Teacher guide: lab practical “Gay-Lussac’s law”

Quick reference

A simulated lab practical in which students trap air in a flask with a three-way valve, cool it in ice water and heat it with a hot plate to about 80 °C. They read the temperature on a thermometer and the pressure on a digital pressure gauge, check that, at constant volume, P / T does not change if the temperature is in kelvin and, by extending the line of P against t to P = 0, reach absolute zero. It is not an explanation projected for the class but a practical that each student or pair carries out: the temperature never appears in writing and has to be read off the thermometer, 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-gay-lussac
Student lab sheet	simulaciencia.es/en/lab-sheets/practica-gay-lussac, 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, graph paper and a ruler
Prior knowledge	Pressure and its units (kPa), temperature in °C, the particle model of a gas. The Kelvin scale can be introduced with the practical itself
Accessibility	Dark, light and high-contrast themes (gear button). It can be used with a mouse, a finger or the keyboard, and “Describe the instruments” says which marks the thermometer liquid is between, what the gauge shows and the state of the hot plate and the lab jack

How the practical works

On the bench there is a digital pressure gauge, a three-way valve, a 250 mL flask closed with a stopper and held by a clamp stand, a thermometer and a 600 mL beaker of ice water on a hot plate with a magnetic stirrer. The hot plate sits on a lab jack. The magnifier is dragged with the mouse or a finger; the valve lever, the lab jack arrows and the hot plate buttons are pressed. On a phone, buttons under the bench do the same as the controls.

- **The valve** points to the outlet it closes. **Pointing up**, the flask is open to the room air; **pointing down**, the air in the flask is trapped and, from then on, it is always the same air, in the same volume.
- **The lab jack** has three heights: down (the water does not touch the flask), halfway (it only covers the bottom) and up (it covers the whole flask).
- **The hot plate** has three buttons: on/off, with a red light; power (low, medium or high); and stirrer. When it is switched off it stays hot and the water still rises 2 or 3 °C. It switches itself off at 90 °C so that the water does not boil.

- **Time runs ten times faster,** and a clock shows how much lab time would have passed. The whole guided run takes about 30 minutes of lab time.

Two levels

Level	What students do	What the simulation checks
Guided (step by step)	They follow nine numbered steps and record six measurements in an on-screen lab notebook: the room, the ice water and near 20, 40, 60 and 80 °C. They calculate P / t in °C and see that it is not constant; they convert to kelvin and calculate P / T. They place a ruler over their points to reach P = 0, look at the graph in kelvin and answer a particle question	Each reading and each calculation as it is entered, where the ruler crosses P = 0, and the answer. The stirrer switches on with the hot plate and the power is medium
Open (with a lab sheet)	They follow the student lab sheet, use the five controls (valve, lab jack, on/off, power and stirrer), decide at which temperatures to measure and do the calculations and the graph 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: with the valve open, read the room temperature and pressure; close the valve; raise the ice water to cover the flask and read; heat, switch off near 20, 40, 60 and 80 °C and read; try P / t with the temperature in °C; convert to kelvin and calculate P / T; extend the line of P against t to P = 0; look at the graph of P against T in kelvin; and explain it with particles.

What to know about the measurement

- **The temperature never appears in writing.** The thermometer goes from −10 to 110 °C with 1 °C divisions. It is read with the magnifier, whose yellow line marks eye level and is placed at the end of the red column.
- **The pressure gauge is digital,** reading to 0.1 kPa, and shows absolute pressure. With a dial gauge, absolute zero would come out several tens of degrees off.
- **You have to wait for everything to settle.** The air in the flask takes a few seconds to reach the temperature of the water, and so does the thermometer. That is why the hot plate is switched off a few degrees before the target temperature and the reading is taken when neither the thermometer nor the gauge is changing.
- **While there is ice left, the water does not go above 0 °C.** The ice cubes shrink and a message explains that the heat is being used to melt them.
- **Each set-up number is always the same day in the lab:** the atmospheric pressure (typical for Madrid, 93 to 96 kPa), the room temperature and the amount of ice. 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 temperature is accepted to within half a degree of the thermometer reading, and the pressure shown on the display. The hot rows are accepted within a range (the 20 °C row, between 15 and 30 °C), and if the water overshoots a row, that row is skipped. T is accepted as t + 273 or t + 273.15. P / T is taken as constant with less than 2 % difference, and the point where the ruler crosses P = 0, within 15 °C of the line through the student’s data.

Mistakes with consequences

The law holds exactly in the simulation: what moves the result away are procedural mistakes, each for a physical reason that can be explained in class.

Mistake	What happens in the simulation
Opening the valve after closing it, with the air warmer or colder than when it was closed	Air gets out or in and it is no longer the same gas. At the guided level a red warning appears and you have to start again with the same set-up. At the open level, the pressure goes back to room pressure without a warning
Reading with the hot plate on or without waiting	The air lags behind the water, and so does the thermometer: temperature and pressure do not correspond to the same moment, and P / T is not constant
Leaving the lab jack halfway	The water only covers the bottom of the flask and the air does not reach the temperature of the water. The pressure comes out low
Reading the thermometer without the eyes level with the liquid	You read one degree too many or too few. At the guided level, the hint explains this
Heating without stirring (open level)	The water at the bottom heats up before the water at the top, where the thermometer is, and the temperature read is not that of the water around the flask
Switching off the hot plate exactly at the target temperature	The hot plate holds heat and the water keeps rising 2 or 3 °C

Handing out the practical ready set up

The address of the practical accepts two 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-gay-lussac/?nivel=libre
`montaje=N`	Starts with set-up N (from 1 to 12)	.../practica-gay-lussac/?nivel=libre&montaje=7

Key to the set-ups

For marking. If the valve is closed at room temperature, every measurement satisfies **$P / T = P_{atm} / (t_{room} + 273.15)$**, with T in kelvin. The table gives that constant and the pressure the gauge shows at some temperatures.

Set-up	P_{atm} (kPa)	Room (°C)	P / T (kPa/K)	P at 0 °C (kPa)	P at 40 °C (kPa)	P at 80 °C (kPa)
1	94.6	21	0.322	87.8	100.7	113.6
2	93.4	22	0.316	86.4	99.1	111.8
3	95.2	20	0.325	88.7	101.7	114.7
4	94.1	23	0.318	86.8	99.5	112.2
5	94.2	21	0.320	87.5	100.3	113.1
6	93.0	24	0.313	85.5	98.0	110.5
7	94.9	22	0.322	87.8	100.7	113.5
8	93.7	20	0.320	87.3	100.1	112.9
9	95.5	22	0.324	88.4	101.3	114.3
10	94.3	19	0.323	88.2	101.1	114.0
11	96.0	23	0.324	88.5	101.5	114.5

Set-up	P_{atm} (kPa)	Room (°C)	P / T (kPa/K)	P at 0 °C (kPa)	P at 40 °C (kPa)	P at 80 °C (kPa)
12	93.9	21	0.319	87.2	100.0	112.7

With good readings, P / T is constant to within 1 % and the line of P against t crosses the P = 0 axis near −273 °C. A result between −250 and −300 °C is reasonable when the line is drawn by hand; if it is very far off, the usual cause is reading without waiting or with the flask not covered. If a student closes the valve at another temperature, their constant is P_{atm} divided by the temperature of the air when it was closed, in kelvin.

Use in each year group

In ESO 3 the practical is used to discover Gay-Lussac's law and the need for the Kelvin scale from students' own measurements; in ESO 4, to work on extrapolation, error and the combined gas law. 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 Gay-Lussac's law and absolute zero

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 thermometer with the eyes level with the liquid. Check that, at constant volume, the pressure of a gas rises as its temperature rises. See that P / t is not constant with the temperature in °C, but P / T in kelvin is. Reach absolute zero by extending a straight line. Explain the law with the particle model.

Suggested lesson (50 min).

1. **Opening question (5 min).** "Why shouldn't you leave an aerosol can in the sun?" and "what happens to a football left outside on a frosty night?". Collect prior ideas.
2. **Guided level, in pairs (20 min).** Each pair with whatever set-up comes up. Step 5 (P / t in °C) is usually a surprise: if the pressure rises with temperature, why don't you get the same number? Step 7, with the ruler, gives a temperature below which you cannot go.
3. **Open level with the lab sheet (15 min).** Hand out different set-ups with the `montaje=N` parameter. Each pair chooses its temperatures and draws the P–t graph on graph paper, with the temperature axis starting at −300 °C.
4. **Whole-class discussion (10 min).** Each pair says where its line crosses the axis. With different set-ups the pressures do not match, but all the crossing points fall near −273 °C. That is where the Kelvin scale comes from: start counting from that point.

ESO 4: extrapolation, error and the combined gas law

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".

Objectives. Plan the measurements and control the variables that spoil them (stirring, waiting time, immersion of the flask). Calculate absolute zero from the line through the data. Estimate how reading error affects a long extrapolation. Relate this practical to the Boyle's law practical to build up the combined gas law.

Suggested lesson (50 min).

1. **Planning (10 min).** Before measuring, answer the questions on the lab sheet: why the valve is closed at room temperature, why the flask must be covered and the water stirred, and when to switch off the hot plate.
2. **Open level with deliberate mistakes (20 min).** Half the pairs measure properly; the other half without the stirrer or with the lab jack halfway. Each group calculates its absolute zero.
3. **Analysis (20 min).** Compare the crossing points. Calculate the gradient of P against t and the crossing point at P = 0 as −P(0 °C) / gradient. Discuss why an error of one degree in the readings moves the crossing point by tens of degrees: the line is extended about three times the measured range.

Assessment

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

Criterion	What to look for
Procedure	Closes the valve at room temperature and does not open it again, covers the flask, stirs, switches off the hot plate before the target temperature and waits for everything to settle. If they had to start again because of a mistake, they explain what it was
Measurement	Temperatures to the division of the thermometer (1 °C) and pressures to that of the gauge (0.1 kPa), with units
Calculation	Conversion to kelvin done correctly and P / T to three decimal places, with units
Graph	Axes with quantity and unit, temperature axis down to −300 °C, line drawn properly and crossing point at P = 0 read off
Conclusion	States the law, explains why the Kelvin scale is needed, gives their value for absolute zero and relates it to the particle model

Misconceptions it helps to address

Students' idea	Correct idea	How to show it
"When air is heated, its particles expand"	Particles do not change size: they move faster	The particle question at the guided level, which explains each wrong answer
"Heating makes more particles appear"	The flask is closed: the particles are the same	The valve stays closed for the whole practical; when it is opened, air comes out
"Heat is a substance that gets in and pushes"	Heat is energy that passes from the water to the air and makes its particles move faster	When the hot plate is switched off, the pressure stops rising once the air reaches the temperature of the water

Students' idea	Correct idea	How to show it
"Pressure is proportional to temperature in °C"	It is proportional to absolute temperature, in kelvin	Step 5: P / t in °C is not constant. At 0 °C, P / t makes no sense and the pressure is not zero
"Temperature and heat are the same thing"	Temperature measures how fast the particles move; heat is the energy that is transferred	While there is ice left, the hot plate supplies heat and the temperature does not rise above 0 °C
"A thermometer reads instantly"	The thermometer and the air take time to reach the temperature of the water	Read just after switching off the hot plate and again a while later: the readings differ
"You can keep cooling below −273 °C"	−273 °C is absolute zero: the pressure of the gas would be zero	The ruler in step 7 and the whole class's graphs, which cross at the same point

Simplifications worth knowing

1. **Perfectly constant volume.** The expansion of the glass of the flask is not taken into account.
2. **No dead volume.** The air in the tube and the gauge, which is not heated, does not count. In the lab, that air shifts absolute zero somewhat.
3. **Ideal gas.** Air follows the law exactly. Over the range of the practical, real air does so to a very good approximation.
4. **Dry air.** There is no water vapour inside the flask.
5. **Accelerated time.** Time runs ten times faster and the hot plate heats faster than a real one, so that the practical fits into one lesson.
6. **Simplified ice and heat losses.** The ice melts at a constant rate, the bath loses heat to the room very slowly and the hot plate never lets the water boil.
7. **Perfect alcohol thermometer.** The scale has no calibration error and the liquid does not separate in the column.

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