2 Atoms, Molecules and Ions

If an atom were the size of a football stadium, the nucleus would be a peppercorn at midfield, and it would hold nearly all of the mass. The rest is empty space with electrons in it. Rutherford's lab found this by firing particles at gold foil and watching a few of them bounce straight back, which he compared to an artillery shell bouncing off tissue paper. Everything in this chapter is bookkeeping on that picture: what is in the peppercorn, and how many electrons are around it. The mock exam gives this chapter 7 of its 70 questions.

2.1 Dalton and the Laws of Mass

Matter is made of atoms, and a reaction rearranges them without changing them. John Dalton built this into a theory in 1808 because two measurements needed an explanation.

- Matter is made of atoms. They are not created or destroyed in a chemical reaction.
- Atoms of one element are identical, and differ from the atoms of every other element.
- Atoms combine in small whole-number ratios to form compounds.

The second statement is only partly right. Section 2.4 shows that atoms of one element can differ in mass.

Atoms combine as whole units, so a compound has a fixed makeup. Water always holds about 8 g of oxygen for every 1 g of hydrogen, in any sample. This is the **law of definite proportions**.

Two elements can also form more than one compound. If one oxygen atom can join a carbon atom, and then two can, the oxygen mass per gram of carbon doubles. You cannot add half an atom. This is the **law of multiple proportions**.

Law of definite proportions
A compound has the same mass ratio of its elements in every sample.

Law of multiple proportions
Fixed mass of one element: the masses of the other are in small whole-number ratio.

EXAMPLE 2.1

Carbon forms two oxides. Oxide I holds 1.33 g of oxygen per 1.00 g of carbon. Oxide II holds 2.66 g of oxygen per 1.00 g of carbon. What is the ratio of oxygen masses?

What is asked	The ratio of oxygen masses for the same mass of carbon.
Same carbon	Both are already given per 1.00 g of carbon.
Divide	$\frac{2.66}{1.33} = 2.00$
Whole numbers	The ratio is $2:1$. Oxide II has twice as many oxygen atoms per carbon atom: CO and CO_2.
Check	A ratio of small whole numbers is what the law predicts.
Answer	**2 : 1**

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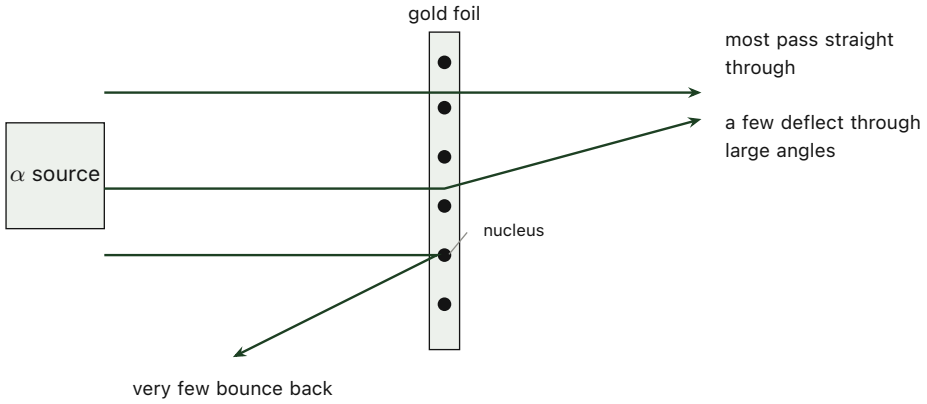
2.2 The Nuclear Atom

Dalton's atoms were solid and featureless. Three experiments in about 15 years showed that atoms have parts.

Experiment	Observation	What it showed
Cathode rays (Thomson, 1897)	A beam from a negative plate bent toward a positive plate. The bending gave its charge-to-mass ratio, the charge divided by the mass.	Atoms contain negative particles, electrons, far lighter than any atom.
Oil drop (Millikan, 1909)	Charged oil drops hung in an electric field. Every charge was a whole-number multiple of one smallest value.	The charge of one electron is 1.602×10^{-19} C. With Thomson's ratio this gives its mass.
Gold foil (Rutherford, 1911)	Most alpha particles passed straight through. A few turned through large angles. Very few bounced back.	Positive charge and most of the mass sit in a tiny nucleus. The rest of the atom is empty space.

Alpha particle
A fast, positive particle with a mass of about 4 amu, given off by some radioactive atoms.

An alpha particle is positive and heavy. If positive charge were spread evenly through the atom, as Thomson's model pictured, every alpha particle would pass through with little deflection. A particle that bounces back must have met a concentrated positive charge with a large mass. Put a peppercorn at midfield of a football stadium: the peppercorn is the nucleus and the stadium is the atom.



Reading the paths
A straight path means no nearby nucleus. A bend means a near miss. A rebound means a direct hit.

The nucleus holds **protons** and **neutrons**. Chadwick identified the neutron in 1932. Electrons move outside the nucleus.

Particle	Charge	Mass (amu)	Location
Proton	$+1$	1.007	nucleus
Neutron	0	1.009	nucleus
Electron	-1	0.00055	outside the nucleus

Atomic mass unit
One amu is one twelfth of the mass of a carbon-12 atom.

An electron is about 1800 times lighter than a proton, so the mass of an atom is the mass of its nucleus, to a good approximation. The nucleus is about 10^{-5} of the width of the atom, like the peppercorn in the stadium.

RULE Almost all of the mass is in the nucleus. Almost all of the volume is the region the electrons occupy.

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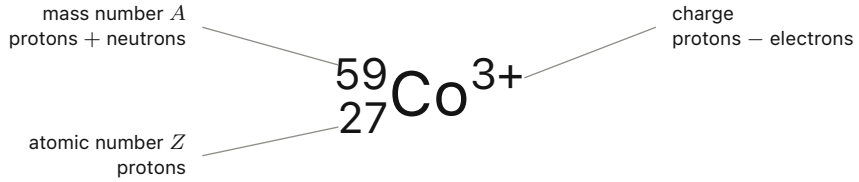
EXAMPLE 2.2

Thomson measured $e/m = 1.759 \times 10^{11}$ C/kg. Millikan measured $e = 1.602 \times 10^{-19}$ C. What is the mass of an electron?

What is asked	A mass in kilograms, from a ratio and a charge.
Rearrange	$m = \dfrac{e}{(e/m)}$
Substitute	$m = \dfrac{1.602 \times 10^{-19}\ \text{C}}{1.759 \times 10^{11}\ \text{C/kg}}$
Calculate	$m = 9.11 \times 10^{-31}$ kg
Check	Coulombs cancel and leave kilograms. A proton is 1.67×10^{-27} kg, about 1800 times heavier.
Answer	9.11×10^{-31} **kg**

2.3 Atomic Number, Mass Number and Symbols

Each element has its own number of protons. This is the **atomic number**, Z. It is the only thing that sets which element an atom is. The **mass number**, A, is the number of protons plus neutrons. It is a whole number, and it is not the same as the atomic mass on the periodic table.



Nuclide symbol
The charge is the protons minus the electrons.

Neutrons are $A - Z$. A neutral atom has as many electrons as protons. An ion has gained or lost electrons and leaves the nucleus alone. A positive ion, a **cation**, has fewer electrons than protons. A negative ion, an **anion**, has more.

Species	Protons	Neutrons	Electrons	How
$^{23}_{11}Na$	11	12	11	$23 - 11 = 12$
$^{23}_{11}Na^{+}$	11	12	10	lost one electron
$^{32}_{16}S^{2-}$	16	16	18	gained two electrons

RULE Protons name the element. Neutrons name the isotope. Electrons set the charge.

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PRACTICE SET 2A 12 questions · 18 minutes

1. Thomson found that cathode rays bend toward a positive plate and have the same charge-to-mass ratio for every gas. What does this show?

(A) Atoms contain a small, dense, positive nucleus.

(B) Atoms are mostly empty space.

(C) Atoms contain negative particles far lighter than any atom.

(D) Each electron carries a charge of 1.602×10^{-19} C.

2. What did Millikan's oil-drop experiment measure, and what did that allow?

(A) The charge-to-mass ratio of the electron, which gave its charge.

(B) The charge of the electron, which gave its mass with Thomson's ratio.

(C) The mass of the proton, which showed the nucleus is dense.

(D) The deflection of alpha particles, which gave the nuclear charge.

3. Which list ranks the three subatomic particles from smallest to largest mass?

(A) electron, proton, neutron

(B) neutron, proton, electron

(C) proton, neutron, electron

(D) electron, neutron, proton

4. In the gold-foil experiment a very small fraction of alpha particles bounced almost straight back. Which conclusion does this support?

(A) Electrons are spread evenly through a positive sphere.

(B) Alpha particles are negatively charged.

(C) Gold atoms have the same mass as alpha particles.

(D) Positive charge and most of the mass sit in a very small region.

5. How many protons, neutrons and electrons are in one ion of $^{59}_{27}\mathrm{Co}^{3+}$?

(A) 27 protons, 32 neutrons, 24 electrons

(B) 27 protons, 32 neutrons, 30 electrons

(C) 27 protons, 59 neutrons, 24 electrons

(D) 27 protons, 32 neutrons, 27 electrons

6. A neutral atom has mass number 31 and 15 electrons. How many neutrons does it have?

(A) 15 **(B)** 16 **(C)** 31 **(D)** 46

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