Gas Laws and the Heat Engine

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Outline

- Introduction
- Calibration of potentiometer
- Charles's law
- Pressure versus temperature
- Boyle's law
- Making a heat engine
- Results
- Conclusion

Introduction

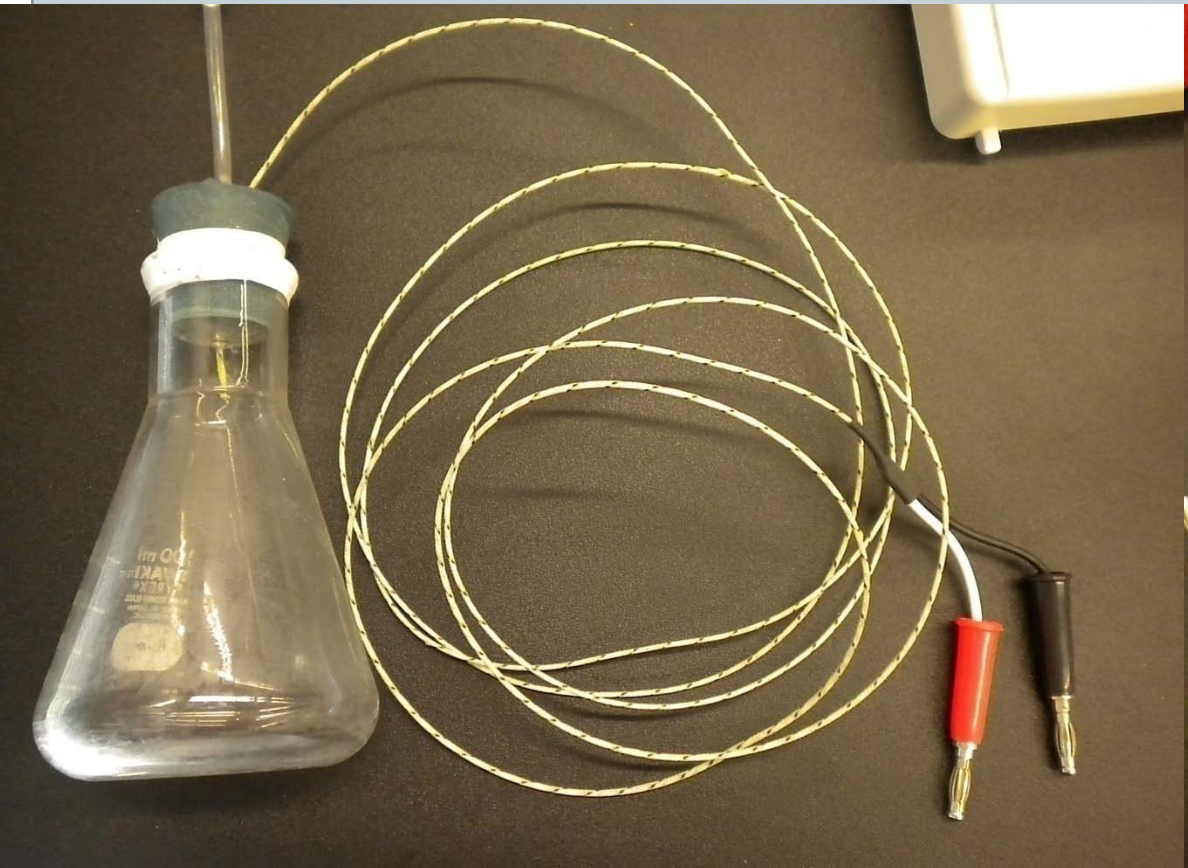
- This work has been described in,

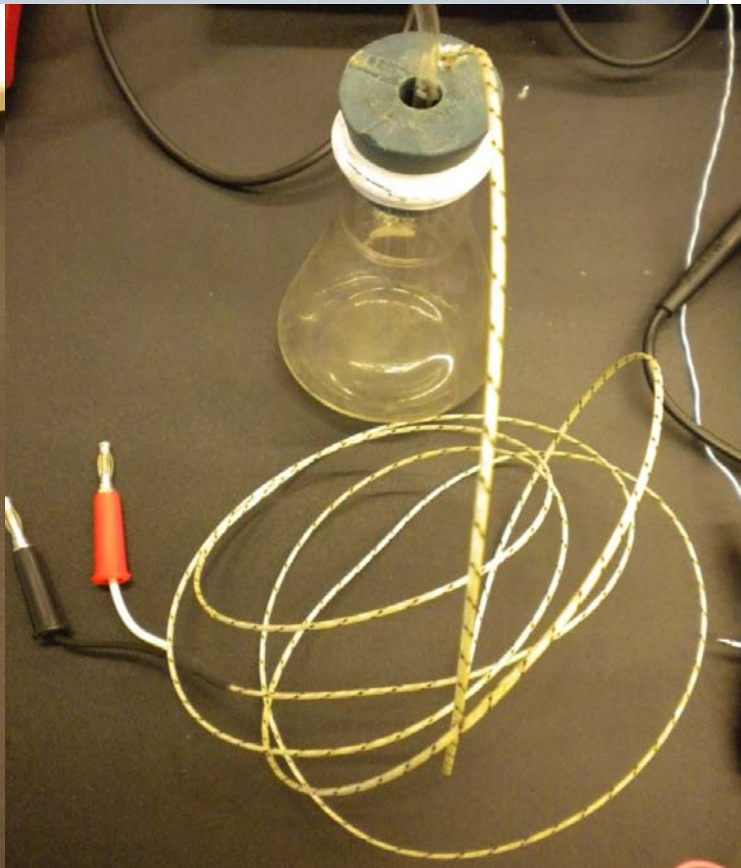
  David P. Jackson and Priscilla W. Laws, *Syringe thermodynamics: The many uses of a glass syringe, American Journal of Physics, (2005).*

- We will be using a linear potentiometer to measure the change in volume in our experiment. This experiment has been finally included in the freshmen lab.

Placing the thermocouple inside the flask

- Place the thermocouple inside the flask.
- Seal it properly using Teflon tape or silicone available in our workshop.
- Connect the thermocouple to multi-meter with a selection to measure temperature.





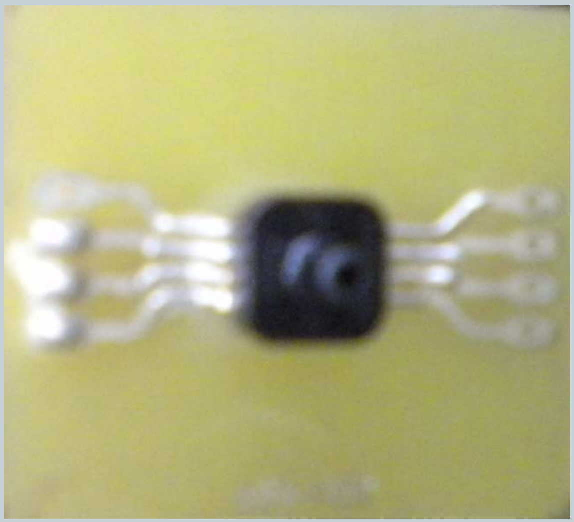
Selection of flask

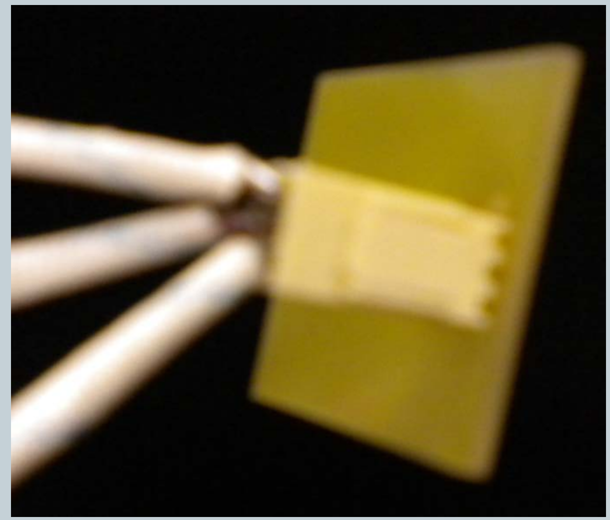
- We have flasks of different volumes but the choice is important to have reasonable expansion of the syringe.

▪ We have used a pipette to measure the volume of the flask (since, the gas occupies the volume of the container).

Pressure sensor

- MPXH6400 (Manufacturer: free scale semiconductors), the date sheet can be downloaded from http://www.freescale.com/.

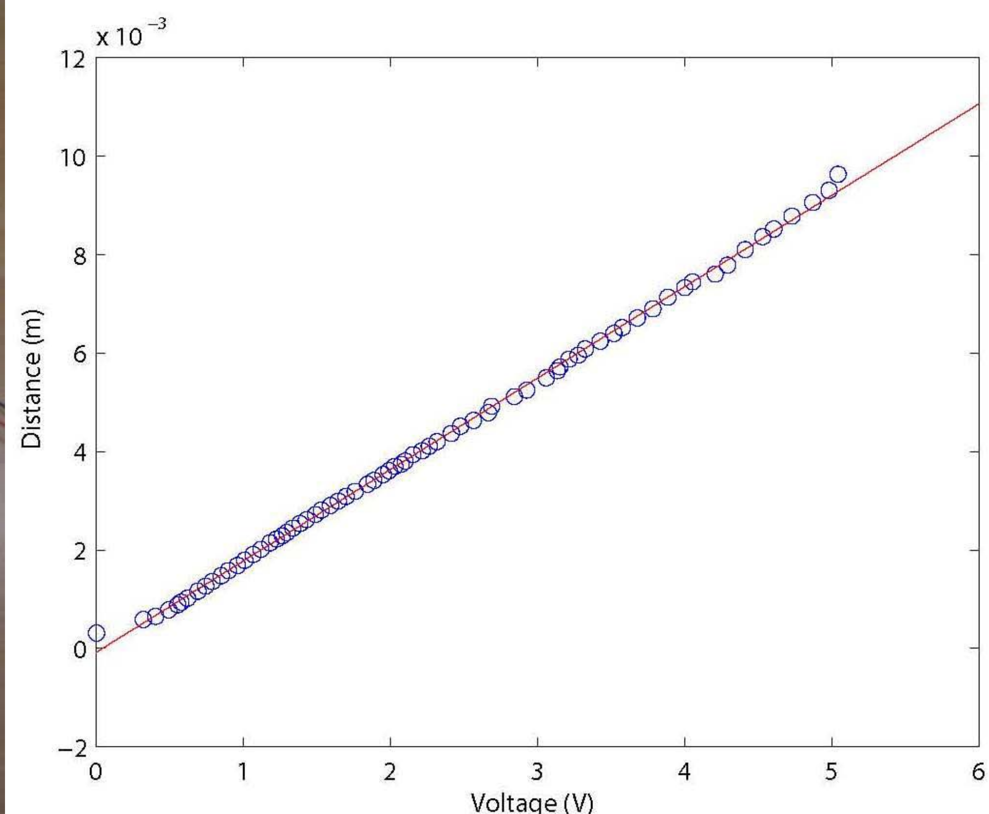




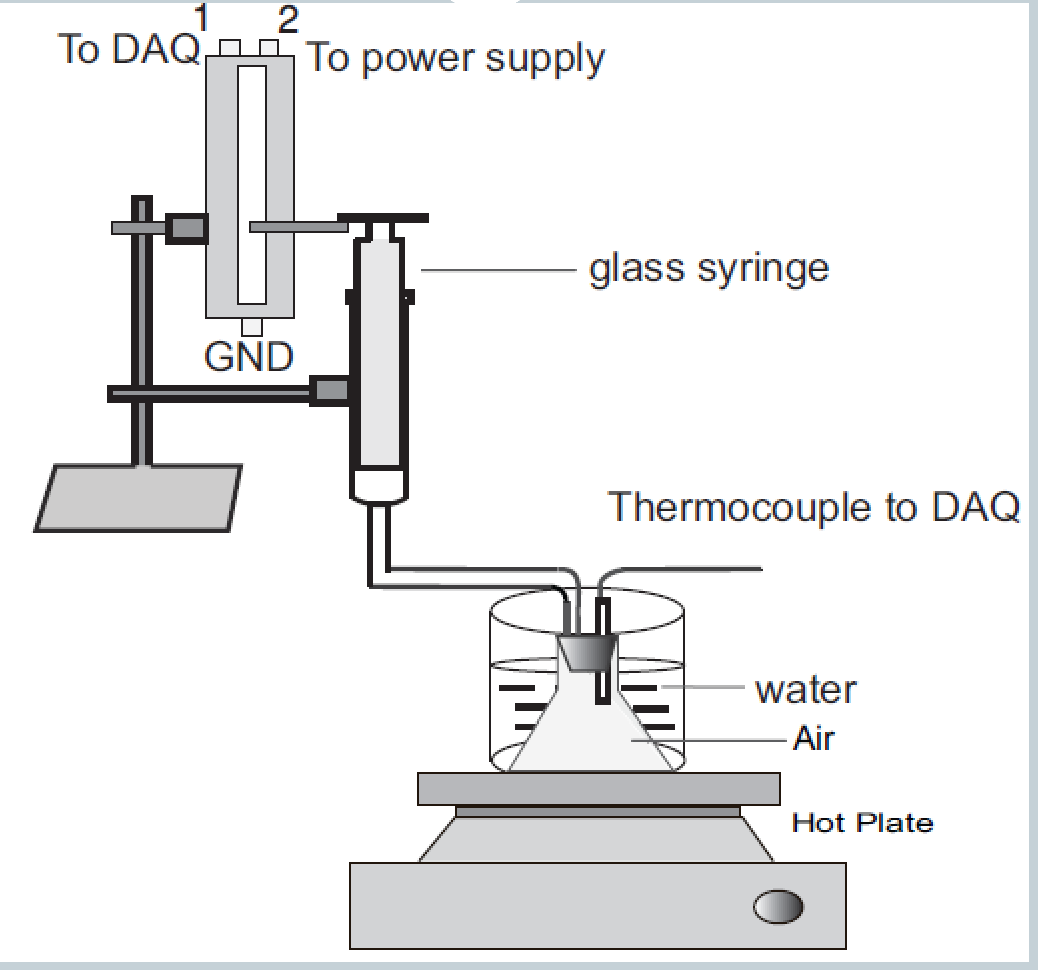
Characteristics	Symbol	Min	Typ	Max	Unit
Pressure range	P_{OP}	20	-	400	kPa
Supply voltage	V_S	4.64	5.0	5.36	Vdc

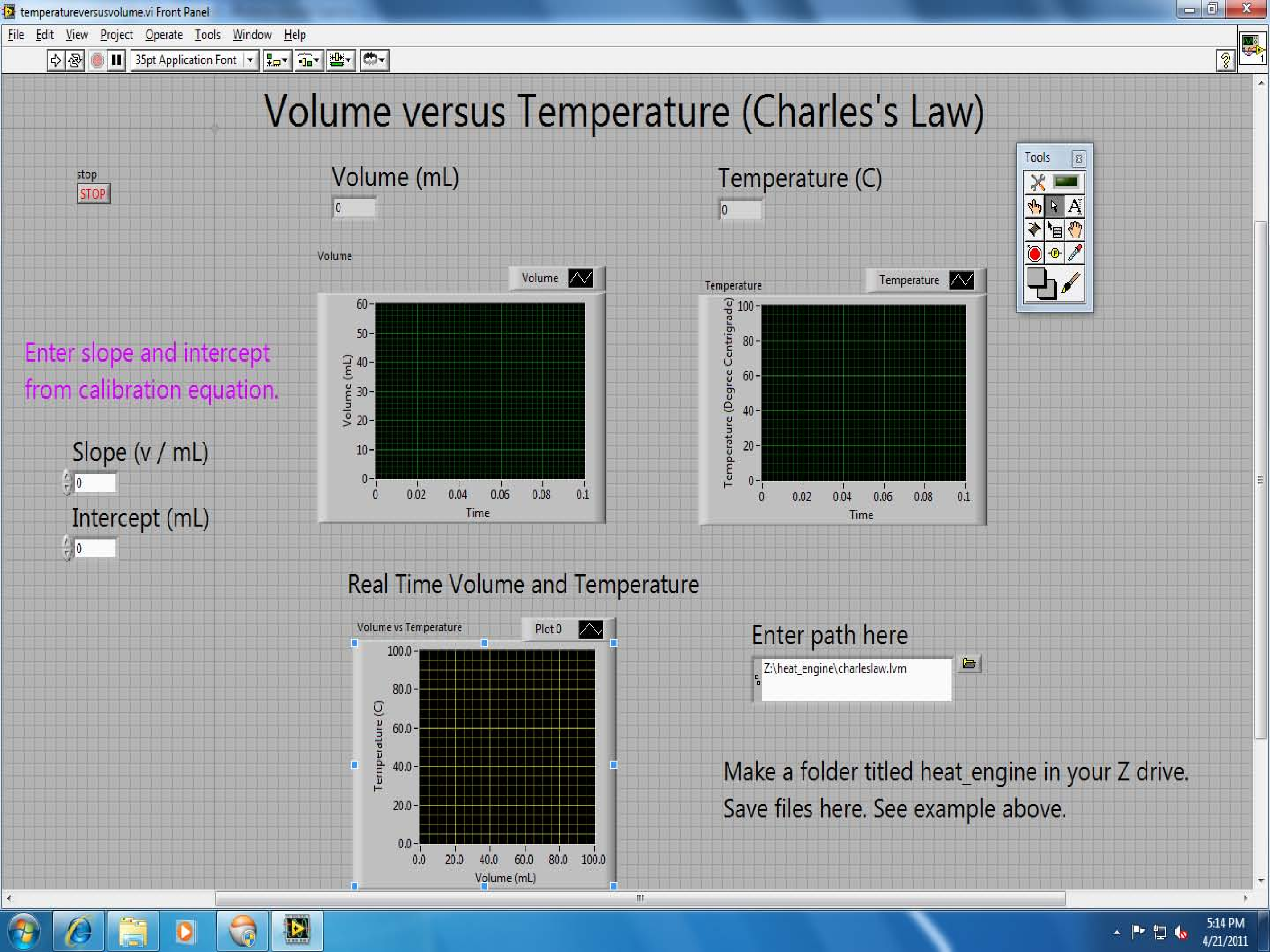
Calibration of the Potentiometer

Calibration equation is, Y = 0.002 X – 7.9 e - 5



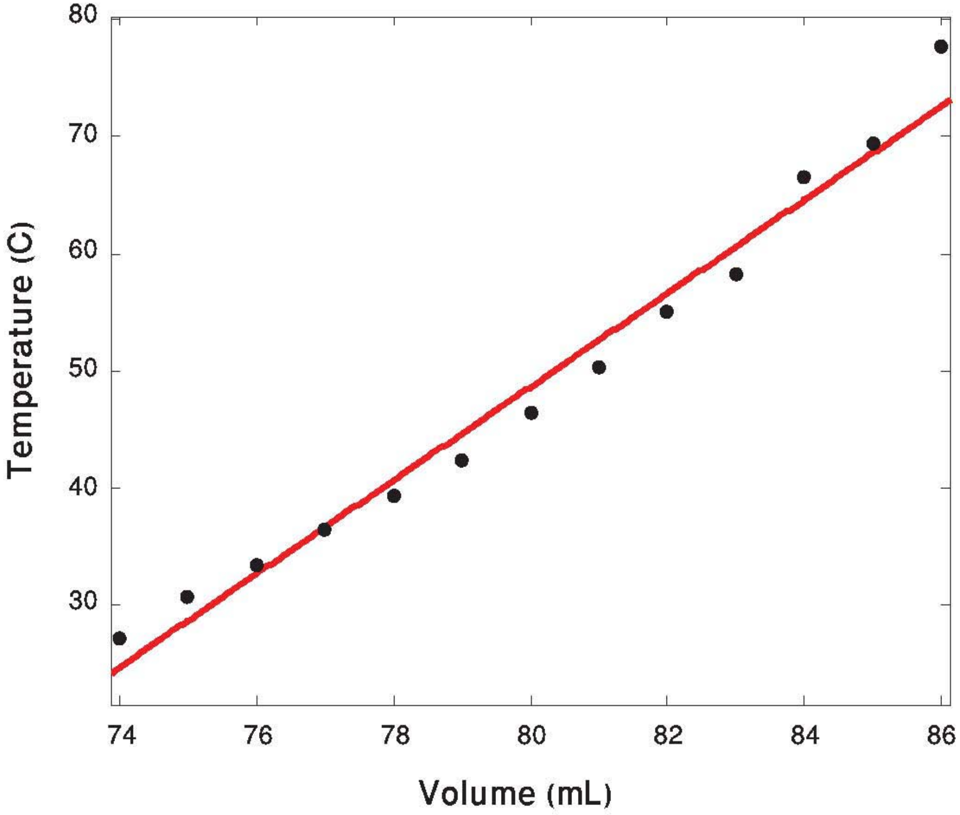
Charles's Law :Volume vs Temperature

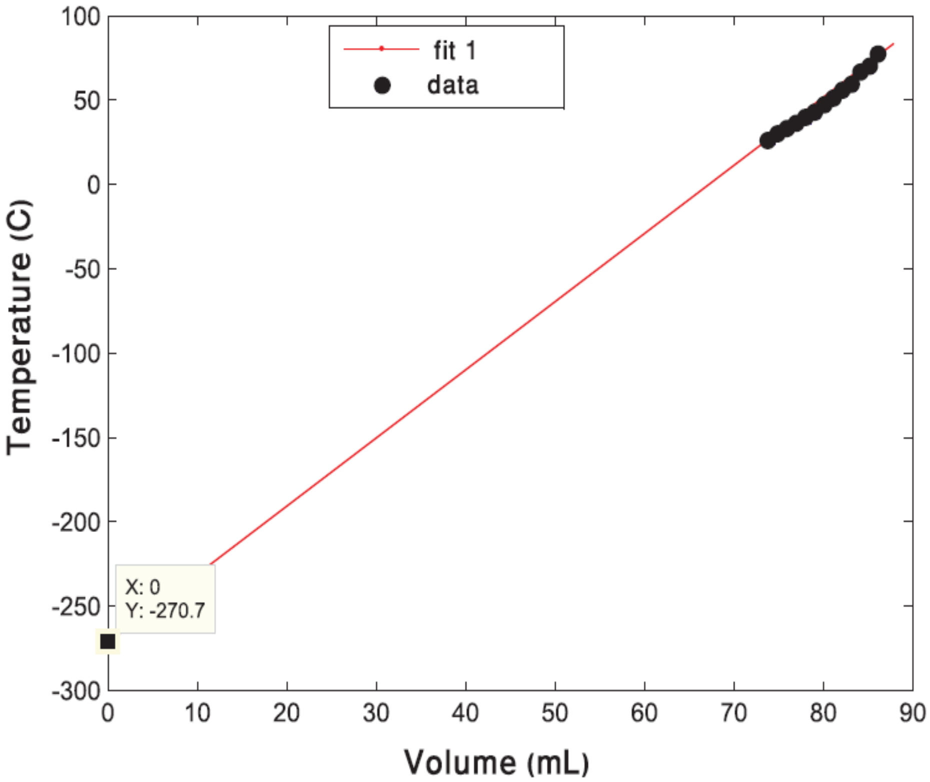




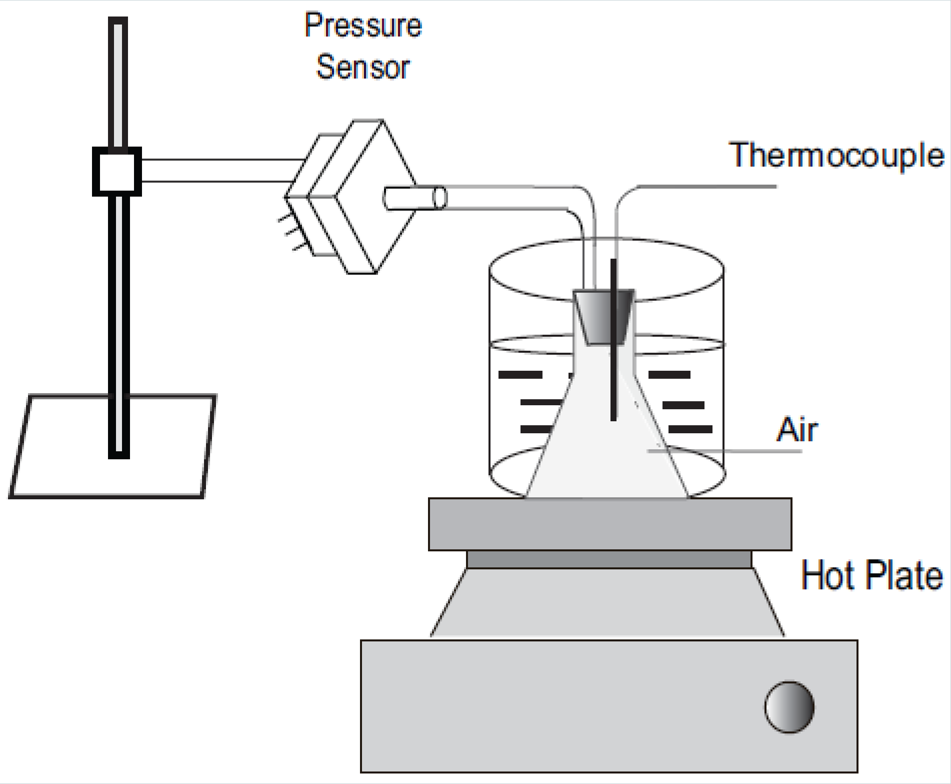
temperatureversusvolume.vi Front Panel
File Edit View Project Operate Tools Window Help
35pt Application Font
Volume versus Temperature (Charles's Law)
stop
STOP
Volume (mL)
0
Temperature (C)
0
Tools
Volume
Volume
Volume (mL)
Time
Temperature
Temperature
Temperature (Degree Centrigrade)
Time
Enter slope and intercept
from calibration equation.
Slope (v / mL)
0
Intercept (mL)
0
Real Time Volume and Temperature
Volume vs Temperature
Plot 0
Temperature (C)
Volume (mL)
Enter path here
Z:\heat_engine\charleslaw.lvm
Make a folder titled heat_engine in your Z drive.
Save files here. See example above.
5:14 PM
4/21/2011

Absoulte zero of temperature

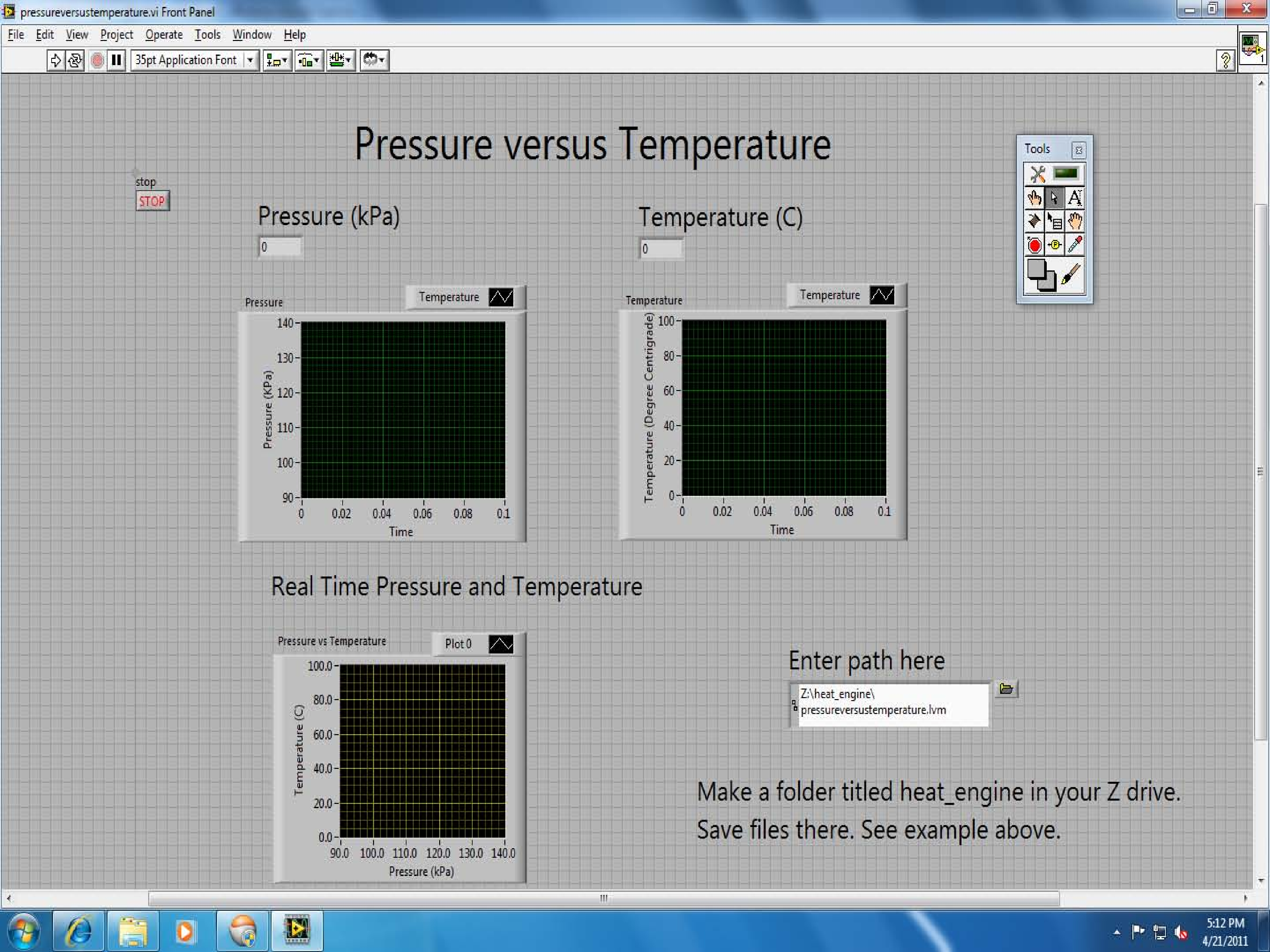




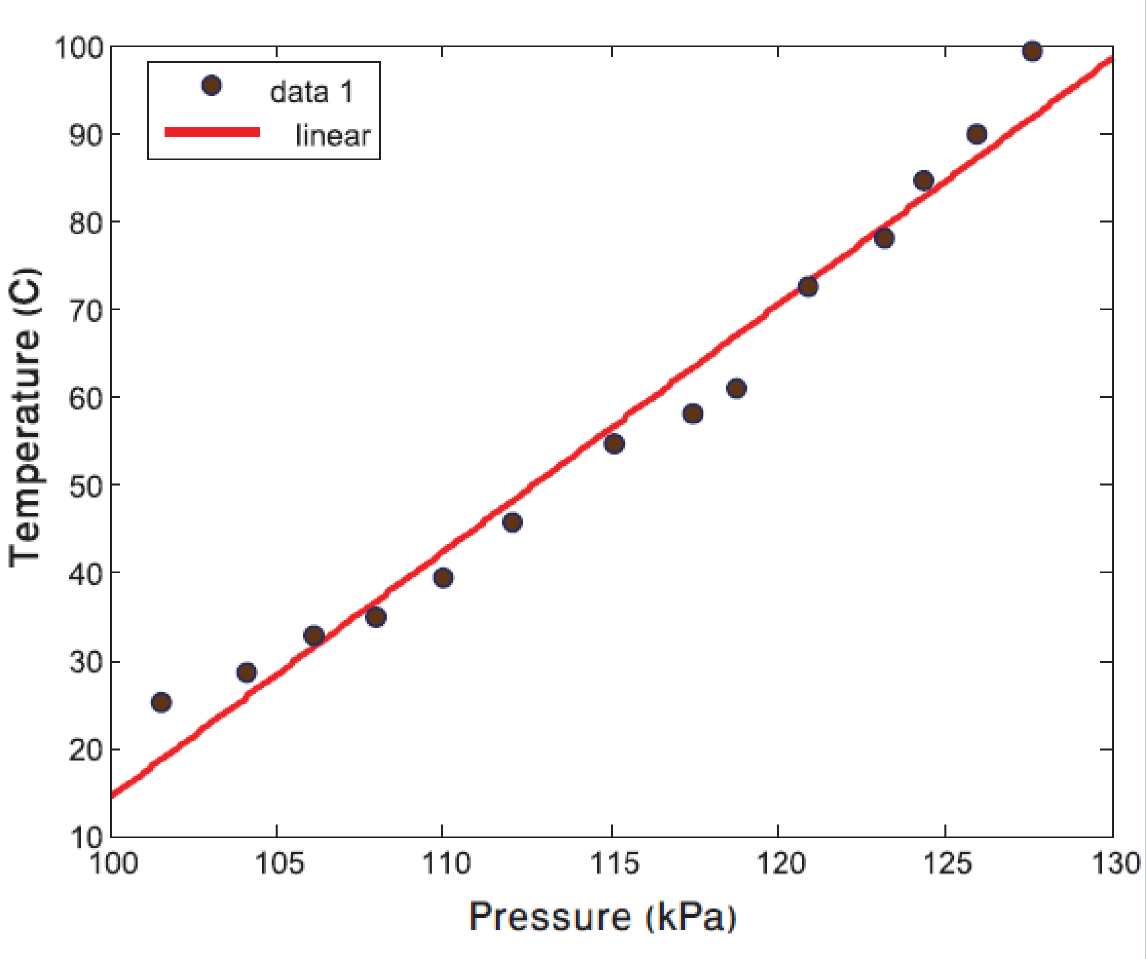
Pressure versus Temperature



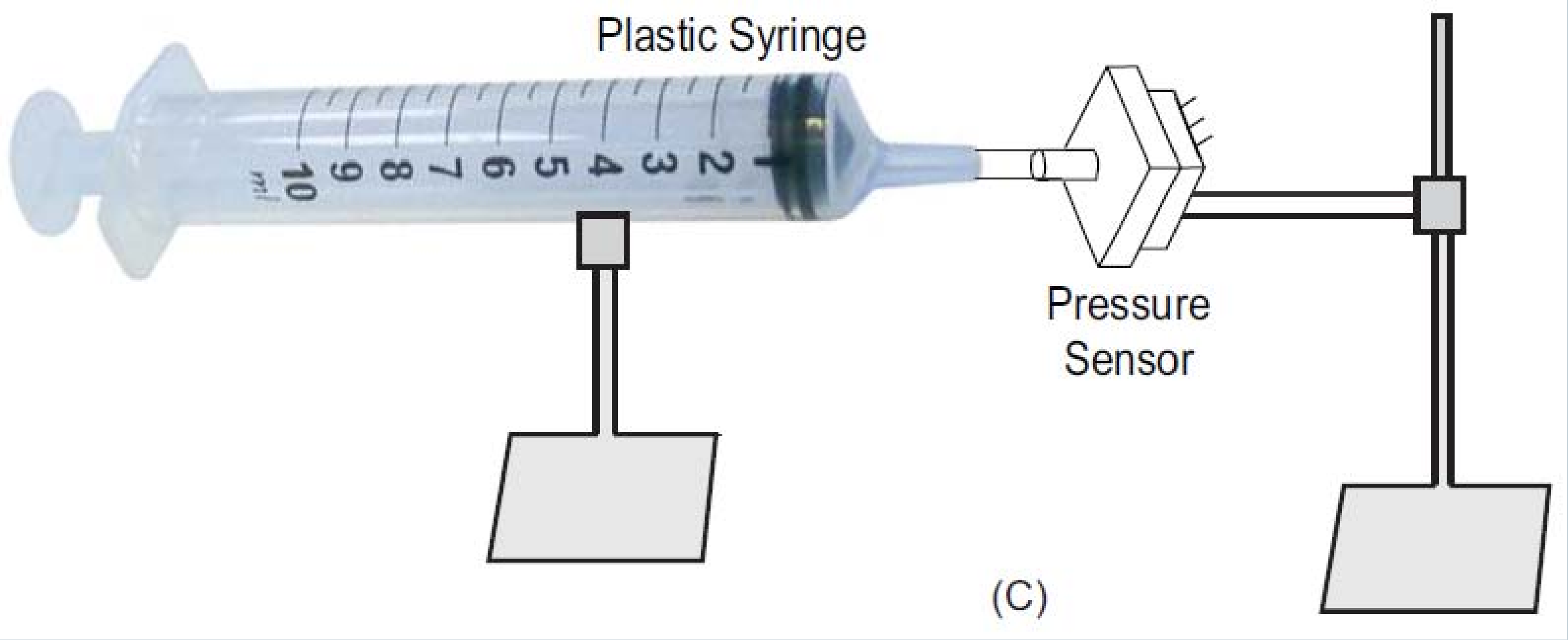
Make sure you do not exceed the bearing pressure of flask.


pressureversustemperature.vi Front Panel
File Edit View Project Operate Tools Window Help
35pt Application Font
Pressure versus Temperature
stop
STOP
Pressure (kPa)
0
Temperature (C)
0
Tools
Pressure
Temperature
140
130
120
110
100
90
Pressure (KPa)
0 0.02 0.04 0.06 0.08 0.1
Time
Temperature
Temperature
100
80
60
40
20
0
Temperature (Degree Centrigrade)
0 0.02 0.04 0.06 0.08 0.1
Time
Real Time Pressure and Temperature
Pressure vs Temperature
Plot 0
100.0
80.0
60.0
40.0
20.0
0.0
Temperature (C)
90.0 100.0 110.0 120.0 130.0 140.0
Pressure (kPa)
Enter path here
Z:\heat_engine\
pressureversustemperature.lvm
Make a folder titled heat_engine in your Z drive.
Save files there. See example above.
5:12 PM
4/21/2011

Data with a curve fit

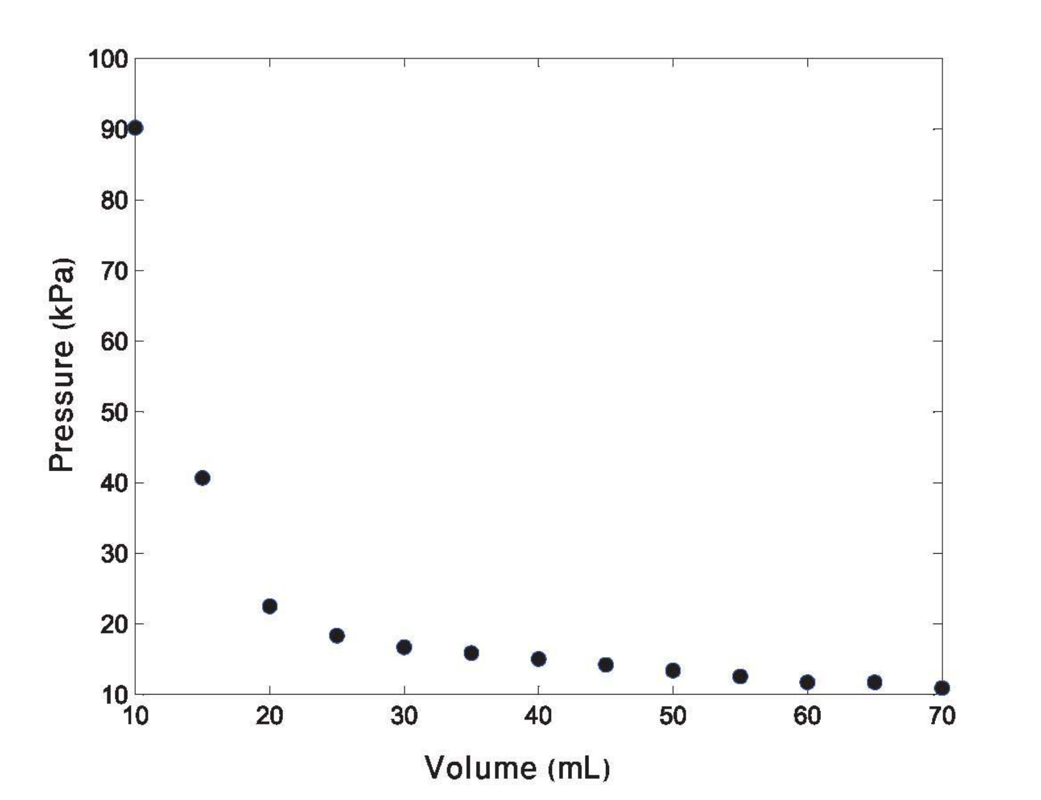


Boyle's Law: Pressure versus Volume



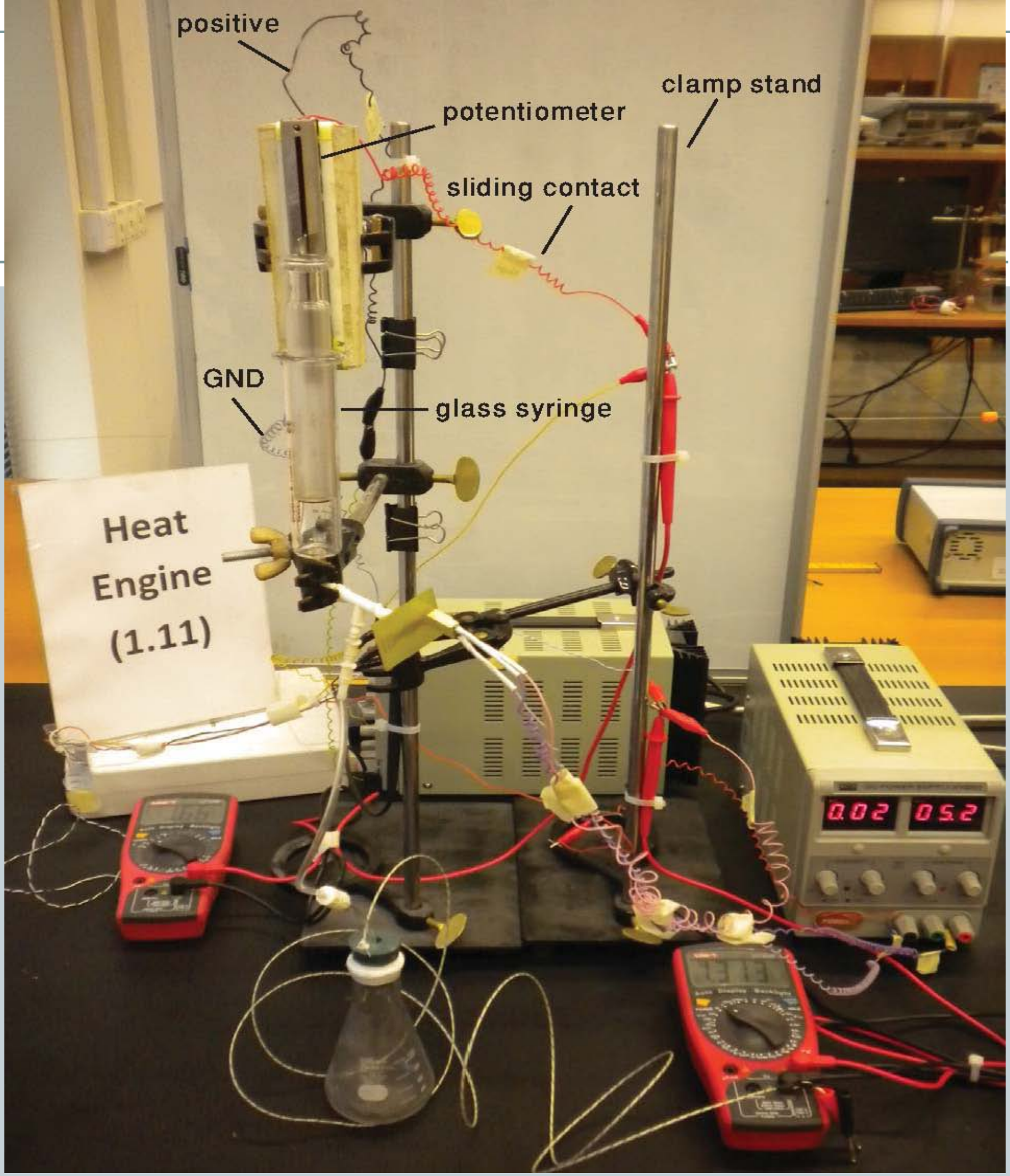
Either pull or push the plunger.

Data obtained: V = Constant/P

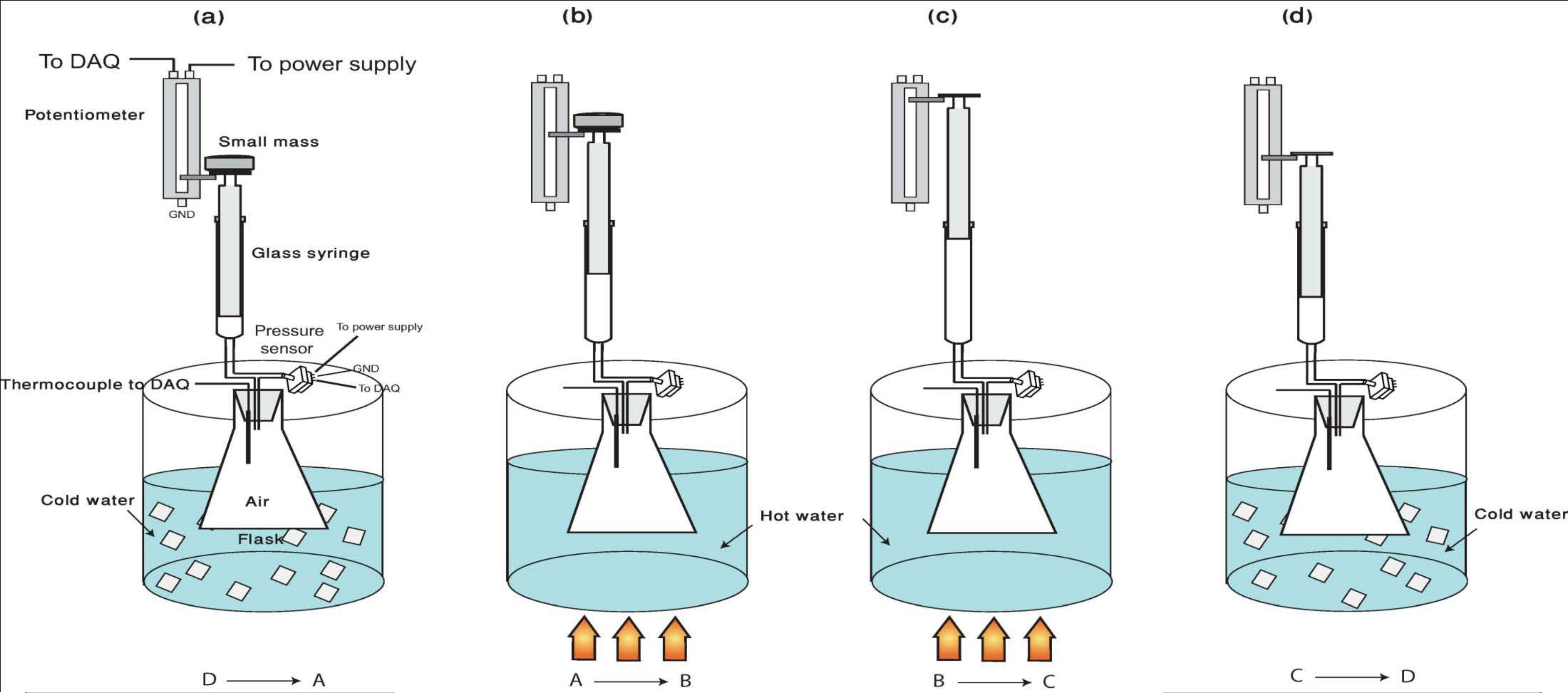


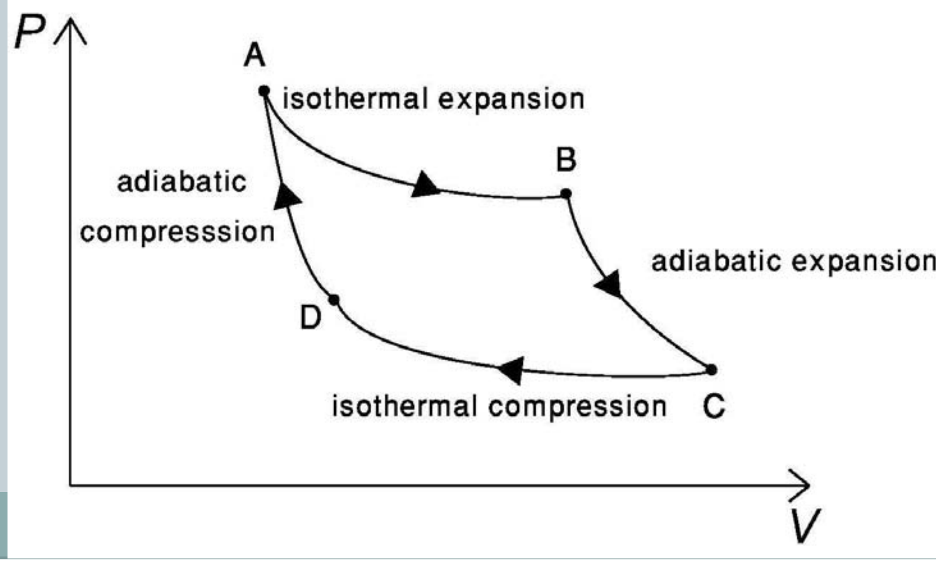
Making a heat engine

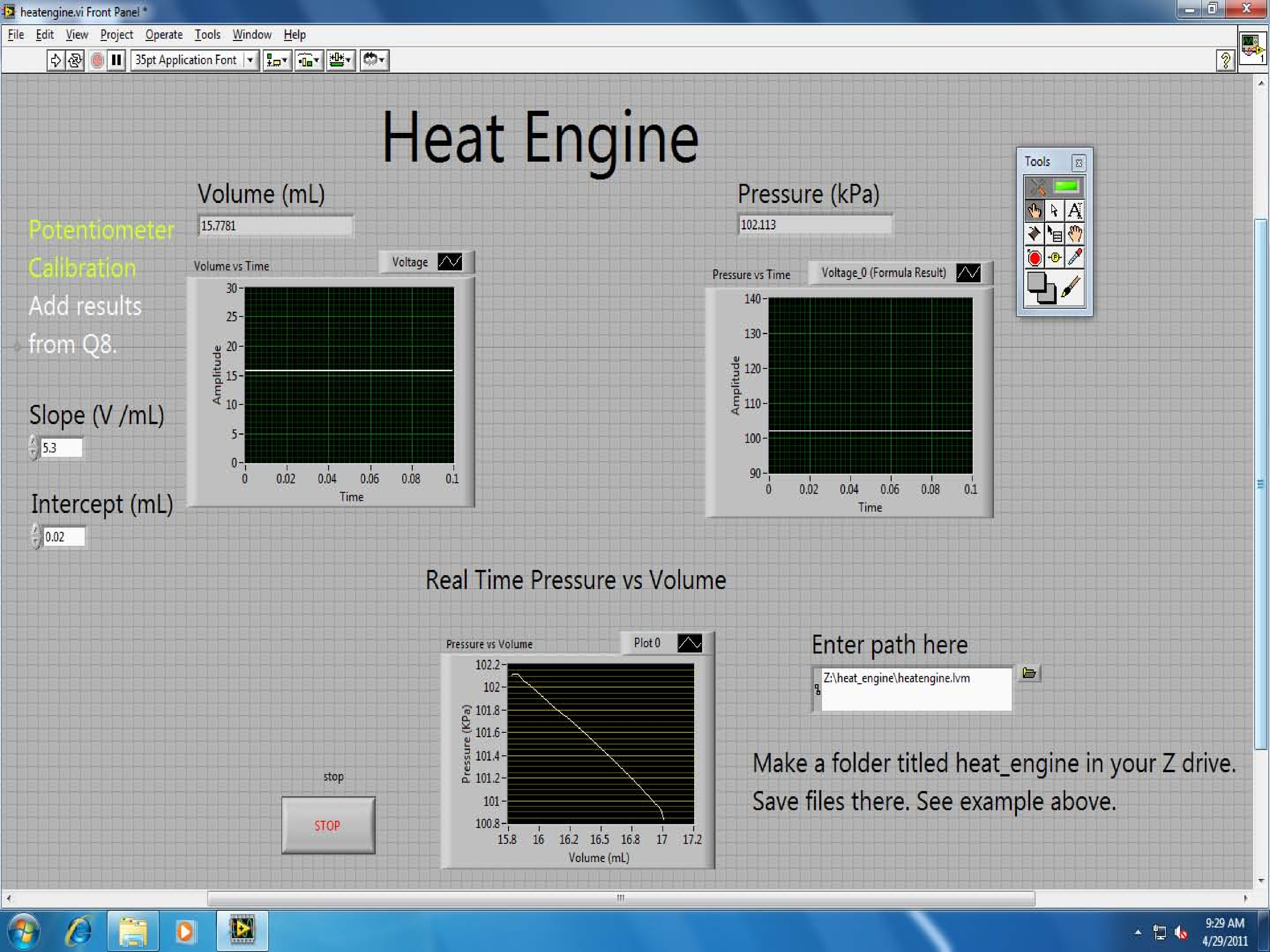
- Salman Mahmood Qazi (A student of Electronics at the Government College University) worked on the making of a potentiometer.
- Imran Hanif worked on the electronic data taking but he was unable to get a complete cycle.
- Waqas Mahmood started working on the experimental data taking after Imran.



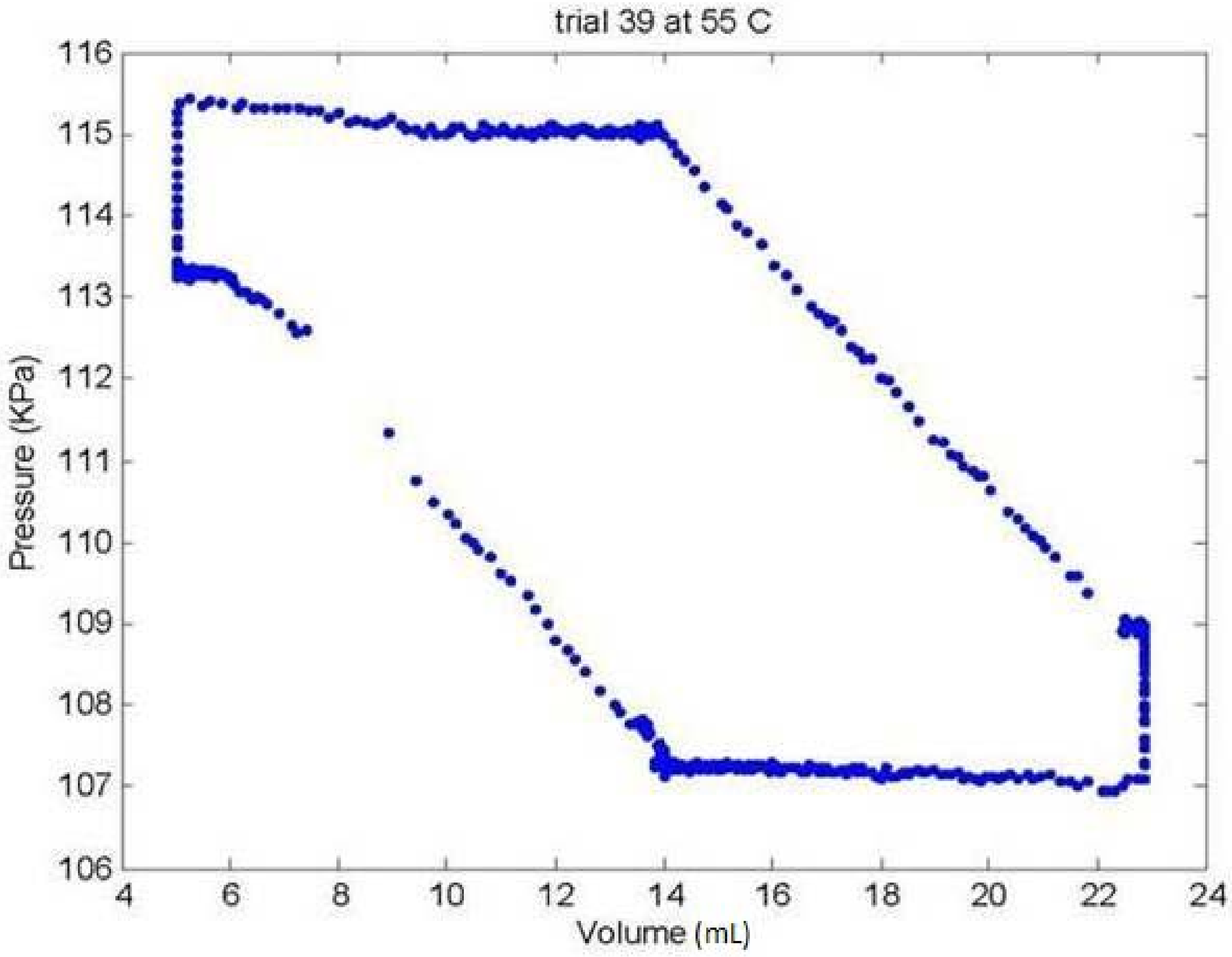
- Initially balance the potentiometer for the free movement of the sliding contact.
- Friction may give not required but interesting results.


(a)
(b)
(c)
(d)
To DAQ
To power supply
Potentiometer
Small mass
GND
Glass syringe
Pressure sensor
To power supply
GND
Thermocouple to DAQ
To DAQ
Air
Cold water
Flask
Hot water
Cold water
D → A
A → B
B → C
C → D

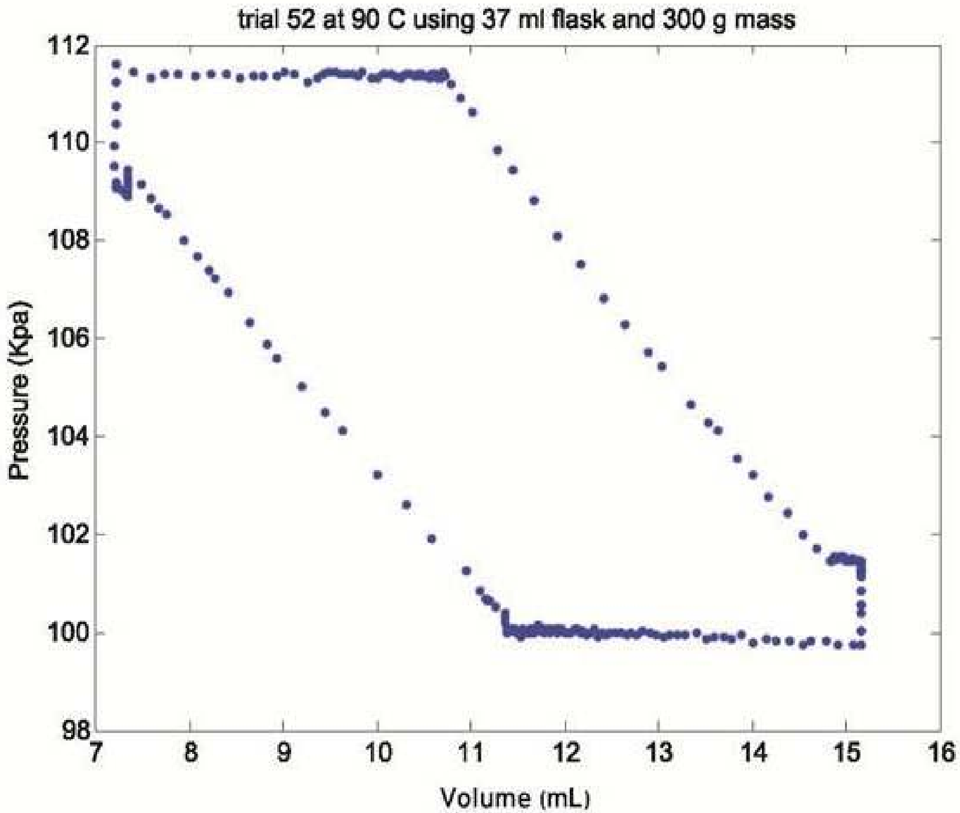

P
V
A
B
C
D
isothermal expansion
adiabatic expansion
isothermal compression
adiabatic compresssion


heatengine.vi Front Panel *
File Edit View Project Operate Tools Window Help
35pt Application Font
Heat Engine
Volume (mL)
15.7781
Pressure (kPa)
102.113
Potentiometer
Calibration
Add results
from Q8.
Volume vs Time
Voltage
Amplitude
Time
Pressure vs Time
Voltage_0 (Formula Result)
Tools
Slope (V /mL)
5.3
Intercept (mL)
0.02
Real Time Pressure vs Volume
Pressure vs Volume
Plot 0
Pressure (KPa)
Volume (mL)
Enter path here
Z:\heat_engine\heatengine.lvm
Make a folder titled heat_engine in your Z drive.
Save files there. See example above.
stop
STOP
9:29 AM
4/29/2011

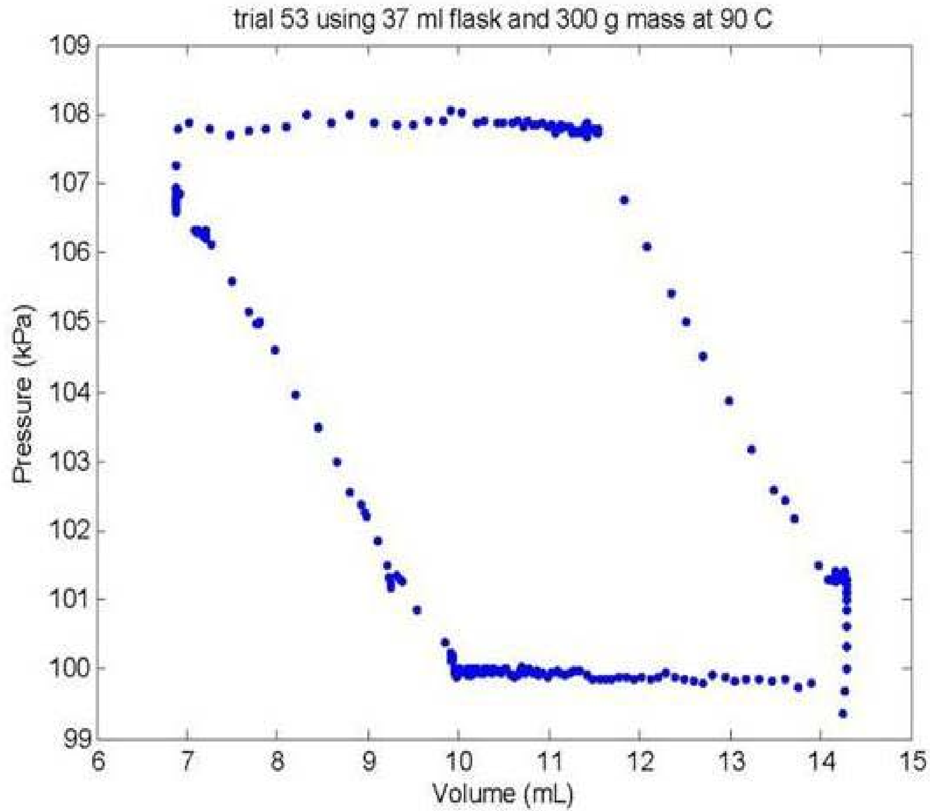
Results: Trial 39



Trial 52

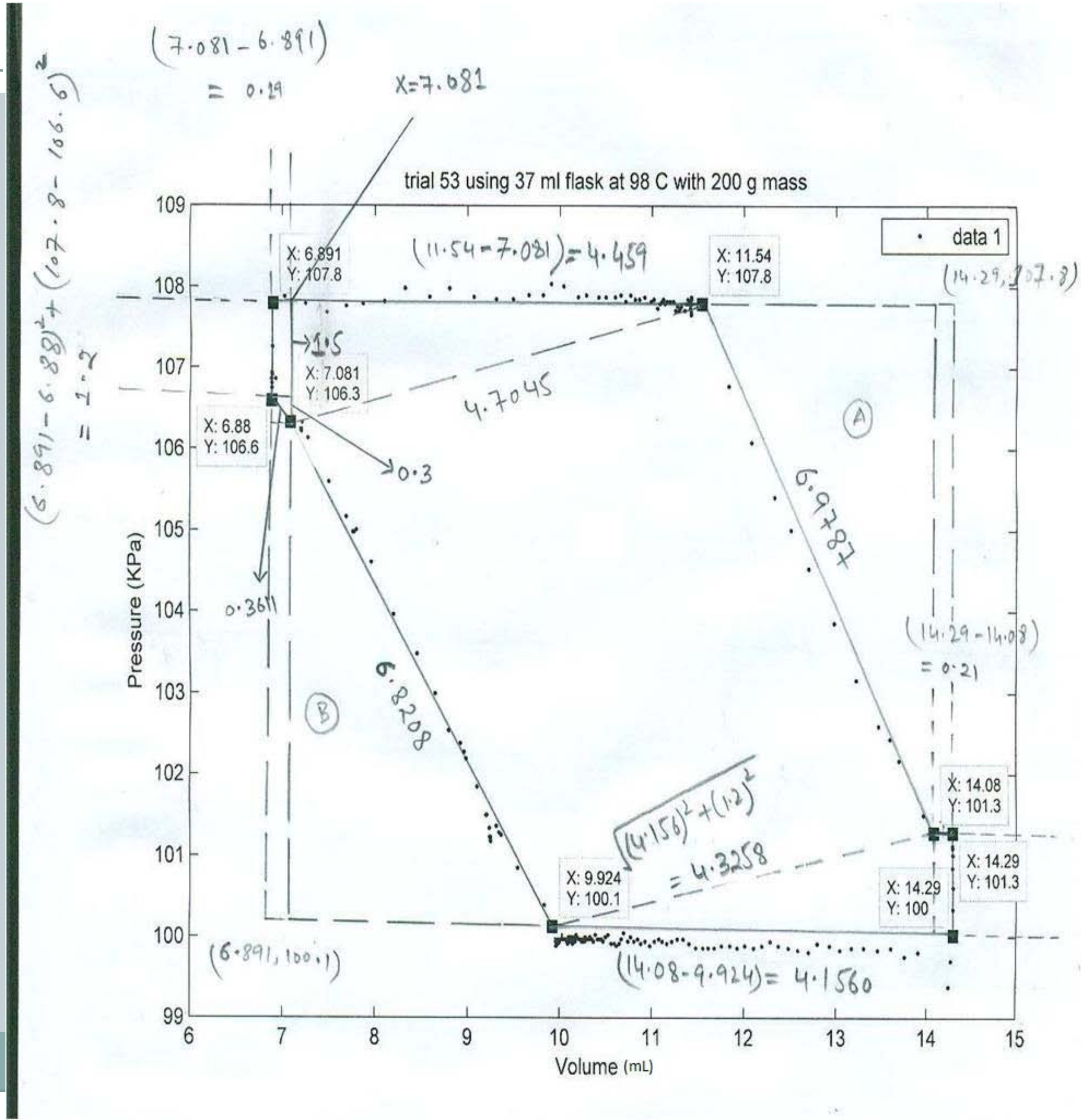


trial 52 at 90 C using 37 ml flask and 300 g mass
Pressure (Kpa)
Volume (mL)
112
110
108
106
104
102
100
98
7
8
9
10
11
12
13
14
15
16



trial 53 using 37 ml flask and 300 g mass at 90 C
Pressure (kPa)
Volume (mL)
109
108
107
106
105
104
103
102
101
100
99
6
7
8
9
10
11
12
13
14
15

Calculation for the area under the curve



Me

Area under the curve = ?

Area of big rectangle = 7.399 × 7.7 = 56.9723 — ①

Area of region A = $\frac{1}{2}(2.54)(6.5) + (0.21)(6.5)$

= 9.62 — ②

Area of region B = $\frac{1}{2}(2.843)(6.2) + (0.19)(6.2) + \frac{1}{2}(0.29)(0.3)$

= 10.0198 — ③

Area under the curve = ① − ② − 3

= 56.9723 − 9.62 − 10.0198

Area under the curve = 37.3325 KPa (ml) (ml = cc)

1 KPa = 0.00986 atm

Area under the curve = 0.3681 (atm. ml)

= 0.03729

Area Under Curve ≅ 37.3 mJ

Calculation for Efficiencies

Calculations for trial 53

$T_h = 98\,C^\circ = 371\,K$

$T_c = 20\,C^\circ = 293\,K$

Mechanical efficiency $(\eta_{th}) = \frac{W_{out}}{W_{in}}$

"c" for air at $25\,C^\circ = 1.012\,\frac{J}{g\,K}$

$Q_{in} = mc\Delta T$

$= 0.0602\,g\,(1.012)\,\frac{J}{g\,K}\,(371-293)\,K$

$Q_{in} = 4.75 \approx 4.8\,J$

Carnot efficiency $= \eta_c \le 1 - \frac{T_c}{T_H}$

$\Rightarrow \quad \eta \le 1 - \frac{(20+273)}{(98+273)} \le 0.2102$

$\eta_c \le 21.02\,\%$

At 20C° density of air = $1.2041 \frac{Kg}{m^3}$

$$\rho = \frac{m}{vol.}$$

mass = vol × density

volume = 50 ml

$= 5 \times 10^{-5}\ m^3$

mass = $5 \times 10^{-5}\ m^3 \cdot 1.2041 \frac{Kg}{m^3}$

mass = 6.0205×10^{-5} Kg

mass = 0.0602 g

$Q_{in} = mc\Delta T$

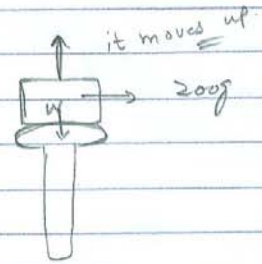
$= 0.0602\ g\ (1.012) \frac{J}{g\,K} (371 - 293)$

$Q_{in} = 4.75$

$Q_{in} \simeq 4.8 J$

Thermal efficiency = $\frac{W_{out}}{heat\ in}$

$= \frac{37.3\,mJ}{4.8\,J} = 0.77\ \%$



$W = mg = 200 \times 10^{-3} \times 9.81$

$W = 1.962$ = This is downward force F

Pressure or upward force has to be > W

Work done in ~~adiabatic~~ isothermal expansion from

graph = $40.9112 \times 0.00986 \times 0.101325$

$= 0.0409$ J — (1)

This work done exerts F & moves the piston through distance d.

$11.54 - 6.891 = 4.649$ ml

1 ml = 0.32×10^{-2} m

4.649 ml = $0.32 \times 10^{-2} \times 4.649$ m

$= 0.0149$ m

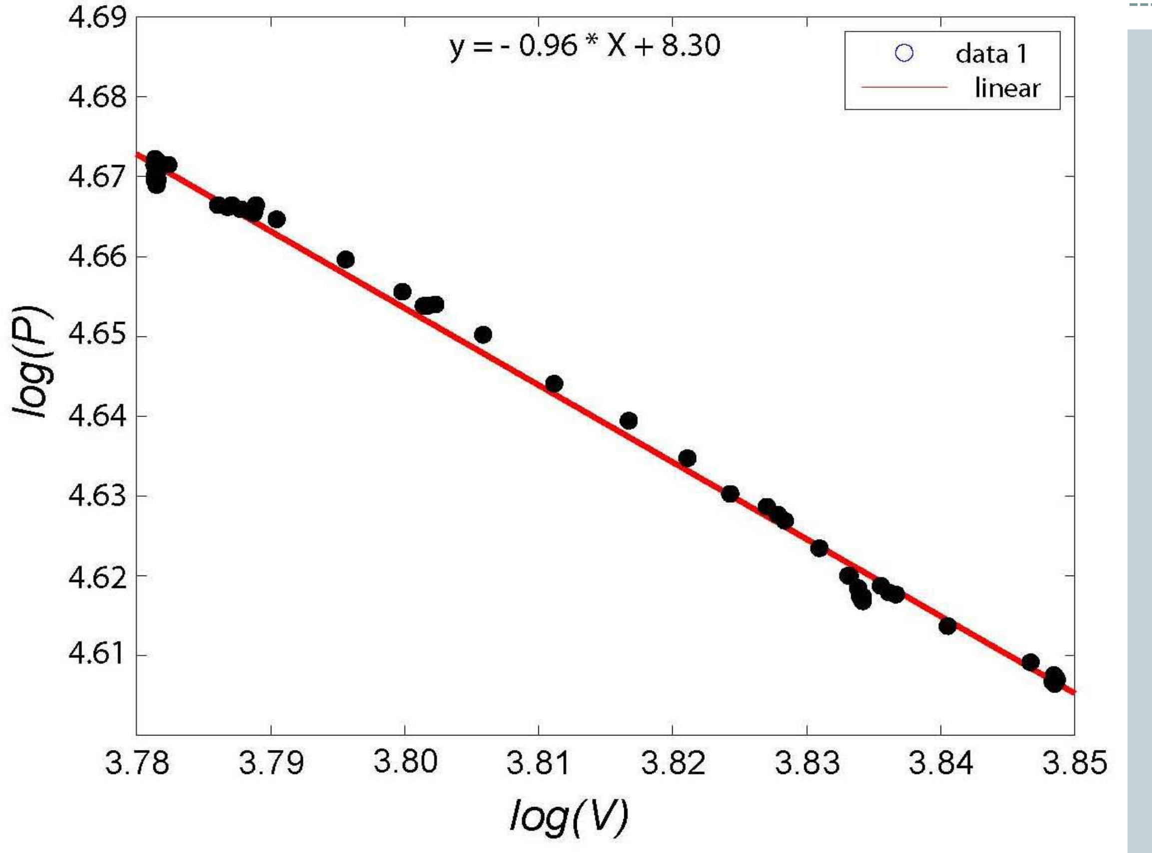
$0.0409 = F' \times 0.0149$

$\Rightarrow$ $F' = 2.745$ N

$\frac{F}{F'} = \frac{1.962}{2.745} \times 100\%$

$\frac{F}{F'} = 71.5\%$

Gamma for air using PV^{Γ}= constant



- We have obtained the value of Γ ~ 1.0 that is in close to the published value of 1.3 by Paul F. Rebillot, *Determining the Ratio Cp/Cv using Rucchart's Method, Wooster, Ohio, April (1998),* http://www3.wooster.edu/physics/jris/Files/Rebillot.pdf.

Conclusion

- We have achieved a mechanical efficiency > 70% and thermodynamic efficiency of < 1%.

Can we improve it and how much?

- Yes! We can improve slightly but not much.
- If we have flasks up to 25 mL volume, the PV curve might be in a more desired shape.
- Even if you go to more smaller volumes, we can not increase the thermodynamic efficiency > 1%.
- Reason: If the volume of the container is made much smaller than 25mL, the air inside the flask may not be able to lift the piston.

- Although, this setup does not yield better thermodynamic efficiency but it teaches basic concepts such as pressure, heat, work done and internal energy etc. powerfully.
- It serves as a small bridge between theoretical understanding of thermodynamics and experimental application at the freshmen level.

Thanks