D10 - Measuring Boltzmann's Constant 16/3/17

Aim:

Be familiar with some of the features of computer aided data aquisition.
Be aware of the limitations of the ideal diode approximation.
Determine an experimentally value for Boltzmann's Constant.

A ~~Cassy~~ CASSY system is the computer software used in this experiment. This allows a computer to mimic a range of different Instruments such as Voltmeters ammeters, function generators and oscilloscopes to automatically control experimental parameters and to Collect data.

~~We will~~ meassure how current varies with Voltage for a semiconductor diode at different temperatures with the computer and then use the ideal diode equation to estimate boltzmanns constant k

~~We will use~~ There is a forward bias current through a semiconductor diode depends on k to estimate it

for a diode:

$$I = I_0\left(\exp\left(\frac{eV}{\eta kT}\right) - 1\right)$$

Where I_0 is the reverse bias leakage current, e is elementary charge, T is temperature (K) and η is the ideality factor of the diode.

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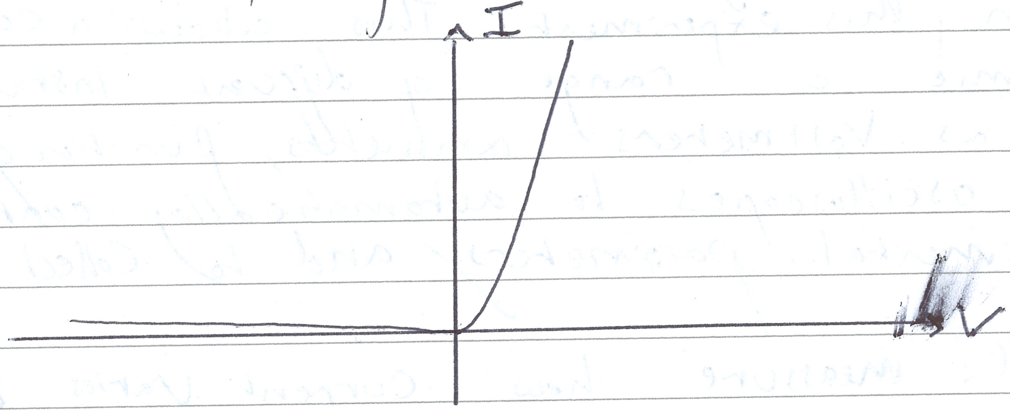
Silicon diode type BAT48 used.
η is close to 1 for this diode.
for sufficiently large forward bias (V positive) the exp term is very large compared to 1

$$\Rightarrow I \approx I_0 \exp\left(\frac{eV}{\eta kT}\right)$$

typical I-V plot for a diode:

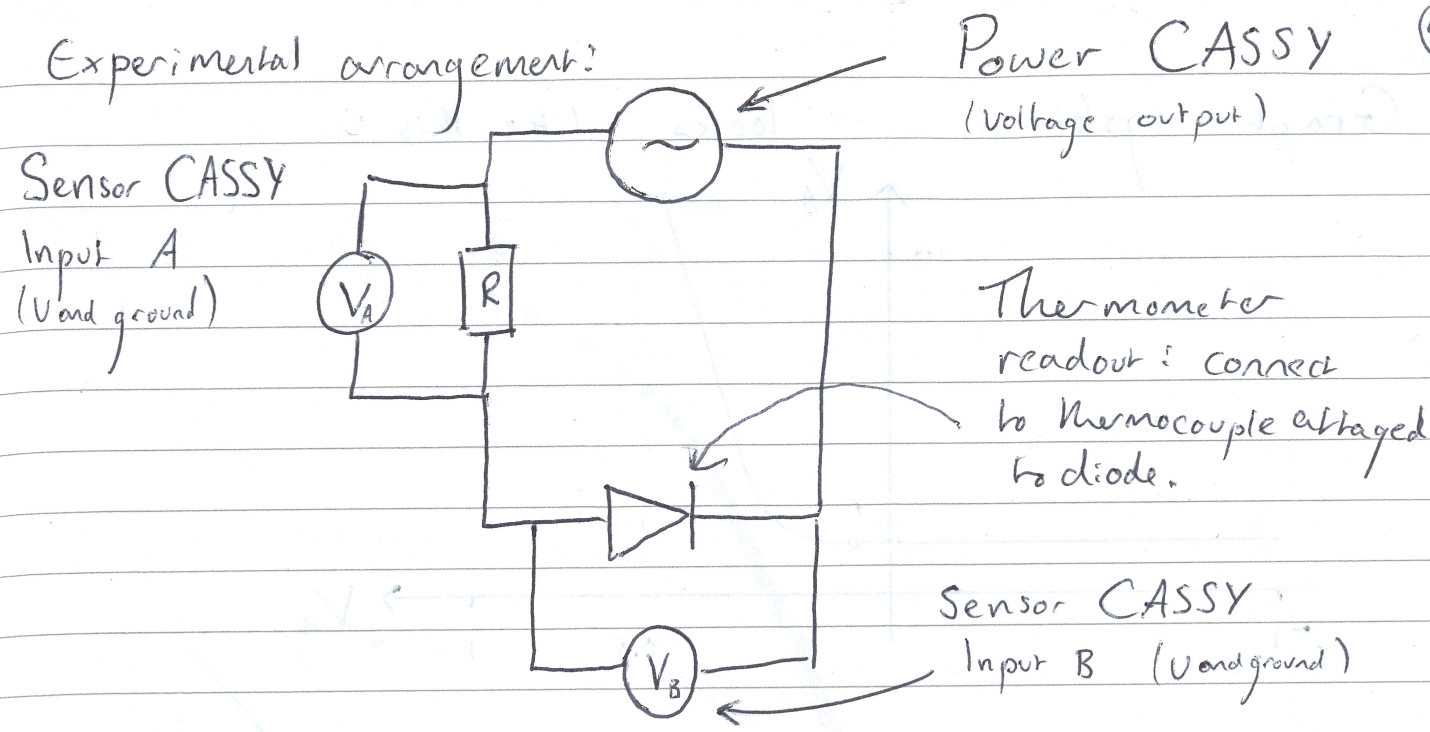


If ln(I) against V were plotted for a given T or ln(I) plotted ~~to~~ against $\frac{1}{T}$ for fixed voltage an estimate for k could be made assuming $\eta = 1$. However I_0 (independent of voltage) is dependent exponentially on the inverse temperature so gradient doesn't allow us to estimate k and gradient is -ve unlike what is expected.

Experiment

Power CASSY acts as a source of current
Sensor CASSY acts as a pair of voltmeters to measure voltage across diode

Experimental arrangement:



and resistor (1kΩ).
Current not measured directly as small and hard to reliably measure.

~~De~~diode Clapmped to top of brass block with a thermocouple.

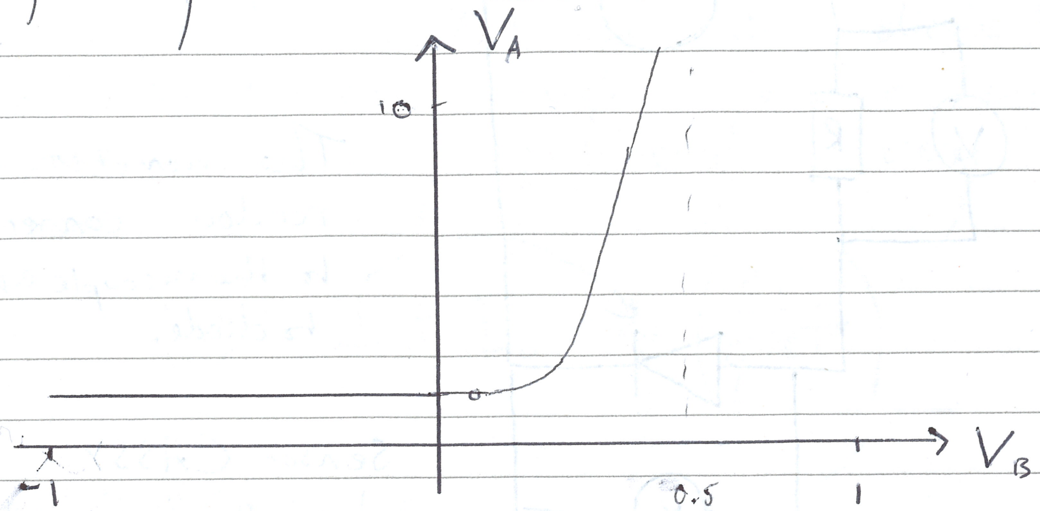
Resistance heater (powerd by DC supply) is under the brass block

Software used is CASSY Lab 2.

Starting temperature $T = 22.3°C \pm 0.1°C$

V_A is plotted against V_B and Power CASSY sweeps up and down from -1V up to 1V and then back to -1V

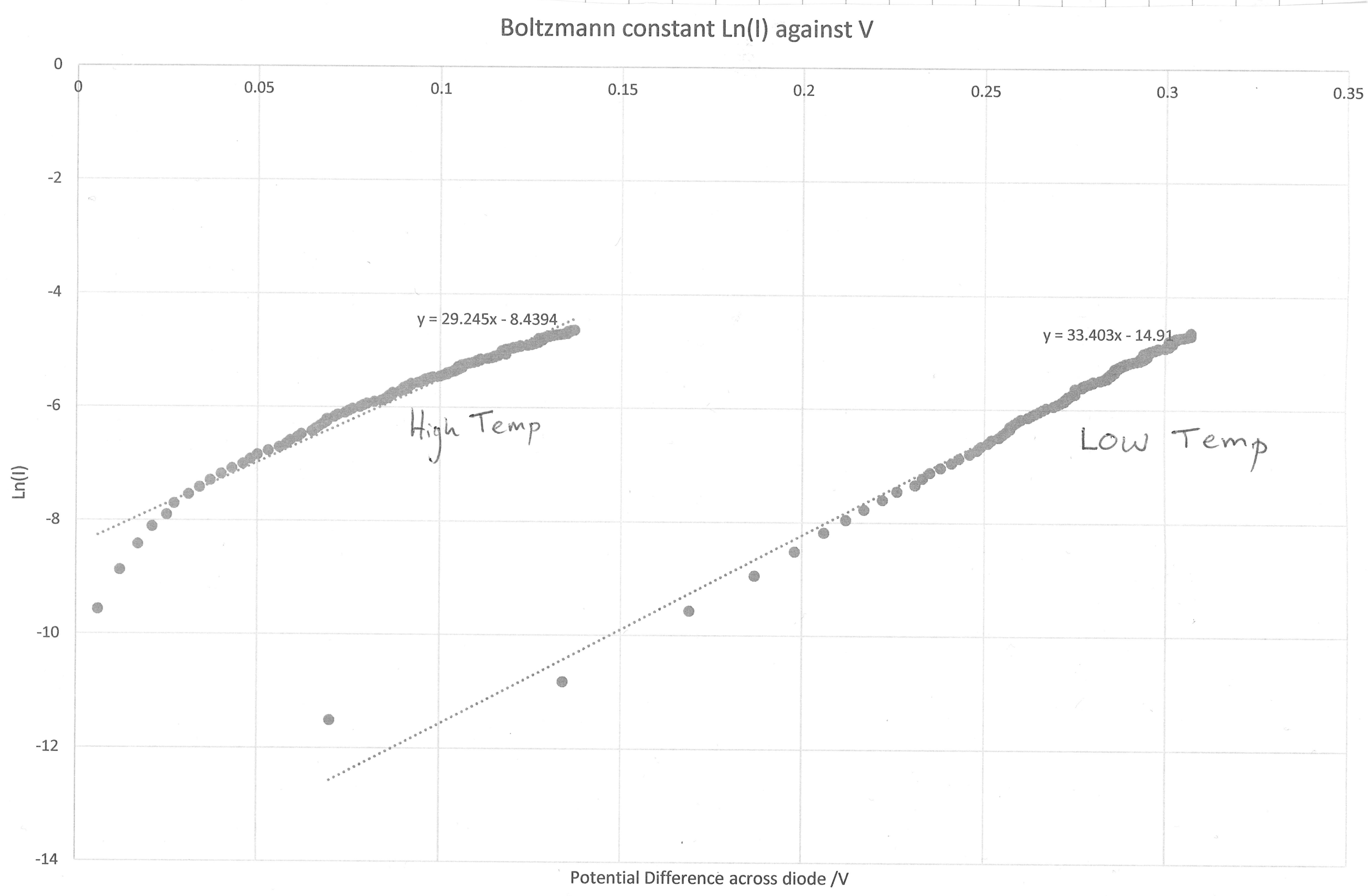
Graph plotted looks like this:



Which is as expected

The heater supply is turned on and a current of 0.5-0.6 A is used. (0.50 A used)
Every time the temperature rises by 10K a new measurement of the response curve is taken.

Measurement	Temperature /°C ±0.1°C
(5) 0	22.2
(6) 1	32.2
2	42.2
3	52.2
4	62.2
5	72.2
6	82.2
7	92.2
8	102.2
9	112.2
10	122.2
11	132.2
12	142.2
13	152.2



Boltzmann constant Ln(I) against V
y = 29.245x - 8.4394
High Temp
y = 33.403x - 14.91
Low Temp
Ln(I)
Potential Difference across diode /V
0
-2
-4
-6
-8
-10
-12
-14
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

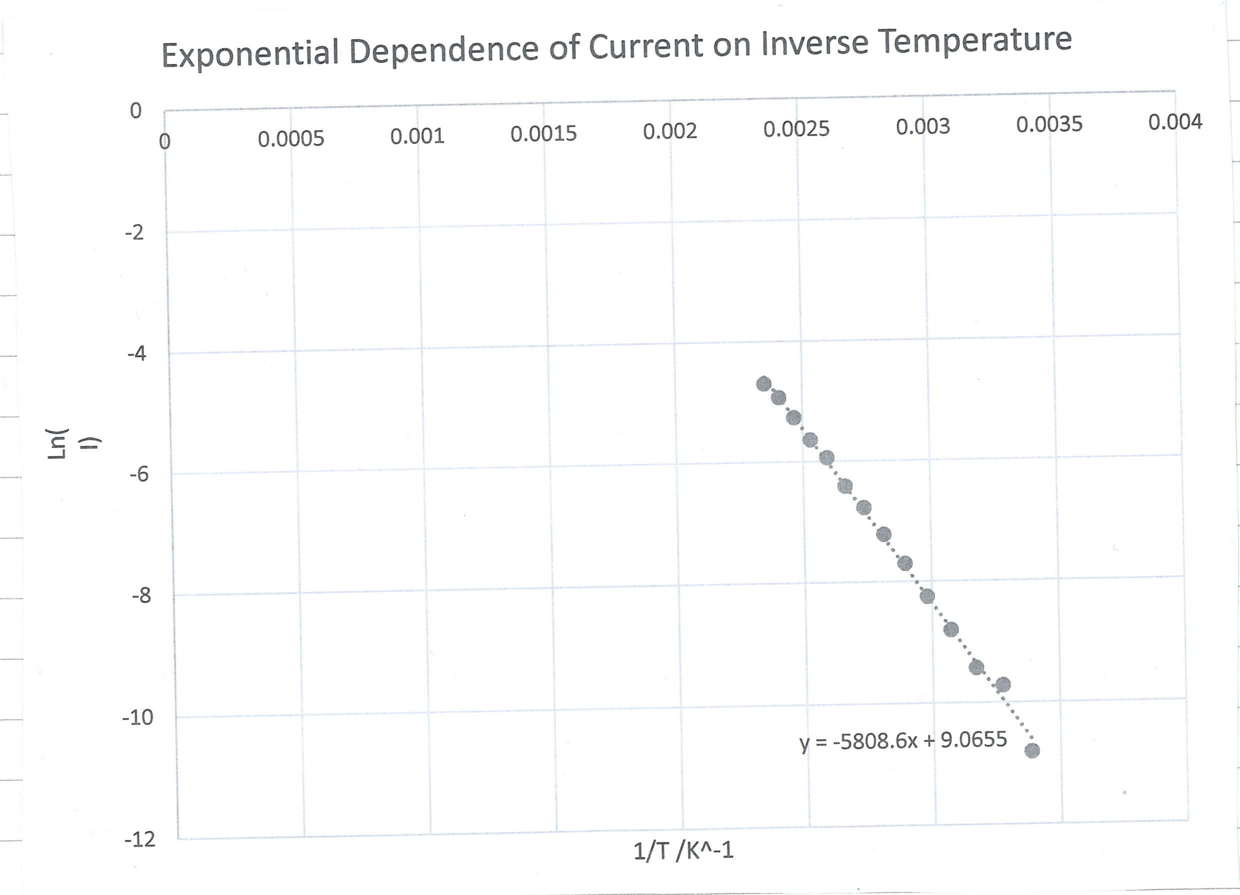
High Temperature recording was done at 152.2°C, 425.4K ± 0.1K

Low Temperature recording done at 22.2°C, 295.4 ±0.1 K

Error in gradients were determined using regression analysis in excel.

Error in High Temp gradient = ± 0.5

Error in Low Temp gradient = ± 0.3



Error in gradient = ± 89.09

This forms a straight line graph which verifies gradient = constant where we know gradient should be equal to $\frac{eV}{k}$ where V is constant

Therefore exponential dependence of current on inverse temperature

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from the equation earlier : $I = I_0 \exp\left(\frac{eV}{\eta kT}\right)$

taking natural log of both sides gives

$$\ln(I) = \ln(I_0) + \frac{eV}{\eta kT}$$

Therefore by plotting a graph of $\ln(I)$ against ~~ln~~ V for a constant temperature the gradient must be equal to $\frac{e}{\eta kT}$. For the diode we are using η is assumed to be ~~wrong~~. equal to 1.

For high temperature (425.4 ± 0.1 K)

gradient of ln(I) against V

$$= \frac{e}{\eta kT} \approx \frac{e}{kT}$$

$$29.2 \pm 0.5\,V^{-1} \approx \frac{1.602\times10^{-19}\,C}{k \times (425.4 \pm 0.1)K}$$

$$k = \frac{1.602\times10^{-19}C}{29.2\,CJ^{-1} \times 425.4K}$$

$$= \cancel{1.3 \times 10^{-23} \pm 0.2} \quad JK^{-1}$$
$$(1.3 \pm 0.2) \times 10^{-23}$$

for low temperature (295.4 ± 0.1 K)

$$33.4 \pm 0.3\,V^{-1} \approx \frac{1.602\times10^{-19}\,C}{k \times (295.4 \pm 0.1)K}$$

$$k = \frac{1.602\times10^{-19}C}{33.4\,CJ^{-1} \times 295.4K}$$

$$= (1.62 \cancel{\times10^{-23}} \pm 0.08) \times 10^{-23}\,JK^{-1}$$

This second value could be more out

Excellent

due to the greater the rate of change of Temperature at the lower temperatures due to the heater.

Conclusion

From our use of the CASSY system we were able to analyse and record data from a Semiconductor diode whilst changing it's temperature from analysing this data we were able to plot a graph in which Boltzmann's constant can be directly calculated from.
We did this for a high and low temperature and got two values for boltzmanns constant both reasonably close to the published value one (Low temp) being correct to 1 sf.
From the graphs made we also ~~showed~~ verified the exponential relationship between I and V and the exponential dependence of current on inverse temperature for a Semiconductor diode.