MODULUS – Ptolemy

Ptolemy Sensors Calibration

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1 Introduction

1.1 Purpose

This document describes the process of converting the sensor voltages measured by Ptolemy into calibrated sensor readings.

1.2 References

	Reference	*Title*	*Issue*	*Date*
RD1	RO-LPT-OU-TN-3401	Hardware Software Interface Document Issue 5	5	03/04/2001
RD2	RO-LPT-RAL-TN-3403	Ptolemy Telecommand and Telemetry Definitions	5.1	26/02/2001

1.3 Abbreviations and Acronyms

ADC	Analogue to Digital Converter
ASIC	Applications Specific Integrated Circuit (i.e a custom chip)
CDMS	Command and Data Management System (Lander on-board computer)
CSS	Chemistry Set Simulator
DAC	Digital to Analogue Converter
FM	Flight Model – The Ptolemy instrument on the Rosetta space craft
GRM	Ground Reference Model
HK	House Keeping - telemetry required to confirm correct operation of instrument
HT	High Tension (high voltage - ~2kV in this case)
HV	High voltage (same as HT)
OU	Open University
QM	Qualification Model
RAL	Rutherford Appleton Laboratory
RICA	Rosetta Ion-Counter ASIC – one of the ASICs used to control & read the Ion-trap
TC	Telecommands
Tlm	Telemetry
TM	Telemetry

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1.4 Ptolemy model summary

There are four versions of the Ptolemy instrument.

Flight Model (FM)

The Ptolemy FM is the instrument currently on the Rosetta space craft and is the actual model that will be performing the scientific sequences on the comet in 2014. Much of the calibration of the FM was done during thermal vacuum testing from 21st to 25th May 2001

Qualification Model (QM)

The qualification model is as close as practically possible to being an exact replica of the Flight Model. The QM resides in the laboratories at the Open University where calibration and characterisation continues.

Ground Reference Model (GRM)

An electrical representation of the FM. This model has approximately the same size as the FM and resides at DLR as part of the Lander Ground Reference Model. It simulates the power requirements of Ptolemy as close as possible whilst being able to operate at atmospheric pressure.

Chemistry Set Simulator (CSS)

An electrical simulation of the FM. This model was designed to help test the Ptolemy software and simulate TC sequences. The CSS resides in the laboratories at the Open University where TC sequences are tested before being uploaded on to the QM.

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2 Overview of Sensor measurements

Ptolemy sensors measure the desired feature and produce a voltage. Usually this voltage is conditioned to bring it within the +/- 10V voltage range of the 16 bit Analogue to Digital Converter. One of the 32 sensor signals is then selected by a multiplexer to be sent to the 16 bit analogue to digital converter where it is converted to a 16 bit word (in 2's complement format). Sensor measurements within Ptolemy Science packets are transmitted as the full 16 bit word. Ptolemy Housekeeping reports only transmit the 8 most significant bits of the 16 bit word in order to compress the data whilst maintaining the adequate precision. The "bit shift" for each sensor is described in the Ptolemy hardware/software interface document (RD1, pages 21 to 23).

The procedure to convert the raw data to a sensor reading is:
For 8 bit housekeeping reports apply the bit shift to convert the 8 bit data to the original 16 bit reading.
Convert the 16 bit (2's complement) reading to a measured voltage.
Apply the transfer function to obtain the original sensor measurement.

Science TM channel		Sensor Description	HK bit shift
Hex	Decimal		
00	00	Reactor R1 thermocouple (N-type)	7
01	01	Reactor R2 thermocouple (N-type)	7
02	02	Reactor R4 thermocouple (N-type)	7
03	03	Reactor R5 thermocouple (N-type)	7
04	04	Reactor R6 thermocouple (N-type)	7
05	05	Reactor R7 thermocouple (N-type)	7
06	06	Reactor R8 thermocouple (N-type)	7
07	07	Reactor R9/R14 thermocouple (N-type)	7
08	08	Reactor R13 thermocouple (N-type)	7
09	09	Reactor R15 thermocouple (N-type)	7
0A	10	Lindau valve LV1 thermocouple (N-type)	4
0B	11	Lindau valve LV2 thermocouple (N-type)	4
0C	12	Spare not used	
0D	13	Spare not used	
0E	14	Lindau valve LV5 thermocouple (N-type)	4
0F	15	Lindau valve LV6 thermocouple (N-type)	4
10	16	Lindau valve LV7 thermocouple (N-type)	4
11	17	GC thermocouple (N-type)	5
12	18	Manifold (Thermal enclosure) A thermocouple (N-type)	4
13	19	Manifold (Thermal enclosure) B thermocouple (N-type)	4
14	20	Ion trap thermocouple (N-type)	4

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15	21	Oven thermocouple (K-type)	7
16	22	Pipe heater thermocouple (N-type)	4
17	23	Absolute pressure sensor G1	7
18	24	Absolute pressure sensor G2	7
19	25	Absolute pressure sensor G3	7
1A	26	Absolute pressure sensor G4	6
1B	27	Absolute pressure sensor G5	5
1C	28	Reactor R14 thermocouple (N-type)	7
1D-1F	29-31	3 unused channels	
2X	32-47	reference junction thermometer (AD590)	6
3X	48-63	Docking station potentiometer	5
4X	64-79	Nanotip current	6
5X	80-95	Detector bias (HT)	6
6X	96-111	5V voltage monitor	6
7X	111-127	28V voltage monitor	6
8X	128-143	5V current monitor	5
9X	144-159	28V current monitor	5
AX	160-175	RF amplitude	5
BX	176-191	Spare channel	
CX-FX	192-255	not used	

X – Don’t care; these bit fields are not decoded by the hardware, it is suggested that 0 be used.

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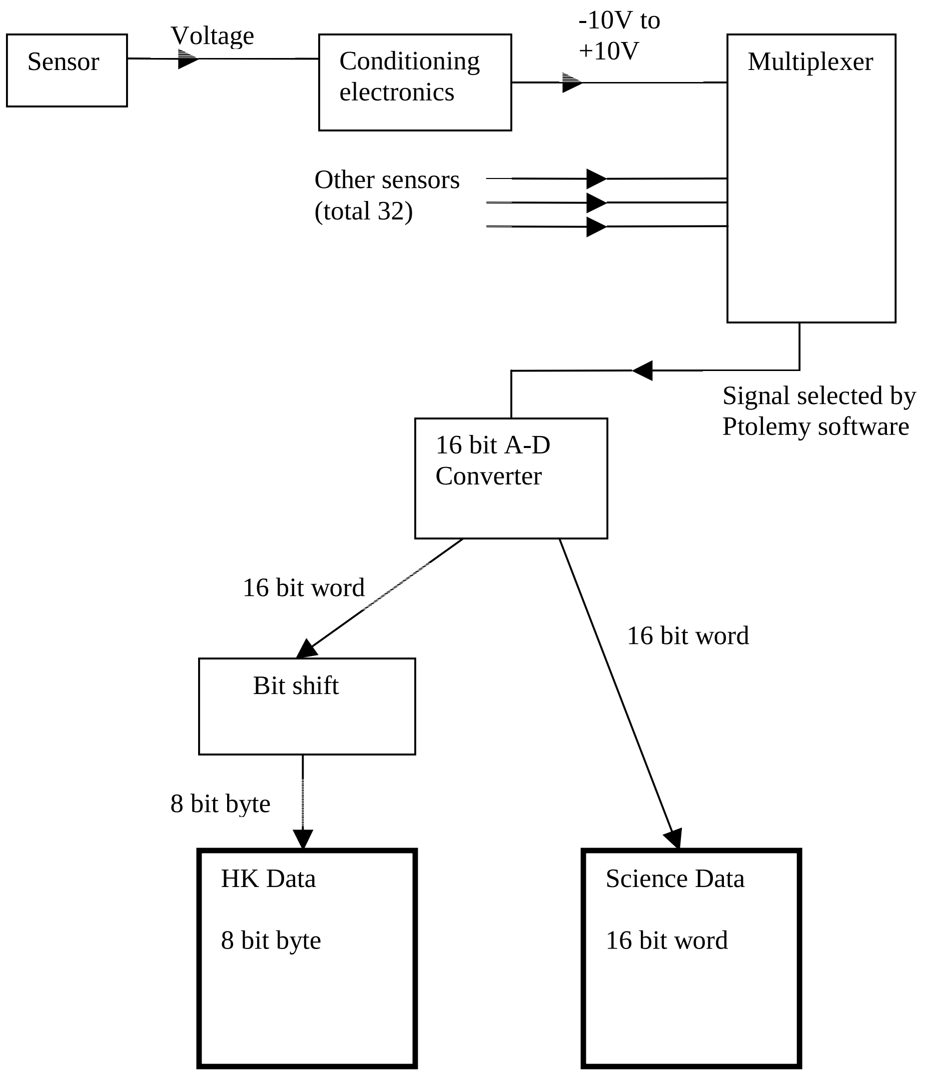

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3 Ptolemy Sensor Transfer Functions

3.1 Reference junction temperature (AD590)

The temperature of the thermocouple reference junction is measured by an AD590 which gives an output of 1µA/Kelvin. The conditioning circuit measures the voltage drop across a 10 kΩ resistor.

The bit shift for HK data is 6
The AD590 reading in °C = measured voltage x 100 -273

For housekeeping reports (8 bit), 1 bit = 1.9°C
For Science reports (16 bit), 1 bit = 0.03°C

3.2 Thermocouple temperatures

A thermocouple sensor measures the emf (electro-motive force) created at a junction of two dissimilar metals caused by the temperature difference between the thermocouple junction and a reference junction. As the emfs generated are small, the conditioning circuit increases the signal by a gain of 100. The transfer function is complicated because it is not a linear function and the reference junction also generates an emf depending upon its temperature.

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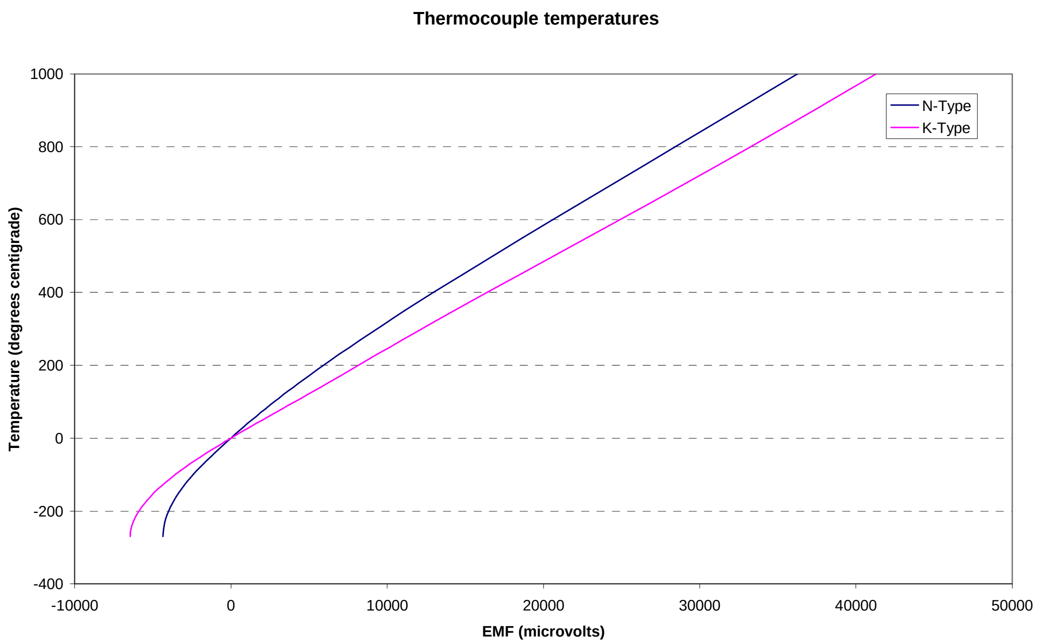

Plot of temperature reading against thermocouple emf for type K and type N thermocouples. Data plotted from Appendix A.

Three methods are suggested for calculating temperatures from thermocouple emfs.

1. Compile a data table of thermocouple emfs for all temperatures and then just read off the temperature against the emf. The data are available on data sheets and the web, but the Ptolemy team views that manual data entry of data for every degree from -200 to +1000 °C is likely to lead to errors.
2. Use a polynomial transfer function to convert emf to degrees centigrade. A second order polynomial is accurate to 1°C for temperature ranges -100°C to + 130°C and gives errors of more than 30°C above 500°C
3. Compile a coarse data table of thermocouple emfs against temperature and then calculate the transfer function. This is the method used by the Ptolemy EGSE. Data of the emfs generated by type K and N thermocouples and used by the Ptolemy EGSE are shown in appendix A.

The Ptolemy EGSE method of calculating temperature.

1. Calculate the gradient, rate of change of gradient, 1/gradient and rate of change of 1/gradient for each temperature point for both K-type and N-type thermocouples.

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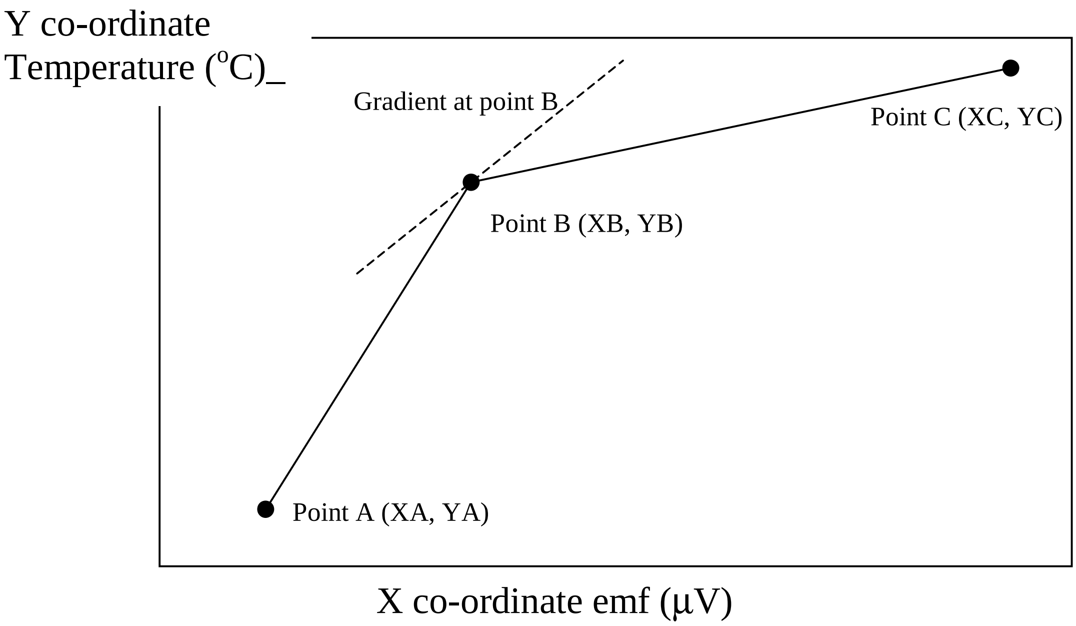

For point B, the gradient is the weighted average of the gradient from point A to B and the gradient of point B to C.

So the gradient at point B,

$$\text{Grad B} = \left\{\frac{(YB-YA)}{(XB-XA)}(XC-XB)+\frac{(YC-YB)}{(XC-XB)}(XB-XA)\right\}\left(\frac{1}{(XC-XA)}\right)$$

The rate of change of gradient at point B,

$$\delta\text{GradB} = \left\{\frac{(Grad_C - Grad_B)}{(XC-XB)}\right\}$$

1/gradient at point B,

$$\text{Grad B}^{-1} = \left\{\frac{1}{Grad_B}\right\}$$

And the rate of change of 1/gradient,

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$$\delta \text{Grad } B^{-1} = \left\{ \frac{\left(Grad_C^{-1} - Grad_B^{-1}\right)}{\left(XC - XB\right)} \right\}$$

2. Calculate the emf generated by the temperature of the reference junction for both K-type and N-type thermocouples. This is achieved by using the data point with a temperature just below the reference junction temperature.

$EMF_{ref} = EMF_{data} + (Temp_{ref} - Temp_{data}) \times Grad_{data}^{-1} + 0.5 \times (Temp_{ref} - Temp_{data})^2 \times \delta Grad_{data}^{-1}$

Example:
Reference junction temperature = 23°C
Data point used is 20°C which for an N-type thermocouple,
EMF_{data} = 525µV, $Grad_{data}^{-1}$ = 26.597µV/°C and $\delta Grad_{data}^{-1}$ = 0.04 µV °C^{-2}

$EMF_{ref\text{-}N} = 525 + 3 \times 26.597 + 0.5 \times 3^2 \times 0.04 = 604.97$ µV

For K-type thermocouple,
EMF_{data} = 798µV, $Grad_{data}^{-1}$ = 40.298µV/°C and $\delta Grad_{data}^{-1}$ = 0.04 µV °C^{-2}

$EMF_{ref\text{-}K} = 798 + 3 \times 40.298 + 0.5 \times 3^2 \times 0.04 = 919.07$µV

3. The conditioning circuits for all thermocouples have a gain of 100. To obtain the thermocouple emf then apply the bit shift for HK data, convert the reading to a voltage and then multiply by 10000 to give a thermocouple emf in µV.

Example:
Reactor 1 HK value 45(hex)
Apply bit shift of 7 gives 2280(hex) = 8832(dec) = 2.6953V, which gives a measured emf of 26953 µV.

4. Add the appropriate emf (K/N type) for the reference junction.
   Example: Reactor 1 emf 26953µV, with a reference junction temperature of 23°C gives an emf of 26953 + 605 = 27558 µV.

5. Calculate the temperature to generate the emf of thermocouples. This is achieved by using the data point with an emf just below the measured thermocouple emf.

$Temp_{tc} = Temp_{data} + (emf_{tc} - emf_{data}) \times Grad_{data} + 0.5 \times (emf_{tc} - emf_{data})^2 \times \delta Grad_{data}$

Example: N-type thermocouple emf = 27558µV
Data point used is 750°C, which for N-type thermocouple,
emf_{data} = 26491µV, $Grad_{data}$ = 0.025458 °C/µV and $\delta Grad_{data}$ = 9.923x10^{-9} °C µV^{-2}

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$Temp_{tc} = 750 + 1067 \times 0.025458 + 0.5 \times 1067^2 \times 9.923 \times 10^{-9} = 777°C$

3.3 Pressure Sensors

The transfer function for the pressure sensors is linear.

Pressure = AxV + B
Where A and B are constants determined for each sensor and V is the measured voltage from the ADC.

Values determined for the Flight Model are:

Sensor	Bit shift	Constant A	Constant B	Units
G1 (0-4 Bar)	7	13.25	0.0	Bar
G2 (0-10 Bar)	7	7.8	-0.75	Bar
G3 (0-4 Bar)	7	12.3	-1.6	Bar
G4 (0-1.6 Bar)	6	18.7	0.0	Bar
G5 (0-0.6Bar)	5	37.5	0.0	mBar

3.4 Docking Station

The docking station position is measured by a sliding potentiometer.

The bit shift for HK data is 5
The docking station position in mm = measured voltage x 5.2

For housekeeping reports (8 bit), 1 bit = 0.0058 mm
For Science reports (16 bit), 1 bit = 0.0016 mm

3.5 Nanotip current

This gives the current emitted by the field effect electron source in the mass spectrometer

The bit shift for HK data is 6
The nanotip current in µA = measured voltage x 100

For housekeeping reports (8 bit), 1 bit = 7.6µA

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For Science reports (16 bit), 1 bit = 0.5μA

3.6 Detector Bias

The conditioning circuit for the electron multiplier detector has a gain of 0.001

The bit shift for HK data is 6
The detector bias in kV = measured voltage

For housekeeping reports (8 bit), 1 bit = 0.0195 kV
For Science reports (16 bit), 1 bit = 0.0003 kV

3.7 Voltage monitors of power supply rails

The conditioning circuit fort the 5V monitor has a gain of 0.5 and for the 28V monitor has a gain of 0.1

For the 5 V monitor:
The bit shift for HK data is 6
The 5V rail voltage = measured voltage x 2 V

For housekeeping reports (8 bit), 1 bit = 0.039 V
For Science reports (16 bit), 1 bit = 0.00061 V

For the 28V monitor:
The bit shift for HK data is 6
The 28V rail voltage = measured voltage x 10 V

For housekeeping reports (8 bit), 1 bit = 0.195 V
For Science reports (16 bit), 1 bit = 0.003 V

3.8 Current monitors of power supply rails

For both the 5 V and 28 V current monitors:
The bit shift for HK data is 5
The current = measured voltage x 1000mA

For housekeeping reports (8 bit), 1 bit = 9.7mA
For Science reports (16 bit), 1 bit = 0.3mA

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3.9 RF calibration

The output from the mass spectrometer RF circuit is measured by a separate DAC from the other sensors and is used to tune the RF generator by onboard software. The conditioning circuit has a gain of 0.01

The bit shift for HK data is 5
The RF voltage = measured voltage x 100 V

For housekeeping reports (8 bit), 1 bit = 0.98 V
For Science reports (16 bit), 1 bit = 0.03 mV

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4 Appendix A

Temperature (oC)	N – Type thermocouples				
	Emf (μV)	Grad ($^oC\ \mu V^{-1}$)	δGrad x 10^{-6} ($^oC\ \mu V^{-2}$)	Grad $^{-1}$ ($\mu V\ ^oC^{-1}$)	δGrad^{-1} ($\mu V\ ^oC^{-2}$)
-270	-4345				
-260	-4336	0.9205	-24302.846	1.086	0.151
-250	-4314	0.3858	-3966.397	2.592	0.159
-240	-4277	0.2391	-1189.423	4.183	0.142
-230	-4226	0.1784	-553.801	5.605	0.139
-220	-4162	0.1430	-318.254	6.994	0.149
-210	-4083	0.1178	-177.055	8.487	0.138
-200	-3990	0.1014	-109.097	9.865	0.127
-190	-3884	0.0898	-78.782	11.136	0.129
-180	-3766	0.0805	-57.144	12.422	0.128
-170	-3634	0.0730	-39.359	13.706	0.115
-160	-3491	0.0673	-30.387	14.852	0.112
-150	-3336	0.0626	-24.233	15.969	0.109
-140	-3171	0.0586	-19.545	17.058	0.107
-130	-2994	0.0552	-14.712	18.128	0.095
-120	-2808	0.0524	-12.767	19.074	0.096
-110	-2612	0.0499	-10.482	20.030	0.090
-100	-2407	0.0478	-8.299	20.931	0.081
-90	-2193	0.0460	-6.497	21.739	0.070
-80	-1972	0.0446	-5.916	22.439	0.070
-70	-1744	0.0432	-4.688	23.139	0.061
-60	-1509	0.0421	-3.957	23.745	0.055
-50	-1269	0.0412	-3.720	24.293	0.055
-40	-1023	0.0402	-2.561	24.845	0.040
-30	-772	0.0396	-2.124	25.248	0.035
-20	-518	0.0391	-1.768	25.597	0.030
-10	-260	0.0386	-0.858	25.899	0.015
0	0	0.0384	-1.112	26.050	0.020
10	261	0.0381	-1.892	26.248	0.035
20	525	0.0376	-2.079	26.597	0.040
30	793	0.0370	-1.749	26.997	0.035
40	1065	0.0366	-1.674	27.348	0.035
50	1340	0.0361	-1.842	27.697	0.040
60	1619	0.0356	-1.765	28.097	0.040
70	1902	0.0351	-1.693	28.497	0.040
80	2189	0.0346	-1.428	28.897	0.035
90	2480	0.0342	-1.371	29.248	0.035
100	2774	0.0338	-1.512	29.597	0.040
110	3072	0.0333	-1.453	29.997	0.040
120	3374	0.0329	-1.228	30.397	0.035

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130	3680	0.0325	-1.181	30.749	0.035
140	3989	0.0322	-1.143	31.097	0.035
150	4302	0.0318	-0.970	31.447	0.031
170	4937	0.0312	-0.922	32.068	0.031
190	5585	0.0306	-0.802	32.694	0.029
210	6245	0.0301	-0.697	33.270	0.026
230	6916	0.0296	-0.634	33.796	0.025
250	7597	0.0292	-0.577	34.296	0.024
270	8288	0.0288	-0.497	34.772	0.021
290	8988	0.0284	-0.478	35.198	0.021
310	9696	0.0281	-0.410	35.622	0.019
330	10413	0.0278	-0.340	35.999	0.016
350	11136	0.0275	-0.312	36.320	0.015
400	12974	0.0270	-0.245	37.094	0.013
450	14846	0.0265	-0.190	37.735	0.010
500	16748	0.0261	-0.137	38.257	0.008
550	18672	0.0259	-0.100	38.649	0.006
600	20613	0.0257	-0.067	38.939	0.004
650	22566	0.0255	-0.037	39.140	0.002
700	24527	0.0255	-0.010	39.250	0.001
750	26491	0.0255	0.010	39.280	-0.001
800	28455	0.0255	0.030	39.250	-0.002
850	30416	0.0255	0.044	39.160	-0.003
900	32371	0.0256	0.061	39.030	-0.004
950	34319	0.0257	0.086	38.849	-0.005
1000	36256	0.0259	0.102	38.599	-0.006
1050	38179	0.0261	0.119	38.309	-0.007
1100	40087	0.0263	0.145	37.978	-0.008
1150	41977	0.0266	0.161	37.588	-0.008
1200	43846	0.0269	0.199	37.168	-0.010
1250	45694	0.0273		36.665	
1300	47513				

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Temperature (oC)	K – Type thermocouples				
	Emf (μV)	Grad ($^oC\ \mu V^{-1}$)	δGrad x 10^{-6} ($^oC\ \mu V^{-2}$)	Grad $^{-1}$ ($\mu V\ ^oC^{-1}$)	δGrad^{-1} ($\mu V\ ^oC^{-2}$)
-270	-6458				
-260	-6441	0.4881	-6956.320	2.049	0.229
-250	-6404	0.2308	-1382.976	4.334	0.243
-240	-6344	0.1478	-453.593	6.767	0.228
-230	-6262	0.1106	-204.127	9.043	0.215
-220	-6158	0.0893	-109.838	11.192	0.199
-210	-6035	0.0758	-68.447	13.186	0.197
-200	-5891	0.0660	-43.268	15.156	0.179
-190	-5730	0.0590	-31.288	16.944	0.179
-180	-5550	0.0534	-22.018	18.732	0.165
-170	-5354	0.0491	-16.960	20.379	0.162
-160	-5141	0.0455	-13.097	21.999	0.155
-150	-4913	0.0425	-10.523	23.546	0.152
-140	-4669	0.0399	-8.441	25.061	0.145
-130	-4411	0.0377	-6.989	26.508	0.141
-120	-4138	0.0358	-5.389	27.920	0.126
-110	-3852	0.0343	-4.714	29.175	0.125
-100	-3554	0.0329	-4.188	30.422	0.126
-90	-3243	0.0316	-3.301	31.677	0.111
-80	-2920	0.0305	-2.836	32.785	0.105
-70	-2587	0.0296	-2.595	33.832	0.105
-60	-2243	0.0287	-2.048	34.886	0.091
-50	-1889	0.0279	-1.786	35.791	0.085
-40	-1527	0.0273	-1.581	36.639	0.080
-30	-1156	0.0267	-1.384	37.443	0.075
-20	-778	0.0262	-1.227	38.192	0.070
-10	-392	0.0257	-0.917	38.895	0.055
0	0	0.0254	-0.722	39.447	0.045
10	397	0.0251	-0.620	39.898	0.040
20	798	0.0248	-0.602	40.298	0.040
30	1203	0.0246	-0.442	40.698	0.030
40	1612	0.0244	-0.288	41.000	0.020
50	2023	0.0243	-0.284	41.200	0.020
60	2436	0.0242	-0.211	41.400	0.015
70	2851	0.0241	0.000	41.550	0.000
80	3267	0.0241	0.140	41.550	-0.010
90	3682	0.0241	0.141	41.450	-0.010
100	4096	0.0242	0.214	41.350	-0.015
110	4509	0.0243	0.361	41.200	-0.025

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120	4920	0.0244	0.292	40.949	-0.020
130	5328	0.0245	0.375	40.750	-0.025
140	5735	0.0247	0.378	40.498	-0.025
150	6138	0.0248	0.174	40.250	-0.011
170	6941	0.0250	0.058	40.024	-0.004
190	7739	0.0250	-0.117	39.950	0.007
210	8539	0.0249	-0.192	40.100	0.012
230	9343	0.0248	-0.262	40.349	0.017
250	10153	0.0246	-0.257	40.698	0.018
270	10971	0.0244	-0.197	41.049	0.014
290	11795	0.0242	-0.158	41.324	0.011
310	12624	0.0241	-0.121	41.550	0.009
330	13457	0.0240	-0.106	41.725	0.008
350	14293	0.0239	-0.094	41.879	0.007
400	16397	0.0237	-0.063	42.229	0.005
450	18516	0.0235	-0.034	42.470	0.003
500	20644	0.0235	-0.003	42.600	0.000
550	22776	0.0235	0.031	42.610	-0.002
600	24905	0.0235	0.066	42.490	-0.005
650	27025	0.0237	0.097	42.239	-0.007
700	29129	0.0239	0.116	41.878	-0.008
750	31213	0.0241	0.131	41.458	-0.009
800	33275	0.0244	0.145	40.997	-0.010
850	35313	0.0247	0.153	40.507	-0.010
900	37326	0.0250	0.162	40.007	-0.010
950	39314	0.0253	0.176	39.497	-0.011
1000	41276	0.0257	0.186	38.966	-0.011
1050	43211	0.0260	0.213	38.426	-0.012
1100	45119	0.0264	0.246	37.835	-0.013
1150	46995	0.0269	0.281	37.184	-0.014
1200	48838	0.0274	0.328	36.482	-0.015
1250	50644	0.0280		35.711	
1300	52410				

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