1. It is found in the nucleus of an atom.
- **mass number** – The number of protons and neutrons in the nucleus of an atom.
- **proton** – A positively particle, with a mass of 1. It is found in the nucleus of an atom.

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**Summary of Atomic Structure**

Complete these sentences about atomic structure:

1. Elements are made up of tiny particles called ____________, which are the smallest particles that can exist on their own.
2. Atoms are made up of the subatomic particles ____________, ____________, and ____________.
3. An element’s ____________ number tells you how many ____________ are in an element's nucleus.

**Match the words about atoms to their definitions**

- **mass number**: layers of electrons
- **configuration**: particle with no charge
- **neutron**: number of protons plus neutrons
- **shells**: arrangement
- **atomic number**: number of protons
- **isotopes**: atoms with different numbers of neutrons

**Can you find eight words in the atomic structure wordsearch?**

- LLLIKGMUQYVYPY
- SPZEMODYGTVAGE
- UGESBFIRUZOLKVI
- EDMAITBXFSDCNB
- LOGMDCLHGWTOUQ
- CLWCTOYEEFJBRYYQ
- UXLKRFNASTULQ
- NYRMJERSUQOPTU
- LFCQYSSQREJOSCL
- BCAUTIONMCNUMERKU
- QRACKVXJONGPQYV

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Spring 2007
It's time to assemble all you know about atomic structure!