

King of Dumbs

Level: ♦ Intermediate

What is a wall made of? Atoms and elements without fear

Protons, neutrons and electrons, elements and isotopes, diamond versus graphite and the mole, explained with building blocks, in three levels.

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<https://kingofdumbs.com/en/lessons/atoms-and-elements>

What you'll learn

- What's inside an atom
- Element, isotope and ion
- Molecule and bond: diamond versus graphite
- The mole

Symbols you'll meet

Δ change: how much it moved (♠) · E_a subscript: the label underneath (♦♠) · H° ° for standard, not degrees (♠) · Σ sum: add them all up (♠) · x_i index i: item number i (♠) · $\approx$ approximately equal (♦♠) · $\sim$ on the order of / distributed as (♠) · $\rightarrow$ arrow: turns into / tends to (♠) · 10^{-3} negative exponent: divide (♦♠) · J/(mol·K) compound units (♦♠) · α alpha: learning rate or particle (♦♠)

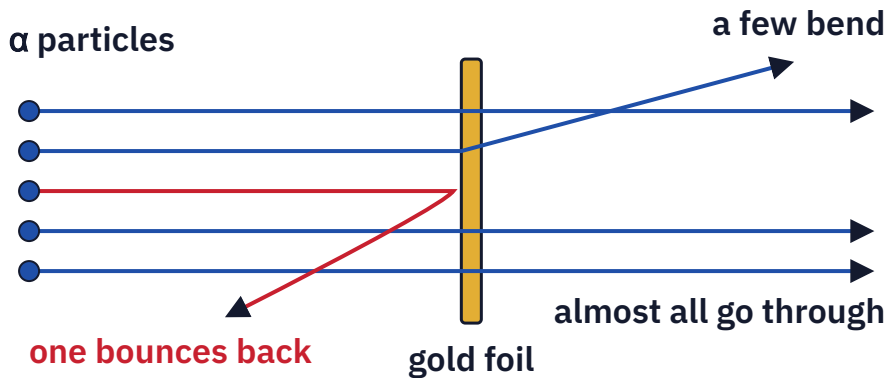
Look at a wall. It's made of bricks, and each brick is made of baked clay. Now imagine you keep breaking it: the brick into chunks, the chunks into grains, the grains into smaller and smaller bits. Keep going and you always end up at the same place: **atoms**.

The dumb question of this lesson is: **what is a wall made of?** The answer is surprising: just three kinds of piece. They're the same ones that make up your hand and the air you breathe. What changes is how many you use and how you put them together, just like a box of building blocks.

This lesson teaches four ideas: what's inside an atom, what makes an atom one element or another, how the same pieces give very different things, and how you count atoms by the heap.

Pick your card: ♣ if you're starting from scratch, ♦ if a simple formula doesn't scare you, ♠ if you want the notation. You can switch at any time.

Inside the atom



An atom is on the order of 10^{-10} m across and its nucleus on the order of 10^{-15} m: the nucleus is **about a hundred thousand times smaller** in diameter. Masses are measured in **atomic mass units (u)**, roughly what a proton weighs:

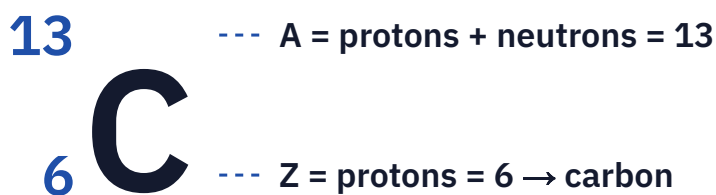
Piece	Where it is	Charge	Mass
Proton	nucleus	+1	1.007 u
Neutron	nucleus	0	1.009 u
Electron	around it	-1	0.000 55 u

The protons and neutrons of the nucleus weigh almost the same, and a proton weighs as much as **1,836 electrons**. That's why more than 99.9% of an atom's mass is in the nucleus.

How do we know there's a nucleus if we can't see it? In 1911, Rutherford, Geiger and Marsden fired **α particles** (tiny and positively charged) at a very thin sheet of gold. Almost all went straight through, but a few bounced back. That only makes sense if the positive charge is packed together, with almost all the mass in a tiny point, and the rest of the atom is **almost all empty**. The neutron was discovered later, in 1932.



Elements and isotopes



Na^+ : sodium with one electron fewer

Two numbers describe a nucleus:

- The **atomic number (Z)** is the number of protons. It identifies the element: $Z = 6$ is carbon, always.
- The **mass number (A)** is protons plus neutrons. The **neutrons are $A - Z$** .

It's written with A on top and Z below, to the left of the symbol: $^{13}_6\text{C}$. Since the symbol already gives Z, it's often left out: ^{13}C , or "carbon-13".

The **isotopes** of an element have the same Z and a different number of neutrons. They behave almost the same in chemistry; what changes is the mass and whether the nucleus holds. Natural carbon is a mixture: 98.9% ^{12}C and 1.1% ^{13}C , both stable (that's their **abundance**). There are also traces of ^{14}C , which forms high in the atmosphere and is radioactive: from any amount, half decays in about 5,700 years. That time is called the **half-life**.

An **ion** is an atom with more or fewer electrons than protons, and so it has a **charge**. Na^+ has 11 protons and 10 electrons: charge +1, and it's still sodium.

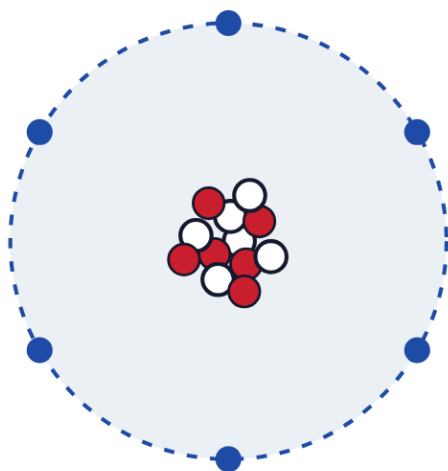
The King of Dumbs says:

Add neutrons to a carbon and it's still carbon. To change the element you have to touch the protons, and that's not chemistry anymore.



Try it: build an atom

Move the protons, neutrons and electrons. See which element you get, whether the nucleus holds and whether the atom ends up charged. Try 6 protons and 8 neutrons.



^{12}C

carbon-12

- proton
- neutron
- electron

Protons (they decide the element) 6

Neutrons 6

Electrons 6

Element Carbon (C)

Isotope carbon-12

Written as ^{12}C

Nucleus Stable: it doesn't fall apart.

Charge Neutral: as many electrons as protons.

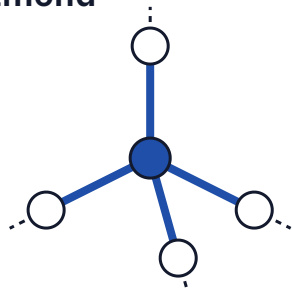
Carbon-12. Stable: it doesn't fall apart. Neutral: as many electrons as protons.



Interactive widget. Try it on the web: <https://kingofdumbs.com/en/lessons/atoms-and-elements>

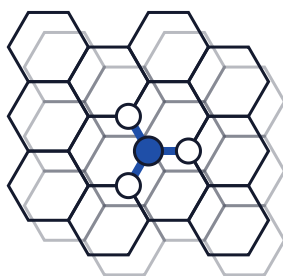
Same pieces, built differently

diamond



4 neighbours, in 3D

graphite



3 neighbours, in sheets

A **molecule** is two or more atoms held together by **chemical bonds**. It's written as a formula: H_2O is one oxygen and two hydrogens; O_2 , two oxygens. A molecule can be made of a single element.

Atoms can also form huge networks instead of separate molecules. Pure carbon forms two well-known ones:

	Diamond	Graphite
Neighbours of each atom	4, at the corners of a tetrahedron	3, in flat sheets of hexagons
Between layers	No layers: 3D network	Weak forces
Hardness	Among the hardest known	Soft: pencil lead
Electricity	Doesn't conduct	Conducts

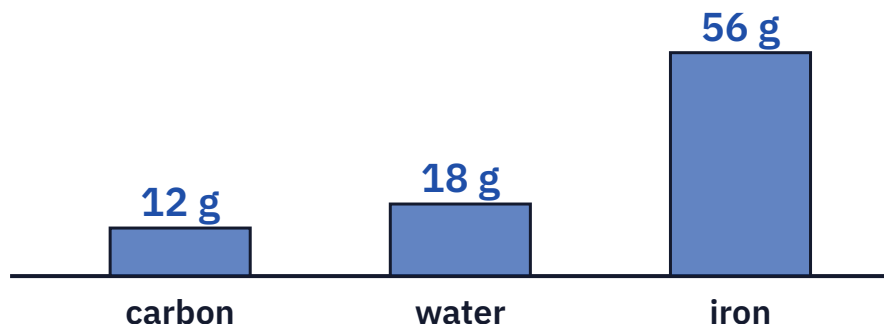
In a graphite sheet, the centres of neighbouring atoms are **$1.4 \times 10^{-10} \text{ m}$** apart.

Watch out for a trap: an **element** isn't the same as a **substance**. Carbon is an element; diamond, graphite and CO_2 are different substances made from it. Changing the substance (rearranging the bonds) is chemistry; changing the element means touching the nucleus.

At 25°C , graphite is **the most stable form** of carbon, and yet a diamond **doesn't turn** into graphite: you'd have to **break its bonds**, and that takes a huge amount of energy. Why a change that "should" happen doesn't is the subject of another lesson on this path.

Counting atoms: the mole

Always 6×10^{23} things; different mass



The **mole** is the unit for counting particles. Since 2019, one mole is **exactly $6.022\,140\,76 \times 10^{23}$** entities (atoms, molecules, ions...), Avogadro's number. It used to be defined as the number of atoms in 12 g of carbon-12.

The handy part is that what a mole weighs, in **grams per mole**, has the same digits as the mass of one particle in u:

- Carbon: 12.011 g/mol.
- Water: $2 \times 1.008 + 15.999 = 18.015$ g/mol.
- Iron: 55.845 g/mol.

Example: a glass with 250 g of water is $250 / 18.015 \approx 13.9$ mol, that is, $13.9 \times 6.022 \times 10^{23} \approx \mathbf{8.4 \times 10^{24}}$ molecules.

Why does carbon weigh 12.011 and not exactly 12? Because natural carbon is a **mixture of isotopes**: almost all ^{12}C , with a little ^{13}C , which is heavier.

And a trap: a mole **isn't a mass**, it's a number of things. One mole of carbon is 12 g; one of iron, almost 56.



Final challenge

1. An atom has 6 protons and 8 neutrons. What is it?

- a. Nitrogen, because it has 14 pieces in the nucleus
- b. Carbon-14: 6 protons is carbon
- c. Oxygen, because it has 8 neutrons

2. What's the difference between a diamond and pencil lead?

- a. Diamond has an element graphite doesn't
- b. Both are just carbon, but their atoms hook together differently
- c. Graphite is dirty carbon

3. A mole of water and a mole of iron have...

- a. The same mass
- b. The same number of particles
- c. The same volume



In three sentences

1. Everything you touch is made of atoms, and every atom is three pieces: protons and neutrons in a tiny nucleus that holds almost all the mass, and electrons around it.
2. Protons decide the element, neutrons the isotope and electrons the charge: changing neutrons or electrons doesn't turn carbon into anything else.
3. The same pieces built differently give different things (diamond and graphite are just carbon), and to count them we use the mole, a giant dozen of 6×10^{23} .



Sources

- Atom, nucleus, particles and sizes: OpenStax, *Chemistry 2e*, [2.2](#) and [2.3](#) (table 2.2, the blueberry and the stadium), cross-checked with [OpenStax, University Physics vol. 1, 1.1](#). Molecules: [OpenStax, 2.4](#).
- Nuclear radius and density, and half-lives: [OpenStax, University Physics vol. 3, 10.1](#), cross-checked with [HyperPhysics](#) and with TUNL, [3H](#) and [14C](#). Carbon-14 in the atmosphere: [OpenStax, Chemistry 2e, 21.3](#).
- History: Rutherford, *Phil. Mag.* 21, 669 (1911), [doi:10.1080/14786440508637080](#); Chadwick, *Nature* 129, 312 (1932), [doi:10.1038/129312a0](#).
- Constants (CODATA 2022): [m_p/m_e](#), [u](#), [M_u](#) and [N_A](#). Definition of the mole and the elementary charge: [BIPM, SI Brochure](#).
- Stable isotopes and abundances: [CIAAW](#). Standard atomic weights (2024): [CIAAW](#). Representative masses and fractions for carbon: [NIST](#).
- Diamond and graphite: [OpenStax, Chemistry 2e, 10.5](#) and [UW–Madison, Chem 109, D26.1](#). Bonds: [OpenStax, 7.5, table 7.3](#). Formation energies: [OpenStax, appendix G](#).
- The mole as a dozen and molar mass: [OpenStax, Chemistry 2e, 3.1](#).

How this lesson was made: researched and written with help from Claude, from the sources above, checked and cross-checked against a second source between 13 and 15 October 2026. Numbers without their own link are calculations from them. The drawings are our own.

Answers

1. **b)** Carbon-14: 6 protons is carbon. That's it. Protons decide the element; neutrons, the isotope.
2. **b)** Both are just carbon, but their atoms hook together differently. Right. Same pieces, different build: 4 neighbours in diamond, 3 in graphite.
3. **b)** The same number of particles. Exactly. A mole is a number, like a dozen: 6×10^{23} . They weigh different amounts: 18 g and almost 56 g.

A King of Dumbs lesson, kingofdumbs.com. Offline version; the original, with widgets you can play with, is at: <https://kingofdumbs.com/en/lessons/atoms-and-elements>

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