Boyle's Law Laboratory (Virtual) – MCA Physics

Introduction

Robert Boyle made many important discoveries in physics and chemistry, including the gas law named after him which states:

If temperature and the quantity of gas remain fixed, the product of gas pressure times the gas volume remain constant in a closed system.

Stated as an equation PV = k, where

P is the gas pressure, V is the volume, and k is the constant. One can solve for pressure to yield the form of the equation this lab tests with the explicit hypothesis:

$P = k/V$ or equivalently, $P = kV^{-1}$.

For more background on Boyle's Law see: https://en.wikipedia.org/wiki/Boyle%27s_law

Method

Robert Boyle's original data has been entered carefully into a spreadsheet from (Boyle 1662) where Column A from his data on p. 57 is his measured gas volume (in arbitrary units) and column D is his measured gas pressure, with atmospheric pressure added to his gauge pressure determined with the height of a mercury column (in units of in Hg, inches of mercury). The pressure vs. volume data for compression (pressure greater than atmospheric) is taken from his table on p. 57. The pressure vs. volume data for rarefaction (pressure less than atmospheric) is taken from his table on p. 64. The surrounding text describes his two original experiments in detail.

Boyle R (1662) A defense of the doctrine touching the spring and weight of air. F.G. for Thomas Robinson, London

Link: https://quod.lib.umich.edu/e/eebo/A28956.0001.001?rgn=main;view=fulltext
http://chemed.chem.purdue.edu/genchem/history/boyle.html

First, we need to replicate Boyle's original analysis in which he predicted the pressure expected for every volume after the first row of his tables by using the pressure and volume in the first row and the volume in the later row: $P_2 = P_1V_1/V_2$. Make a spreadsheet formula to automate this calculation for all the rows in the spreadsheet table for both the condensation and rarefaction experiments. Now, compute the error in Boyle's prediction as the measured pressure minus the predicted pressure in the next column of the spreadsheet. Then, make an additional column where you are squaring the error with a simple spreadsheet formula. This may seem odd, but it is a standard step, because it allows a RMS (root mean square) error to then be calculated as the square root of the mean squared error with a simple spreadsheet formula something like = sqrt(average(E4:E28)) which computes the square root of the average squared error. This is the typical “Error” between Boyle's original measurements and his original predictions.

The method of our re-analysis shall be to copy the original data from the spreadsheet into a suitable graphing and fitting program (Graph.exe), and perform least squares fits to each of the two data sets (condensation and rarefaction). Make sure to save the graph for each fit with properly labeled axes, and make note of the proportionality constant, exponent, and R squared value for the fit in each case. Now, copy the best fit equation into the spreadsheet and modify it appropriately (put a cell reference in place of x) to compute the best fit model prediction for every row in the spreadsheet. Now compute the Error and Squared Error for each of Boyle's original volumes and pressures in both the condensation and rarefaction cases, and compute the RMS error. Note in each case whether the RMS error is larger or smaller for the best fit curve compared with Boyle's original predictions.

Results

Your results section should contain formatted tables taken from your spreadsheet for each case (condensation and rarefaction). It should also include formatted graphs with the original data and best fit curves with proper labeling, units, and best fit equations.

Discussion/Conclusion

Was the hypothesis supported by the data? How good were the fits? Which data set supported the hypothesis more strongly? What are some possible sources of error in the original experiments? How large are the RMS errors in each case compared with the measured values themselves (expressed as percentages)? In historical perspective of a 17^{th} century experiment, are these relative errors pretty good? Given the conditions and equipment Boyle was working with, are these levels of experimental errors impressive? Are the experimental errors larger or smaller than the resolution with which Boyle was measuring the pressure? (Hint, first, consider what resolution Boyle was using to measure the pressure and then relate it to the RMS errors).