Teacher guide: lab practical “Boyle’s law”

Quick reference

A simulated lab practical in which students trap air in a syringe with a three-way valve, change its volume with the plunger, read the pressure on a dial pressure gauge and check that, at constant temperature, the product P · V does not change. It is not an explanation projected for the class but a practical that each student or pair carries out: the simulation never gives the pressure or the volume, which have to be read off the scales, and procedural mistakes have the same consequences as in the lab. Its main use is in ESO 3 (Year 10 in the UK, 9th grade in the US), with applications in ESO 4.

Item	Details
Link	simulaciencia.es/en/simulations/practica-boyle
Student lab sheet	simulaciencia.es/en/lab-sheets/practica-boyle, in Word and LibreOffice to adapt it, and in PDF
Year groups	ESO 3 (main use), ESO 4
Subject	Physics and Chemistry
Suggested time	One 50-minute lesson: 20 minutes at the guided level and 20 at the open level with the lab sheet
Grouping	Individually or in pairs, with a computer, tablet or phone per group
Equipment	A browser, with nothing to install. The lab sheet, printed or digital, for the open level, and graph paper if the graphs are drawn by hand
Prior knowledge	Pressure and its units (kPa), atmospheric pressure, volume in mL, the particle model of a gas
Accessibility	Dark, light and high-contrast themes (gear button). It can be used with a mouse, a finger or the keyboard, and “Describe the scales” says where the needle and the plunger are

How the practical works

On the bench there is a dial pressure gauge, a three-way valve, a syringe lying on its side and a magnifier. The plunger handle and the magnifier are dragged with the mouse or a finger, and the valve lever is pressed. On a phone, buttons under the bench open and close the valve and move the plunger.

The valve has three outlets: the gauge, the syringe and the room air. The lever points to the outlet it closes. **Pointing up**, everything is open to the air and the pressure is that of the room. **Pointing down**, the air in the syringe is trapped with the gauge and, from then on, it is always the same air.

Two levels

Level	What students do	What the simulation checks
Guided (step by step)	They follow nine numbered steps and record seven measurements in an on-screen lab notebook (40, 35, 30, 25, 20, 50 and 60 mL). They see their points on the P–V and P–1/V graphs, predict the pressure at 45 mL and answer a particle question	Each reading and each calculation as it is entered, the prediction and the answer. It always uses the 60 mL syringe and the absolute gauge

Level	What students do	What the simulation checks
Open (with a lab sheet)	They follow the student lab sheet, choose the syringe and the gauge, decide where to close the valve and at which volumes to measure, and do the calculations and graphs on the sheet	Nothing. It only sets out the instruments and the set-up number. The teacher marks the work with the key in this guide

The nine steps of the guided level are: set the plunger to 40 mL with the valve open; read the room pressure; close the valve; push in to 35, 30, 25 and 20 mL and read; pull out to 50 and 60 mL and read; calculate P · V for each measurement; look at the graph of P against 1/V; predict the pressure at 45 mL and check it; and explain it with particles.

Instruments at the open level

Instrument	Scale	Division
60 mL syringe	0 to 60 mL	1 mL
20 mL syringe	0 to 20 mL	0.5 mL
Absolute pressure gauge	0 to 200 kPa	2 kPa
Relative (gauge pressure) gauge, with a wall barometer	−100 to 100 kPa	2 kPa

The relative gauge shows how much the pressure of the air is above atmospheric pressure (or below it, with negative numbers), like a bicycle tyre gauge. To get the absolute pressure, add the reading of the wall barometer, which is in hPa.

What to know about the measurement

- **Neither the pressure nor the volume appears in writing.** They are read with the magnifier on the scale of the gauge and on that of the syringe.
- **The volume is read at the edge of the rubber touching the air,** the left-hand one. The other edge gives a few millilitres too many.
- **The needle overshoots if the plunger is moved quickly.** When you push quickly, the air warms up a little and the pressure rises too much; when you pull quickly, it cools down. In about 4 seconds it returns to room temperature and the needle stops. The first time, a message explains this. It is the reason the law requires constant temperature, and it can be discussed in class.
- **Each set-up number is always the same day in the lab:** the atmospheric pressure (typical for Madrid, 93 to 96 kPa, because of the altitude; at sea level it would be about 101 kPa, 1 atm) and the room temperature. When the practical opens, a random set-up appears; another can be chosen from the drop-down list or with “Random set-up”.
- **At the guided level** the exact volume is accepted, and the pressure to within half a division (1 kPa). With those readings, P · V comes out the same in every measurement to within 3.5 %.

Mistakes with consequences

Procedural mistakes are not punished arbitrarily: each one spoils the measurement for a physical reason that can be explained in class.

Mistake	What happens in the simulation
Measuring with the valve open	Air goes in and out through the valve: the pressure is always that of the room and does not change with the volume. At the guided level, the simulation does not let students close the valve before reading the room pressure
Reading without waiting for the needle to stop	The reading is too high when pushing and too low when pulling, and P · V is not repeated
Reading the volume at the wrong edge of the rubber	All the volumes come out a few millilitres too large and P · V grows with the volume
Pushing until the gauge goes past the end of its scale	The tube comes off, air escapes and you have to start again with the same set-up
Pulling the plunger beyond the last mark	The plunger comes out of the syringe, air gets in and you have to start again
Opening the valve after starting to measure (guided level)	Air gets in or out, it is no longer the same gas and you have to start again
Closing the valve with the syringe full and pushing hard (open level)	Closing at 60 mL, the pressure goes over 200 kPa before reaching 20 mL and the tube comes off. The lab sheet asks students to close at 40 mL

Handing out the practical ready set up

The address of the practical accepts four parameters, which can be combined and pasted into Google Classroom, Moodle or Teams:

Parameter	Effect	Example
`nivel=libre`	Opens the open level	simulaciencia.es/en/simulations/practica-boyle/?nivel=libre
`montaje=N`	Starts with set-up N (from 1 to 12)	.../practica-boyle/?nivel=libre&montaje=7
`jeringa=20`	At the open level, starts with the 20 mL syringe	.../practica-boyle/?nivel=libre&jeringa=20
`manometro=relativo`	At the open level, starts with the relative gauge and the barometer	.../practica-boyle/?nivel=libre&manometro=relativo

Key to the set-ups

For marking. If the valve is closed with V_0 mL of air at room pressure, every measurement satisfies $\mathbf{P \cdot V = P_{atm} \cdot V_0}$. The table gives the values with V_0 = 40 mL, which is what the guided level does and what the lab sheet asks for.

Set-up	P_{atm} (kPa)	Room (°C)	P · V (kPa·mL)	P at 20 mL (kPa)	P at 30 mL (kPa)	P at 45 mL (kPa)	P at 60 mL (kPa)
1	94.6	21	3784	189.2	126.1	84.1	63.1
2	93.4	22	3736	186.8	124.5	83.0	62.3
3	95.2	20	3808	190.4	126.9	84.6	63.5
4	94.1	23	3764	188.2	125.5	83.6	62.7
5	95.8	19	3832	191.6	127.7	85.2	63.9

Set-up	P_{atm} (kPa)	Room (°C)	P · V (kPa·mL)	P at 20 mL (kPa)	P at 30 mL (kPa)	P at 45 mL (kPa)	P at 60 mL (kPa)
6	93.0	24	3720	186.0	124.0	82.7	62.0
7	94.9	22	3796	189.8	126.5	84.4	63.3
8	93.7	20	3748	187.4	124.9	83.3	62.5
9	95.5	21	3820	191.0	127.3	84.9	63.7
10	94.3	19	3772	188.6	125.7	83.8	62.9
11	96.0	23	3840	192.0	128.0	85.3	64.0
12	93.9	22	3756	187.8	125.2	83.5	62.6

With a dial gauge, pressure can be read to 1 kPa at best, so it is reasonable to accept P · V within 3 or 4 % of the key. With the 20 mL syringe the lab sheet asks students to close at 15 mL, so P · V is P_{atm} × 15. If a student closes the valve at another volume, their P · V is P_{atm} times that volume. With the relative gauge, the reading plus the barometer pressure (converted from hPa to kPa) should give the values in the table.

Use in each year group

In ESO 3 the practical is used to discover Boyle's law from students' own measurements; in ESO 4, to work on absolute and relative pressure, measurement error and data analysis. The curriculum content quoted is from the LOMLOE Physics and Chemistry curriculum of the Community of Madrid (Spain), in our own translation.

ESO 3: discovering Boyle's law

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

Curriculum content. Block A: "Use of a range of scientific learning environments and resources, such as the laboratory or virtual environments" and "Recording data and results using tables, graphs and mathematical expressions". Block B: "Deeper study of the kinetic-molecular model of matter [...]. Gas laws. Kinetic-molecular model of matter" and "Carrying out guided experiments related to material systems".

Objectives. Follow a lab procedure in the right order. Read a dial pressure gauge and the scale of a syringe. Check that, at constant temperature, P · V does not change. Recognise an inverse proportion on a graph and turn it into a straight line by plotting P against 1/V. Explain the law with the particle model.

Suggested lesson (50 min).

1. **Opening question (5 min).** Block the tip of a syringe (a real one, if available) with a finger and push the plunger: "why does it get harder and harder?", "what would happen if we pushed it halfway in?". Collect predictions.
2. **Guided level, in pairs (20 min).** Each pair with whatever set-up comes up. When the measurements are done, the P–V graph is a curve; plotting P against 1/V gives a straight line. The prediction at 45 mL is the moment to see that the law is actually useful.
3. **Open level with the lab sheet (15 min).** Hand out different set-ups with the `montaje=N` parameter. Pairs close the valve at 40 mL, measure at volumes of their choice and calculate P · V.
4. **Whole-class discussion (10 min).** Each pair gives its P · V. The whole class does not get the same number, because each set-up is a day with a different atmospheric pressure, but within each pair it is

repeated. Finish with the particle question: half the volume, twice as many collisions with the walls, twice the pressure.

ESO 4: absolute and relative pressure, and measurement error

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

Curriculum content. Block A: "Measurement and its error", "Analysis of experimental data" and "Appropriate use of laboratory equipment and measuring instruments". Block B: "Gases. Combined gas law". Block D: "The concept of pressure. […] Atmospheric pressure".

Objectives. Distinguish absolute and relative pressure and convert between them using a barometer. Choose an instrument according to the precision needed. Obtain the constant of the law from the gradient of the P–1/V line. Relate Boyle's law to the combined gas law.

Suggested lesson (50 min).

1. **Review with the guided level (10 min).** Only up to step 5, to recall how to use it.
2. **Relative gauge (15 min).** At the open level, with `manometro=relativo`. Measure with the valve open: it reads 0, even though the air in the syringe does have a pressure. Repeat the measurements, adding the barometer pressure. Question for discussion: why do bicycle tyres use a relative gauge?
3. **Two syringes (15 min).** Repeat with the 20 mL syringe (`jeringa=20`). Compare how much one division of each syringe contributes to the error in V and therefore in P · V.
4. **Analysis (10 min).** Plot P against 1/V with 1/V in L^{-1} (1000 / V with V in mL), draw the line and calculate its gradient: it is P · V. Compare it with the mean of the products.

Assessment

Each set-up has its own P · V, and at the open level students choose the volumes, so the procedure and the calculation are marked with each student's data and the value of the constant with the key. A simple rubric:

Criterion	What to look for
Procedure	Closes the valve before measuring, moves the plunger slowly and waits for the needle to stop. If they had to start again because of a mistake, they explain what it was and why it spoils the measurement
Measurement	Readings with their unit and the precision of the instrument: volume to the division of the syringe and pressure to that of the gauge
Calculation	P · V done correctly for each measurement, with units. With the relative gauge, absolute pressure correctly obtained with the barometer
Graphs	Axes with quantity and unit, suitable scales, a curve for P–V and a straight line for P–1/V
Conclusion	States the law in their own words, explains where the differences between the products come from and relates it to the particle model

Misconceptions it helps to address

Students' idea	Correct idea	How to show it
"When air is compressed, the particles get smaller"	Particles do not change size: the empty space between them gets smaller	The particle question at the guided level, which explains each wrong answer

Students' idea	Correct idea	How to show it
"The pressure rises because the particles, closer together, repel each other"	In a gas the particles barely interact; pressure is due to their collisions with the walls	The same particles in half the space give twice as many collisions per second on each piece of wall
"If the volume halves, the pressure halves", "more volume, more pressure"	Pressure and volume are inversely proportional: half the volume, twice the pressure	Predict before pushing from 40 to 20 mL and check it on the gauge
"A curve that goes down is a straight line that goes down"	P–V is a hyperbola; P–1/V is a straight line through the origin	The two tabs of the graph at the guided level, with each student's points
"The air in an open syringe has no pressure"	It has atmospheric pressure, about 94 kPa in Madrid	The absolute gauge shows about 94 kPa with the valve open; the relative one shows 0
"Air has no weight and doesn't push"	The room air pushes with atmospheric pressure	The wall barometer and the reading with the valve open
"It doesn't matter whether you move the plunger quickly or slowly"	When it is compressed quickly the air warms up; the law holds at constant temperature	The needle overshoots and takes a few seconds to settle

Simplifications worth knowing

1. **No dead volume.** The air in the tube and the gauge does not count: all the trapped air is in the syringe. In a real syringe, the air in the tube makes P · V come out somewhat different from what is expected.
2. **No leaks or friction.** The rubber of the plunger seals perfectly and the plunger stays where it is left, even when the pressure inside is very different from the pressure outside.
3. **Ideal gas.** Air follows the law exactly over the whole range of pressures in the practical, as it does in reality to a very good approximation.
4. **Smoothed heating.** When the plunger is moved quickly, the air warms up or cools down only a fraction of what it would without heat exchange, and returns to room temperature in about 4 seconds.
5. **Perfect scales.** The gauge has no zero error or hysteresis, and the needle has no play.
6. **Snapping to the millilitre at the guided level.** When the plunger is released, it snaps to the nearest millilitre so that the volume can be read without doubt. At the open level it stays wherever it is released.

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