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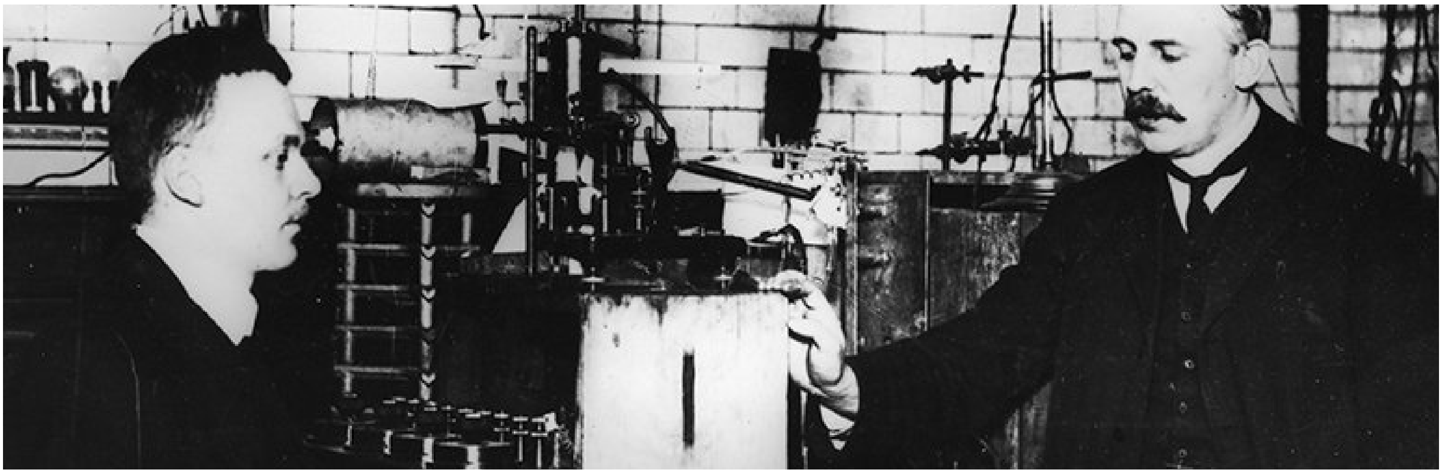

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Investigating the atom

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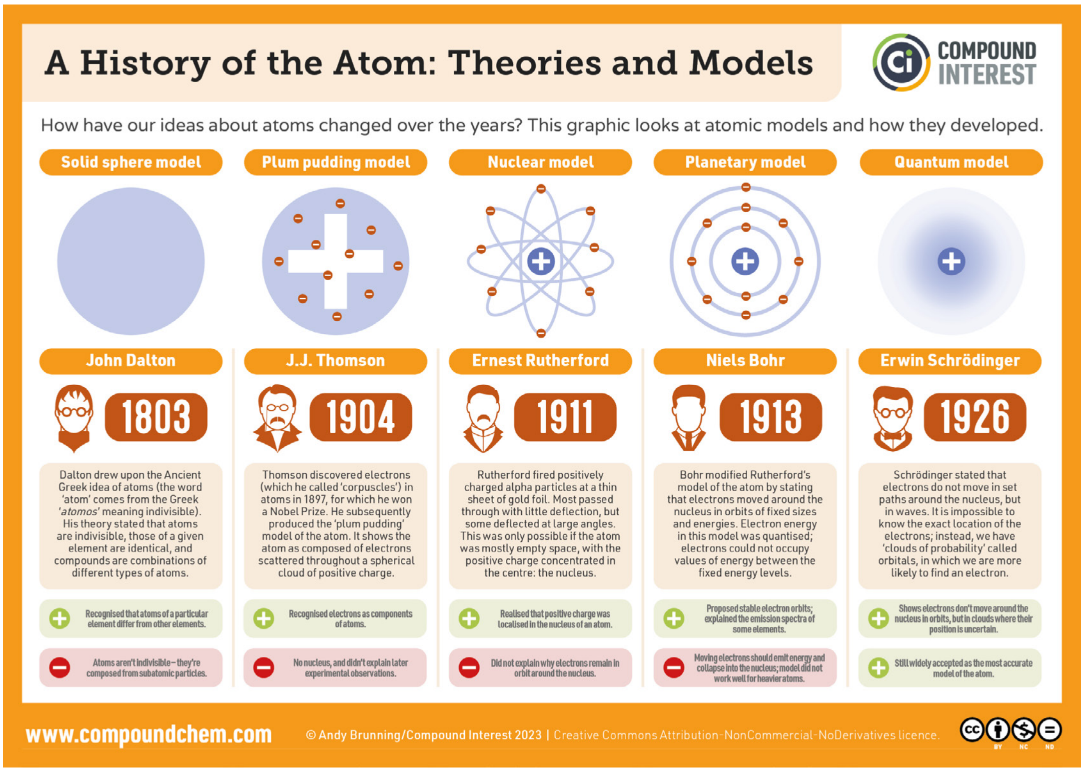
Following Rutherford's steps to see inside the atom.

This activity is aimed at students aged 14–19 years old. In this activity, students learn to:

- recognize that scientific models are not direct copies of reality, but explanatory tools used to make sense of observations;
- understand that models can be proposed, tested, improved or rejected based on evidence;
- experience how scientists infer the internal structure of systems that cannot be directly observed;
- develop and represent hypotheses using diagrams, explanations and physical or conceptual models;
- use tables and graphs to identify patterns in experimental results;
- relate measured data to a mathematical prediction, such as the dependence of the scattering on angle;
- discuss the limits of scientific conclusions, including uncertainty, indirect evidence and alternative interpretations;
- work collaboratively by sharing roles, discussing ideas, justifying conclusions and presenting arguments based on evidence.

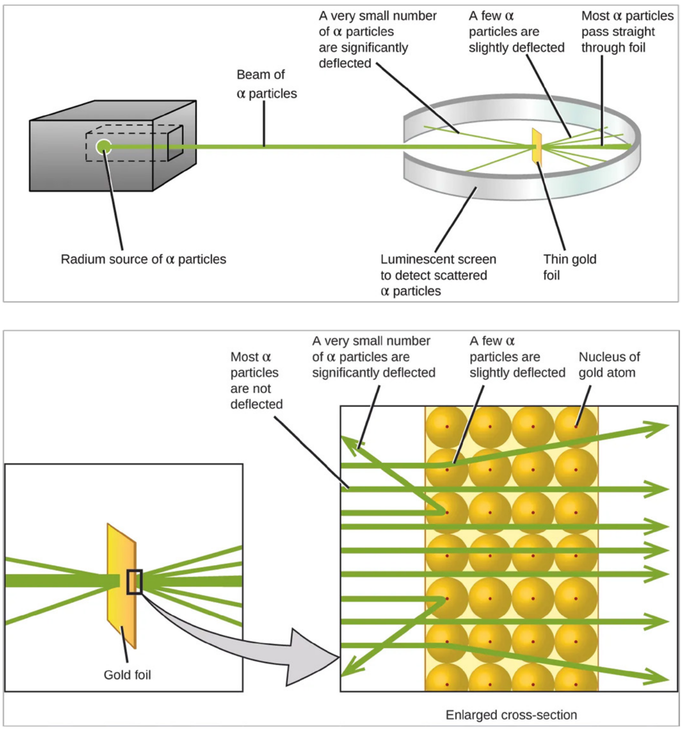
Introduction

The structure of matter and the development of atomic models are standard topics in science curricula. In many classrooms, however, atomic models are introduced mainly through a historical sequence – Dalton, Thomson, Rutherford, Bohr – and later developments are presented one after another, often as a story of successive discoveries. Research on the nature of science has emphasised that students should understand scientific knowledge as evidence-based, tentative and model-dependent, rather than as a fixed body of facts.[1,2] However, when historical episodes are presented only as linear narratives of discoveries, they may oversimplify the way scientific knowledge is actually produced.[3]



This can make it difficult for students to understand the role of models in science. Atomic models are not direct pictures of atoms, but theoretical constructions that organise observations, make predictions and can be challenged by new data. In the case of Rutherford's atomic model, for example, the key issue was not simply that a new model appeared after Thomson's model. Instead, Rutherford proposed a mathematical description for the scattering of charged particles, and this description was later confronted with experimental measurements obtained by Geiger and Marsden (more information on this experiment can be found here).
The activities presented are designed to help students experience this process.

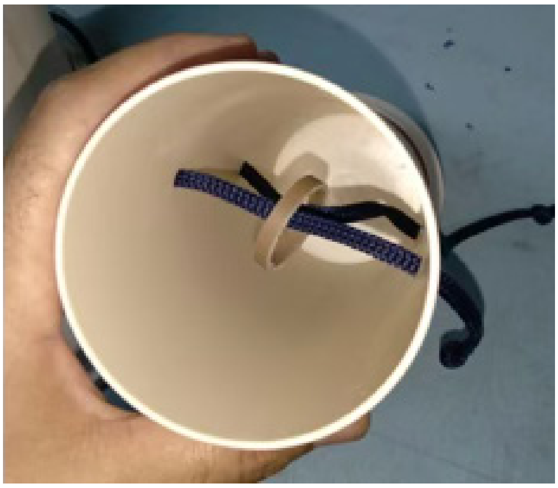
First, they investigate a macroscopic 'mystery tube' whose internal mechanism cannot be directly observed. By proposing, testing and revising possible explanations, students encounter the idea that a model can be useful even when the underlying system is hidden from view.
In the second activity, they analyse original data from Geiger and Marsden's alpha-particle scattering experiments and discuss how evidence can support, constrain or challenge a proposed model of atomic structure. This approach invites students to engage with the practices of science such as observing, modelling, representing and analysing data, as well as arguing from evidence and recognizing the limitations of any explanation. The aim is to shift the focus from 'what Rutherford discovered' to 'how evidence can be used to make sense of something we cannot see directly'.



A schematic diagram of the Geiger-Marsden experiment, or also called Rutherford gold foil
Images: OpenStax, CC BY 4.0

Activity 1: The mysterious tubes

In Activity 1, students investigate tubes constructed as described in reference [4] and try to understand how they are built and why they react the way they do when the strings are pulled. As can be seen in the pictures below, the tubes are sealed with end caps and cannot be opened. Inside them, the cords are connected in different ways.



Mysterious tubes
Image courtesy of the authors

The objective of this activity is to make the students experience the processes of science: observing nature, trying to explain it, testing models, comparing results, revising the hypotheses and working together.

This activity is most suitable for students aged 13–18.

Materials

- One mystery tube per group; it requires:
  - A PVC pipe: approximately 7–8 cm in diameter and 25 cm long (10 inches of a 2 ½ inch PVC pipe)
  - A ring: approximately 5–10 mm-wide cut from a PVC pipe approximately 2.5–3 cm in diameter (A ¼ inch slice of ¾ inch PVC pipe)
  - A nylon cord: approximately 5–6 mm (¼ inch) in diameter, with knotted ends
  - Drill for making four holes on the large PVC pipe (The holes should be slightly wider than the cord, while the knots should be large enough to prevent the cord from slipping through.)
- Instructions for building the mystery tube
- Activity card for Activity 1
- Prototyping materials
  - Paper
  - Pens
  - Tape
  - Glue
  - Strings
  - Card stock
  - Cardboard tubes

Procedure

Preparations before class:

1. Assemble the mysterious tubes according to the instructions.
2. Print the activity cards (one per group).
3. Provide a table of prototyping materials (paper, pens, tape, glue, strings, card stock, and cardboard tubes) for groups wishing to build a physical model to support their hypothesis presentations.

During the class:

1. Divide your class into groups of 4 or 5.
2. Explain that each member of the group has a different role in the group. Distribute the roles randomly.

A good set of roles has been suggested by Elisabeth G. Cohen in the book Designing Groupwork: Strategies for the Heterogeneous Classroom:[5]

- **the reporter**: communicates the results of the group to the rest of the class and to the teacher)
- **the resources manager**: manages the material the group uses in the activity
- **the timer**: takes care that the group manages well the time to finish the product of the group
- **the harmonizer**: pays attention to the behaviour of the members of the group and makes sure everybody can contribute equally.

3. Give one tube and one activity card to each group.
4. Let them work in their groups. Walk around the tables observing the groups discussions.
5. Never let them open the tubes!

Suggested sequence:

- Group formation and distribution of the tubes and cards: 10 min
- Investigating the tubes using the activity cards: 40 min
- Presentations of the hypothesis by each group: 30 min
- Discussion with the whole class: 20 min

Activity 2: The Geiger and Marsden experiment: investigating the inside of the atom

In Activity 2, the students analyse the original data collected by Geiger and Marsden to draw conclusions about the structure of the atom.
The objective of this activity is to make the students work with data and learn ways to interpret it.

They will use graphs, mathematics and group discussions to understand what messages the data brings up.
This activity is most suitable for students aged 15–18.

Materials

- Activity card for Activity 2
- 3 resource cards
- Graph paper
- Pencil
- Ruler
- Calculator
- Original articles by Rutherford, Geiger and Marsden (see references [6] and [7])

Procedure

Preparations before class:

1. Print the activity and resources cards (Resource card 1, Resource card 2, Resource card 3) and distribute one set per group. The student activities are all contained in the activity card, which refers to the resource cards when needed.
2. Have a look at the explanation sheet which contains the results that should be obtained by the students. This sheet is for your own record, not to be given to the students.

During the class:

1. Give a short introduction about the Rutherford, Geiger and Marsden experiment (see references [6] and [7]) and the historical context (see suggested material in reference [8])
2. Maintain the same student grouping from Activity 1 but redistribute the roles to ensure each student experiences a different responsibility.
3. Distribute a set of activity and resource cards to each group.
4. Allow time for the groups to read through their cards. Circulate the room, offering tips on how to get started if needed.

Note for teachers

Some groups may choose to analyse the raw data using a calculator to evaluate how values decrease with the angle (table 1) or vary with atomic weight (table 2) rather than creating a plot. If they can justify it, accept this analytical approach. However, if no group attempts to plot the data, use the final plenary discussion to highlight the visual and analytical advantages of graphical representations.

Class discussion

Ask groups to debate the following question: Were you doing science during this activity?
Challenge students to identify differences between their classroom work and authentic scientific inquiry. In this activity, students could ultimately consult a reference or textbook to find the 'correct' answer. In real-world science, however, researchers operate at the frontier of knowledge, where absolute answers do not yet exist.

Suggested sequence:

- Introduction: 20 min
- Investigating conclusion A with table 1 (resource card 2): 35 min
- Investigating conclusion B with table 2 (resource card 2): 35 min
- Presentation of findings by each group: 30 min
- Discussion with the whole class: 30 min

References

[1] Schwarz CV et al (2009) Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching* **46**: 632–654. doi: 10.1002/tea.20311

[2] Lederman NG (1992) Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching* **29**: 331–359. doi: 10.1002/tea.3660290404

[3] Allchin D (2004) Pseudohistory and pseudoscience. *Science & Education* **13**: 179–195. doi: 10.1023/B:SCED.0000025563.35883.e9

[4] Instruction to build the mystery tubes: https://undsci.berkeley.edu/lessons/mystery_tubes.html

[5] Cohen EG, Lotan RA (2014) *Designing Groupwork: Strategies for the Heterogeneous Classroom* 3rd edition. Teachers College Press. ISBN: 978-0-8077-5566-2

[6] Rutherford E (1911) The Scattering of α and β Particles by Matter and the Structure of the Atom. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* **21**: 669–688. 10.1080/14786440508637080

[7] Geiger H, Marsden E (1913) The Laws of Deflexion of α Particles Through Large Angles. *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* **25**: 604–623. doi: 10.1080/14786440408634197

[8] Article on the discovery of the nucleus of the atom: https://history.aip.org/exhibits/rutherford/sections/alpha-particles-atom.html

Resources

- Identify tracks of subatomic particles from their 'signatures' in bubble-chamber photos: Woithe J, Schmidt R, Naumann F (2019) Track inspection: how to spot subatomic particles. *Science in School* **46**: 40–47.
- Introduce students to light and particles through the lens of space exploration: Tezari A et al (2026) Cosmic SOS: exploring light and particles through the lens of space exploration. *Science in School* **77**.
- Build a cloud chamber with your students: Barradas-Solas F, Alameda-Meléndez P (2010) Bringing particle physics to life: build your own cloud chamber. *Science in School* **14**: 36–40.
- Explore how physicists study very small and very large objects: Akhobadze K (2021) Exploring the universe: from very small to very large. *Science in School* **55**.
- Build a particle accelerator in your classroom: Brown A, Merkert J, Wilson R (2014) Build your own particle accelerator. *Science in School* **30**: 21–26.