Improved Gay-Lussac Experiment Considering Added Volumes

Joel D. Krehbiel and Nelson Kilmer

Hesston College, Kansas

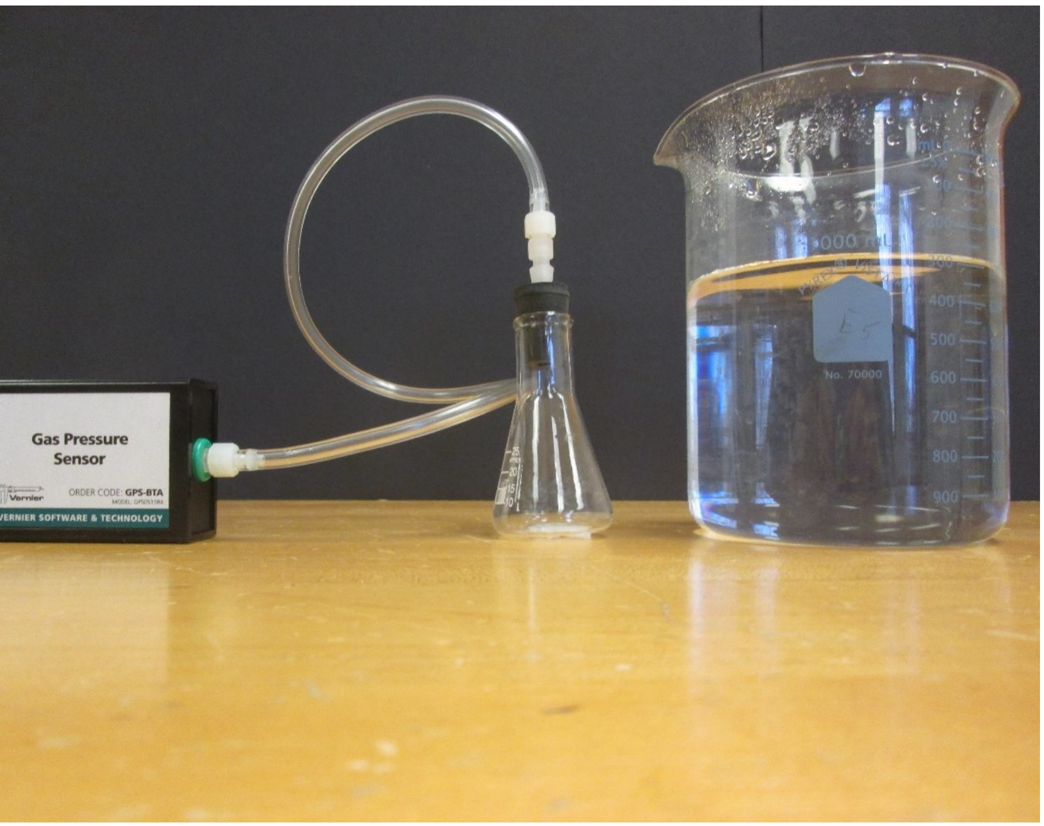
Joel.krehbiel@hesston.edu

AAPT Conference, Provo, UT

July 22, 2019

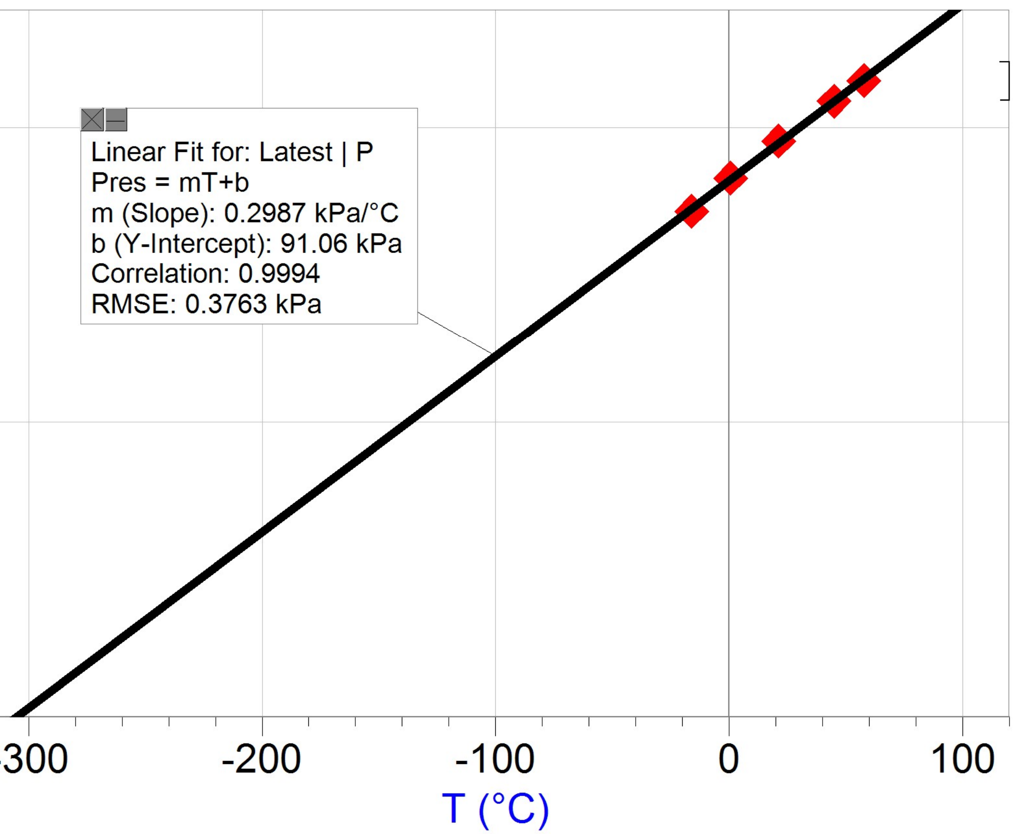
*Work Published in *The Physics Teacher*. 57: 21-25, 2019.

Gay-Lussac's Experiment



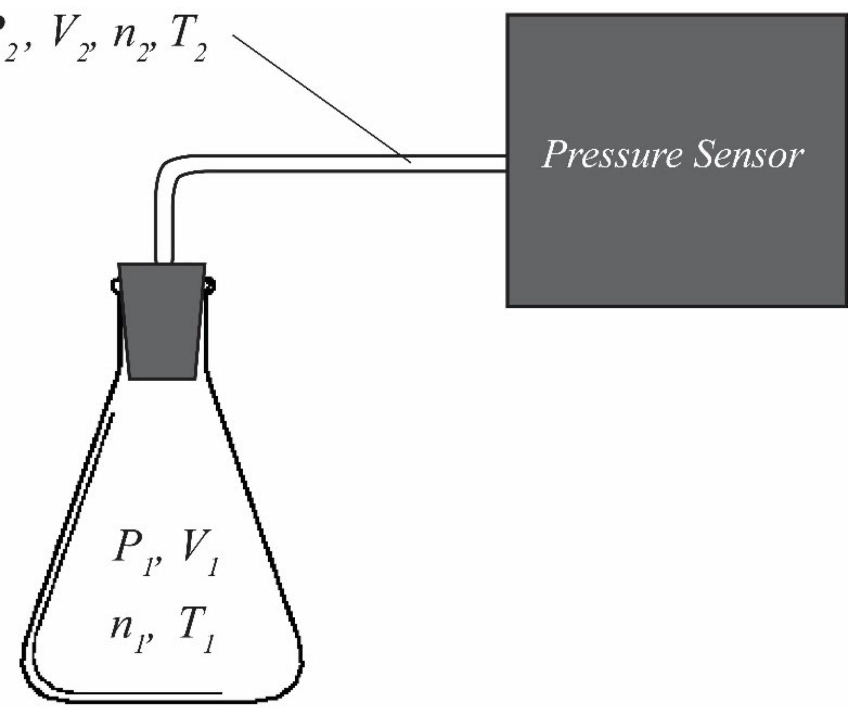
- Place a flask in a water bath
- Measure
  - Temperature (*T*) of the bath
  - Pressure (*P*) in the flask
- Repeat for different temperature water baths
- Since *PV=nRT*, both should increase proportionally
- A best fit line can be used to calculate absolute zero

Typical Data Overestimates Absolute Zero



- *K:* Difference in Celsius and Kelvin Temperature scales
- *K = b/m*
- Here: *K* = 304°C
- Percent Error: 11.3%

Two-volume theory



Ideal Gas Law:

$$P = P_1 = \frac{n_1 R T_1}{V_1} = P_2 = \frac{n_2 R T_2}{V_2}$$

Total moles:

$$n = n_1 + n_2$$

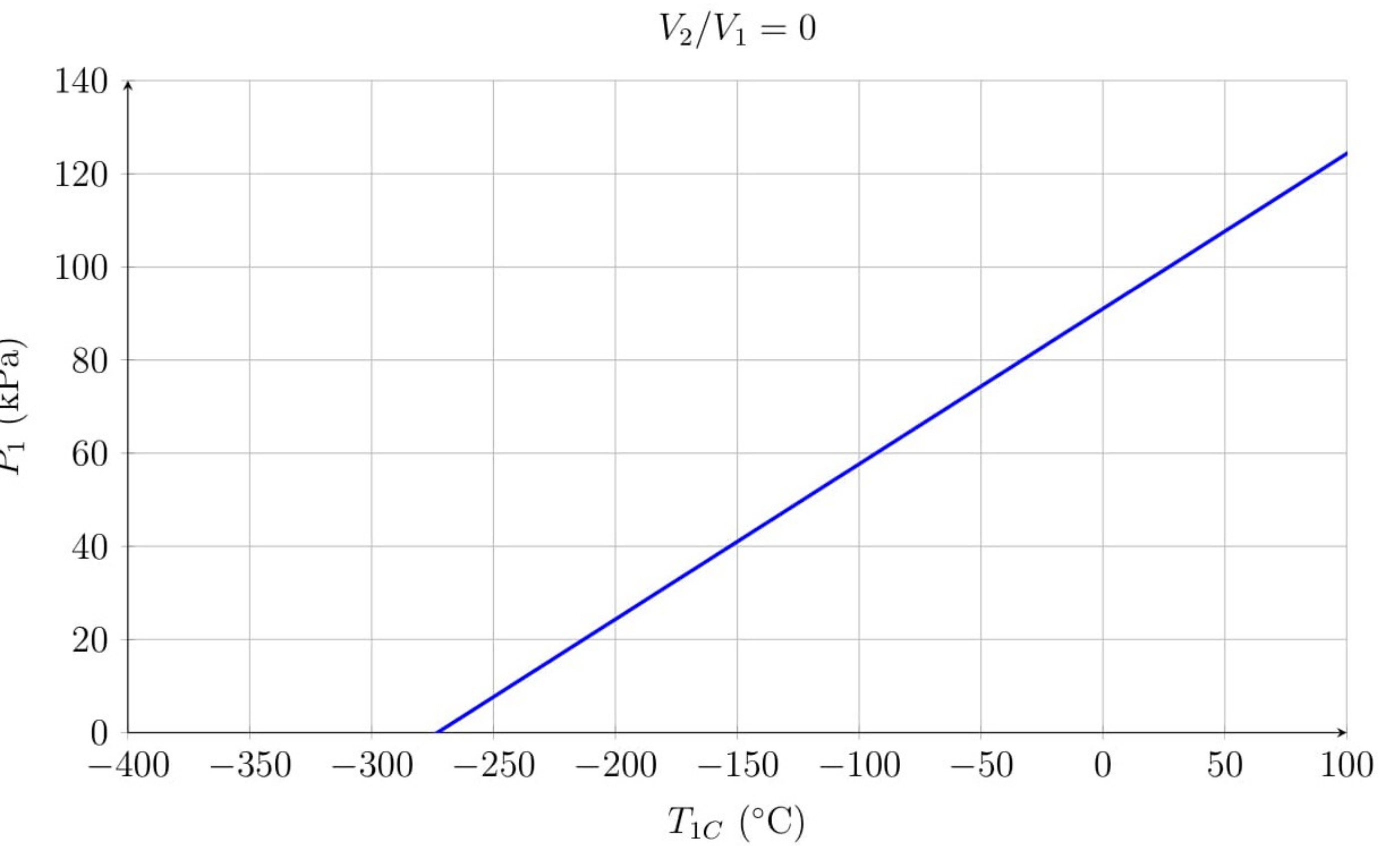
So

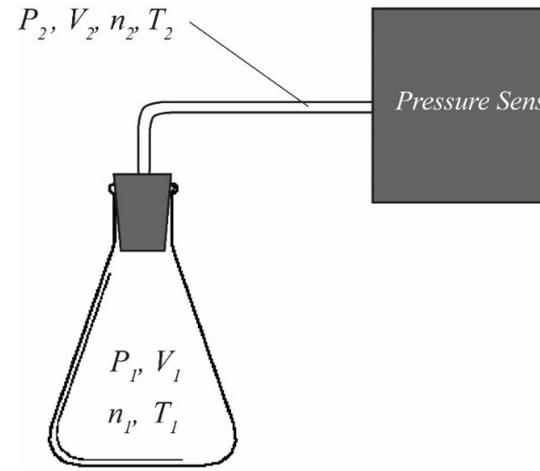
$$n_2 = n - n_1$$

$$n_1 = \frac{n}{1 + \frac{V_2}{V_1}\frac{T_1}{T_2}}$$

$$P = \frac{n R T_1}{V_1 + V_2 \frac{T_1}{T_2}}$$

Slope of $P - T$ curve depends on V_2/V_1

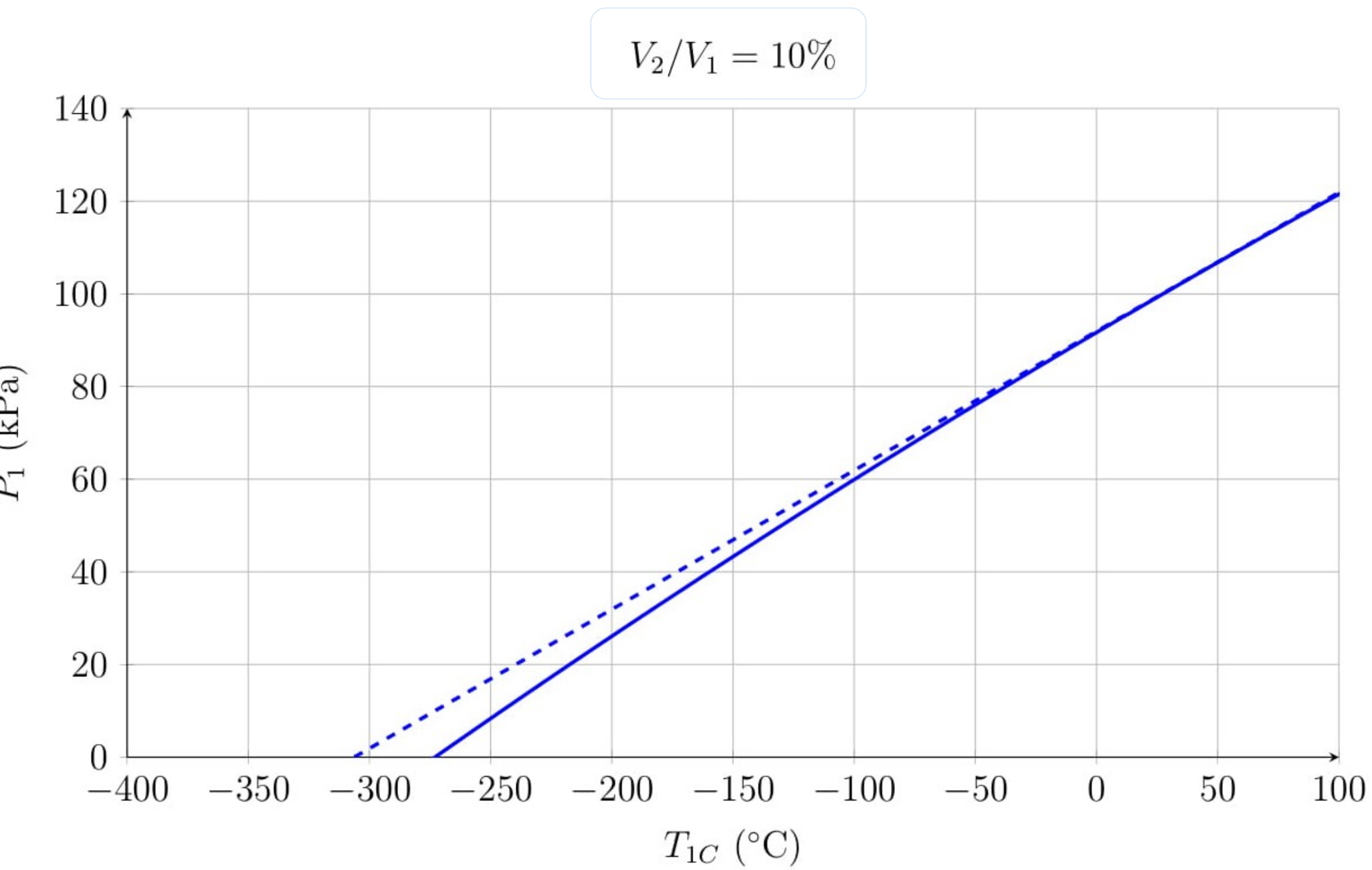


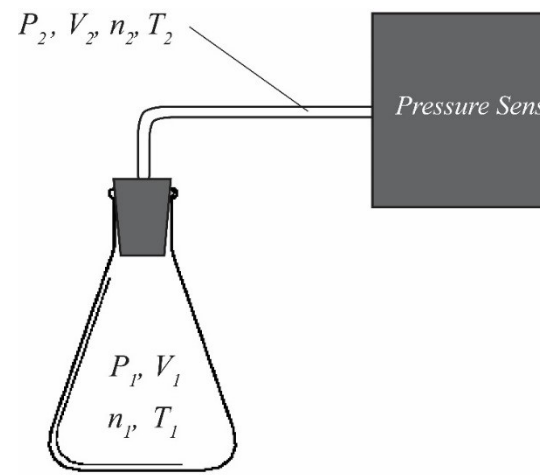


$$P = \frac{nRT_1}{V_1 + V_2 \frac{T_1}{T_2}}$$

Here we assume $P = 100$ k
at $T_{1C} = 27°$ C

Slope of $P - T$ curve depends on V_2/V_1

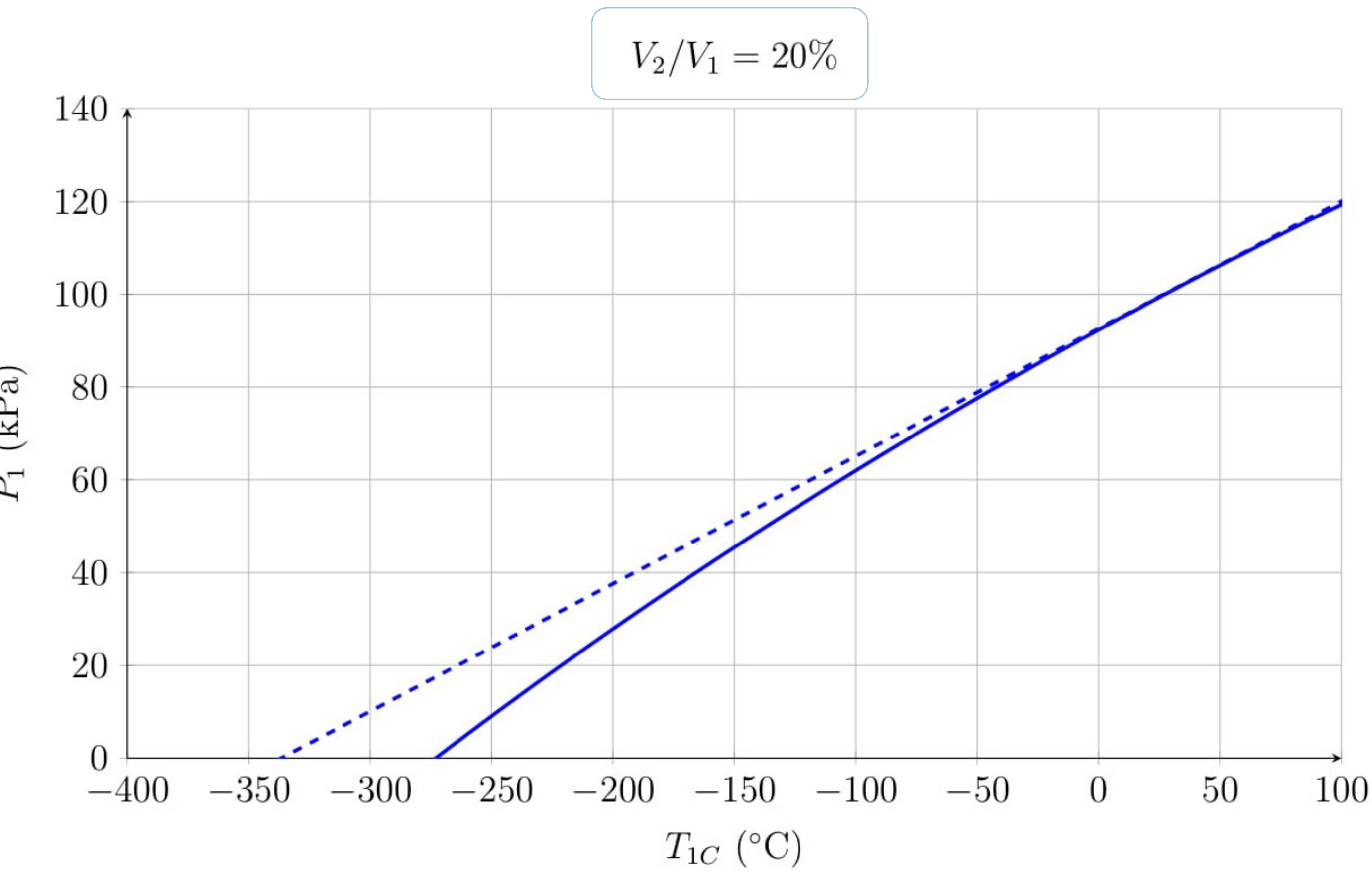


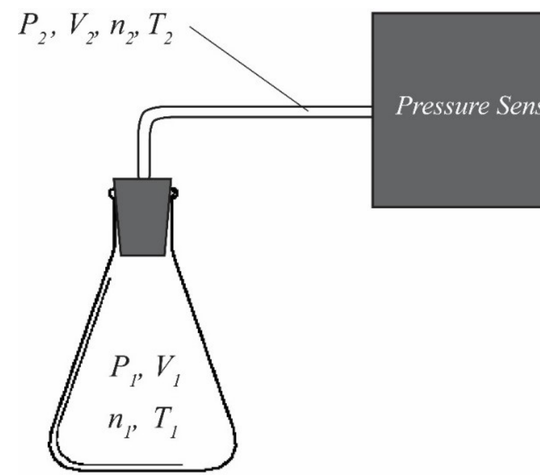


$$P = \frac{nRT_1}{V_1 + V_2 \frac{T_1}{T_2}}$$

Here we assume $P = 100$ k
at $T_{1C} = 27°$ C

Slope of $P - T$ curve depends on V_2/V_1

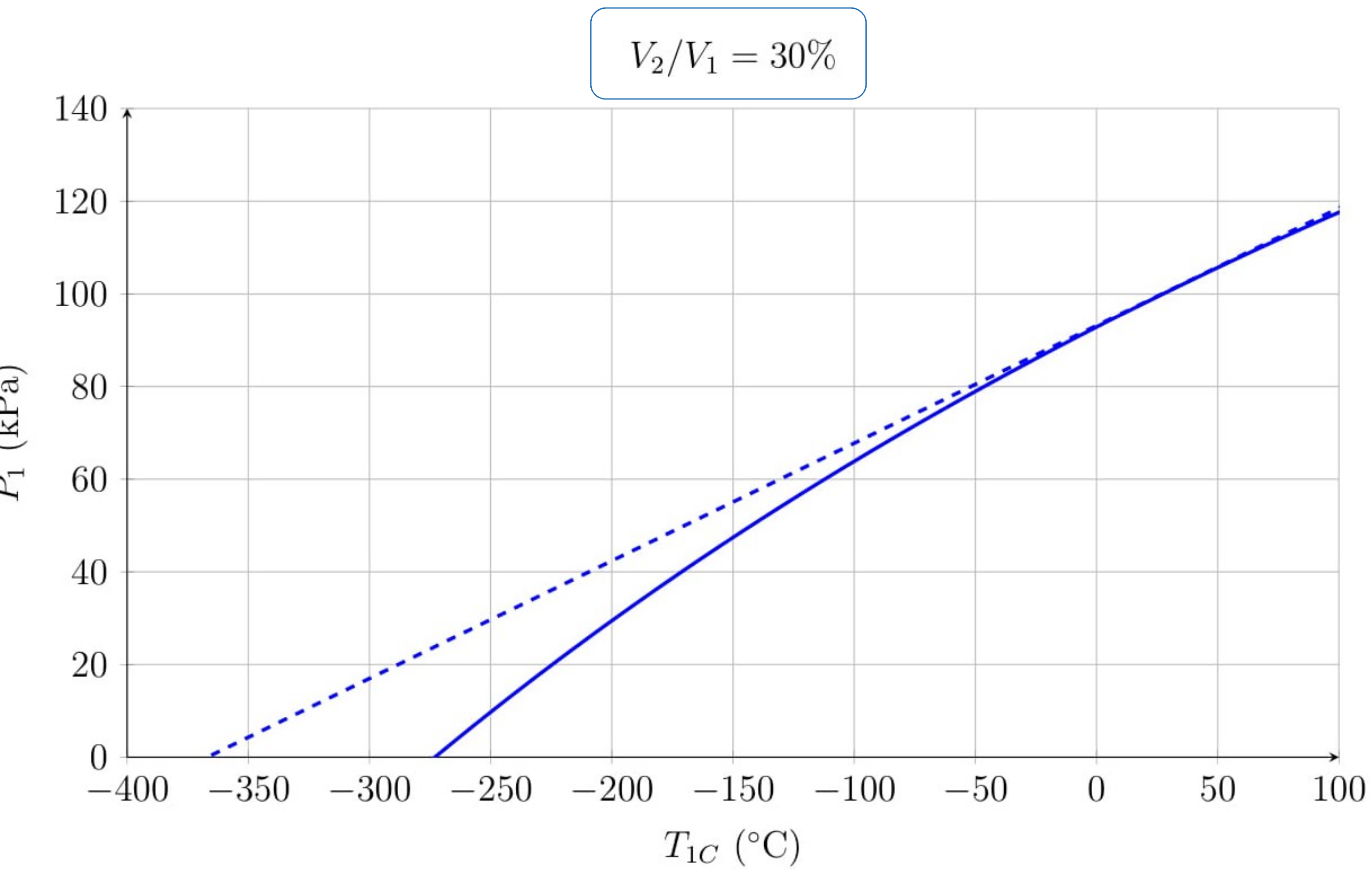


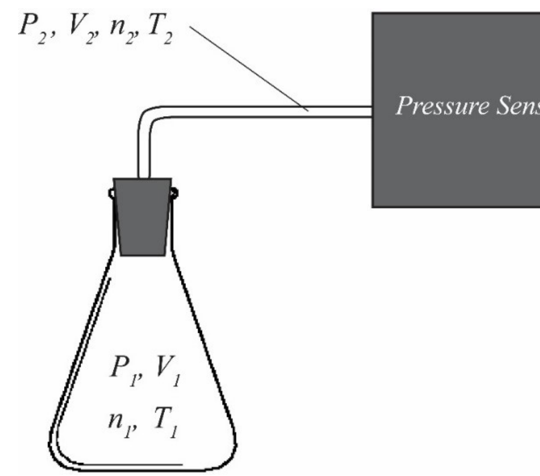


$$P = \frac{nRT_1}{V_1 + V_2\frac{T_1}{T_2}}$$

Here we assume $P = 100$ k
at $T_{1C} = 27°$ C

Slope of $P - T$ curve depends on V_2/V_1

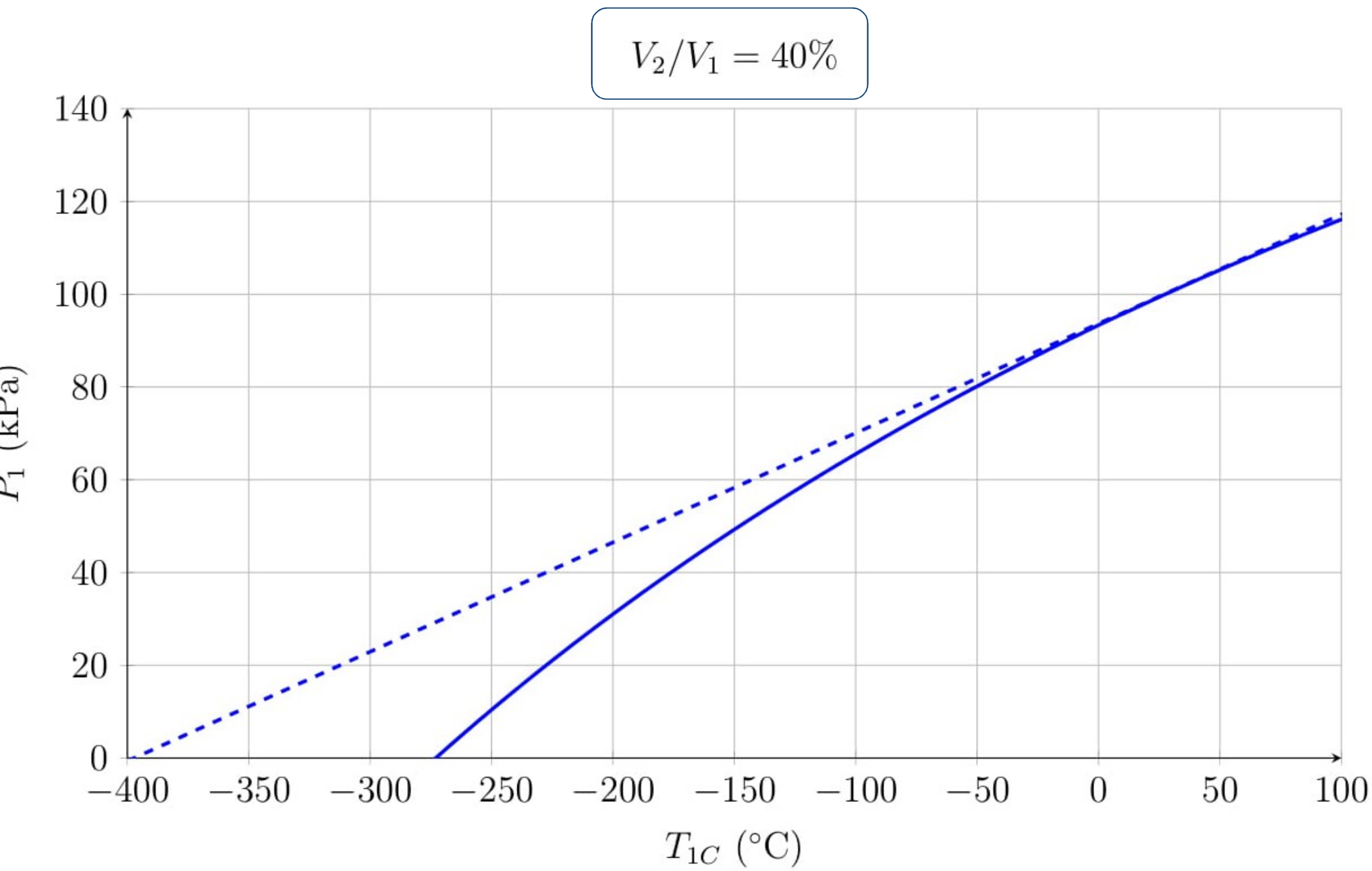


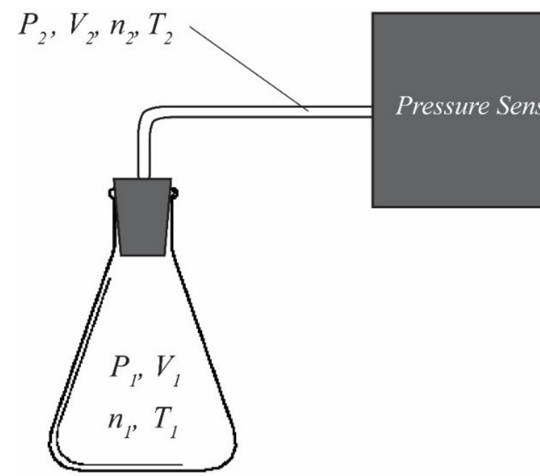


$$P = \frac{nRT_1}{V_1 + V_2\frac{T_1}{T_2}}$$

Here we assume $P = 100$ k
at $T_{1C} = 27°$ C

Slope of $P - T$ curve depends on V_2/V_1

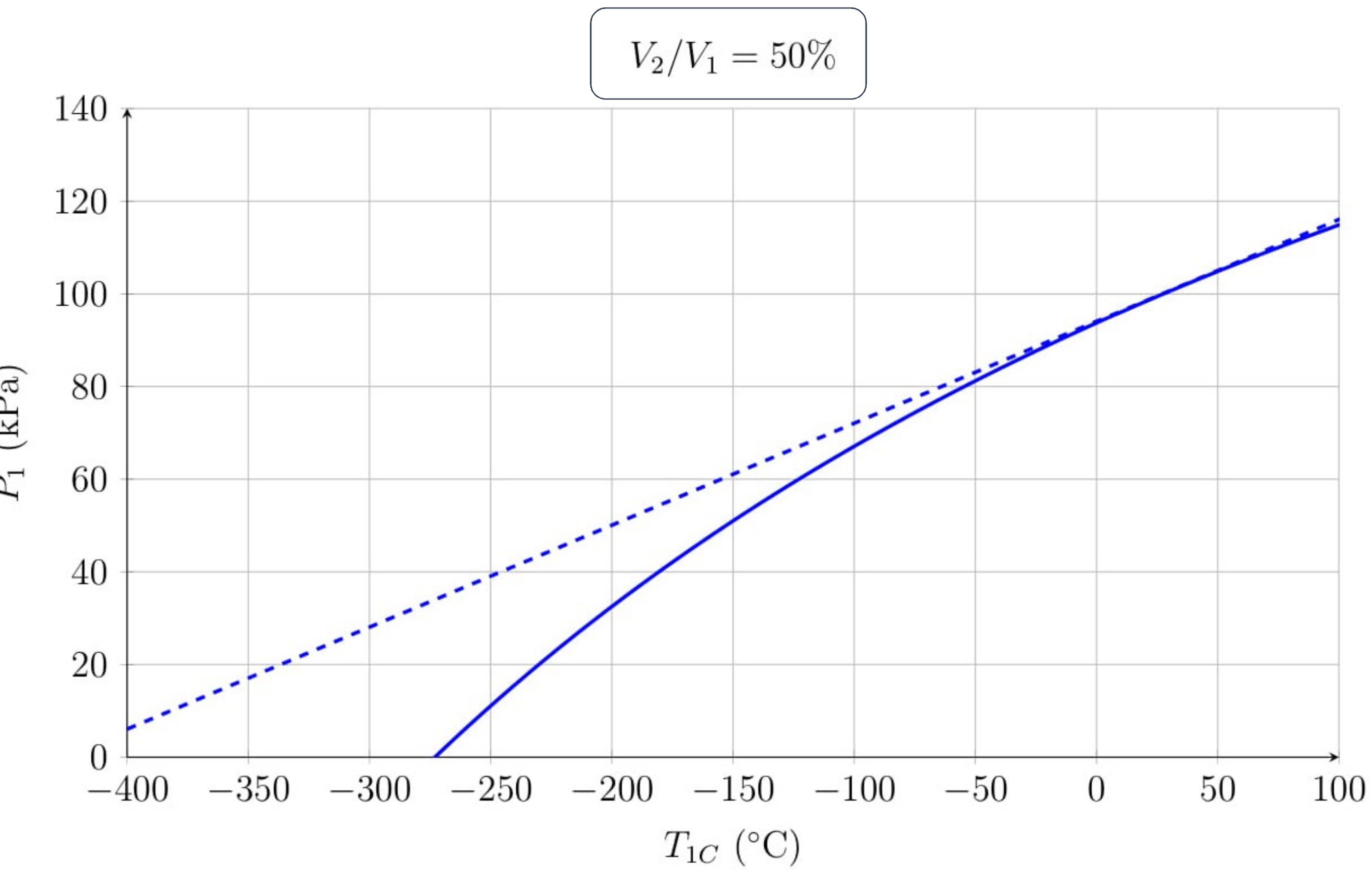


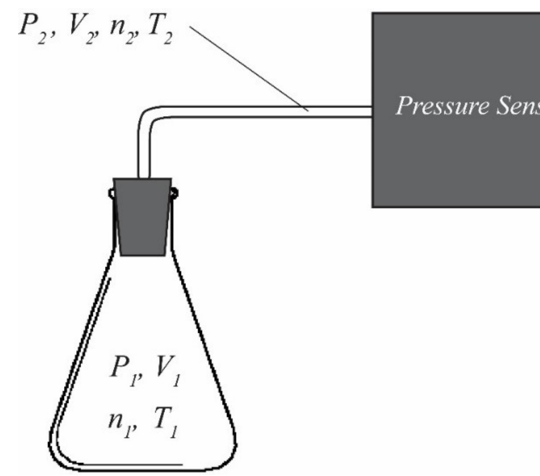


$$P = \frac{nRT_1}{V_1 + V_2\frac{T_1}{T_2}}$$

Here we assume $P = 100$ k
at $T_{1C} = 27°$ C

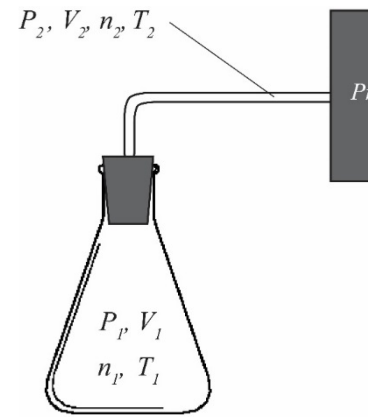
Slope of $P - T$ curve depends on V_2/V_1





$$P = \frac{nRT_1}{V_1 + V_2\frac{T_1}{T_2}}$$

Here we assume $P = 100$ k
at $T_{1C} = 27°$ C



Modifications to Experiment

Best fit to two-volume equation

- Measure air temperature: T_{2C}
- Determine volumes of flasks and tubing $(V_1, V_2, V_T = V_1 + V_2)$
- Enter a new best-fit line in data collection software

$$T_{1C} = \frac{P}{A - \frac{V_2}{V_1}\frac{P}{T_{2C}+K}} - K$$

- Best Fit parameters: A and K

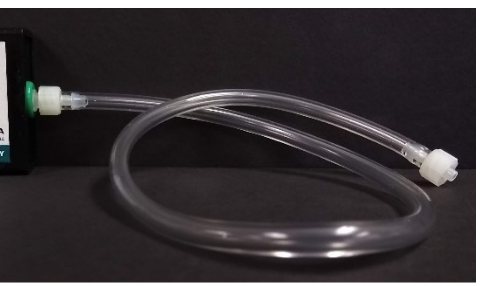
Slope Correction *(K = b/m)*

- Measure air temperature: T_{2C}
- Determine volumes of flasks and tubing $(V_1, V_2, V_T = V_1 + V_2)$
- Measure pressure $P_1 = P_{air}$ at air temperature
- Best to center temperature measurements around T_{2C}

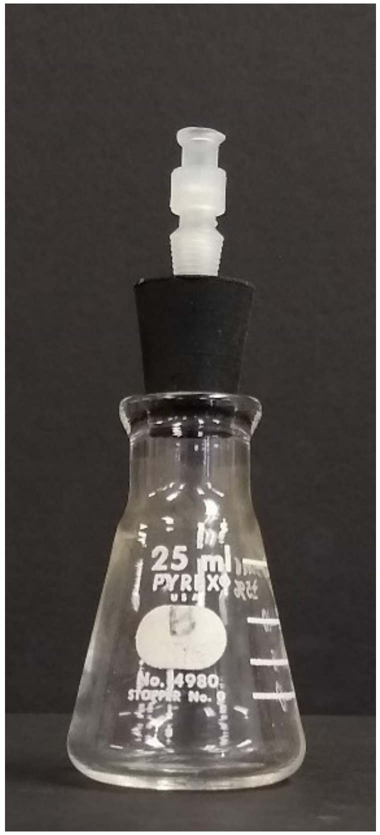
$$K = \frac{P_{air}}{\frac{dP}{dT}\left(\frac{V_T}{V_1}\right)} - T_{2C}$$

Volumes of different flasks

mined by weighing a
filled with water



V_2= 4.5 ml



V_1= 30 ml

V_2/V_1=15%

V_1= 40 ml

V_2/V_1=11.25%

V_1= 57 ml

V_2/V_1=7.9%

V_1= 141 m

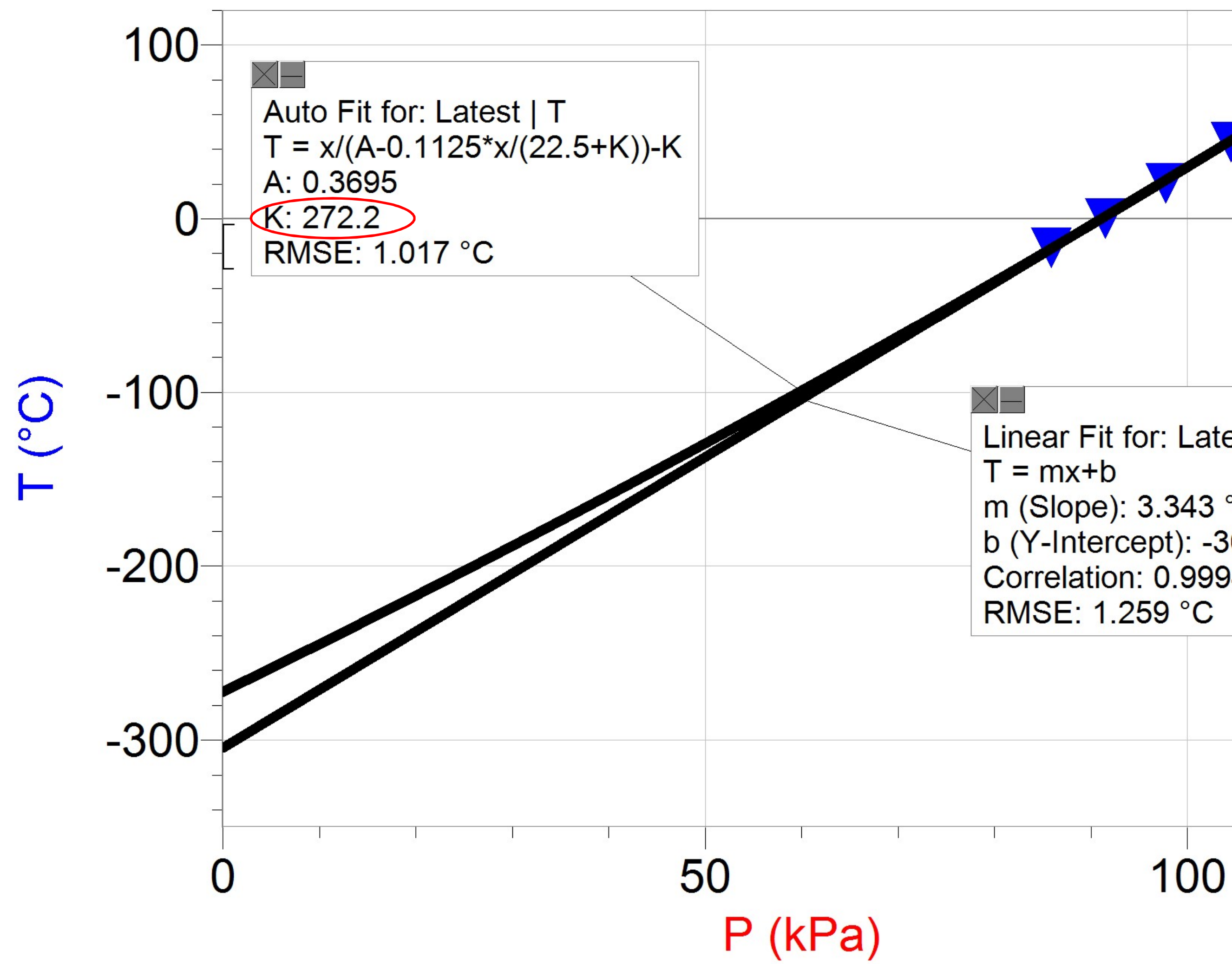
V_2/V_1=3.2%

Representative Data – Curve Fit

V_2/V_1=11.25%, T_{2C} = 22.5°C, P_{air} = 97.75 kPa

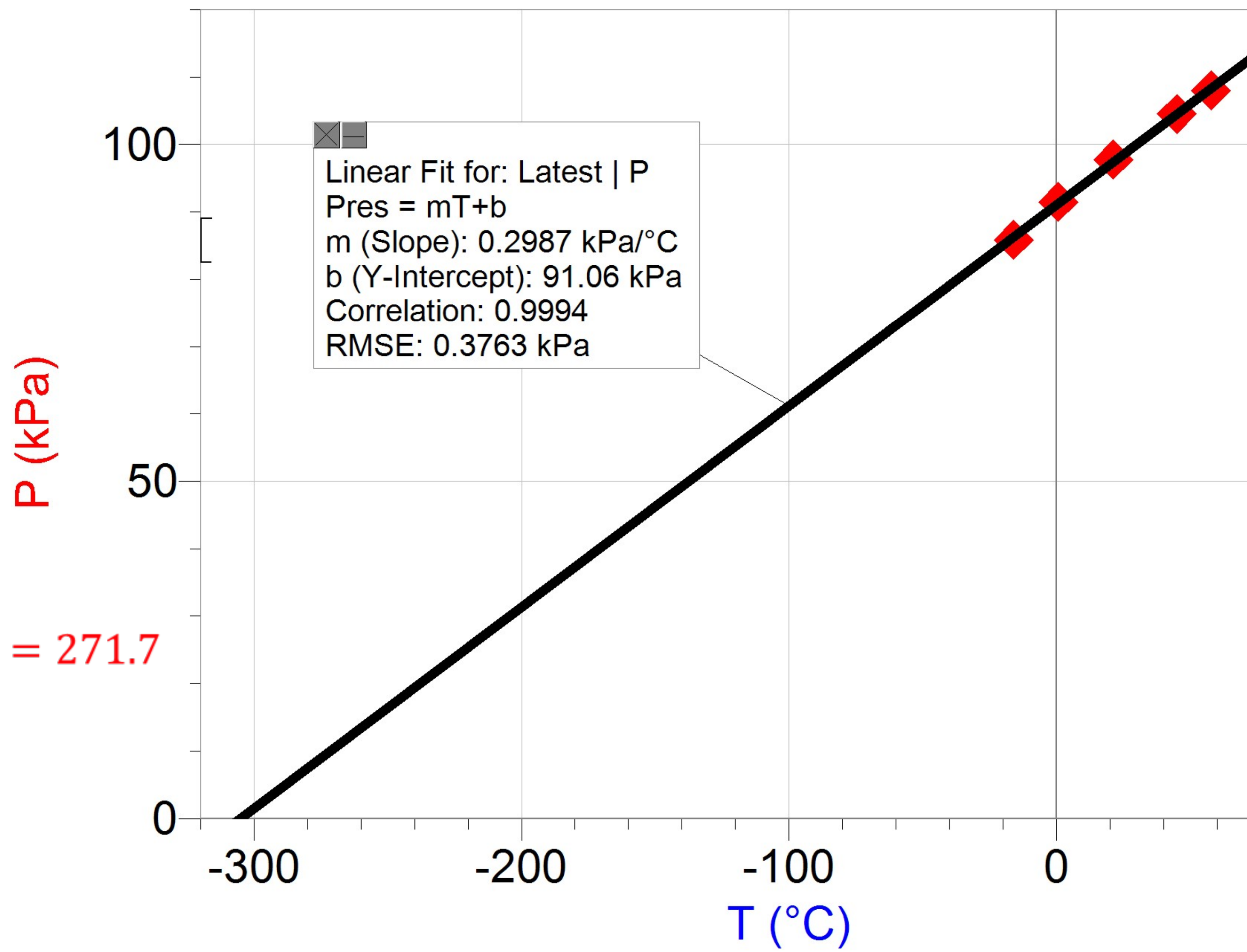
$$T_{1C} = \frac{P}{A - \frac{V_2}{V_1}\frac{P}{T_{2C}+K}} - K$$

K=272.2



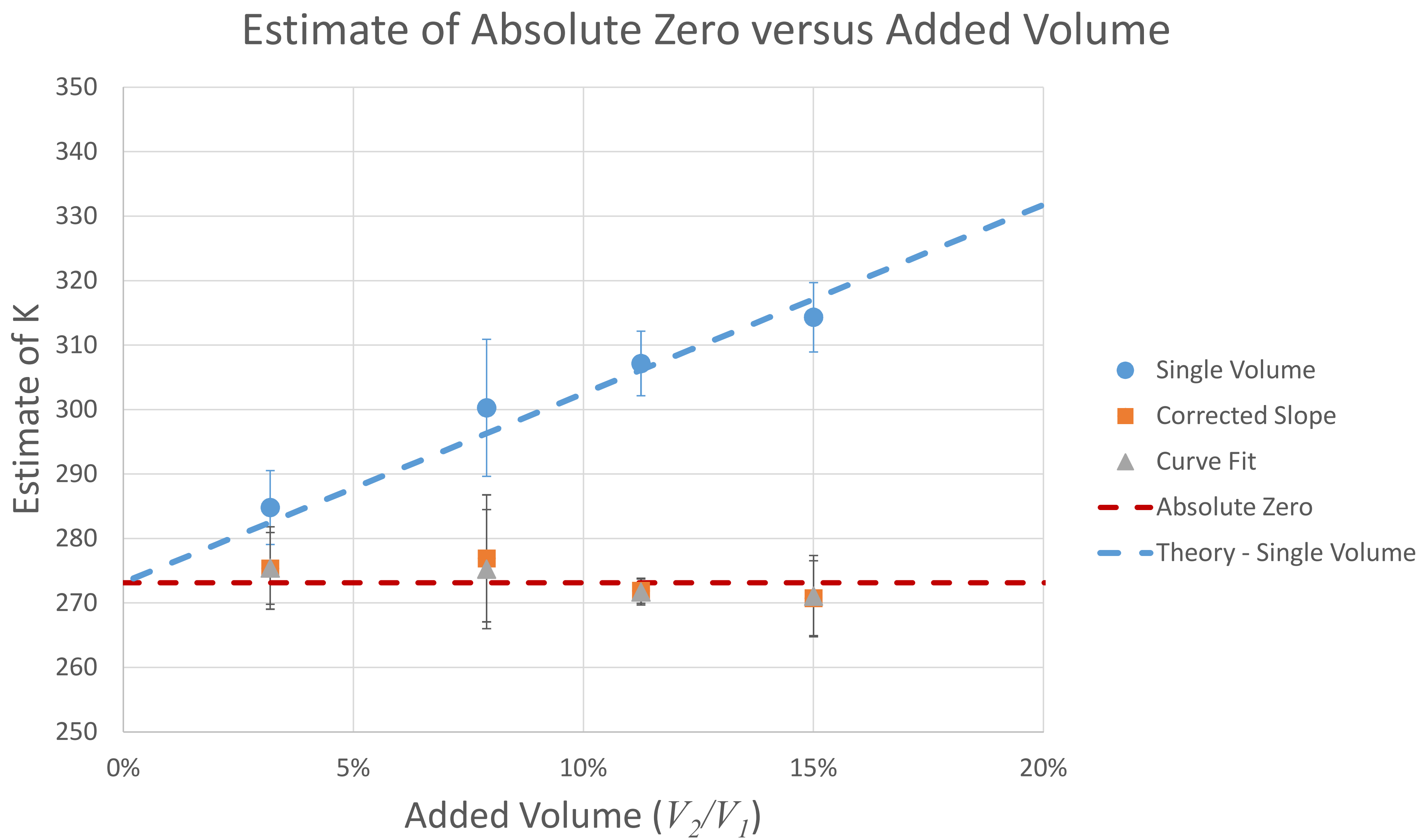
Representative Data – Corrected Slope

V_2/V_1=11.25%, T_{2C} = 22.5°C, P_{air} = 97.75 kPa



$$\frac{\ldots ir}{\ldots\left(\frac{V_T}{V_1}\right)} - T_{2C} = \frac{97.75}{0.2987 \cdot 1.1125} - 22.5 = 271.7$$

Student Results



Conclusions

Error in Gay-Lussac experiment due to volume of tubing

New two-volume theory developed

This method provides several benefits

- Errors reduced to less than 0.70% on average
- Significant learning opportunity

Some disadvantages

- Volumes must be known
- An equation must be defined in the software
- Data should be centered on room temperature for slope correction