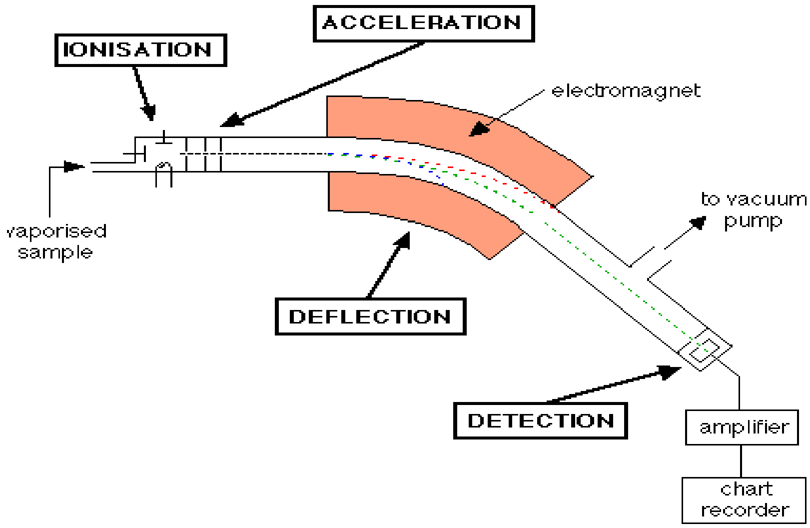
THE MASS SPECTROMETER

The most accurate method of determining atomic masses is by the use of the mass spectrometer. The principle is to determine the relative abundance of the isotopes of the element, and their isotopic masses; the weighted mean of these (that is, taking into account the percentage abundances) is then the atomic mass.



Five main operations performed by the spectrometer are:

1. The sample of the element is vaporized
2. Positive ions are produced from the vapour
3. The positive ions are accelerated by a known electric field
4. The ions are then deflected by a known magnetic field
5. The ions are then detected

*Study Aid: an easy way to remember this is through an antonym; **VIADD**: (Vaporization, Ionization, Acceleration, Deflection, Detection)

The manner in which these stages are achieved may be seen from the above figure.

1. A stream of vaporized element enters the main apparatus which is maintained under high vacuum. The sample must be in the gaseous state before they can be ionised. The mass spectrometer is operated under conditions of high vacuum to minimise collisions between ions and molecules.

2. The atoms of the element are bombarded by a stream of high-energy electrons, which on collision with the atoms knock electrons out of them and produce positive ions.

$$X_{(g)} \quad + \quad e^{-1} \longrightarrow X^{+1}_{(g)} \quad + \quad 2\ e^{-1}$$

These positive ions have different masses, depending on the masses of the molecules from which they are formed. Thus some molecules have large masses and give heavy ions, while some have small masses and give light ions.

3. The positive ion stream passes through holes in two negatively charged parallel plates to which a known electric field is applied, and the ions are accelerated by this field. A pair of slits restricts the ions into a narrow sharply defined beam.

4. They then enter a region to which a magnetic field is applied, and they are deflected by it. One of the properties of charged particles, both positive and negative is that their paths become curved as they pass through a magnetic field.

This is exactly what happens to the positive ions in the mass spectrometer as they pass through the poles of the magnet. However, the extent to which their paths are bent depends on the masses of the ions. This is because the path of a heavy ion, like that of a speeding cement truck is difficult to change, but the path of a light ion, like that of a motorcycle, is influenced more easily.

As a result, heavy ions emerge from the magnet's poles along different lines than the lighter ones. In effect, an entering beam containing ions of different masses is sorted by the magnet into a number of beams, each containing ions of the same mass.

This spreading out of the ion beam thus produces an array of different beams called a mass spectrum.

The amount of deflection also depends on the charge of the particle, greater the charge, higher the deflection. Doubly charged ions will be deflected more than singly charged and will behave in the same way as a single charged ion of half the mass.

Hence, the amount of deflection experienced by the ions depends on their charge and mass as well as the strength of the magnetic field.

5. For given electric and magnetic fields only ions with one particular mass will reach the detector at the end of the apparatus, all other ions having hit the walls of the instrument.

   By gradually increasing the strength of the magnetic field, ions of different masses may be brought successively to the detector.

   Their masses are calculated from the known applied fields, and their relative abundance is found from the relative magnitudes of the current produced in the detector.

In a mass spectrograph, (aka: mass spectrum), the number of focuses is equal to the number of isotopes present in the beam, and the height of each line indicates the proportion of each isotope present.

Summary

gas inlet ⟶ ionisation chamber ⟶ ion accelerating voltage ⟶ magnetic field ⟶ Detector

1.vaporiser	2.ioniser	3. Accelator and aligner	4. Deflector	5. Detector and Recorder

Example of an isotope calculation

Suppose that a mass spectrometer of neon was run which indicated three isotopes of neon present with atomic masses of 20, 21, and 22 and percentage proportions were:

^{20}Ne 90.9 % ^{21}Ne 0.30 % ^{22}Ne 8.80 %

Calculate the atomic mass of naturally occurring neon.

Atomic mass of neon = fraction of at. Mass due to the isotope ^{20}Ne + fraction of at. Mass due to the isotope ^{21}Ne + fraction of at. Mass due to isotope ^{22}Ne

$$= \frac{90.9}{100} \times 20 + \frac{0.30}{100} \times 21 + \frac{8.80}{100} \times 22$$

= 20.18 amu

[This is commonly known as the atomic mass, the reference standard for which is the mass of one atom of $^{12}_{6}C$ isotope which is taken as exactly 12 units of atomic mass.]

Example 2

The percentage abundances of the stable isotopes of chromium are:

^{50}Cr	^{52}Cr	^{53}Cr	^{54}Cr
4.31%	83.76%	9.55%	2.38%

a. Sketch the mass spectrum that would be obtained from naturally occurring chromium. (Let 10.0 cm represent 100 % on the vertical scale for the percentage abundance.)

b. Calculate the relative atomic mass of chromium, correct ot three significant figures.

c. Label each peak on the mass spectrum using isotopic symbols.