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~~[illegible]~~

MASTER

CALCULATOR THERMOMETER*

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ABSTRACT

An inexpensive substitution for calibrated thermocouples, linearizing electronics, and the N.B.S. thermocouple tables is obtained through the use of a hand-held calculator. Automatic offset corrections and interpolations to an output temperature are possible in a one button operation beginning with voltmeter EMF. The inverse operation is also given. Appropriate constants have been found for the Cu-constantan, iron-constantan, and chromel-alumel thermocouples.

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DISCLAIMER

Need to determine sample temperature over hundreds of degrees K? Lack the funds to purchase calibrated instruments? Faced with this problem we have devised a simple thermocouple conversion with a hand-held programmable calculator which fits the copper-constantan N.B.S. tables to an accuracy of ± 2 μeV. We have made a similar fit to the iron-constantan and chromel-alumel thermocouples to less accuracy. The calculator program also allows a linear correction for experimentally introduced diode effects, thermal E.M.F.'s, and individual wire discrepancies. It is ideally suited for a linear amplifier following a thermocouple and a less expensive digital voltmeter. The correction allows calibration at three known temperatures: $T_1 < T_2 < T_3$. The reference temperature may be user chosen. If any of these standard temperatures are used in the process of routine measurements, run to run calibration may be easily incorporated into the routine. In principle, any thermocouple may be used in any temperature range.

Programmable calculators with as few as 16 program steps and three addressable memories may be used for one way conversion over a limited temperature range. If as many as nine addressable memories are available, the calculator may be programmed to choose the appropriate set of constants from the storage registers for three different temperature ranges. With an HP 67 or 97 calculator, sufficient memory is available to allow storage of copper-constantan or iron-constantan constants for all temperature ranges and the flexibility of one button conversion of thermocouple voltage to Kelvin, Centigrade, or Farenheit temperatures and vice versa.

The functional form of the fit for table EMF in mV is:

$$EMF = aT + bT^2 + cT^3 \qquad (1)$$

with T in degrees Centigrade and with a, b, and c as chosen from Table I. These constants were obtained via a fit to the standard N.B.S. EMF tables with an ice bath reference at 0°C.

For the inversion of the cubic expression, the relation

$$T = 2\left|\left(\frac{b}{3c}\right)^2 - \left(\frac{a}{3c}\right)\right|^{1/2} \cos\left\{240 + \frac{1}{3}\cos^{-1}\left[\frac{\frac{3}{2}\left(\frac{b}{3c}\right)\left(\frac{a}{3c}\right)+\frac{3}{2}\left(\frac{EMF^*}{3c}\right)-\left(\frac{b}{3c}\right)^3}{\left|\left(\frac{b}{3c}\right)^2-\left(\frac{a}{3c}\right)\right|^{3/2}}\right]\right\} - \left(\frac{b}{3c}\right)$$

$$\text{if } b^2 > 3ac \qquad (2)$$

or

$$T = 2\left|\left(\frac{b}{3c}\right)^2-\left(\frac{a}{3c}\right)\right|^{1/2}/\mathrm{TAN}\left\{2\mathrm{TAN}^{-1}\left\{\mathrm{TAN}\left[\frac{1}{2}\mathrm{TAN}^{-1}\frac{\left|\left(\frac{b}{3c}\right)^2-\left(\frac{a}{3c}\right)\right|^{3/2}}{\frac{3}{2}\left(\frac{b}{3c}\right)\left(\frac{a}{3c}\right)+\frac{3}{2}\left(\frac{EMF^*}{3c}\right)-\left(\frac{b}{3c}\right)^3}\right]\right\}\right\} - \left(\frac{b}{3c}\right)$$

$$\text{if } b^2 < 3ac \qquad (3)$$

gives the appropriate root (with the calculator in the degrees mode) over the entire range of temperatures. For the values given in Table I, Eq. 2 is used for all negative values of c, and Eq. 3 is used for positive values of c.

For many measurements, it is convenient to have a reference bath at a temperature other than 0°C. The program may be written to incorporate this possibility. In some experiments it is also possible that one or more of the calibration temperatures (T_1, T_2, T_3) is encountered in the process of routine measurement, and small variations may be observed in the corresponding measured voltage (E_1,E_2,E_3) due to fluctuations in junction E.M.F.'s or diode effects from a low input impedance voltmeter. The program can be designed to incorporate these variations from run-to-run or long-term discrepancies as desired. Multiple thermocouple conversions may be handled by correcting (E_1, E_2, E_3) in three storage registers.

We have chosen to linearly correct voltmeter readings E to provide an EMF for the N.B.S. conversion of Eqn. (2) as follows:

$$EMF = \begin{cases} EMF_2 + (EMF_3 - EMF_2)\left(\frac{E-E_2}{E_3-E_2}\right) & T > T_2 \\ EMF_2 + (EMF_1 - EMF_2)\left(\frac{E-E_2}{E_1-E_2}\right) & T < T_2 \end{cases} \quad (4)$$

Here EMF_1, EMF_2, and EMF_3, correspond to N.B.S. Table values (or values from Eqn. (1)) for the temperatures T_1, T_2, and T_3, whereas E_1, E_2, and E_3 correspond to the values given by the voltmeter. An example of a typical data set from one of our copper-constantan thermocouples using a liquid nitrogen reference bath and calibration temperatures at liquid helium, liquid nitrogen, and ice water is:

$$\begin{array}{lll} T_1 = -268.96 & EMF_1 = -6.256 & E_1 = -0.707 \\ T_2 = -195.76 & EMF_2 = -5.536 & E_2 = 0.001 \\ T_3 = 0.00 & EMF_3 = 0.000 & E_3 = 5.518 \end{array}$$

Note the discrepancy for this thermocouple in E_1, E_2, E_3 from expected values -0.720, 0.000, 5.536 with a liquid nitrogen reference bath.

In some cases it is desired to stabilize a sample at a chosen temperature T. By using Eqn. (1) and the invverse of Eqn. (4), the inverse linear correction may be applied to find the voltmeter reading the thermocouple should produce. The magnetic card stored HP-67 program provides this one button calculation.

The validity of the linear correction function for the copper-constantan thermocouple has been examined via the magnetic susceptibility of Gd_2O_3. The thermocouple was placed in contact with the same insulated gold wire which held the Gd_2O_3 sample. The measurements were made over the range 15 K to 100 K and were found to agree within our experimental error of $\pm$ 0.2°K.

The program and constant cards have been submitted to the Hewlett-Packard Corporation for distribution thru its user library facility.

Table I. Constants Used in the Conversion of Thermocouple EMF to Degrees Centigrade and Vice Versa.

Thermocouple and range	a x 10^2 in mV/(°C)	b x 10^5 in mV/$(°C)^2$	c x 10^8 in mV/$(°C)^3$	Maximum Error	
				±μV	±°C
Cu-Cons.					
-270°C<T<-220°C	3.216970697	-1.393084143	-17.49237660	1	0.15
-220°C<T<0°C	3.876312865	4.592192982	- 3.909356725	1	0.05
0°C<T<220°C	3.857506506	4.462402402	- 2.674674675	2	0.05
220°C<T<410°C	3.890598291	4.220512821	- 2.260208927	2	0.03
Iron-Cons.					
-210°C<T<-90°C	4.954454004	1.397429654	-18.27110390	3	0.13
-90°C<T<100°C	5.039733333	3.120000000	- 9.333333333	2	0.04
100°C<T<380°C	5.109821543	1.904402864	- 2.622307242	10	0.18
380°C<T<760°C	5.690834936	-1.144906052	1.428921782	15	0.27
Chromel-Alumel					
-270°C<T<-180°C	3.888185185	2.346141975	-11.83641975	2	0.67
-180°C<T<0°C	3.953333333	2.958333333	-10.41666666	1	0.04
0°C<T<160°C	3.938333333	2.660000000	-10.93333333	2	0.05
160°C<T<330°C	4.258794983	-1.573022959	3.117772109	5	0.12
Chromel-Alumel					
0°C<T<230°C	4.023155310	0.9805827409	- 3.639591742	13	0.32
230°C<T<540°C	4.015003899	0.1391316958	0.1698108365	9	0.21
540°C<T<1000°C	3.876908274	0.7670126334	- 0.5170209075	12	0.30
1000°C<T<1360°C	4.049500892	0.3838205128	- 0.3064214047	3	0.08

Program Description

Program Title Thermocouple EMF ↔ Temperature Conversion

Name Paul G. Huray Date
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City Oak Ridge State Tenn. Zip Code 37830

Program Description, Equations, Variables, etc. The program provides a two way conversion between thermocouple EMF (in mV) and temperature (in °C, °F, or K). The program also allows a linear correction for experimentally induced diode effects, thermal EMF's and individual wire discrepancy. The reference temperature and three calibration temperatures T_1, T_2, and T_3 may be user chosen. In principle, any thermocouple may be used in any temperature range. Constants have been found for copper-constantan, iron-constantan, and chromel-alumel thermocouples and are provided on data cards. Conversion equations are listed in the comments of the program listing. A reference article may be found in the Review of Scientific Instruments.

Operating Limits and Warnings 1. The functional fit to the N.B.S. reference table data is approximate. The quality of the fit varies with thermocouple type but always produces an error less than ± 0.7°C. For the copper-constantan thermocouple the error is always $< \pm 0.15$°C (or $< \pm 2$ μV).

2. For input temperatures or EMF above the melting point (or the validity of constant fits in the case of one chromel-alumel data set) the calculator will give ERROR or an enormous answer.

DO NOT USE THIS SPACE

Program Submittal

[X] New Program

[ ] Revision to Program No.

HP-67 Serial No. 1706A03425 HP-97 Serial No.

Program Title (Underline 1 or 2 Keywords): 7-THERMOCOUPLE EMF ⇄ TEMPERATURE CONVERTER

Keyword(s) Underlined in Title: 1 THERMOCOUPLE 2 TEMPERATURE

No. of Steps: 222

Category No.: 0214

Category Name: SOLID STATE DEVICES

Abstract- 75 Word Maximum: The N.B.S. thermocouple tables of temperature vs. thermocouple EMF are approximately reproduced through four ranges of cubic fits. Offsets and linear corrections of voltmeter EMF are made using three calibration points to produce temperature in °F, °C, and K. The inverse operation is also produced. Appropriate constants are given on data cards for the Cu-constantan, Iron constantan and Chromel-Alumel thermocouples.

Name: Paul (First) G. (Initial) Huray (Last)

Address: Transuranium Research Laboratory, Oak Ridge National Laboratory

City: Oak Ridge State: Tennessee Zip Code: 37830

Acceptance Choice: [ ] Four Programs or [X] Two Programs and 10 blank cards.

00578D 00353D

Submittal Checklist: Please use the checklist below to insure submittal of all the proper program documentation.

[X] Program Submittal
[X] Program Description I
[X] Program Description II
[X] User Instructions
[X] Program Form(s)
[X] Magnetic Card (s)

Signature: Paul G. Huray Date: 9/18/79

Program Description I

Program Title THERMOCOUPLE EMF ⇆ TEMPERATURE CONVERTER

Contributor's Name Paul G. Huray

Address Transuranium Research Lab, Oak Ridge National Laboratory

City Oak Ridge **State** Tennessee **Zip Code** 37830

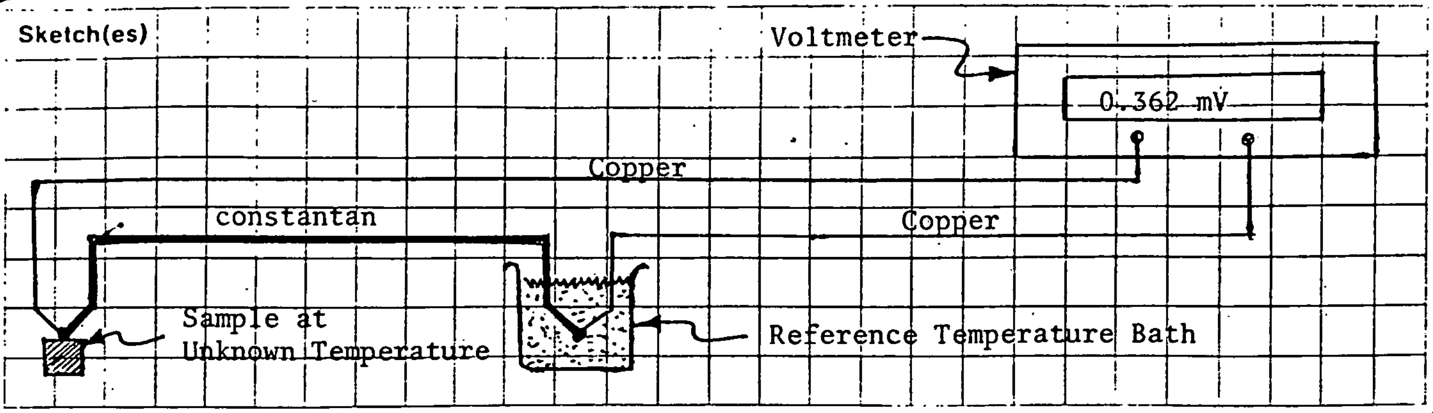
Program Description, Equations, Variables The program provides a two way conversion between thermocouple EMF (in mV) and temperature (in °C, °F, or K). The program also allows a linear correction for experimentally induced diode effects, thermal EMF's and individual wire discrepancy. The reference temperature and three calibration temperatures T_1, T_2, and T_3 may be user chosen. In principle, any thermocouple may be used in any temperature range. Constants have been found for copper-constantan, iron-constantan, and chromel-alumel thermocouples and are provided on data cards. Conversion equations are listed in the comments of the program listing. A reference article may be found in the Review of Scientific Instruments.

Operating Limits and Warnings 1. The functional fit to the N.B.S. reference table data is approximate. The quality of the fit varies with thermocouple type but always produces an error less than ± 0.7°C. For the copper-constantan thermocouple the error is always < ± 0.15°C (or < ± 2 μV).

2. For input temperatures or EMF above the melting point (or the validity of constant fits in the case of one chromel-alumel data set) the calculator will give ERROR or an enormous answer.

Program Description II

Sketch(es)



Sample Problem(s) A dry ice bath is used (-78.4°C) as a reference with a Copper-Constantan thermocouple as shown. The sample is immersed in Liq. N_2 (T_1 = -195.76° C), ice water (T_2 = 0°C), and boiling water (T_3 = 100°C) for calibration. The voltmeter reads E_1 = -2.790 mv, E_2 = 2.735 mv, and E_3 = 7.010 mv respectively (instead of -2.797 mv, 2.738 mv, and 7.015 mv as expected from the N.B.S. reference table[1]). The program and data cards are read into the HP-67 calculator. The following changes are made: R_C = -2.790, R_D = 2.735, R_E = 7.010, S_7 = -5.535, S_8 = 0, S_9 = 4.277. [a]Suppose that an unknown sample temperature now produces 0.362 mV. [b]Suppose you wish to raise sample temperature to +58°C and wish to know voltmeter reading. [c]Same problem as b except 100.3 K.

Solution(s) [a]Push 0.362. Push button D. Result: temperature = -66.9°C. [b]Push 58.0. Push button f,d. Result: Voltmeter should read 5.116 mV. [c]Push 100.3. Push button f,c. Result: Voltmeter should read -2.382 mV.

Reference(s) [1]N.B.S. thermocouple table as given in the 1979 Temperature Measurement Handbook of Omega Engineering Inc. for example.

User Instructions

EMF-THERMOCOUPLE CONVERSION

1 | E1 | E2 | E3 | 2

TABLE: mV ⇆ °C | mV ⇆ °F

THERMOCOUPLE: mV ⇆ K | mV ⇆ °C | mV ⇆ °F

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Load program side 1 and side 2			
2	Load data card side 1 and side 2 (use data card corresponding to the thermocouple type used)			
3	Calibrate owner thermocouple at three user chosen temperatures $T_1<T_2<T_3$. Load corresponding voltmeter EMF $E_1^{**}, E_2^{**}, E_3^{**}$ into R_C, R_D, R_E. If calibration changes from run to run, change R_C, R_D, R_E appropriately.			
	Check the values EMF_1^*, EMF_2^* and EMF_3^*, in registers S7, S8, and S9. If these do not correspond to the NBS reference table values for the user chosen T_1, T_2, and T_3, change them.			
4	Enter EMF* in mV from NBS table	-5.603/mV	A	-200.0/°C
	Enter °C	-200.0/°C	f A	-5.603/mV
	Enter EMF* in mV from NBS table	-5.439/mV	B	-310.0/°F
	Enter °F	-310.0/°F	f B	-5.439/mV
	Enter EMF** in mV from voltmeter	-0.500/mV	C	39.6/ K
	Enter K	39.6/ K	f C	-0.500/mV
	Enter EMF** in mV from voltmeter	-0.500/mV	D	-233.6/°C
	Enter °C	-233.6/°C	f D	-0.500/mV
	Enter EMF** in mV from voltmeter	-0.500/mV	E	-388.5/°F
	Enter °F	-388.5/°F	f E	-0.500/mV
	* Assumes reference junction at 0°C .			
	**Assumes reference junction at user chosen temperature.			
	All example input-output data is for the copper-constantan thermocouple and a reference junction at $T_2 = -195.8°C$.			

STEP	KEY ENTRY	KEY CODE
001	f, LBL, A	31 25 11
	STO, A	33 11
	0	00
	h, ST I	35 33
	h, CF, 0	35 61 00
	h, GSB, 0	31 22 00
	RCL, A	34 11
	f, DSZ	31 33
	RCL, (i)	34 24
010	3	03
	X	71
	STO, A	33 11
	÷	81
	f, DSZ	31 33
	RCL, (i)	34 24
	RCL, A	34 11
	÷	81
	STO, B	33 12
	h, RV	35 53
020	f, DSZ	31 33
	RCL, (i)	34 24
	RCL, A	34 11
	÷	81
	STO, A	33 11
	RCL, B	34 12
	X	71
	+	61
	1	01
	.	83
030	5	05
	X	71
	RCL, B	34 12
	3	03
	h, y^x	35 63
	-	51
	RCL, B	34 12
	g, x^2	32 54
	RCL, A	34 11
	-	51
040	f, x<0?	31 71
	h, SF, 2	35 51 02
	h, ABS	35 64
	f, $\sqrt{x}$	31 54
	STO, A	33 11
	3	03
	h, y^x	35 63
	÷	81
	h, F?, 2	35 71 02
	GTO, 2	22 02
050	g, $\cos^{-1}$	32 63
	3	03
	÷	81
	2	02
	4	04
	0	00
	+	61

Converts EMF* (in mV) from N.B.S. reference table to T (in °C) via

$$T = 2\left|\left(\frac{b}{3c}\right)^2 - \left(\frac{a}{3c}\right)\right|^{1/2} \cos\left\{240 + \frac{1}{3}\cos^{-1}\left[\frac{\frac{3}{2}\left(\frac{b}{3c}\right)\left(\frac{a}{3c}\right) + \frac{3}{2}\left(\frac{EMF^*}{3c}\right) - \left(\frac{b}{3c}\right)^3}{\left|\left(\frac{b}{3c}\right)^2 - \left(\frac{a}{3c}\right)\right|^{3/2}}\right]\right\} - \left(\frac{b}{3c}\right)$$

if $b^2 > 3ac$

or

STEP	KEY ENTRY	KEY CODE
	f, cos	31 63
	GTO, 5	22 05
	f, LBL, 2	31 25 02
060	h, 1/x	35 62
	g, TAN^{-1}	32 64
	2	02
	÷	81
	f, TAN	31 64
	3	03
	h, 1/x	35 62
	h, y^x	35 63
	g, TAN^{-1}	32 64
	2	02
070	x	71
	f, TAN	31 64
	h, 1/x	35 62
	f, LBL, 5	31 25 05
	RCL, A	34 11
	x	71
	2	02
	x	71
	RCL, B	34 12
	-	51
080	DSP, 1	23 01
	h, RTN	35 22
	f, LBL, 0	31 25 00
	4	04
	h, RCI	35 34
	+	61
	h, STI	35 33
	1	01
	8	08
	-	51
090	f, X > 0	31 81
	h, RTN	35 22
	RCL, A	34 11
	RCL, (i)	34 24
	h, F?, 0	35 71 00
	GTO, 1	22 01
	g, FRAC	32 83
	EEX	43
	3	03
	X	71
100	f, LBL, 1	31 25 01
	-	51
	f, X < 0	31 71
	h, RTN	35 22
	GTO, 0	22 00
	g, LBL, a	32 25 11
	STO, A	33 11
	0	00
	h, ST I	35 33
	h, SF, 0	35 51 00
110	f, GSB, 0	31 22 00
	RCL, A	34 11
	f, DSZ	31 33

$$T = \frac{2\left|\left(\frac{b}{3c}\right)^2 - \left(\frac{a}{3c}\right)\right|^{1/2}}{TAN\left\{2TAN^{-1}\left\{TAN\left[\frac{1}{2}TAN^{-1}\left(\frac{\frac{3}{2}\left(\frac{b}{3c}\right)\left(\frac{a}{3c}\right) + \frac{3}{2}\left(\frac{EMF^*}{3c}\right) - \left(\frac{b}{3c}\right)^3}{\left|\left(\frac{b}{3c}\right)^2 - \left(\frac{a}{3c}\right)\right|^{3/2}}\right)\right]\right\}^{1/3}\right\}} - \left(\frac{b}{3c}\right)$$

if $b^2 < 3ac$

Converts T (in °C) to N.B.S. reference table EMF* (in mV) via

REGISTERS

0	1	2	3	4	5	6	7	8	9
273.16	a_1	b_1	c_1	$T_{12}\cdot\frac{E_{12}}{1000}$	a_2	b_2	c_2	$T_{23}\cdot\frac{E_{23}}{1000}$	a_3

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
b_3	c_3	$T_{34}\cdot\frac{E_{34}}{1000}$	a_4	b_4	c_4	$T_{lim}\cdot\frac{E_{lim}}{1000}$	EMF_1*	EMF_2*	EMF_3*

A	B	C	D	E	I
Work	Work	E_1**	E_2**	E_3**	Address

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL, (i)	34 24	$EMF^* = aT + bT^2 + cT^3$
	x	71	
	f, DSZ	31 33	
	RCL, (i)	34 24	
	+	61	
	RCL, A	34 11	
	x	71	
120	f, DSZ	31 33	
	RCL, (i)	34 24	
	+	61	
	RCL, A	34 11	
	x	71	
	DSP, 3	23 03	
	h, RTN	35 22	
	f,LBL,B	31 25 12	Same as A with T in °F.
	f,GSB,A	31 22 11	
	f,LBL,3	31 25 03	
130	1	01	
	.	83	
	8	08	
	x	71	
	3	03	
	2	02	
	+	61	
	h, RTN	35 22	
	g,LBL,b	32 25 12	Same as a with T in °F.
	f,GSB,4	31 22 04	
140	g,GSB,a	32 22 11	
	h,RTN	35 22	
	f,LBL,4	31 25 04	
	3	03	
	2	02	
	-	51	
	1	01	
	.	83	
	8	08	
	÷	81	
150	h,RTN	35 22	
	f,LBL,C	31 25 13	Same as D with T in °K.
	f,GSB,D	31 22 14	
	RCL, 0	34 00	
	+	61	
	h, RTN	35 22	
	g,LBL,c	32 25 13	Same as d with T in °K.
	RCL, 0	34 00	
	-	51	
	g,GSB,d	32 22 14	
160	h,RTN	35 22	
	f,LBL,D	31 25 14	Converts E^{**} (in mV from voltmeter to EMF^* (in mV) for N.B.S. reference table via
	f,P ≷ s	31 42	
	RCL, D	34 14	
	-	51	
	f, x > 0	31 81	
	GTO, 6	22 06	
	RCL, 7	34 07	
	RCL, 8	34 08	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	-	51	$EMF = \begin{cases} EMF_2+(EMF_3-EMF_2)\frac{(E-E_2)}{(E_3-E_2)} & \text{for } T > T_2 \\ EMF_2+(EMF_1-EMF_2)\frac{(E-E_2)}{(E_1-E_2)} & \text{for } T < T_2 \end{cases}$
170	x	71	
	RCL, C	34 13	
	GTO, 7	22 07	
	f,LBL,6	31 25 06	
	RCL, 9	34 09	
	RCL, 8	34 08	
	-	51	
	x	71	
	RCL, E	34 15	
	f,LBL,7	31 25 07	
180	RCL, D	34 14	
	-	51	
	÷	81	
	RCL, 8	34 08	
	+	61	
	f,P ≷ s	31 42	and then to T (in °C).
	f,GSB,A	31 22 11	
	h, RTN	35 22	
	g,LBL,d	32 25 14	
	g,GSB,a	32 22 11	
190	f, p ≷ s	31 42	Converts T (in °C) to EMF^* (in mV) for N.B.S. reference table and then to E^{**} (in mV) for voltmeter via
	RCL, 8	34 08	
	-	51	
	f, x > 0	31 81	
	GTO, 8	22 08	
	RCL, 7	34 07	
	RCL, 8	34 08	
	-	51	
	÷	81	
	RCL, C	34 13	$E = \begin{cases} E_2+(E_3-E_2)\frac{(EMF-EMF_2)}{(EMF_3-EMF_2)} & \text{for } EMF > EMF_2 \\ E_2+(E_1-E_2)\frac{(EMF-EMF_2)}{(EMF_1-EMF_2)} & \text{for } EMF < EMF_2 \end{cases}$
200	GTO, 9	22 09	
	f,LBL,8	31 25 08	
	RCL, 9	34 09	
	RCL, 8	34 08	
	-	51	
	÷	81	
	RCL, E	34 15	
	f,LBL,9	31 25 09	
	RCL, D	34 14	
	-	51	
210	x	71	
	RCL, D	34 14	
	+	61	
	f,P ≷ s	31 42	
	h, RTN	35 22	
	f,LBL,E	31 25 15	Same as D with T in °F.
	f,GSB,D	31 22 14	
	f,GSB,3	31 22 03	
	h, RTN	35 22	
	g,LBL,e	32 25 15	Same as d with T in °F.
220	f,GSB,4	31 22 04	
	g,GSB,d	32 22 14	
	h,RTN	35 22	

LABELS

A $mV^* \to °C$	B $mV^* \to °F$	C $mV^{**} \to K$	D $mV^{**} \to °C$	E $mV^{**} \to °F$
a $°C \to mV^*$	b $°F \to mV^*$	c $K \to mV^{**}$	d $°C \to mV^{**}$	e $°F \to mV^{**}$
0 Range Selector	1 Range Criterion	2	3 $°C \to °F$	4 $°F \to °C$
5	6 $T > T_2$	7 $T < T_2$	8 $EMF^* > EMF_2^*$	9 $EMF^* < EMF_2^*$

FLAGS

0	Temperature or Voltage?
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n 1	