ANSWER KEY. Values match the simulation readouts for the settings in each step.

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Gas Laws Virtual Lab

Chemistry | ANSWER KEY

Open **activities.zornscience.org/gas-laws/** and follow each step. To type a value, click the number box, type, and press Enter. Show your work with units.

Objective

Lock two variables at a time to find how the **pressure**, **volume**, **temperature** and **amount** of a gas are related, and explain each gas law with moving particles.

NGSS alignment: HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
Practices and concepts: Developing and using models; Analyzing and interpreting data; Using mathematics; Patterns; Scale, proportion, and quantity.

Meet the simulation



Figure 1. The Gas Laws Sandbox.

(1) Gas law menu. Each law locks two variables.

(2) Reset: 1.00 atm, 273 K, 1.00 mol, 22.4 L.

(3) Readouts of P, V, T and n (3 significant figures).

(4) to (6) Number boxes for pressure, volume and temperature. The amount (n) box is below them. Locked variables are gray.

The live graph and a PV = nRT check are below the controls (Figure 2). The simulation uses R = 0.0821 L·atm/(mol·K).

Pre-lab

1. Gas law calculations must use kelvins, not °C. Convert 27 °C to kelvins. Then explain why doubling a temperature in °C does not double the particle energy.

K = °C + 273 = 27 + 273 = <u>300 K</u>. The Celsius scale does not start at zero energy (0 °C is 273 K), so doubling °C does not double the kelvin temperature. Only kelvin temperature is proportional to the average kinetic energy of the particles.

2. Predict: a gas at 1.00 atm fills 22.4 L. At the same temperature, it is squeezed to 11.2 L. What will the pressure be? Use $P_1V_1 = P_2V_2$.

$P_2 = P_1V_1 / V_2$ = (1.00 atm)(22.4 L) / (11.2 L) = <u>2.00 atm</u>

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Part A. Boyle's law (T and n locked)

1. Select **Reset**. Choose **Boyle's law · lock T and n**.
2. Type each volume below in the Volume box and record the pressure readout. Calculate P × V.

Volume (L)	Pressure (atm)	P × V (atm·L)
40.0	**0.560**	**22.4**
20.0	**1.12**	**22.4**
10.0	**2.24**	**22.4**
5.00	**4.48**	**22.4**

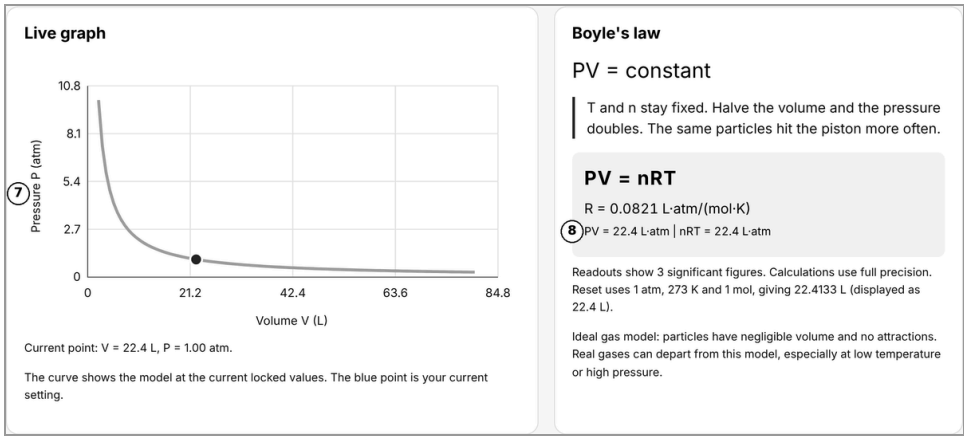


Figure 2. The live graph (7) for Boyle's law and the PV = nRT check (8).

3. Describe the relationship between pressure and volume (direct or inverse). What shape is the graph in Figure 2? Use two rows of your table to show the pattern.

Inverse: as volume increases, pressure decreases, and P × V stays 22.4 atm·L. The graph is a curve (hyperbola) that falls quickly and then levels off. Halving V from 20.0 L to 10.0 L doubles P from 1.12 atm to 2.24 atm.

4. Watch the particle model as you change from 40.0 L to 5.00 L. Use particles to explain why the pressure goes up.

The same number of particles moves at the same speed (same temperature) in a smaller space, so they hit the walls and piston more often. More collisions with the walls each second means a greater pressure.

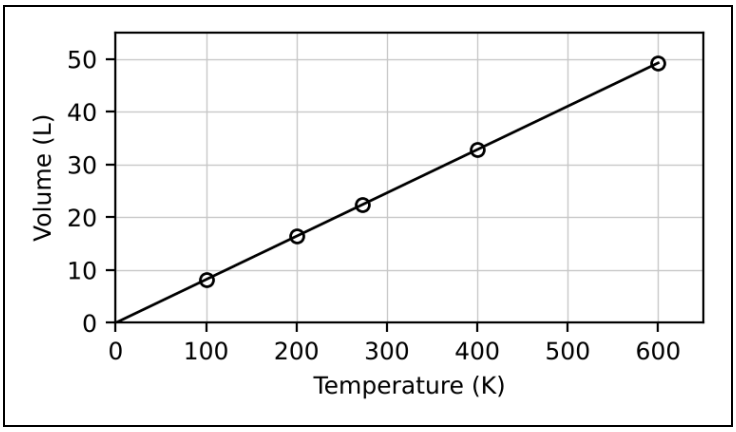
Part B. Charles's law (P and n locked)

1. Select **Reset**. Choose **Charles's law · lock P and n**.
2. Type each temperature below and record the volume. Calculate V / T.

Temperature (K)	Volume (L)	V / T (L/K)
100	**8.21**	**0.0821**
200	**16.4**	**0.0820**
273	**22.4**	**0.0821**
400	**32.8**	**0.0820**
600	**49.3**	**0.0822**

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5. Graph volume (y-axis) against kelvin temperature (x-axis) for Part B. Label both axes with units and draw a line of best fit. Extend your line to where the volume would be zero.



Straight line through the origin. Slope = V/T = 0.0821 L/K. The line reaches V = 0 at 0 K (absolute zero, −273 °C).

6. Describe the relationship between volume and kelvin temperature. Explain with particles why the gas expands when it is heated at constant pressure.

Direct (proportional): doubling T from 200 K to 400 K doubles V from 16.4 L to 32.8 L. Heated particles move faster and hit the piston harder and more often, so they push it out until the pressure falls back to 1.00 atm.

Part C. Gay-Lussac's law (V and n locked)

1. Select **Reset**. Choose **Gay-Lussac's law · lock V and n**.
2. Type each temperature below and record the pressure. Calculate P / T.

Temperature (K)	Pressure (atm)	P / T (atm/K)
150	**0.549**	**0.00366**
300	**1.10**	**0.00367**
600	**2.20**	**0.00367**
900	**3.30**	**0.00367**

7. What happens to the pressure when the kelvin temperature doubles? Explain with particles why a sealed, rigid container of gas can burst when heated.

The pressure doubles (300 K to 600 K: 1.10 atm to 2.20 atm). Faster particles hit the walls more often and harder. The walls cannot move to make more room, so the pressure keeps rising until the container may burst.

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Part D. Avogadro's law (P and T locked)

1. Select **Reset**. Choose **Avogadro's law · lock P and T**.
2. Type each amount below in the n box and record the volume.

Amount of gas, n (mol)	Volume (L)	V / n (L/mol)
0.500	**11.2**	**22.4**
1.00	**22.4**	**22.4**
2.00	**44.8**	**22.4**
3.00	**67.2**	**22.4**

8. Describe the relationship between volume and amount of gas. At 1.00 atm and 273 K, what volume does 1 mole of any ideal gas fill?

Direct (proportional): doubling n doubles V. V / n is always 22.4 L/mol, so 1 mol fills <u>22.4 L</u> at 1.00 atm and 273 K (STP).

Analysis

9. A gas is at 2.24 atm, 10.0 L and 273 K. Use the combined gas law, $P_1V_1/T_1 = P_2V_2/T_2$, to predict the pressure if it is heated to 546 K in the same 10.0 L. Then test it: Reset, choose Boyle's law, type V = 10.0 L, switch to Gay-Lussac's law, and type T = 546 K. Record the pressure readout.

V stays the same, so $P_2 = P_1T_2 / T_1$ = (2.24 atm)(546 K) / (273 K) = <u>4.48 atm</u>. The simulation shows 4.48 atm.

10. The simulation is an ideal gas model. Give two ways a real gas, or a real gas law lab, would differ from it.

Any two: real gas particles have their own volume and attract each other, so real gases are not ideal at high pressure or low temperature (a real gas turns to liquid before 0 K); a real container can leak gas; squeezing a real gas quickly warms it, so T does not stay constant; pressure gauges, thermometers and volume marks have measurement error.

Conclusion

11. Write a claim that answers the objective. Support it with evidence from at least three parts (specific numbers), then explain your reasoning with particle motion.

Claim: Pressure is inversely proportional to volume, and volume and pressure are each directly proportional to kelvin temperature; volume is also directly proportional to the amount of gas.
Evidence: Halving V from 20.0 L to 10.0 L doubled P from 1.12 to 2.24 atm. Doubling T from 200 K to 400 K doubled V from 16.4 to 32.8 L. Doubling T from 300 K to 600 K doubled P from 1.10 to 2.20 atm. Doubling n from 1.00 to 2.00 mol doubled V from 22.4 to 44.8 L.
Reasoning: Pressure comes from particles hitting the walls. Less space or more particles means more frequent hits; a higher temperature means faster particles that hit harder and more often. When pressure is held constant, the gas expands until the hits balance again.

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