Teacher guide: the atom to scale simulation

Quick reference

The simulation travels in ×10 jumps from the atom down to its nucleus, using the real sizes of eight elements. Its main use is in ESO 3 (Year 10 in the UK, 9th grade in the US), with applications in ESO 2 and ESO 4.

Item	Details
Link	simulaciencia.es/en/simulations/atomo-real/
Year groups	ESO 3 (main use), ESO 2, ESO 4; occasional use in Bachillerato 1 and Bachillerato 2 Physics
Subject	Physics and Chemistry
Suggested time	15–20 minutes of explanation with the simulation projected
Equipment	Projector or interactive whiteboard; runs in the browser, also on phones and tablets, with nothing to install
Prior knowledge	Protons, neutrons and electrons; powers of 10; units of length (m, nm, pm)
Accessibility	Dark Mode, Light Mode and High Contrast (gear button). “Tablet / Interactive whiteboard” interface size for touchscreens. Keyboard: → zooms in, ← zooms out, R restarts

How the simulation works

The screen has three areas. On the left, the panel with “Quick guide”, “Element” and “Zoom journey”. In the centre, the canvas with the atom and a dimension line that measures the diameter drawn. At the bottom, a strip of bars for the comparison at real scale. When it opens it shows hydrogen at “Natural scale”.

Mode	What the teacher controls	What it shows
Natural scale (start)	Element: Hydrogen, Helium, Carbon, Oxygen, Sodium, Iron, Gold or Uranium	The atom with its shells and electrons. The dimension line gives the real diameter, for example “D = 62 pm = 6.20 × 10^{-11} m” for hydrogen. A box warns: “The nucleus is at the centre, but it is too small to see.”
Zoom in	“Zoom in →” button, four ×10 jumps	The image is magnified ×10 at each jump. While the nucleus cannot be seen, the dimension line is the same length on screen but represents a length ten times smaller. The nucleus appears first as a red dot and then with its nucleons
End of the journey	Fourth press of “Zoom in →”	The label “Nucleus reached! ×10,000”, the whole nucleus in the centre of the canvas and the box “You are looking at the nucleus. The whole atom is 25,833 times bigger…” (hydrogen)
Zoom out	“← Zoom out” button, up to four jumps from natural scale	The atom shrinks and the dimension line shows larger regions, up to 620 nm for hydrogen
Bottom strip	Gear: “Show intermediate zoom lines” and “Show pixels on the bars” (off at the start)	One bar for the atom and another for the nucleus, at the same scale. With the first checkbox, bars for “1/10 of the atom”, “1/100 of the atom”, etc. appear

Three elements support the explanation:

- **The element card.** Below the selector appear “Protons (Z)”, “Neutrons (N)”, “Diameter of nucleus”, “Diameter of atom”, “Atom is bigger than its nucleus” and “Electron shells”. For hydrogen: 2.4 fm, 62 pm and 25,833 times.
- **The dimension line in scientific notation.** Each jump shows the diameter in the most convenient unit and in metres, for example “D = 2.4 fm = 2.40 × 10^{-15} m”. It lets you count the powers of 10 out loud.
- **The nucleus ruler in the strip.** The red bar for the nucleus sits on a track as long as the atom. The track has a mark every 100 nuclear diameters (“100·D”, “200·D”…). For hydrogen there are 258 marks; when they are very close together only one in every few is labelled.

The “Quick guide” drop-down summarises what you see, the zoom journey, the bottom strip and the keyboard shortcuts.

Use in each year group

In ESO 2 the simulation illustrates Rutherford's model. In ESO 3 it works on atomic structure with scientific notation. In ESO 4 it supports the comparison of models and electron shells. The curriculum content quoted is from the LOMLOE Physics and Chemistry curriculum of the Community of Madrid (Spain), in our own translation.

ESO 2: Rutherford's atom

Ages 13–14 · Year 9 in the UK · 8th grade in the US

Curriculum content. Block A: “the laboratory and virtual environments”. Block B: “The first atomic models: the Thomson model and the Rutherford model”, “Introduction to the periodic table of the chemical elements” and “Atomic numbers”.

Objectives. Recognise that the atom has a central nucleus with electrons around it. Understand that the nucleus is very small compared with the atom. Relate the atomic number to the number of protons.

Teaching sequence (15–20 min).

1. Hydrogen at “Natural scale” (starting set-up). Ask where the nucleus is. Read the box: it is at the centre, but it cannot be seen.
2. Recall Thomson's model: positive charge spread throughout the atom. Contrast it with Rutherford's: positive charge concentrated in a tiny nucleus.
3. Press “Zoom in →” one jump at a time. After the first, the nucleus is still invisible and the label reads “Magnified ×10”.
4. Carry on until a red dot appears, on the second or third jump depending on the screen. On the fourth and last jump you can see the whole nucleus and the label “1p · 0n”.
5. Read “Atom is bigger than its nucleus”: 25,833 times. Put it into words: if the nucleus were a 1 cm marble, the atom would measure about 258 m.
6. Switch to Carbon and read “Protons (Z)”: 6. Point out that Z identifies the element and appears in the selector as “Carbon (Z=6)”.

ESO 3: atomic structure to scale

Ages 14–15 · Year 10 in the UK · 9th grade in the US

Curriculum content. Block A: “Unit conversion” and “Scientific notation. Significant figures”. Block B: “Atomic structure of matter. Isotopes.”, “Atoms and ions” and “The periodic table and the properties of the

elements".

Objectives. Describe the atom as a nucleus with protons and neutrons and an outer region with electrons. Express atomic and nuclear sizes in scientific notation. Calculate how many times bigger the atom is than the nucleus. Interpret Z, N and A.

Teaching sequence (15–20 min).

1. Hydrogen at "Natural scale". Write the dimension line on the board: D = 62 pm = 6.20×10^{-11} m. Review pm = 10^{-12} m.
2. Press "Zoom in →" once. The dimension line changes to "D = 6.2 pm = 6.20×10^{-12} m". Ask what has happened to the exponent: it goes down by one at each jump.
3. Keep zooming in until the dimension line changes to "Hydrogen nucleus", with "D = 2.4 fm = 2.40×10^{-15} m". Introduce the femtometre, 10^{-15} m.
4. Divide on the board: 6.20×10^{-11} m / 2.40×10^{-15} m ≈ 2.6×10^{4}. Check it against "Atom is bigger than its nucleus": 25,833 times.
5. Switch to Sodium. Read Z = 11 and N = 12, and deduce A = 23. On the fourth jump the nucleus shows "11p · 12n". Count 2 + 8 + 1 = 11 electrons in "Electron shells": the atom is neutral.
6. Finish with Uranium: 92 protons and 146 neutrons (uranium-238). Explain that another isotope would change N, not Z. The simulation does not let you change it.

ESO 4: atomic models and electron shells

Ages 15–16 · Year 11 in the UK · 10th grade in the US

Curriculum content. Block B: "Atomic models: historical development of the main classical and quantum atomic models and description of the subatomic particles, establishing their relationship with advances in physics and chemistry", "Elementary particles" and "Electron configuration of the elements and position in the periodic table".

Objectives. Place Rutherford's model and the shell model in their historical development. Describe protons, neutrons and electrons by where they are found. Relate the number of shells to the period. Recognise the limits of drawing orbits.

Teaching sequence (15–20 min).

1. Gold at "Natural scale". Recall Rutherford's experiment with gold foil. Ask why almost all the alpha particles went through the foil.
2. Zoom in to the fourth jump: the nucleons appear with the label "79p · 118n". Read the ratio, 19,478 times. Almost the whole atom is space with no nuclear matter.
3. Go back with "Restart journey" and read "Electron shells": "6 (K:2, L:8, M:18, N:32, O:18, P:1)". Relate six shells to period 6.
4. Compare Sodium, "3 (K:2, L:8, M:1)", with Iron, "4 (K:2, L:8, M:14, N:2)". Point out that the M shell of iron does not have 8 electrons.
5. Point out the blue box: "Electrons are shown as dots so you can see which shell they are in, not to show their real size." Explain that neither the Bohr–Sommerfeld model nor the quantum model has sharp circular orbits.

Bachillerato 1: occasional review

Ages 16–17 · Year 12 in the UK · 11th grade in the US

There is no specific content on nuclear size. The simulation can be used for review when dealing with "Periodic properties of the chemical elements: atomic radius, ionisation energy and electron affinity" (Block A). For example, sodium (Z = 11) has a diameter of 332 pm and gold (Z = 79), 272 pm. Size does not increase with Z. All the radii are covalent and come from the same table, so they can be compared with each other (see simplifications).

Bachillerato 2 Physics: the size of the nucleus

Ages 17–18 · Year 13 in the UK · 12th grade in the US

In Block D, the simulation illustrates "Atomic nuclei and the stability of isotopes" and "The atomic nucleus: nuclear forces and binding energy". The nuclear diameter is calculated with R = 1.2 fm · A^(1/3). Compare Hydrogen (2.4 fm) with Uranium (14.9 fm): the ratio is 6.2, the cube root of 238. From this it follows that the nuclear volume grows with A and the nuclear density is almost constant.

Misconceptions it helps to address

The simulation mainly tackles the idea of a solid atom with a large nucleus. Each row gives a common prior idea and how to break it down with the simulation.

Students' idea	Correct idea	How to show it
"The nucleus takes up a good part of the atom, as in textbook drawings"	The atom is between 14,699 and 48,643 times bigger than its nucleus	Hydrogen, "Natural scale": the nucleus cannot be seen. Read "Atom is bigger than its nucleus": 25,833 times
"The atom is a little solid ball"	Almost the whole atom is empty space between the nucleus and the electrons	Gold, zoom in four jumps: the nucleus is visible and there is nothing around it; the K shell is off the screen
"There is air between the nucleus and the electrons"	Air is made of molecules, which in turn are atoms; inside the atom there is empty space	Hydrogen at the first jump: the whole canvas is the inside of the atom and contains no particles
"With a magnifying glass or a slightly stronger microscope you can see the nucleus"	You need about four orders of magnitude of magnification beyond the atom	Press "Zoom in →" once: at ×10 the box still says that the nucleus is too small to see
"Atoms with more protons are much bigger"	Atomic size does not increase in proportion to Z	Compare the "Diameter of atom" of Sodium (Z = 11, 332 pm) and Gold (Z = 79, 272 pm)
"All nuclei are the same size"	The nucleus grows with the number of nucleons	Compare "Diameter of nucleus": 2.4 fm for Hydrogen and 14.9 fm for Uranium
"Electrons are little balls the size of the dots drawn"	Electrons have no measurable size at this scale	Read the blue box on the canvas, which explains that the dots only show the shell

Simplifications worth knowing

The simulation puts the idea "the nucleus is tiny compared with the atom" first. To do so it simplifies the drawing of the electron shells and the nucleus. It is worth knowing about these liberties so as not to reinforce wrong ideas by accident.

1. **The journey does not reach the exact size of the nucleus.** There are four jumps (×10,000) for every element, although the real ratio goes from 14,699 (Helium) to 48,643 (Sodium). At the end the nucleus

fills between a fifth and two thirds of the atom's circle; the “You are looking at the nucleus” box gives the exact factor.

2. **The jumps are powers of 10.** The “Quick guide” gives the range (from 15,000 to 49,000 times) and each element's card gives its exact ratio. It is best to use the one on the card in calculations.
3. **The jump at which the nucleus appears depends on the screen.** The red dot appears when its radius exceeds 0.5 pixels. The nucleons are drawn from 5 pixels and the “p · n” label from 20. On a small screen it can take one more jump.
4. **Shells as circles.** The shells grow with n^2, as in the Bohr atom: the inner ones are crowded near the nucleus and spread apart when you zoom in. The electrons move in circular orbits. From ESO 4 onwards it is worth reminding students that there are no defined paths.
5. **Covalent radii.** All the radii are covalent and come from the same table (Cordero et al., 2008): for example, 31 pm for hydrogen and 136 pm for gold. The diameter of the atom is twice that. Other tables (metallic radii, van der Waals radii) give different values: the “size” of an atom depends on how it is measured.
6. **Nucleus from an empirical formula.** The nuclear diameter comes from 2 · 1.2 fm · A^(1/3). For a proton it gives 2.4 fm, a little more than its measured size. In Bachillerato 2 it is worth presenting it as an approximation.
7. **A flat nucleus with a sharp edge.** Protons (red) and neutrons (grey) jiggle at random inside a circle. In reality the nucleus is three-dimensional and its surface is diffuse.
8. **A single isotope per element.** Each element has a fixed mass number: H-1, He-4, C-12, O-16, Na-23, Fe-56, Au-197 and U-238. Isotopes have to be discussed verbally.
9. **Spaced-out ruler labels.** When the “100·D” marks are very close together, only one in every few is labelled so they can be read; the ones in between are still marked.

Student activity worksheet

The activity worksheet follows a predict, observe and explain structure. Each activity links to the simulation already set up, so it works in the computer room, with tablets or as homework. It downloads in Word and LibreOffice formats so it can be adapted.

Year group	Activities	Suggested time
ESO 2 (Year 9)	Before you start, activities 1, 2 and 4, questions 3 and 4 of Apply what you have learnt, Review your ideas and Self-assessment	One lesson
ESO 3 (Year 10)	Before you start, activities 1 to 6, Apply what you have learnt, Review your ideas and Self-assessment	One 50–55 minute lesson
ESO 4 (Year 11)	Activities 4 to 6 and Going further	30 minutes

The “Before you start” table collects five prior ideas about the atom. It is best not to correct it at the beginning: students come back to it in “Review your ideas”. The jump at which the nucleus starts to be visible depends on the screen size.

Answers

Section	Answer
Before you start	a) F: the atom is about 25,000 times bigger (activity 2). b) F: it would need to be magnified thousands of times (activity 1). c) F: the dots show the shell, not the size (activity 6). d) F: gold, with 79 protons, is smaller than sodium (activity 5). e) T: Z identifies the element (activity 4)
Activity 1	Natural scale: not visible; D = 62 pm = 6.20 × 10^{-11} m. ×10: not visible; 6.2 pm. At around ×100 or ×1000 a red dot appears. ×10,000: "Nucleus reached!", D = 2.4 fm = 2.40 × 10^{-15} m. It cannot be seen because it is very much smaller than the atom
Activity 2	Nucleus 2.4 fm = 2.4 × 10^{-15} m; atom 62 pm = 6.2 × 10^{-11} m; 25,833 times. 6.2 × 10^{-11} / 2.4 × 10^{-15} ≈ 2.6 × 10^{4}. With a 1 cm nucleus, the atom would measure about 258 m, like two or three football pitches end to end
Activity 3	Jump 0: the atom, 272 pm = 2.72 × 10^{-10} m. Jump 1: the atom, 27.2 pm = 2.72 × 10^{-11} m. From jump 2 (depending on the screen) the scale bar measures the nucleus: 14 fm = 1.4 × 10^{-14} m. The exponent goes down by 1 at each jump, because each jump magnifies ×10. 2.72 × 10^{-10} / 1.4 × 10^{-14} ≈ 1.9 × 10^{4}: 19,478 times
Activity 4	Carbon: 6, 6, 12, 6, 2 (K:2, L:4). Oxygen: 8, 8, 16, 8, 2 (K:2, L:6). Sodium: 11, 12, 23, 11, 3 (K:2, L:8, M:1). Iron: 26, 30, 56, 26, 4 (K:2, L:8, M:14, N:2). It is neutral because it has as many electrons as protons. Z identifies the element
Activity 5	Sodium: 6.83 fm and 332 pm. Gold: 14 fm and 272 pm. Uranium: 14.9 fm and 392 pm. The nucleus grows with Z (and A); the atom does not: it depends on how many shells it has and how strongly the nucleus attracts the electrons
Activity 6	"Electrons are shown as dots so you can see which shell they are in, not to show their real size." Gold: 6 shells (K:2, L:8, M:18, N:32, O:18, P:1). Electrons are not little balls going round in circles: in the current model we only know where they are most likely to be found (orbitals)
Apply what you have learnt	1) 6.2 × 10^{-11} m; 2.4 × 10^{-15} m; 1.5 × 10^{-10} m. 2) 1.52 × 10^{-10} / 5.49 × 10^{-15} ≈ 2.77 × 10^{4}, about 27,700 times. 3) 13 protons, 14 neutrons and 13 electrons. 4) Almost all the mass is in the nucleus, which takes up a tiny part of the volume of the atom
Going further	1) $^{238}_{92}U$; uranium-235 has the same 92 protons and 143 neutrons (another isotope). 2) Ten 1/10 bars fit; in hydrogen about 25,800 nuclei would fit in a row

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