Ozobot Evo Classroom Application: Boyle's Law Simulation

By Richard Born
Associate Professor Emeritus
Northern Illinois University
rborn2@niu.edu

Introduction

Gas laws such as Boyle's Law, which deals with the relationship between pressure and volume under constant temperature, and Charles's Law, dealing with the relationship between volume and absolute (Kelvin) temperature under constant pressure, are studied in virtually every introductory course in chemistry and physics. This Ozobot Bit classroom application provides a ***simulation*** that will allow students to investigate ***Boyle's Law*** without the need to use actual apparatus that is standard when studying this law. All that is needed are Ozobot Evo, and the Ozomap and OzoBlockly program **(share code is i8ja9m)** that are included with this classroom application.

Boyle's Law

Boyle's law can be expressed as follows: *The pressure,* ***P****, exerted by a given mass of an ideal gas is inversely proportional to its volume,* ***V****, provided the temperature and mass of the gas kept are kept constant in a closed system.* In mathematical terms, this inverse relationship in Boyle's law can be stated as

$$P \propto \frac{1}{V} \quad or \quad P = \frac{k}{V} \quad or \quad PV = k$$

where *k* is the constant of proportionality. It should be noted that an ideal gas is a theoretical gas consisting of numerous randomly moving particles that do not interact except through elastic collisions. Most real gases behave like an ideal gas when under normal conditions.

The Map for this Classroom Application

For reference while discussing this application, Figure 1 shows a small version of the Ozomap that students will be using. A full page version that can be printed for use with Evo appears on the last page of this document.

The light green "cylinder", which is imagined to be oriented vertically, with graduations at equal "volume" intervals from 0 through 105 by steps of 15 Arbitrary Volume Units (AVUs), is to be imagined as containing a gas, in this case air. After placing Evo at the top, imagine that a little weight is added to Ozobot so that he moves down to the first graduation at 105 AVUs and traps the air, due to an imagined very tight fit between Ozobot and the inside surface of the cylinder. Ozobot will act as though he is a ***gas pressure sensor*** and will speak the pressure of the gas in Arbitrary Pressure Units (APUs). There are many commonly used units for measuring gas pressure, including millibars, psi—pounds per square inch, mm of Hg, and kPa—the kilopascal. But there is no need here to be fancy—we can just go with our APUs as the unit of measure for gas pressure.

Next, imagine that just the right amount of weight is added to Ozobot (increasing the pressure on the gas) to move him down to the 90 AVU graduation mark. He will again speak the new value for the pressure in APUs. This process of adding just the right amount of weight continues until Evo has provided pressure readings for the final 15 AVU graduation mark. After this Evo stops and turns off.

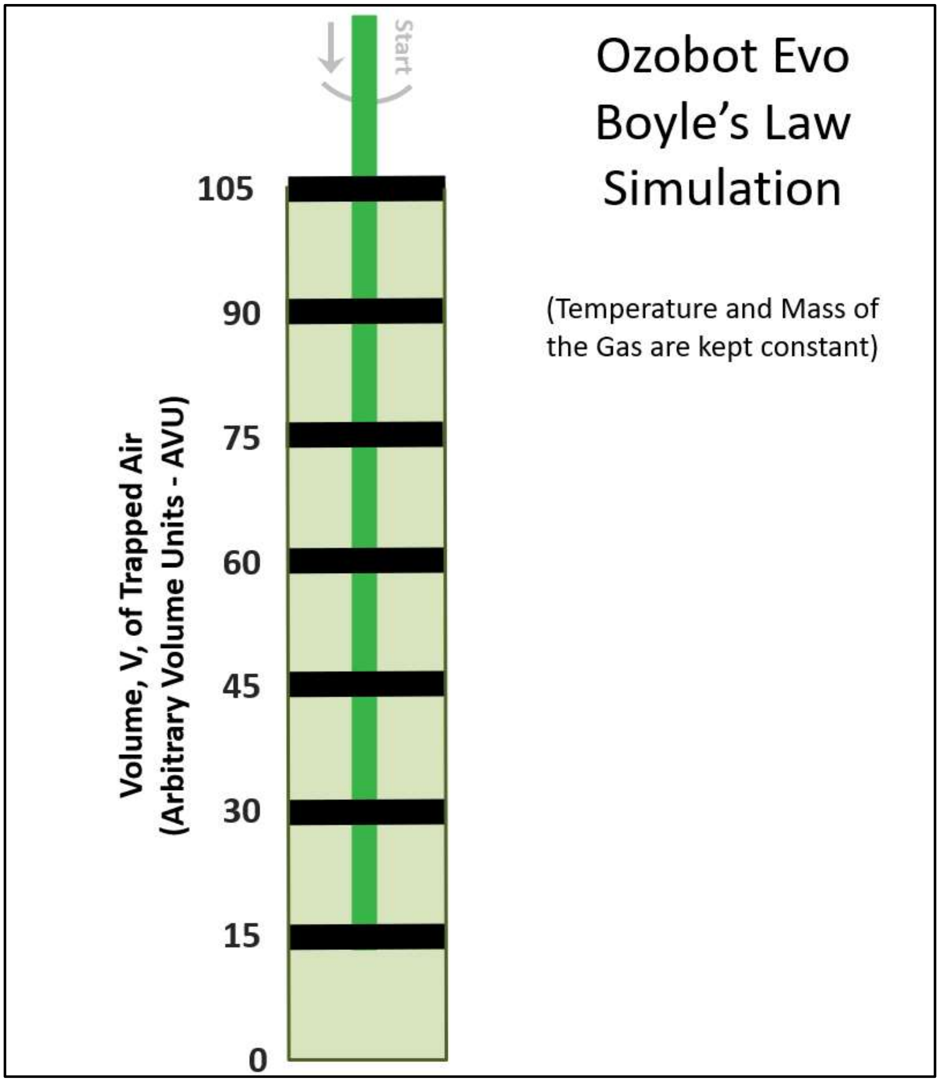


Figure 1

Running the OzoBlockly Program

1. Load the OzoBlockly program *BoylesLaw.ozocode* **(share code i8ja9m)**.
2. Place Evo at the location labeled "Start", facing the direction shown by the gray arrow, and with Evo's leading edge on the curved gray line. Ozobot Bit will display an AQUA LED while moving.
3. Start the OzoBlockly program that has been loaded into Evo.
4. Evo will then behave as described in the previous section of this document. After displaying the gas pressure for the 15 AVU graduation, he will stop and power down. Each time a student lab group runs the program, the results will be slightly different as the program has randomness built-in.

Student Exercises:

Student Exercise #1 (Grades 7-12): *Have each of the lab groups run their OzoBlockly program while explaining to them how gas pressure in APUs is spoken by Evo. There is no need for them to record this data now, as the purpose of this exercise is to make sure that they understand that Evo speaks the gas pressure each time he stops at a graduation mark on the cylinder.*

Student Exercise #2 (Grades 7-12): *Ask the students to collect gas pressure data for three runs and record their data in the data table at the top of page 5. To reduce the effects of randomness, have them compute the average pressure of the three runs for each of the volume graduations. (The right-most column of the data table, PV, will be used in student exercise 5.)*

Student Exercise #3 (Grades 7-12): *Ask the lab groups to plot the average gas pressure and corresponding gas volumes on the graph at the bottom of page 5. The students will clearly observe that the points do not fall on a straight line. Ask them to use their best judgment in drawing a curved line that fits the data well even though it may not lie on every point. Then ask the students to explain* ***in their own words*** *what the relationship seems to be between pressure and volume.*

Student Exercise #4 (Grades 7-12): *Explain the concepts of* ***interpolation*** *(estimating between known data points) and* ***extrapolation*** *(estimating beyond the ends of the known data points) to the class.*

a) *Which (interpolation or extrapolation) would you be doing if you were to estimate the gas pressure when the volume of the trapped gas is 22.5 AVUs? What is the value of your estimate in AVUs?*
b) *Which (interpolation or extrapolation) would you be doing if you were to estimate the gas pressure when the volume of the trapped gas is 35 AVUs? What is the value of your estimate in AVUs?*
c) *Which (interpolation or extrapolation) would you be doing if you were to estimate the gas pressure when the volume of the trapped gas is 7.5 AVUs? What is the value of your estimate in AVUs?*
d) *Which (interpolation or extrapolation) would you be doing if you were to estimate the gas pressure when the volume of the trapped gas is 120 AVUs? What is the value of your estimate in AVUs?*
e) *Ask the students if they feel more confident in their interpolated gas pressures or their extrapolated gas pressures. Why?*

Student Exercise #5 (Grades 7-12): *The idea of "one variable getting bigger while the other variable gets smaller" may suggest what is referred as an* ***inverse*** *relationship between the variables. Such a relationship is described mathematically in the following way:*

$$P \propto \frac{1}{V} \quad or \quad P = \frac{k}{V} \quad or \quad PV = k$$

The symbol $\propto$ is read "is proportional to" and k is the constant of proportionality. In the case of our experiment, we can test this by finding the product of gas pressure P by gas volume V. If this product is nearly the same for each (P, V) data pair, we have pretty convincing evidence that P and V are inversely proportional. Ask the students to determine the PV products and record their data in the right-most column of their data *tables. They should find the products all quite similar in value, in which case they should determine the average of these PV products and record this average in the bottom-right cell of the data table.*

Student Exercise #6 (Grades 7-12): *Now that we have an equation relating pressure and volume, e.g., PV = 1425, we should be able to make much more accurate interpolation and extrapolation predictions than we did back in student exercise 4. Using the equation, determine the gas pressure for volumes of (a) 22.5 AVUs, (b) 35 AVUs, (c) 7.5 AVUs, and (d) 120 AVUs.*

Student Exercise #7 (Grades 11-12, Using Spreadsheet Software such as Excel): *When experimental data suggests an inverse relationship between the two variables **A** and **B**, there are many possibilities, the most common being:*

(a) *A is inversely proportional to B, an **inverse first power** relationship.*
(b) *A is inversely proportional to B^2, an **inverse square** relationship.*
(c) *A is inversely proportional to B^3, an **inverse cube** relationship.*

In student exercise 5, we found that the relationship between volume V and pressure P for Boyle's Law is an inverse first power relationship. But how do you proceed if you are not sure what the power is? With spreadsheet software such as Excel, there is a nice way to determine the power.

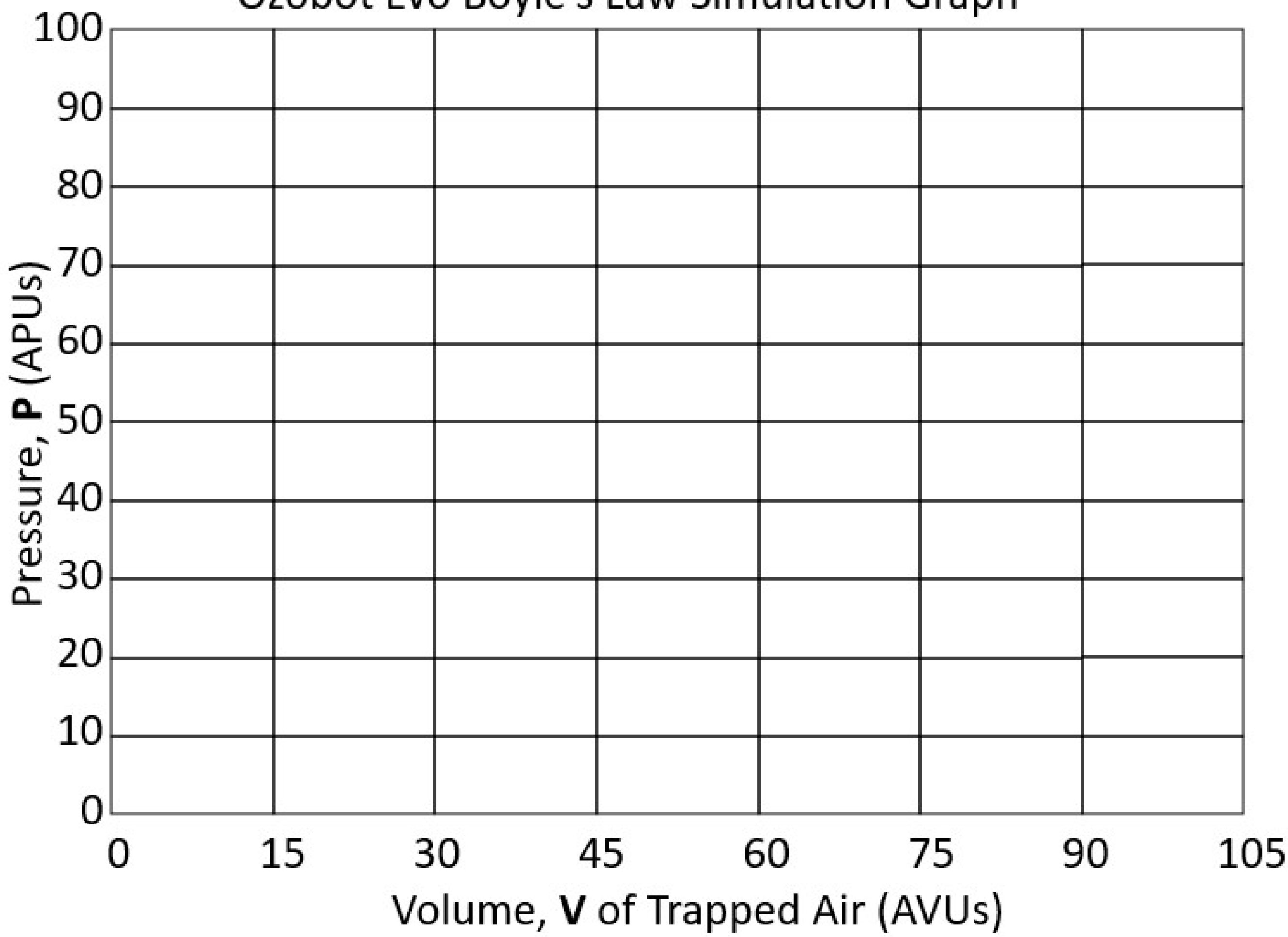
Copy your volume and average pressure data pairs into two columns in Excel, and then create an Excel scatter graph of P (on the y-axis) vs. V (on the x-axis). Click on one of the data points and select "Add Trendline". Select "Power" as the "Trend/Regression Type", and also check the box for "Display Equation on chart". You should get an equation similar to $\mathbf{y = 1530.7x^{-1.018}}$. *Since the power, -1.018, of x (volume) is very close to -1, you can feel confident that the relationship between pressure and volume is an inverse first power relationship.*

Student Exercise #8 (Grades 11-12, Using Vernier Software and Technology's Logger Pro Software): *If you have access to Logger Pro, this can be used instead of spreadsheet software such as Excel. Enter your Volume and average Pressure data from student exercise 2 into a new Logger Pro file. Using the "Analyze" option in Logger Pro, test the* **Power** *"Curve Fit" equation **A*x^B** on your data. You should find that the value of the constant **B** is very close to -1, providing strong evidence that the relationship between pressure and volume is an inverse first power relationship. Also, the value of the constant **A** should be in the ballpark of the average value of the PV products in your original data table.*

Ozobot Evo Boyle’s Law Simulation Data Table

Volume, **V**, of Trapped Air (AVUs)	Pressure, **P** (APUs)				Product of Pressure times Volume, **PV**
	Run 1	Run 2	Run 3	Average	
105					
90					
75					
60					
45					
30					
15					
				Average PV →	

Ozobot Evo Boyle’s Law Simulation Graph



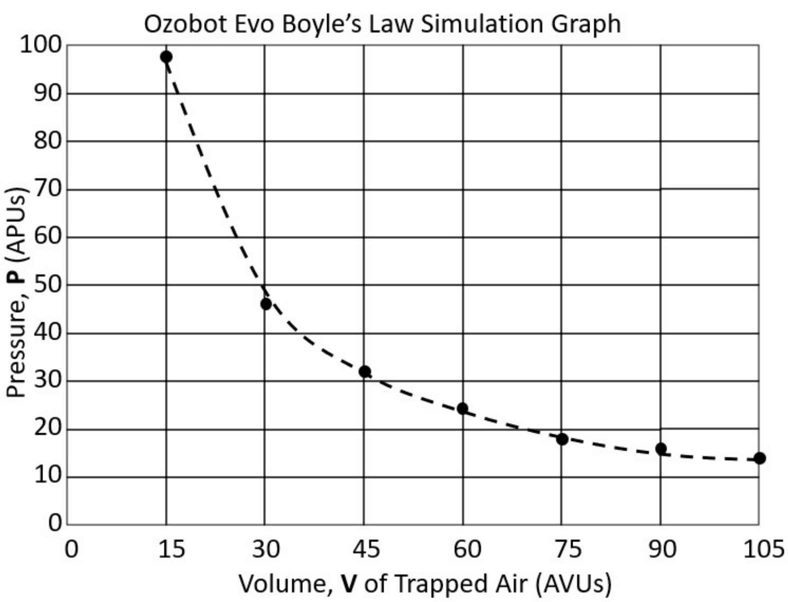
Answers to Exercises

1. *See the section entitled "The Map for this Classroom Application".*
2. *Here is a typical data table that might be obtained by a lab group:*

Ozobot Evo Boyle's Law Simulation Data Table

Volume, **V**, of Trapped Air (AVUs)	Pressure, **P** (APUs)				Product of Pressure times Volume, **PV**
	Run 1	Run 2	Run 3	Average	
105	14	13	13	13.3	
90	16	16	15	15.7	
75	18	20	20	18.7	
60	24	25	23	24.0	
45	33	34	30	32.3	
30	47	45	48	46.7	
15	98	99	96	97.7	
				Average PV →	

3. *A typical lab group's graph might appear as follows:*



Typical responses regarding the relationship between P and V might be:

When one gets big the other gets smaller.
As the volume increases the pressure decreases. As the pressure increases, the volume decreases.

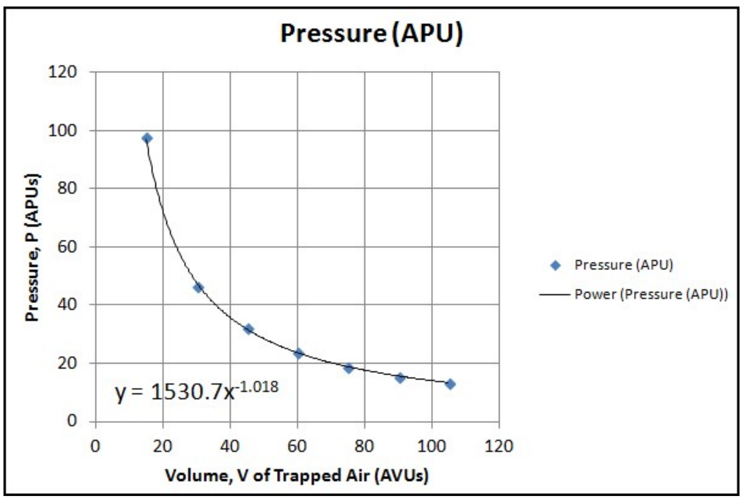
4. *(a) Interpolation. The pressure would be approximately 70 APUs.*
   (b) Interpolation. The pressure would be approximately 40 APUs.
   (c) Extrapolation. The pressure would be approximately 150 APUs.
   (d) Extrapolation. The pressure would be approximately 12 APUs.
   (e) Most students will indicate that they are more confident in the interpolated values. The extrapolated values are beyond the ends of the graph, and it is difficult to know exactly how to extend the curve.

5. *Typical lab group data tables will appear as follows, with PV values nearly the same, and having an average of about 1425.*

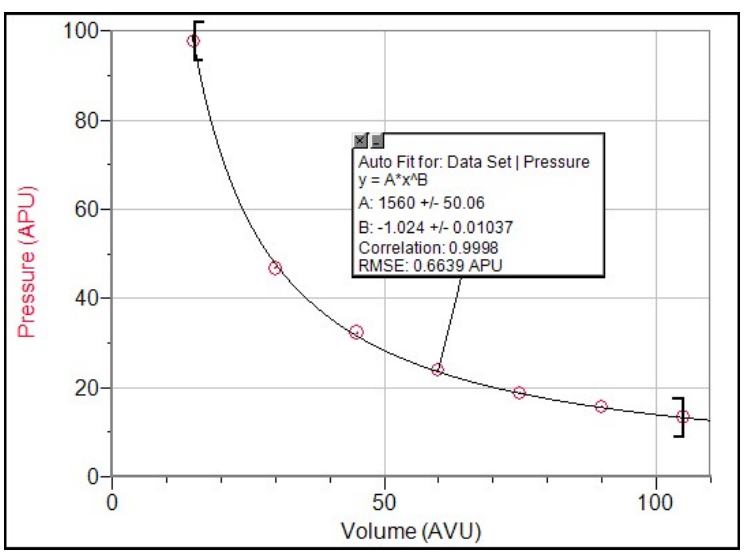
Ozobot Evo Boyle's Law Simulation Data Table

Volume, **V**, of Trapped Air (AVUs)	Pressure, **P** (APUs)				Product of Pressure times Volume, **PV**
	Run 1	Run 2	Run 3	Average	
105	14	13	13	13.3	1396.5
90	16	16	15	15.7	1413.0
75	18	20	20	18.7	1402.5
60	24	25	23	24.0	1440.0
45	33	34	30	32.3	1453.5
30	47	45	48	46.7	1401.0
15	98	99	96	97.7	1465.5
				Average PV →	1424.6

6. *(a) 63 APU, (b) 41 APU, (c) 190 APU, (d) 12 APU*
7. *A typical Excel chart would look like this:*



8. *A typical Logger Pro chart would look like this:*



Ozobot Evo Boyle's Law Simulation

(Temperature and Mass of the Gas are kept constant)