HP Prime Application Note Physics:

07. Boyle's Law

Boyle's law states that, for a given temperature, the product of the pressure p and the volume V is constant: $p \cdot V = \text{constant}$. If you decrease the volume of a sealed vessel, the pressure will increase. For this experiment, we use Hewlett-Packard's Mobile Calculating Laboratory (MCL), which includes the interfacing module HP StreamSmart 410, the Fourier pressure sensor DT015-1, and a 10 ml syringe:

The experimental setup is simple. The syringe inserts into the tube of the pressure sensor. Connect the HP StreamSmart 410 to the pressure sensor and the HP Prime. Start the Data Streamer app in the HP Prime and squeeze the syringe. The Fourier pressure sensor has a resolution of 0.18 kPa, measuring with an accuracy of ±3% over the entire range. At the start of the experiment, the ambient pressure was 123.93 kPa. The volume values are those as marked on the syringe. We took the following readings:

V in ml	p in kPa
10	124.29
9	135.71
8	148.21
7	164.82
6	186.25
5	212.68
4	254.64
3	314.11

First, we will answer the question: is the product of the data constant? Enter the values in the Spreadsheet app and calculate $p \cdot V$:

The third colum is highlighted in blue and lists the respective products of the first two colums, clearly showing that the values are not constant: $p \cdot V \neq \text{constant}$. Now, you have entered the realm of experimental physics. That is you have to explain why the experiment does not follow Boyle's rule. So you have to analyse the experimental setup and the sources of the measurement errors. You may want to see how FlinnScientific worked out this problem. See *Pressure vs. Volume and Boyle's Law* at https://www.flinnsci.com/api/library/Download/7ee0bddcb4334e6aa1c61cd0f4b91de7 and watch the video *Pressure vs. Volume and Boyle's Law* at https://www.youtube.com/watch?v=LOCgHxTVFvY.

Let us consider the errors in our data. The accurate and sensitive Fourier probe hops in discrete steps of ±0.36 kPa. Since the first reading and the ambient pressure only differ 124.29-123.93 = 0.36 kPa, we do not have to correct our pressure data. The real error is in the syringe. The error in adjusting the volume using a syringe amounts to some 0.1 ml. There is a soft plastic tube, 19.5 cm long and some 2 mm thick, which connects the syringe to the Fourier probe, thus adding an extra volume *B* to the syringe volume *V*. So our volume actually is $V + B$ and we need to estimate *B*. In order to do so, we draw a line through *V* versus $\frac{1}{p}$ and determine the intercept. So calcalute $\frac{1}{p}$ in the Spreadsheet app and copy the data to the Statistics 2Var app, using the *x* and *y* axes for $\frac{1}{p}$ and *V* respectively:
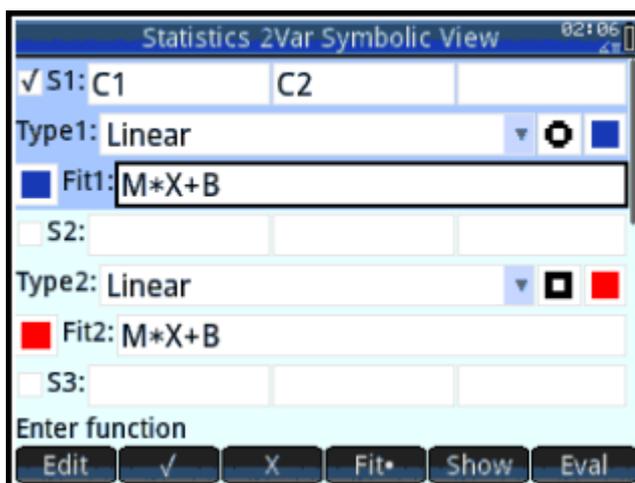
In the Symb[olic View] menu, select the Linear curve fit:

Plot the data, use Autoscale and zoom out to view the *y*-axis intercept:

S1:1 X:8.04569957ᴇ⁻3   Y:10
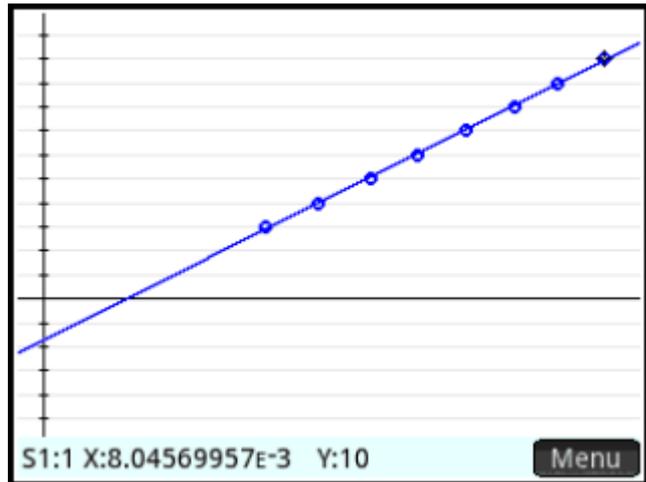
The plot confirms that our volume data are systematically too small. The Symb[olic View] menu shows that we need to add B = 1.7 ml to the volume V:

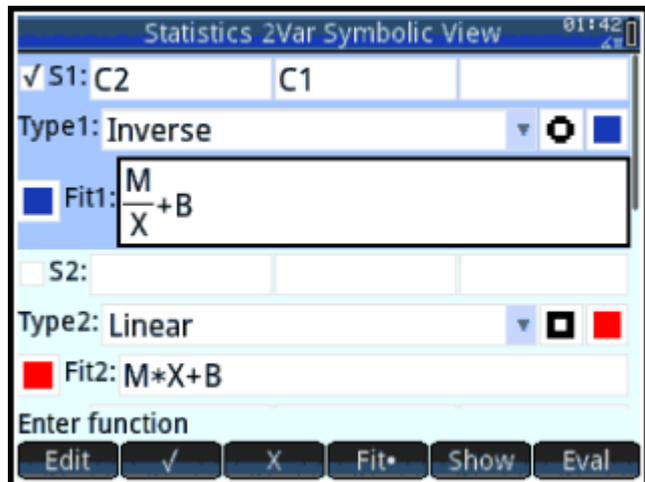We thus add 1.7 ml to our volume data and, again, verify the product $p \cdot V$ in the Apreadsheet app:

So having added 1.7 ml to the volume data, the product $p \cdot V$ seems quite constant, varying between 1424 and 1476.
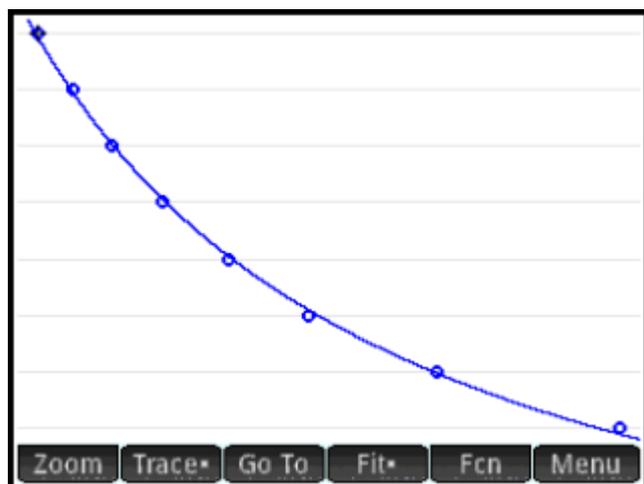
On the HP Prime, the shortcut to this approach is to use the Inverse curve fit $\frac{M}{X} + B$. Just enter the original values from the Spreadsheet app to the Statistics 2Var app:

	C1	C2	C3	C4
1	10	124.29		
2	9	135.71		
3	8	148.21		
4	7	164.82		
5	6	186.25		
6	5	212.68		
7	4	254.64		
8	3	314.11		

Make the following selections in the Symb[olic View] menu:

√ S1: C2   C1

Type1: Inverse

Fit1: $\frac{M}{X} + B$

S2:

Type2: Linear

Fit2: M*X+B

Plot the data, using autoscale:

In the Symb[olic View] menu, the regression value of the Inverse curve fit shows the additional volume factor $B = 1{,}70$ ml:

The value 1445 is about the average of the product $p \cdot V$.