#### **TEACHER NOTES**

# Thermistor Boltzmann

 $R_0$ R Е  $\overline{k_B}T$ e

Dr Andrew French. October 2020.

Ludwig Boltzmann 1844-1906



Given the minimum thermistor resistance (at  $100^{\circ}$ C) is about  $100\Omega$ , you don't actually need the fixed resistor, as the maximum current draw is still much less than an amp. However its inclusion does help to reinforce a current-limiting precautionary principle in experimental work.

Fixed resistor (100ohm)



### Fixed resistor



PASCO USB Sparklink with ammeter, voltmeter and thermocouple

a shall a s

Thermistor

Laptop running Capstone

> Thermistor & thermocouple in water on a hotplate



$$V_0 = I ig( R + R_1 ig)$$
 Ohm's Law  $V = I R$ 

$$\therefore \frac{V}{V_0} = \frac{R}{R + R_1}$$

One can use a thermistor in a **potential divider** circuit.

If we know the **temperature** 

variation of thermistor resistance, we can find temperature from the potential divider voltage ratio (assuming we know the fixed resistance  $R_1$ ).

## In this experiment, the idea is to find the temperature variation of thermistor resistance *R*.

This is achieved by immersing a thermistor in water, which is slowly heated and its temperature is recorded independently. A direct measurement of resistance can be made by recording the current flowing through, and voltage across, the thermistor during the heating process. Screenshot from Capstone datalogger software. Temperature, voltage, current are logged at 10Hz for about 30mins, as the water is heated from 20°C to about 98°C.







Boltzmann's constant  $k_B = 1.38 \times 10^{-23} \text{ JK}^{-1}$ 

-udwig Boltzmann 1844-1906

The conductance (1 / resistance) of a thermistor varies with temperature (in K) via a **Boltzmann factor**. For electrons to be promoted to a 'conduction band,' with modest probability, their average thermal energy  $k_BT$  must exceed the 'band gap' or 'activation energy'  $\varepsilon$  associated with the semiconductor that constitutes the thermistor.



So if  $\ln(R)$  vs 1/T is a **straight line**, the Boltzmann factor model is plausible. And if there is a strong *correlation*, the gradient of the line yields the 'band gap' energy  $\varepsilon$ .

#### Resistance vs temperature of a thermistor Reference

Andy French. 17/10/2020. Winchester College, laboratory P5.

	Temperat	Temperat		Current	Voltage			MODEL R
Time (s)	ure (°C)	ure /K	1/T (K^-1	(mA)	(V)	R /ohms	In( R/ohms )	/ohms
0.0	20.4	293	3.41E-03	2.770	1.956	706	6.56	684.72
0.1	20.4	293	3.41E-03	2.770	1.956	т	7 6	684.72
0.2	20.4	293	3.41E-03	2.770	1.956	. V	6	684.72
0.3	20.4	293	3.41E-03	2.770	1.956	? = -	- 6	684.72
0.4	20.4	293	3.41E-03	3.099	1.961	` ı	5	684.72
0.5	20.4	293	3.41E-03	3.099	1.956	1	5	684.72
0.6	20.4	293	3.41E-03	2.770	1.956	706	6.56	684.72
0.7	20.4	293	3.41E-03	2.770	1.961	708	6.56	684.72
0.8	20.4	293	3.41E-03	2.770	1.956	706	6.56	684.72
0.9	20.4	293	3.41E-03	3.099	1.956	631	6.45	684.72
1.0	20.5	294	3.41E-03	3.099	1.956	631	6.45	682.70
1.1				1 N		631	6.45	682.70
1.2	T/K	) - (	T /°C	י⊥(ר	$772^{-}$	631	6.45	682.70
1.3	1/1	J - (		~J⊤4	213	706	6.56	680.69
1.4		· · ·		, '		631	6.45	680.69
1.5	20.7	294	3.40E-03	3.099	1.956	631	6.45	678.68
1.6	20.7	294	3.40E-03	3.099	1.956	631	6.45	678.68
1.7	20.7	294	3.40E-03	3.099	1.956	631	6.45	678.68
1.8	20.8	294	3.40E-03	2.770	1.956	706	6.56	676.69
1.9	20.8	294	3.40E-03	3.099	1.956	631	6.45	676.69
2.0	20.9	294	3.40E-03	2.770	1.956	706	6.56	674.70
2.1	20.9	294	3.40E-03	3.099	1.956	631	6.45	674.70
2.2	20.9	294	3.40E-03	3.099	1.956	631	6.45	674.70
2.3	21.0	294	3.40E-03	2.770	1.956	706	6.56	672.71
2.4	21.0	294	3.40E-03	2.770	1.956	706	6.56	672.71
2.5	21.0	294	3.40E-03	3.099	1.956	631	6.45	672.71
2.6	21.0	294	3.40E-03	3.099	1.956	631	6.45	672.71
2.7	21.1	294	3.40E-03	2.770	1.956	706	6.56	670.74
2.8	21.1	294	3.40E-03	2.770	1.956	706	6.56	670.74
2.9	21.1	294	3.40E-03	3.099	1.956	631	6.45	670.74
3.0	<b><b>T T T</b></b>	7					5	670.74
$\frac{3.1}{t}$	1.1.V	′ dai	talog	gger			ĵ	670.74
3.2	, , .		C	50 -			5	670.74
3.3 m	າດວຸດ	Iron	nont	c im	nort	۵d	ĵ	670.74
3.4	icasi	uren	ient	5 1111	ρυτ	eu	5	670.74
3.5	<b>.</b>		- 1-		مامام	<b>+</b>	<u>5</u>	670.74
3.6	ito a	n ex	cei s	prea	aasn	eet.	5	670.74
3.7							5	670.74
3.8	21.1	294	3.40E-03	2.770	1.956	706	6.56	670.74
3.9	21.1	294	3.40E-03	3.099	1.956	631	6.45	670.74
4.0	21.1	294	3.40E-03	2.770	1.956	706	6.56	670.74

ln(R) vs 1/T is a straight line to a high degree of positive correlation.

3.40E-03 3.099

1.956

631

6.45

4.1

21.1

294

Boltzmann' constant /J/K kB Electron charge / e





Thermistor band gap energy /eV 8



Model curve

670.74

