THE INSTITUTE OF EDUCATION

Chemistry

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Higher Level

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The mass spectrometer, principle and uses, isotopes

THE MASS SPECTROMETER

How do we know the relative atomic masses of the atoms of different elements? Atoms are too small to measure their mass directly by weighing. The mass spectrometer is an instrument that helps to investigate the presence and abundances of the isotopes of an element and the masses of molecules.
Inside there is a vacuum so that it is possible to produce and study ions that do not otherwise exist.

How a mass spectrometer works

The basic principle

If something is moving and you subject it to a sideways force, instead of moving in a straight line, it will move in a curve - deflected out of its original path by the sideways force.

Suppose you had a cannonball travelling past you and you wanted to deflect it as it went by you. All you've got is a jet of water from a hose-pipe that you can squirt at it. Frankly, it's not going to make a lot of difference! Because the cannonball is so heavy, it will hardly be deflected at all from its original course.

But suppose instead, you tried to deflect a table tennis ball travelling at the same speed as the cannonball using the same jet of water. Because this ball is so light, you will get a huge deflection.

The amount of deflection you will get for a given sideways force depends on the mass of the ball. If you knew the speed of the ball and the size of the force, you could calculate the mass of the ball if you knew what sort of curved path it was deflected through. The less the deflection, the heavier the ball.

You can apply the same principle to atomic sized particles.

THE PRINCIPLE

The principle involved is that different ions are separated according to their masses (mass / charge ratio) when moving in a magnetic field.

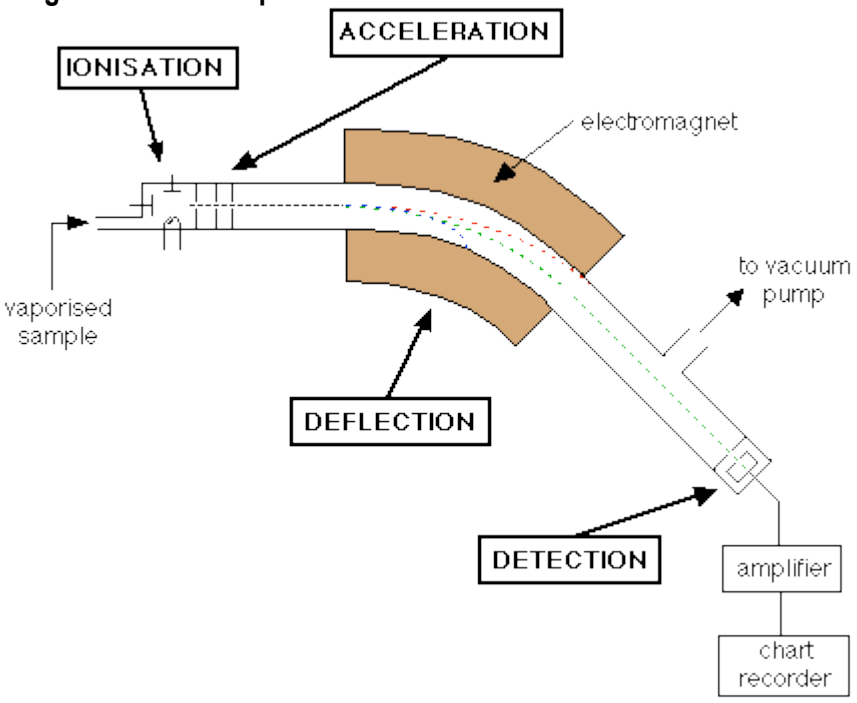
Uses of the mass spectrometer.

(a) To identify the presence of different isotopes in a sample.
(b) To show the relative abundance of the isotopes of an element.
(c) To calculate relative atomic and molecular masses.
(d) It helps in identifying compounds if they come from an unknown source.

Stages involved

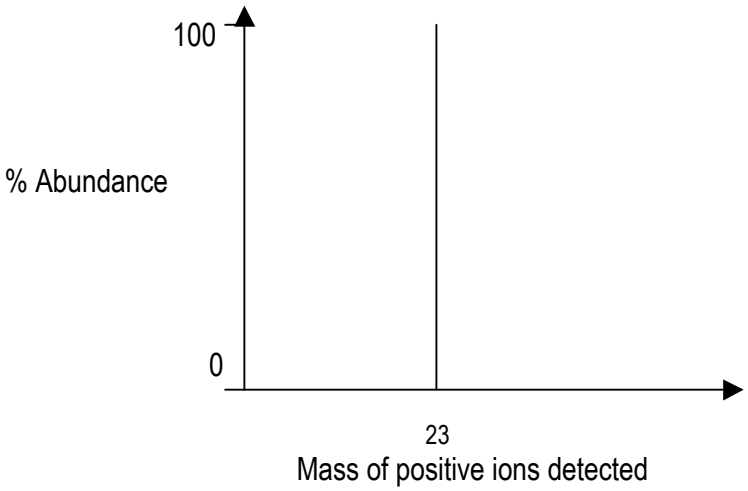
1. **Vaporisation** – the substance is injected into the mass spectrometer that contains a vacuum. The high temperature vaporises the substance. To move through the machine the particles must be in the gaseous phase.
2. **Production of positive ions** - an 'electron gun' fires high-energy electrons at the vaporised substance. This causes electrons in the vaporised substance to be removed (knocked out of orbit) and thus forms positive ions.
3. **Acceleration** – the spectrometer contains negatively charged plates/grid that attract the positive ions and causes these positive ions to move at high speeds and concentrates them into a narrow beam.
4. **Deflection**– the beam of positive ions is then deflected by a magnetic field. The lighter particles deflect readily, the heavier particles less readily so the ions are now being separated per their 'heaviness' or mass (and their charge).
5. **Detection** – these particles hit against an analyser which sends different impulses to a recording device which shows up as a series of lines and peaks on a piece of paper. The resulting 'picture' is called a mass spectrum. The detector counts the numbers of different ions hitting against it and therefore can measure the relative abundance of each type of isotope.

Diagram of a mass spectrometer -

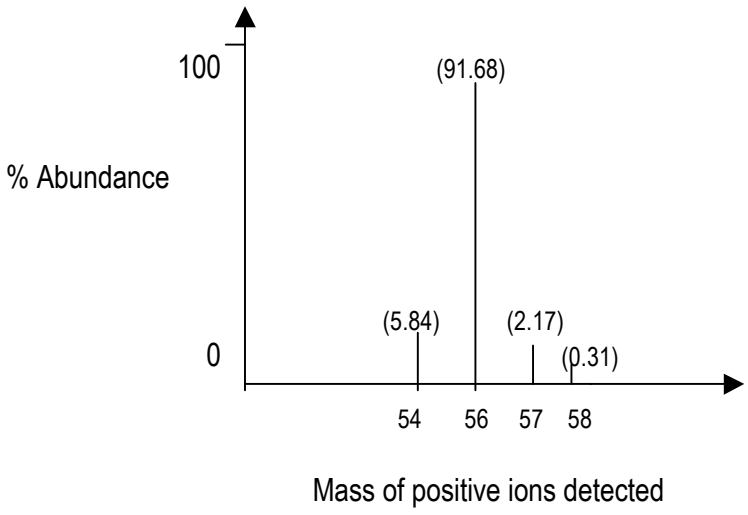


Examples of mass spectra –

Mass spectrum of sodium sample – this tells us that all the atoms in a sample of sodium have the same mass. There is only one peak.



Mass spectrum of iron – this tells us that iron may have one of four possible masses, each in a different relative abundance, as there are four peaks.



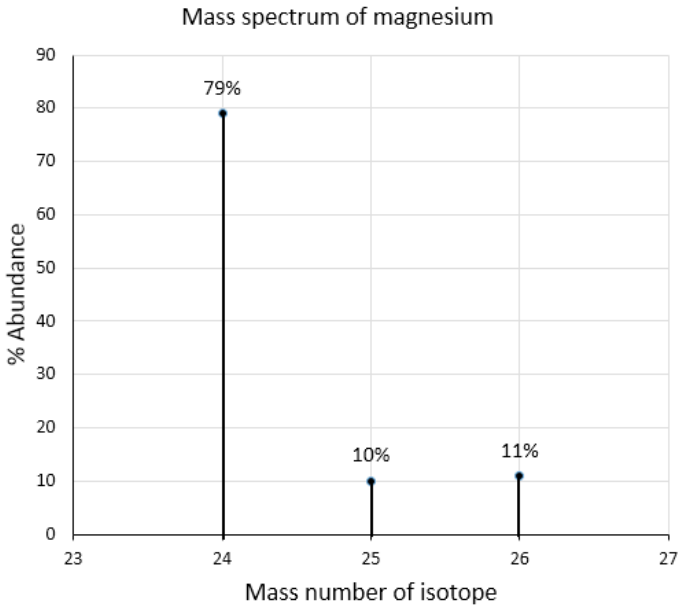
Note – it is not necessary to learn these off by heart, just recognise them for what they are.

LEAVING CERT 2018

Define (*i*) mass number of an atom, (*ii*) relative atomic mass of an element. (8) A sample of magnesium metal was introduced into a mass spectrometer and vaporised.

What were the next three fundamental processes that occurred in the mass spectrometer? (9)

The mass spectrum of the sample, given below, shows that magnesium has three naturally occurring isotopes.



Use the data given to calculate the relative atomic mass of magnesium correct to two decimal places. (6)

LEAVING CERT 2014

Define (*i*) mass number, (*ii*) relative atomic mass. (9)

Three of the five fundamental processes that occur in mass spectrometry are *detection*, *acceleration* and *vaporisation of substance*. What are the two other fundamental processes that occur in mass spectrometry? (6)

List all five processes in the order in which they occur. (3)

A sample of the element gallium is composed of 60.1% gallium–69 and 39.9% gallium–71. Calculate the relative atomic mass of gallium from this information. (7)

LEAVING CERT 2006 and 2009

What is the principle on which the mass spectrometer is based? (9)