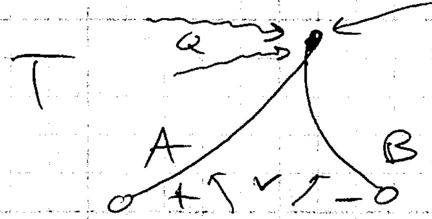
(1)

THERMOCOUPLE

PROBE

(TWISTED / SOLDERED / BRAZED)



WIRES OF DIFFERENT METAL

$\Delta T \Rightarrow \Delta V$

DUE TO METAL ELECTRON AFFINITY DIFFERENCES, WHICH VARY W/ TEMP.

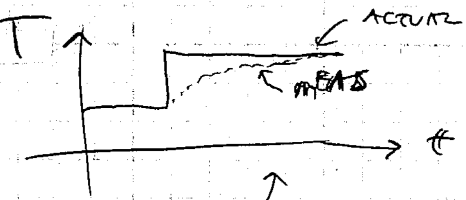
(SEEBECK EFFECT)

SEE VIDEO

1st-ORDER SYSTEM

THERMAL RESISTANCE (HEAT TRANSFER)

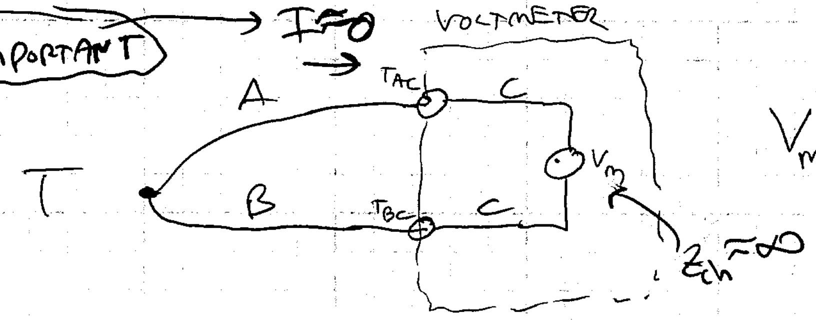
+ CAPACITANCE (HEAT CAPACITY OF PROBE)



STEP RESPONSE LIMITED + FREQ. RESPONSE

TYPICAL MEASUREMENT CIRCUIT

IMPORTANT → IFO



$\Rightarrow$ 3 JUNCTIONS

FUNCTION OF

$$V_m = V_m(T, A, B$$

$+ \underbrace{T_{AC}, T_{BC}}_{\text{USU. EQUAL}}, C)$

COMPENSATED BY THERMOCOUPLE MEAS. DEVICE

BASICALLY,

$$V_m = V_m(T)$$

$\Rightarrow$ TEMP. SENSOR

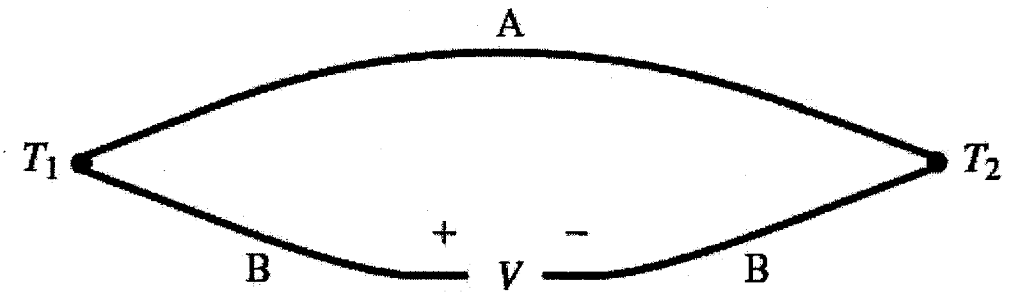


Figure 9.36 (p. 409)

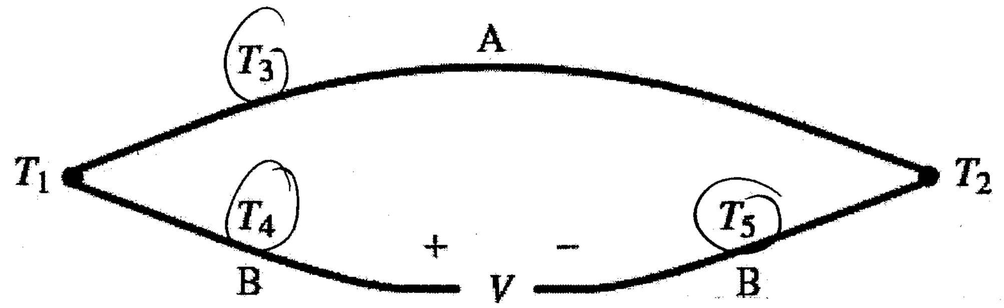
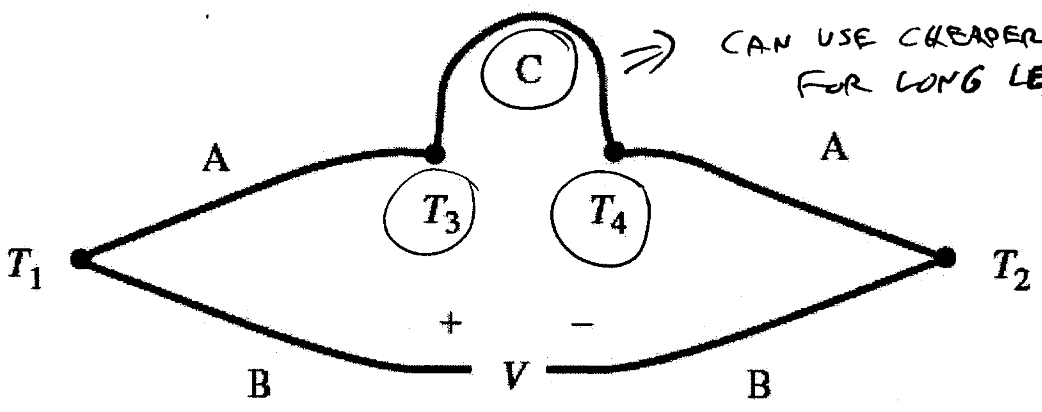


Figure 9.37 (p. 410)

$V = \underbrace{v}_{\text{FUNC OF}}(T_1 - T_2, A, B)$

NOT T_3, T_4, T_5

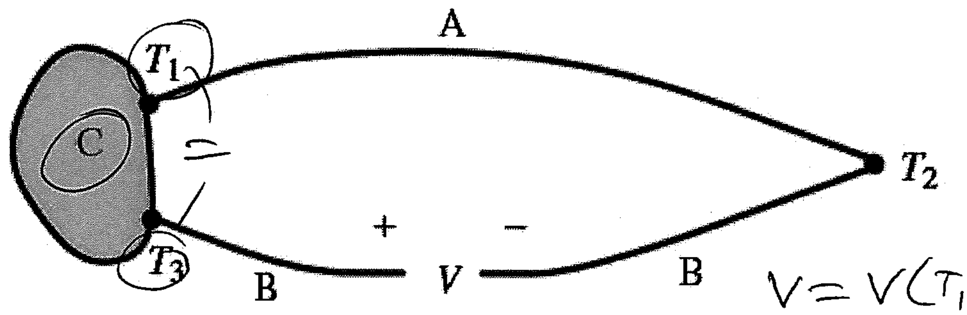


CAN USE CHEAPER WIRE FOR LONG LEADS

Figure 9.38 (p. 410)

$V = v(T_1 - T_2, A, B)$

NOT, $\underbrace{T_3, T_4}_{\text{IF EQUAL}}$, C ex: SOLDER

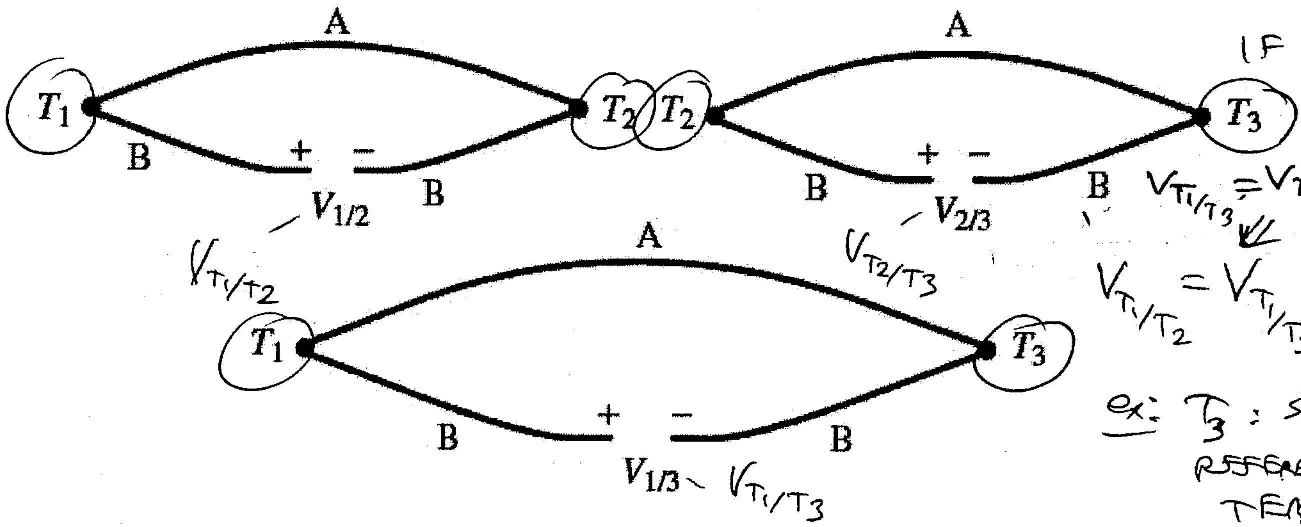


$V = V(T_1 - T_2, A, B)$

NOT C OR T_3

IF $T_3 = T_1$

Figure 9.39 (p. 4.11)
INTERMEDIATE JUNCTION METAL



V_{T_1/T_2}

V_{T_2/T_3}

V_{T_1/T_3}

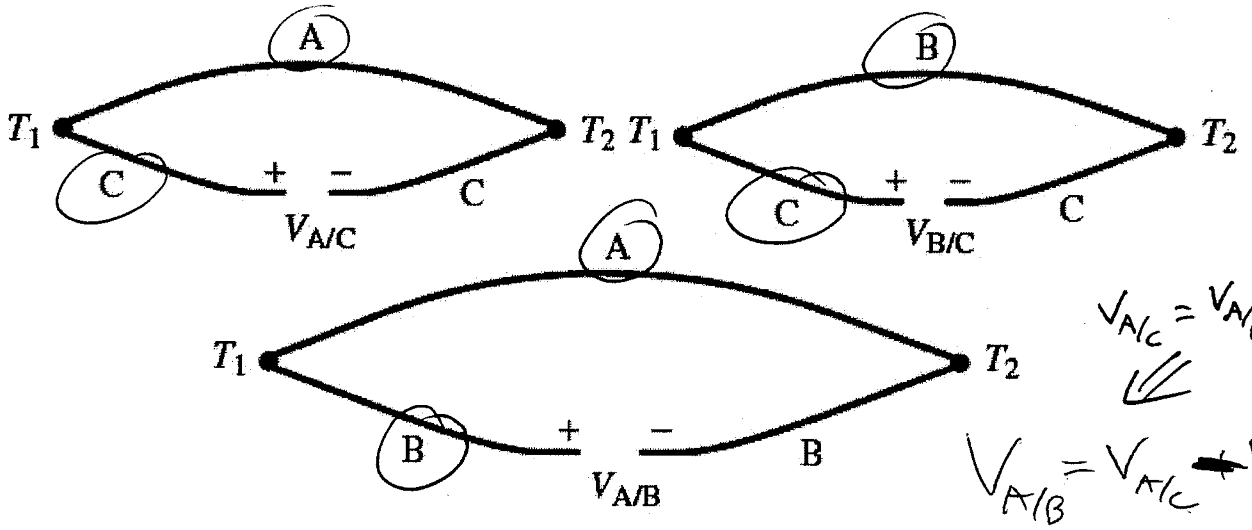
$V_{T_1/T_3} = V_{T_1/T_2} + V_{T_2/T_3}$

$\Downarrow$

$V_{T_1/T_2} = V_{T_1/T_3} - V_{T_2/T_3}$

ex: T_3 : STANDARD REFERENCE TEMP. FOR PUBLISHED TABLES + FORMULAS

Figure 9.40 (p. 411)
INTERMEDIATE TEMPERATURE



$V_{A/C} = V_{A/B} + V_{B/C}$

$\Downarrow$

$V_{A/B} = V_{A/C} - V_{B/C}$

Figure 9.41 (p. 412)
INTERMEDIATE METALS

ex: C: STANDARD REF. MAT'L (e.g., PLATINUM)

DISCUSS NIST TIME SAVING

ALLOWING US TO RELATE ANY COMBO OF MATERIALS KNOWING HOW EACH RELATES TO ON[E]

SIMILAR TO (+ RELATED TO)
GALVANIC SERIES
FOR
(CORROSION)

Thermoelectric sensitivity $S = dE/dT$ of thermoelement made of materials listed against platinum, $\mu V°C^{-1}$†
(Reference junction kept at a temperature of 0°C)

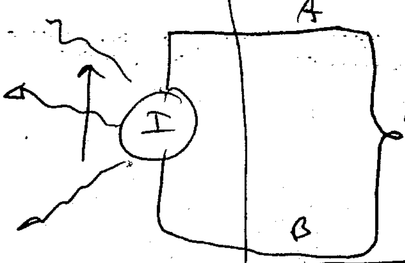
SEEBECK EFFECT

Bismuth	−72	Silver	6.5
Constantan	−35	Copper	6.5
Nickel	−15	Gold	6.5
Potassium	−9	Tungsten	7.5
Sodium	−2	Cadmium	7.5
Platinum	0	Iron	18.5
Mercury	0.6	Nichrome	25
Carbon	3	Antimony	47
Aluminum	3.5	Germanium	300
Lead	4	Silicon	440
Tantalum	4.5	Tellurium	500
Rhodium	6	Selenium	900

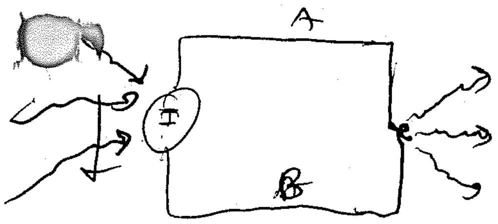
† According to Lion [6].

REF. MAT'L

Iron-Constantan
good separation
⇒ good sensitivity
Also relatively inexpensive



HEAT ABSORBED
[redacted]
(due to change in electron energies across junction)



HEAT RELEASED
(THERMO-ELECTRIC HEATER)
NOT USEFUL SINCE OTHER METHODS BETTER

Useful for other thermoelectric effects
(ex: [thermoelectric refrigerator]
TEC "COOLER")

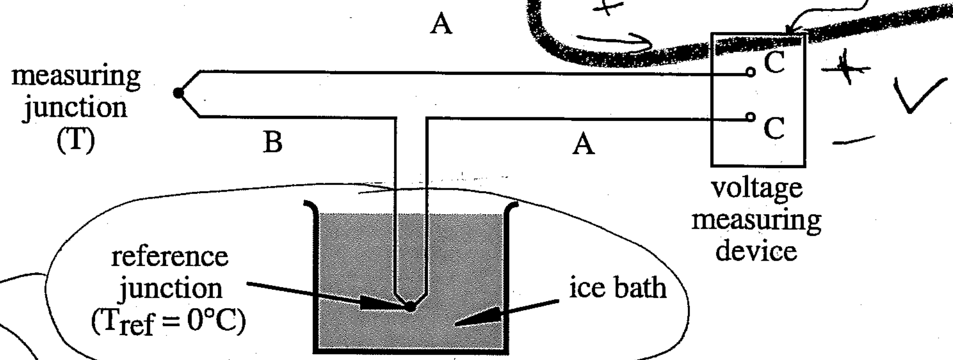
Gaslan
Pelter Effect

DOESN'T AFFECT THERMOCOUPL. MEAS. CIRCUITS SINCE HIGH Z_{IN} V_m used (⇒ I ≈ 0) see video

FIG. 9.42

otherwise, Peltier effect + I^2R heating

$I \approx 0 \Rightarrow Z_{IN} \approx \infty$



+ V −

Tref CAN BE DONE ELECTRICALLY (e.g., IN THERMOCOUPLE THERMOMETER INSTRUMENT)

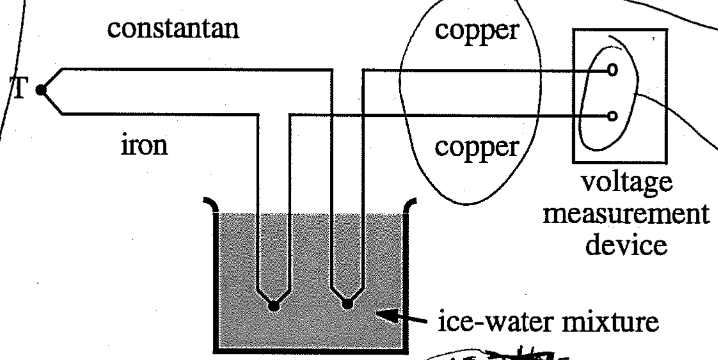
THERMO-METER

w/ a temperature compensator circuit

USES IC TEMP SENSOR

Figure 9.42 Standard Thermocouple Configuration

(p. 373)



e.g. long, cheap extension wires

NO THERMO-ELECTRIC JUNCTIONS

or ~~other~~ constant-temp mount

Figure 9.43 Attaching Leadwires of Selected Metal

$$T = \sum_{i=0}^{9} c_i V^i = c_0 + c_1 V + c_2 V^2 + c_3 V^3 + c_4 V^4 + c_5 V^5 + c_6 V^6 + c_7 V^7 + c_8 V^8 + c_9 V^9 \quad (9.51)$$

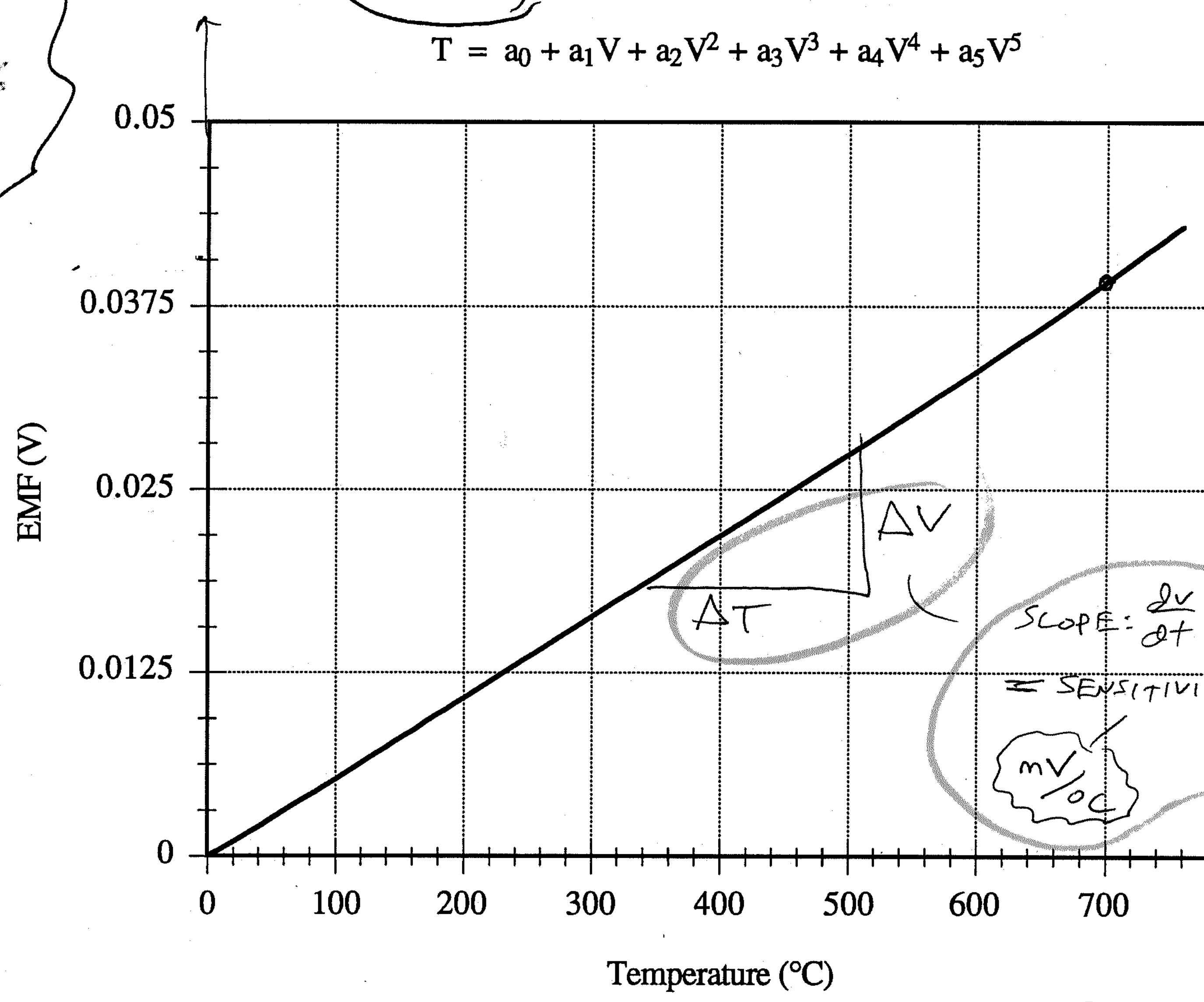
C_i : precalibrated constants for A-B combo material

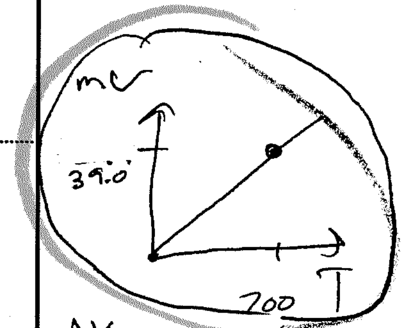
Skip IF NO TIME

DO ON BOARD

Type J (Iron-Constantan) Calibration

$$T = a_0 + a_1 V + a_2 V^2 + a_3 V^3 + a_4 V^4 + a_5 V^5$$





$\frac{\Delta V}{\Delta T}$ $S \approx \frac{39-0}{700-0}$

$= \boxed{.056 \frac{mV}{°C}}$

SMALL BUT MEASURABLE

TYPE J

6

TABLE 9.2 IN BOOK

TABLE 8-5
Polynomial coefficents for Eq. (8-12) for several standard thermocouple combinations

	Type E	Type J	Type K	Type R	Type S	Type T
	Chromel(+) versus constantan(−)	Iron(+) versus constantan(−)	Chromel(+) versus nickel-5%(−) (aluminum silicon)	Platinum-13% rhodium(+) versus platinum(−)	Platinum-10% rhodium(+) versus platinum(−)	Copper(+) versus constantan(−)
	−100°C to 1000°C* ±0.5°C 9th order	0°C to 760°C* ±0.1°C 5th order	0°C to 1370°C* ±0.7°C 8th order	0°C to 1000°C* ±0.5°C 8th order	0°C to 1750°C* ±1°C 9th order	−160°C to 400°C* ±0.5°C 7th order
a_0	0.104967248	−0.048868252	0.226584602	0.263632917	0.927763167	0.100860910
a_1	17189.45282	19873.14503	24152.10900	179075.491	169526.5150	25727.94369
a_2	−282639.0850	−218614.5353	67233.4248	−48840341.37	−31568363.94	−767345.8295
a_3	12695339.5	11569199.78	2210340.682	1.90002E + 10	8990730663	78025595.81
a_4	−448703084.6	−264917531.4	−860963914.9	−4.82704E + 12	−1.63565E + 12	−9247486589
a_5	1.10866E + 10	2018441314	4.83506E + 10	7.62091E + 14	1.88027E + 14	6.97688E + 11
a_6	−1.76807E + 11		−1.18452E + 12	−7.20026E + 16	−1.37241E + 1	−2.66192E + 13
a_7	1.71842E + 12		1.38690E + 13	3.71496E + 18	6.17501E + 17	3.94078E + 14
a_8	−9.19278E + 12		−6.33708E + 13	−8.03104E + 19	−1.56105E + 19	
a_9	2.06132E + 13				1.69535E + 20	

$$T = a_0 + a_1 V + a_2 V^2 + \cdots + a_9 V^9$$

.001

1

MATHCAD file downloadable from book web page

Thermocouple Example

Type J Coefficents:

$c_0 := -0.0488683$ $\quad$ $c_3 := 1.15692 \cdot 10^7$

$c_1 := 19873.1$ $\quad$ $c_4 := -2.64918 \cdot 10^8$

$c_2 := -218615$ $\quad$ $c_5 := 2.01844 \cdot 10^9$

iterative/subscript array

keyboard: "["

Temperature/Voltage Relationship:

$$T(V) := \sum_{i=0}^{5} c_i \cdot V^i$$

$$= C_0 + C_1 V^1 + C_2 V^2 + C_3 V^3 + C_4 V^4 + C_5 V^5$$

Solving for Voltage Given a Temperature:

2 DIFFERENT APPROACHES

$T(V) = 10$

$\Rightarrow T(V) - 10 = 0$

$V := 0$ — initial guess needed for

$V_{10} := \text{root}(T(V) - 10, V)$ $\qquad$ $V_{10} = 5.084 \cdot 10^{-4}$

literal subscript

keyboard: "."

$V := 0$ — initial guess

given

SOLVE BLOCK

$T(V) = 20$

CTRL =

$V_{20} := \text{find}(V)$ $\qquad$ $V_{20} = 1.02 \cdot 10^{-3}$

Test of Results:

$T(V_{10}) = 10$ $\qquad$ $T(V_{20}) = 20$

IF TIME DISCUSS PROJECT STUFF

ESPECIALLY GRADING + LESSONS LEARNED

FROM CURR GROUP

IF HAVE TIME:

LEAVE EARLY OR

DISCUSS,

ANSWER QUESTIONS
ABOUT PROJECT
+ COURSE GRADING

+ LESSONS LEARNED

AND/OR GET FEEDBACK
ON LAB PRACTICAL