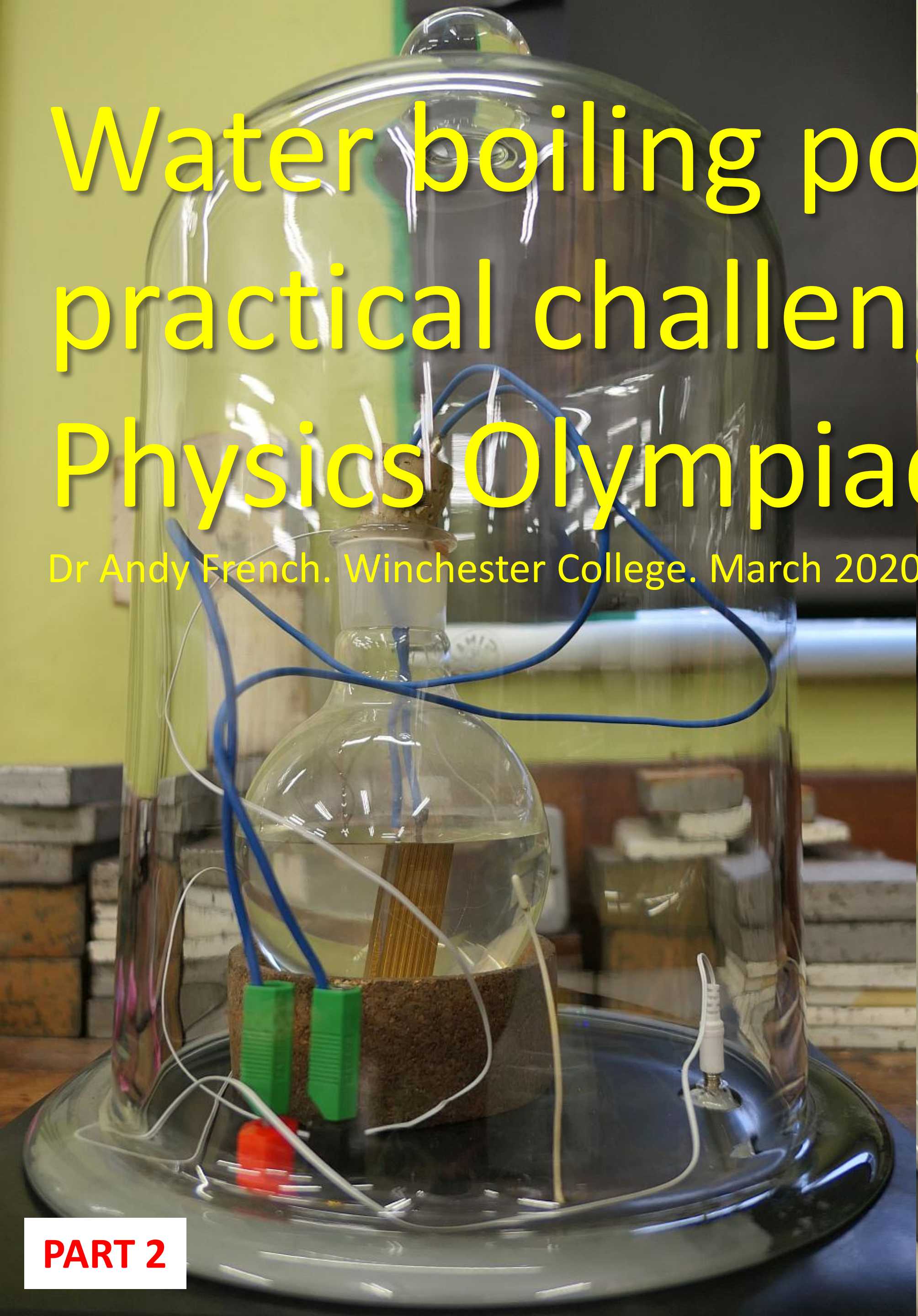
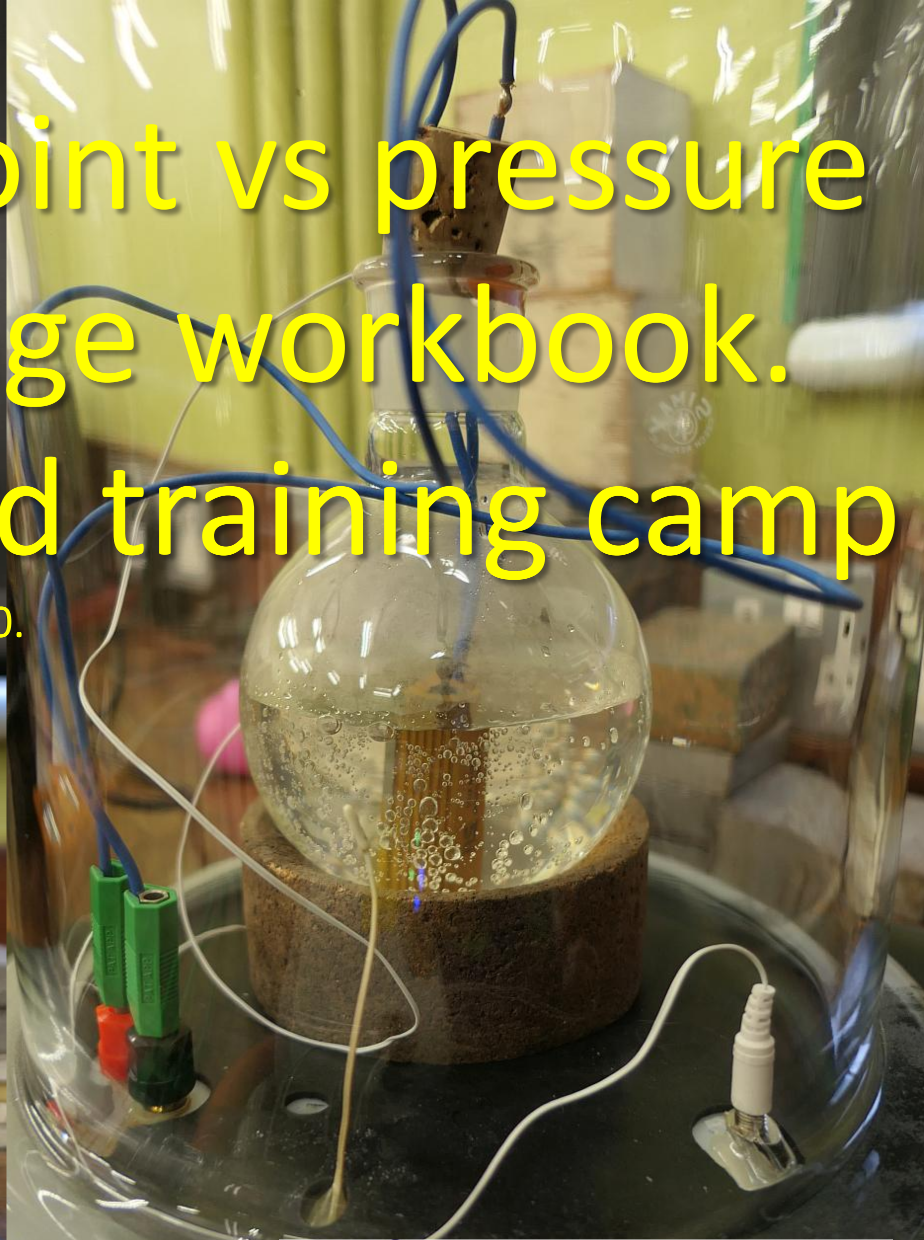
Water boiling point vs pressure practical challenge workbook. Physics Olympiad training camp

Dr Andy French. Winchester College. March 2020.





PART 2

$$p(T_{boil}) = p_* e^{\frac{L_{vap}}{RT_*}} e^{-\frac{L_{vap}}{RT_{boil}}}$$

$$p_* = 101.325\text{kPa}$$
$$T_* = 373\text{K}$$

$$\underbrace{\ln\left(\frac{p_*}{p}\right)}_{y} = \frac{L_{vap}}{R}\underbrace{\frac{1}{T_{boil}}}_{x} \underbrace{-\frac{L_{vap}}{R}\frac{1}{T_*}}_{c}$$

$$y = mc + c$$

$$m = \frac{L_{vap}}{R}, \quad c = -\frac{L_{vap}}{R}\frac{1}{T_*}$$

p/kPa	T_{boil}/°C
18.468	39.97
21.496	45.64
23.897	50.50
28.881	55.58
34.053	60.42
37.919	65.42
45.400	70.38
51.720	75.18
52.297	75.58
52.237	75.78
60.770	80.13
62.742	80.51
69.144	85.10
70.650	86.63
66.039	85.44
66.683	87.64
76.205	89.99
77.338	91.98

QUESTION 7:

(i) **Plot p vs T_{boil} as + marks on a graph. *Don't join them up.* (We have a *model* to underlay!) Are *error bars* appropriate?**

(ii) **Now tabulate y and x using our linearized version. NOTE YOU WILL NEED TO CONVERT TEMPERTURES INTO KELVIN.**

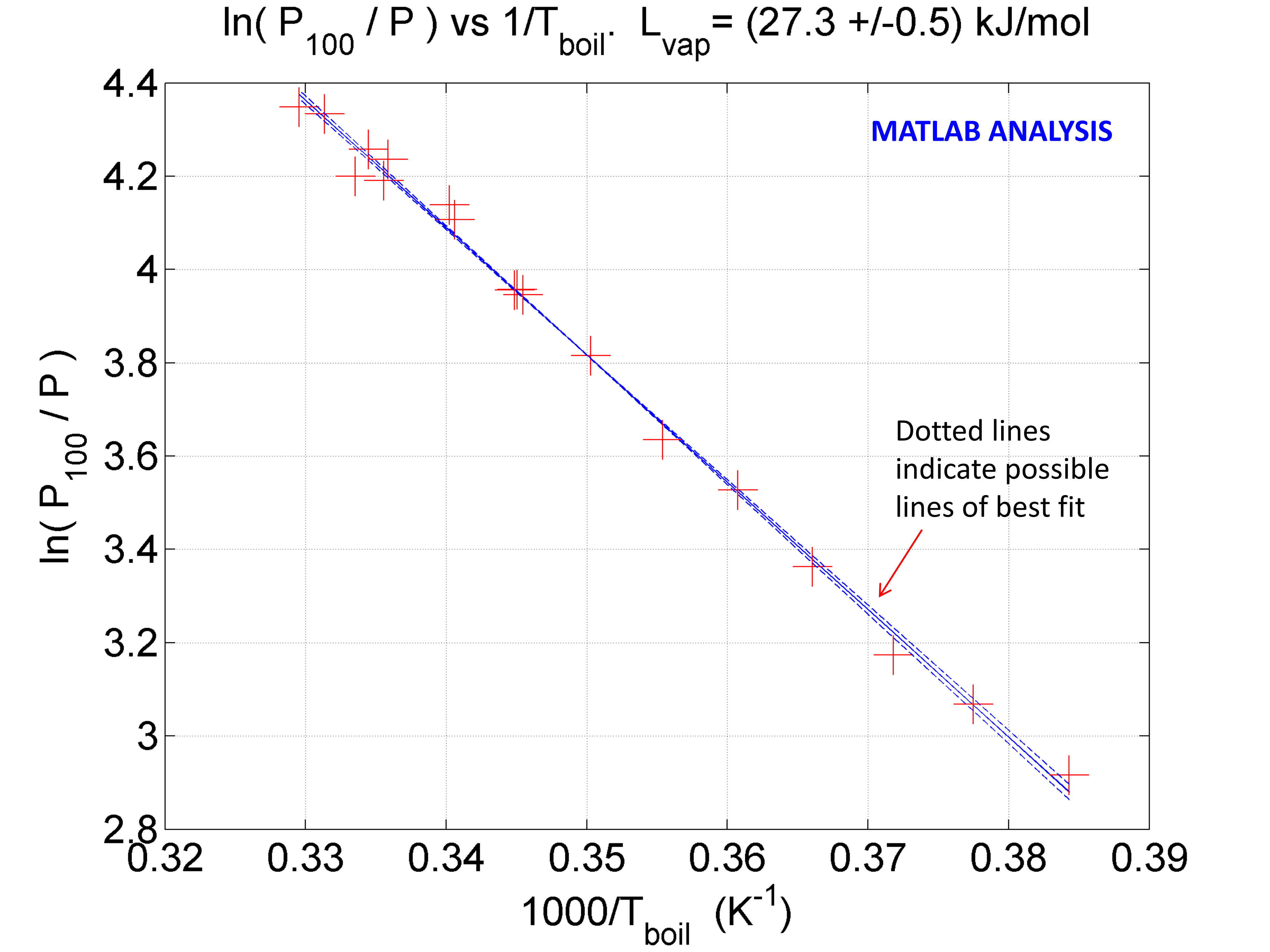
(iii) **From a *line of best fit* (you can do this by eye), determine the specific (molar) latent heat of vaporization L_{vap} in kJ/mol**

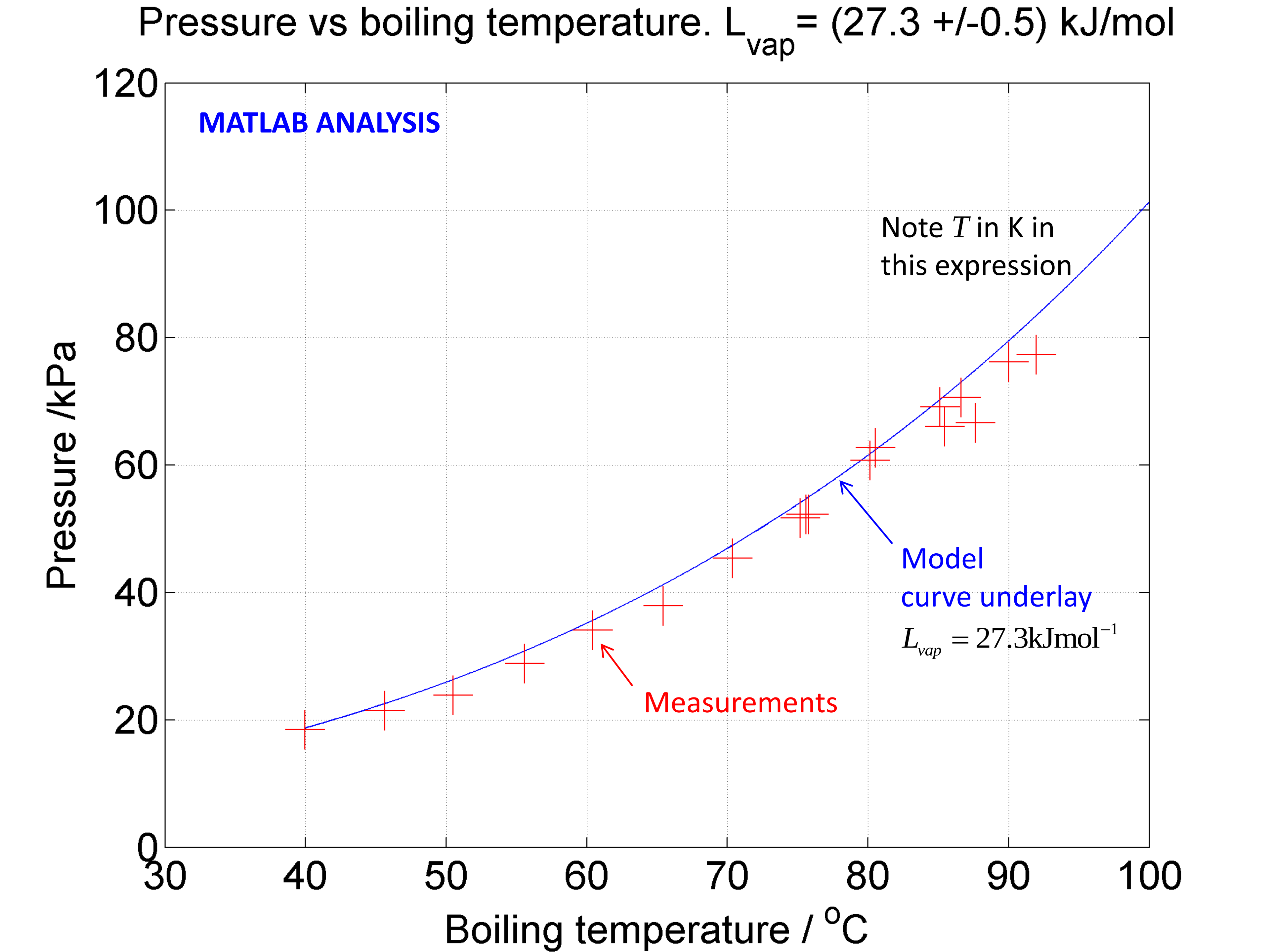
(iv) **Now work out via the *model* (using your value of L_{vap}) what p should be given a sensible range of T between 35°C and 100°C.**

(v) **Overlay this smooth curve on your data points.**

Before you continue, check that you have submitted your answers to Q1-7

Hopefully your analysis graphs (Q7) should look like this…… (See next slides)

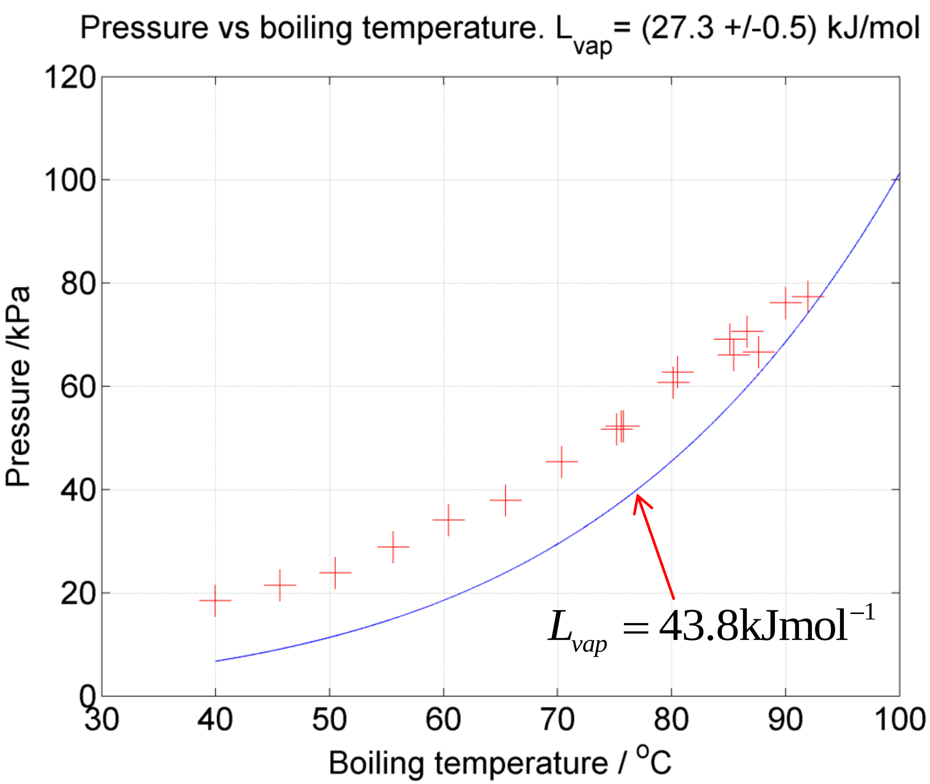

ln(P100 / P) vs 1/Tboil. Lvap= (27.3 +/-0.5) kJ/mol
MATLAB ANALYSIS
Dotted lines indicate possible lines of best fit
ln(P100 / P)
1000/Tboil (K-1)
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
0.32
0.33
0.34
0.35
0.36
0.37
0.38
0.39


Pressure vs boiling temperature. L_{vap} = (27.3 +/-0.5) kJ/mol
MATLAB ANALYSIS
Note T in K in
this expression
Model
curve underlay
$L_{vap} = 27.3 \mathrm{kJmol}^{-1}$
Measurements
Pressure /kPa
Boiling temperature / ^{o}C
0
20
40
60
80
100
120
30
40
50
60
70
80
90
100

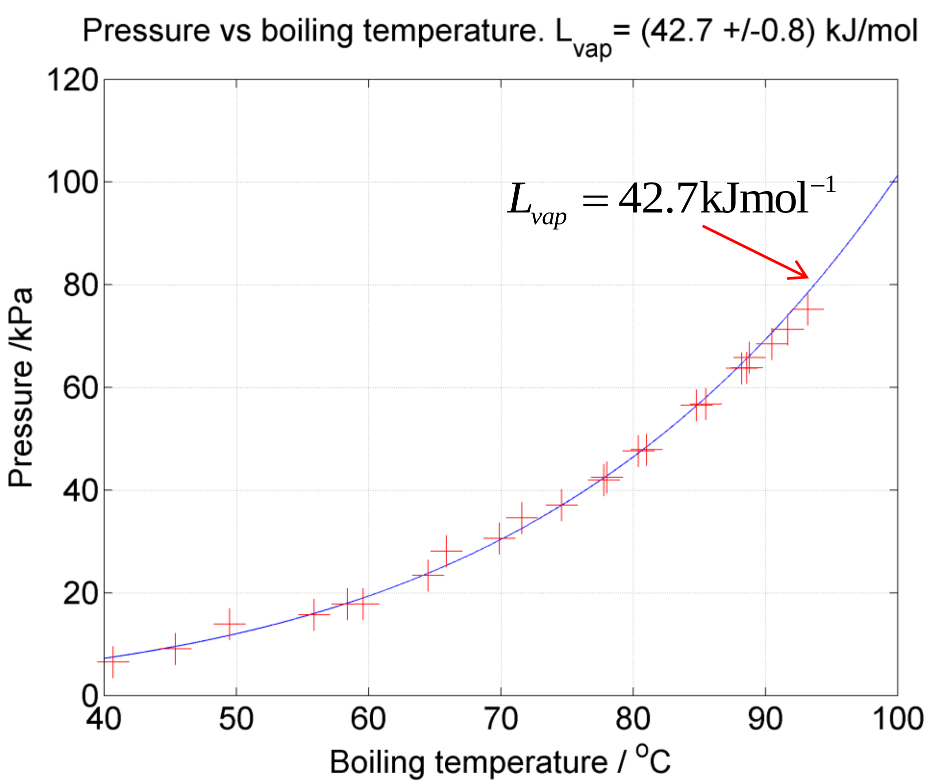
Problem is, L_{vap} is about *half* what it should be! It *should* be **43.8kJ/mol.**
The line of best fit of y vs x has a high correlation, so there must be a ***systematic*** **error.**
It seems our pressures are much higher than they should be, particularly at low boiling temperatures.

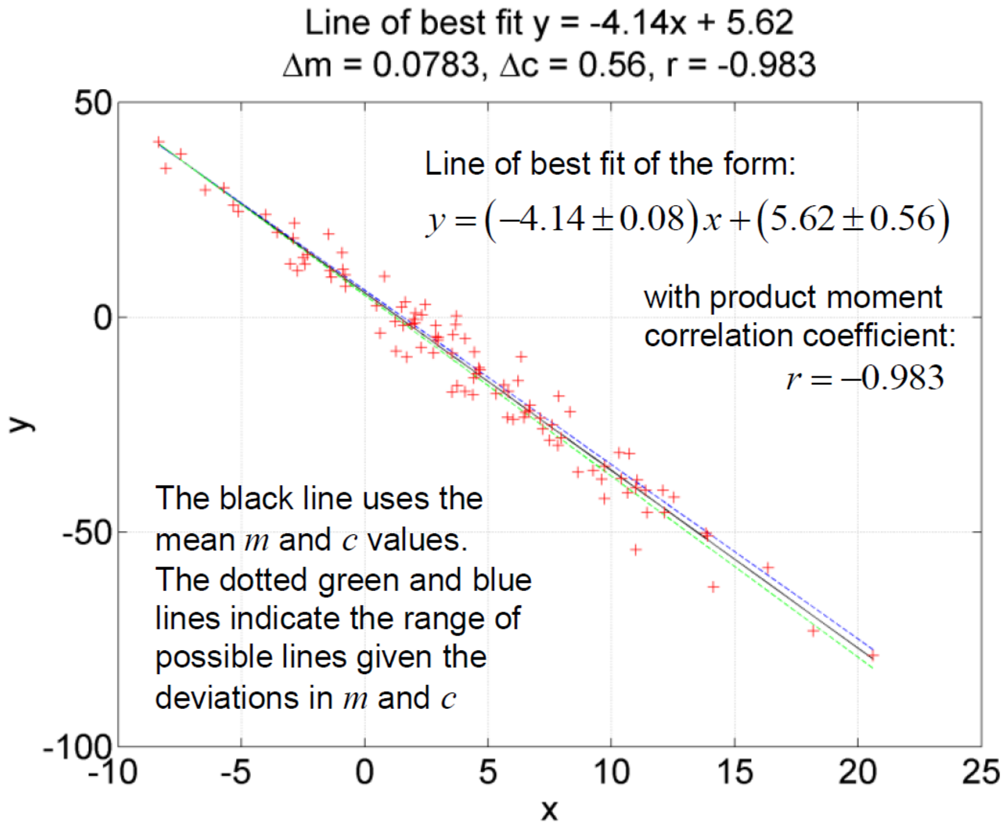
QUESTION 8: Suggest possible *practical* reasons why we appear to be measuring too high a pressure, particular for low boiling temperatures. You may refer to the graphs below.

March 2020 experiment



November 2019 experiment
(*Different* vacuum pump in photos at the start of this presentation)





$y = mx + c$ line of best fit recipe

$$\bar{x} = \tfrac{1}{N}\sum_{i=1}^{N} x_i, \qquad y = \tfrac{1}{N}\sum_{i=1}^{N} y_i,$$

$$\overline{x^2} = \tfrac{1}{N}\sum_{i=1}^{N} x_i^2, \qquad \overline{y^2} = \tfrac{1}{N}\sum_{i=1}^{N} y_i^2$$

$$\overline{xy} = \tfrac{1}{N}\sum_{i=1}^{N} x_i y_i$$

$$V[x] = \overline{x^2} - \bar{x}^2, \quad V[y] = \overline{y^2} - \bar{y}$$

$$\mathrm{cov}[x,y] = \overline{xy} - \bar{x}\bar{y}$$

$$c = \bar{y} - m\bar{x}$$

$$m = \frac{\overline{xy} - \bar{y}\bar{x}}{\overline{x^2} - \bar{x}^2} = \frac{\mathrm{cov}[x,y]}{V[x]}$$

$$r = \frac{\mathrm{cov}[x,y]}{\sqrt{V[x]V[y]}}$$

$$\Delta m = \frac{s}{\sqrt{N}}\frac{1}{\sqrt{V[x]}}$$

$$\Delta c = \frac{s}{\sqrt{N}}\sqrt{1 + \frac{\bar{x}^2}{V[x]}}$$

$$s = \sqrt{\frac{1}{N-2}\sum_{i=1}^{N}\left(y_i - mx_i - c\right)^2}$$

Errors in gradient and y intercept

For reference! You don't need to use this for now – but perhaps in future projects..