physitemp

PHYSITEMP INSTRUMENTS INC

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OPERATING MANUAL

BAT-10
Multipurpose Thermometer

12.0 REPAIRS AND RECALIBRATION

12.1 In the event that a BAT-10 Thermometer is to be returned for repair and recalibration please pack it with care and send it prepaid to:

Physitemp Instruments, Inc.
Service Department
154 Huron Avenue
Clifton, NJ 07013 USA

Please include with the instrument:

(1) A note describing any problems encountered.
(2) The name and telephone number of the user or other person we can contact.
(3) The complete return address for shipping.

12.2 A Service Manual for the BAT-10 is available at additional charge. It includes schematic, component locator, trouble-shooting guide and complete calibration instructions. Specified test equipment is required for recalibration or other servicing. Consult Physitemp for further service information by telephone at:

973-779-5577 or fax 793-779-5954

12.3 Physitemp Instruments, Inc. warrants this instrument to be free from defects in material and workmanship for 12 months from date of shipment. Repair or replacement will be made at no charge at the discretion of Physitemp if the defect is not the result of misuse or abuse. Physitemp accepts no consequential liabilty for delay in delivery, alleged faulty performance of the product, or for any other cause.

Cables and probes are considered expendable and are not covered by this warranty. See separate warranty enclosed with probe.

For your protection, please pack returned items carefully, and insure them against possible damage or loss in transit. Physitemp will not be responsible for damage resulting from careless or inadequate packaging. Please return freight prepaid.

During the warranty period, the instrument may also be returned for a free calibration check.

11.11 **Measurements in Electronics.** BAT-10 and ICT-4 provide the quickest and cheapest method of getting accurate reading on both discreet components and integrated circuits used in electronic equipment. ICT-4 has two important differences from the regular MT-4 probe. There is a 5 1/2" handle suitable for use in the hand or in a micromanipulator and the micro-thermocouple protrudes slightly beyond the steel sheath and has some thermal isolation from it. This probe was designed for use on areas of 5-100 microns in diameter and is used perpendicular to the surface to be measured. The heat loss described in 11.3 occurs and temperature readings are slightly low -- normally about 0.5°C low. Each probe can be readily calibrated on a larger surface. First lay it parallel to the surface and note the reading. Then take a reading with it perpendicular to the surface; note the difference. Add this difference to the subsequent reading when using the perpendicular position.

11.12 BAT-10 with a suitable probe has the ability to measure surface gradients, giving almost instant readings at each point. This feature enables heat sinks to be designed without guesswork, for maximum efficiency with minimum metal. It is equally easy to check the adequacy of thermal bonding between a power transistor or rectifier and its heat sink. General purpose probe BT-1 is suitable for this and many other measurements. When probes such as BT-1 and the larger HT-1 and HT-2 are used for surface measurements, speed of response and accuracy can often be improved by use of a heat conductive material such as 'thermal grease' or silicone grease applied between the probe and surface. Note: BT-1, HT-1 and HT-2 should not be used on electrically conductive surfaces where voltages are present as the sensor is connected to the stainless steel sheath. The following probes are isolated and suitable for use on electrical equipment: RET-1, ESO-1, IT-14, IT-18, IT-21, TFT series.

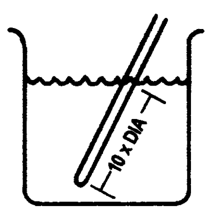
rial. In liquids and semi-solids, the tip and sheath are simply immersed; on solid surfaces, the sheath is laid against the surface.

Here is a useful rough rule: Heat leakage effects are substantially reduced when an amount of probe equal to 10 or more sheath diameters is immersed or laid on the surface. For example, with a probe of 1/16" diameter:

10 x 1/16" = 10/16" = .625" = the minimum immersion depth

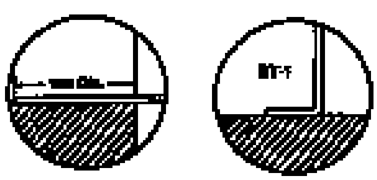
11.7 Errors between thermocouple probes. All Physitemp clinical probes and sensors are made with thermocouple wire that has been specially tested to meet our own stringent standards. Our clinical probes are guaranteed accurate to within 0.1°C in the range 0-50°C. Copper-Constantan (type T) thermocouples from other manufacturers are not normally this accurate. Probes made from wire to "special limits of error" may be accurate to ±0.5°C in this range. This interchangeability of sensor, including microprobes, is a major advantage of Physitemp thermocouple thermometer

11.8 **Measurements in Liquids.** These are quite easy to make, because there is good thermal contact between liquid and probe. The latter quickly reaches liquid temperature and readings can be taken within a few seconds. However, a liquid which has been heated above or cooled below ambient will be losing or gaining heat, and convection currents will give rise to temperature variations of up to several degrees. These variations can be reduced by vigorous stirring. This simple precaution must always be taken.



11.9 **Measurements of Air Temperature.** Temperature can vary widely in different parts of a room; differences of at least several degrees will usually be noted. When a microprobe is used to indicate air temperature, readings will often fluctuate rapidly, responding to actual temperature changes caused by air currents. Breathing near the microprobe will produce wide fluctuations. These effects indicate the sensitivity of the BAT-10/microprobe combination, due to high discrimination of the instrument and almost instant response of the probe. Fluctuations can easily be eliminated by bringing the probe into contact with a metallic object, thus increasing its effective mass and slowing the response. Using a larger probe will have the same results.

11.10 **Measurements on Solid Surfaces**. These are most easily made with surface probes such as our BT-1 and MT-D. The right-angled tip provides the 10 diameters of probe contact specified in Section 11.6. Straight probes may also be used, provided that sufficient shaft length is in contact with the surface to be measured. In general, the smaller the probe, the more accurately it will measure the surface temperature of a solid. For instance, an MT-29 microprobe, because of its small size, needs to be in contact with the surface for as little as 1/8". SST-1 has a 1/4" gold disc sensor. Gold is an excellent conductor, and is non-allergenic and non-polluting. It makes a fine skin surface probe.



11.0 TEMPERATURE MEASUREMENT WITH THERMOCOUPLE SENSORS

11.1 The thermocouple is a simple and widely accepted device for measuring temperature. It comprises two wires of dissimilar metals fused together to form a junction which produces an electrical output proportional to temperature. The National Institute of Standards and Technology (NIST Monograph 125, 1974) has tabulated the voltage/temperature relationships of many commonly used thermocouple pairs; their tables on copper/constantan form the basis for calibration of Physitemp thermometers.

11.2 At one time, accurate thermocouple temperature measurements needed elaborate potentiometers and reference to a source of known temperature, such as an ice bath. The advent of modern solid state devices has made possible the design of an inexpensive thermocouple thermometer which is direct reading. The first of these was Bailey thermometer BAT-4, which was designed in 1969 and is now in use throughout the world. Your BAT-10 is an advanced version of the original equipment using the latest low power digital technology and compensated electronic reference circuitry.

11.3 As compared with thermistor sensors which were formerly used exclusively in portable thermometers, thermocouples have these advantages:

(a) Wide temperature range, e.g. -200°C to over +1300°C.
(b) High stability of output.
(c) Interchangeability - no recalibration required.
(d) Accuracy traceable to NIST calibrations.
(e) Low cost; users can even make their own sensors.
(f) Microscopic size when needed, as in Physitemp microprobes.
(g) Nearly instant response.
(h) Better measurement accuracy due to low mass with smaller heat loss.

11.4 The main disadvantage of the thermocouple, low sensitivity, was overcome by the development of auto zeroing amplifiers which are now used in all Physitemp thermometers. This type of amplifier is essentially drift-free. It makes possible an electronic thermometer which is permanently calibrated, just like a mercury thermometer. The following notes may help the user to avoid some of the errors most frequently made in temperature measurement.

11.5 Faulty measurement technique with any type of thermometer can produce errors of several degrees. Errors attributed to "out of calibration" equipment can often be corrected by a simple change of technique.

11.6 Thermocouple probes, like all other temperature sensing devices, must be placed so that they reach, as closely as possible, the temperature of the material to be measured. Probes are tip-sensitive, but when measuring the temperatures of liquids, semi-solids or hard surfaces, it is not sufficient to bring only the tip into contact with the material being measured. This is because there will be loss of heat along both the thermocouple wires and their sheath, so readings will be low. The effect can be greatly reduced if part of the metal sheath is also placed in contact with the mate-

10.0 SPECIFICATIONS

Temperature Range and Resolution:	-200°C to +400°C, 1°C resolution -100°C to +199.9°C, 0.1°C resolution
Differential Temperature Range:	-19.99°C to +19.99°C. Linearization centered at 40°C See Section 5.0
Accuracy: 1° Range	1°C, (±1 digit)
0.1° Range	0.1°C, (±1 digit)
Diff. Range	0.01°C (±1 digit)
Repeatability:	One least significant digit
Calibration:	Conforms to National Institute of Standards and Technology (Monograph 125)
Sensors:	Any Physitemp type T Thermocouple
Ambient Operating Range:	15 - 45°C
Readout:	3 1/2 digits
Batteries:	BAT-10 - 4 alkaline "C" cells (Battery life, 1000 hours) BAT-10R - (rechargeable unit) - 4 NI-Cads
Special Display Indications:	LO-BAT appears on display when battery voltage is low, but several hours of life remain.
	INPUT appears on display when open probe or input fault condition has occured.
	ALARM, acitivated by user supplied external 5V logic level
Analog output:	Non-linearized set at 1.5V corresponding to temperature of 401°C Linearized (when supplied) 1mV/count

7.0 ANALOG OUTPUT FOR CHART RECORDING

7.1 NON-LINEARIZED ANALOG OUTPUT. BAT-10 is supplied with an analog output that is proportional to the input thermocouple voltage with respect to analog common. This is adequate for most stirp chart recording applications where small temperature ranges are involved. The output bears a non-linear relationship to temperature and thermocouple tables can be used to compensate for linearity changes over wider temperature ranges. The non-linear output can be found on pin 1 of the 9-pin connector on the back of the instrument. The return is pin 7. The 9-pin male D-shell connector (part # 6-2072) should be ordered if this output is to be used. It can also be obtained from any electronic parts store.

7.2 LINEARIZED ANAOLOG OUTPUT. This is only supplied if specified at time of order. It can be retrofitted only at factroy. The 9-pin male D-shell connector is included with this option. The output is directly proportioanl to the number of counts displayed and is equal to 1mV/count with respect to digital common. The linear analog output can be found on pin 6 of the 9-pi D-shell connector on the rear of the instrument. IMPORTANT: The return is digital common, pin 8.

for example: display reads 19.86
number of counts = 1986
output is 1.986V

Please note: The linearized analog output uses a D/A converter which updates at the same rate as the display (approximately 3 times per second) and therefore when temperature is changing rapidly, step changes may be seen in the output voltage as the converter updates.

8.0 BATTERY REPLACEMENT

8.1 NON-RECHARGEABLE INSTRUMENTS

IMPORTANT: Use only alkaline batteries

Switch instrument OFF. Turning counter-clockwise, unscrew the two plastic caps from the battery holders on the back panel. Slide old batteries out and replace with fresh “C”cells.

Install with positive terminals towards the plastic screw caps. Replace caps.

8.2 RECHARGEABLE INSTRUMENTS

Follow the instruction above but install four rechargeable N-Cad batteries.

9.0 RECHARGING THE BATTIERIES

9.1 Plug the Physitemp AC charger (9V @ 50 to 200mA AC) into AC input socket on the back panel and connect to AC supply. Allow 16 hours for complete recharging.

With Ni-Cad batteries installed, the unit may be continuously operated from the AC recharger.

WARNING

The AC input socket is present on all versions (rechargeable and non-rechargeable.)

NEVER attempt to recharge or power a BAT-10 with non-rechargeable batteries.

The batteries may explode or leak. This is a fire hazard and can result in internal damage to the instrument.

BAT-10 can be field upgraded to BAT-10R with our RCK-10 recharger kit, which includes Ni-Cad batteries and wall-mount charger.

When using BAT-10 for differential measurements not centered on the 40°C reference, a correction must be introduced to accomodate changes in sensitivity and linearization at different reference temperatures.

In general, differential measurements are quite correct when the difference reading is small and both sensors are in the 20-60°C range. A correction is required when: (a) differences greater than 1°C are to be measured (b) both sensors are not within 20-60°C (c) when measurements are not centered on the 40°C reference. Calculation of true temperature can be made with reference to Appendix 1.

Note: Input - the digital display warning for open or faulty probe is inactive in the differential mode (DIFF)

Consult factory for further technical information and details in specific applications.

6.0 AUXILIARY OUTPUT CONNECTOR (optional)

6.1 The 9-pin D-shell connector on the back panel is used for the following auxiliary connections:

All signals are with respect to digital ground unless otherwise specified

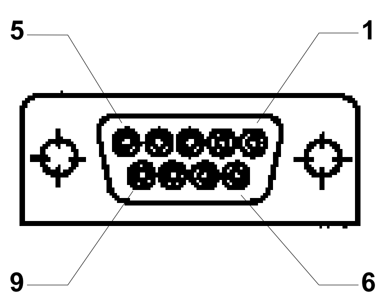
- Non-linearized analog output, with respect to analog ground (see Section 7.1)
- Linearized analog output, optional (see Section 7.2)
- Data True: A gating signal, active low. The number of oscillator pulses during this period is four times the count displayed

  For example: Display reads 38.1°C = 381 counts

  Number of oscillator pulses in the data true period is 381x4=1524
- Oscillator output: 53KHz (±20%)
- Alarm input: User supplied signal, active low. 5V logic level
- Sign out: Low when negative
- Analog common
- Digital common
- V+: Positive supply

Consult factory for further information: (Phone 973-779-5577)

Connection diagram:



PIN #	FUNCTION
1	Non-linear Analog output
2	Data True
3	Oscillator Output
4	Alarm In
5	Sign Out
6	Linear Analog Output
7	Analog Common
8	Digital Common
9	V+

4.2 Select the required range by depressing the 1° or 0.1° RANGE SELECT pushbutton. Be sure that the DIFF pushbutton is not depressed.

4.3 Direct measurements are made with inputs 1 and 2. If two probes are being used, just depress the PROBE SELECT pushbutton which corresponds with the sensor to be monitored.

5.0 DIFFERENTIAL MEASUREMENT TECHNIQUES

5.1 Specifications of the differential range are as follows:

Resolution	0.01°C
Accuracy	0.01°C (±1 digit)
Repeatability	0.01°C
Linearity is centered at 40°C	
Range	-19.99 to +19.99°

5.2 USING THE DIFFERENTIAL RANGE:

Before making measurements, check and adjust the DIFF ZERO as follows:

Remove probes from all sockets.

Select DIFF range pushbutton.

Select DIFF ZERO.

Wait for about 30 seconds for reading to stabilize.

Adjust ZERO with screwdriver until it displays 0.00

Release DIFF ZERO

Connect probes to INPUTS 2 and 3 only.

Read temperature difference between probes:

If probe in input 2 is at the higher temperature, the temperature reading will be positive.

If probe in input 2 is at the lower temperature, the temperature reading will be negative.

5.3 When making differential measurements with 0.01° resolution:

- Keep instrument away from drafts or sources of heat.
- When instrument is moved from one location to another, allow at least one hour for temperature stabilization before use.
- Allow 10-15 minutes after plugging in probes before taking readings.
- While making measurements, never touch probe plugs or allow them to come into contact with sources of heat or cold.
- Check DIFF ZERO periodically to ensure it has not drifted. Reset as necessary using ZERO control.
- When making differential measurements in an electrically conductive medium, at least one of the probes should be electrically isolated from the medium. The following Physitemp probes are isolated: RET-1, ESO-1, IT-14, IT-18, IT-21, IT-23, IT-1E, TFT series. We can also supply an insulated version of our MT-23 microprobes if requested.

1.0 INTRODUCTION

1.0 Physitemp laboratory thermometers are compact, digital thermometers for use with type T thermocouple sensors. The BAT-10 thermometer has two probe inputs for direct temperature readings with a resolution of 0.1°C or 1°C. A third input is used when differential measurements are made. On the differential range, temperature resolution is 0.01°C.

BAT-10 accepts all Physitemp type T thermocouple probes.

2.0 INITIAL INSTALLATION

2.1 Set the handle/angle bracket to the position most convenient for your application. Pull out both side bars slightly at the same time. Adjust as necessary then allow to snap back into place.

2.2 BATTERY OPERATED UNITS are supplied with four alkaline "C" cells installed and are ready for operation.

2.3 RECHARGEABLE UNITS are supplied with fully charged Nicad batteries installed and a charger kit that is also an AC adaptor.

To recharge and for AC use, connect the power jack on the recharger kit to the AC INPUT socket on the back of the instrument. Plug the charger into a live outlet. Charger is for use with 110-115V AC unless otherwise specified on your order. Charger will be labelled for correct voltage. See Section 9.0 for further information.

3.0 OPERATING INSTRUCTIONS

3.1 The following instructions are printed on a label on the top panel of the BAT-10. They are reprinted here in case the label is ever defaced. See Sections 4.0 and 5.0 for detailed information.

TEMPERATURE RANGE	RESOLUTION
-200°C to +400°C	1°C
-100°C to +199.9°C	0.1°C
Differential -19.99°C to +19.99°C	0.01°C

1. **TO MEASURE TEMPERATURE**
   Insert plug of any type T thermocouple probe into input 1 or 2. Switch ON. Select range. Select probe input 1 or 2. Ensure DIFF ZERO button is not depressed. Read temperature.
2. **TO MEASURE DIFFERENTIAL TEMPERATURE**
   Connect probes to input 2 AND 3. Select DIFF range to measure differential temperature between these probes. Select DIFF ZERO ADJUST. Use screwdriver to set zero until display reads 0.00. Release DIFF ZERO to read differential temperature of probe 2 with respect to probe 3. See manual for more detail instructions.
   Note: Input 3 is only activated in differential mode. It is not possible to measure absolute temperature with this input.
3. **SPECIAL DISPLAY INDICATIONS**
   I - Probe is above or below limits of range.
   LO BAT - Replace or recharge the batteries
   INPUT - Probe, input connector or lead may be faulty. Replace probe at input selected.
4. **BATTERY REPLACEMENT** (non-rechargeable units)
   USE ONLY ALKALINE BATTERIES
   Switch instrument OFF. Unscrew two plastic caps from holders on back by turning counter-clockwise. Discard old batteries and replace with fresh "C" cells. Install all four batteries with positive terminals toward plastic screw caps. Replace caps
5. **RECHARGING** (rechargeable units only)
   Plug AC charger (9V @ 250 mA) into AC INPUT socket on back of instrumement. Allow 16 hours for complete recharging.
   With Ni-Cad batteries installed the unit may be continuously operated from AC recharger.

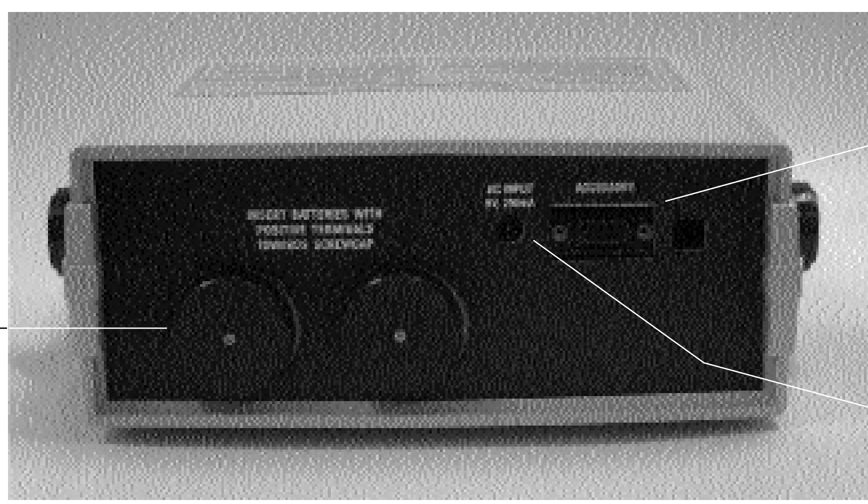
Model BAT-10 **Serial Number:**

4.0 TEMPERATURE MEASUREMENT

4.1 Any type T thermocouple (Copper-Constantan) can be used with the BAT-10. Thermocouple sensors made with "special limits" wire are accurate to 0.5°C in the range 0-50°C. If better accuracy is required, Physitemp's microprobes and clinical probes should be used.. These are manufactured with specially graded wire and are guaranteed accurate to 0.1°C in the range 0-50°C. See Section 11.0 for more information on temperature measurement with thermocouples.

BAT-10 FRONT PANEL

BAT-10 REAR PANEL



OPERATING MANUAL

BAT-10
Multipurpose Thermometer

Section

Table 8.3.2 ***Type T thermocouples****—thermoelectric voltages,* E(T), *Seebeck coefficients,* S(T), *and first derivative of the Seebeck coefficients,* dS/dT, *reference junctions at 0 °C*

T	E	S	dS/dT	T	E	S	dS/dT	T	E	S	dS/dT
°C	μV	μV/°C	nV/°C²	°C	μV	μV/°C	nV/°C²	°C	μV	μV/°C	nV/°C²
-270	-6257.59	1.016	384.94	-240	-6105.09	8.726	230.04	-210	-5753.25	14.305	149.59
-269	-6256.38	1.385	354.18	-239	-6096.25	8.954	227.51	-209	-5738.87	14.454	148.23
-268	-6254.82	1.726	328.78	-238	-6087.18	9.180	224.81	-208	-5724.34	14.602	146.96
-267	-6252.93	2.044	308.01	-237	-6077.89	9.404	221.96	-207	-5709.67	14.748	145.79
-266	-6250.74	2.343	291.24	-236	-6068.38	9.624	218.98	-206	-5694.85	14.893	144.70
-265	-6248.26	2.628	277.85	-235	-6058.64	9.842	215.90	-205	-5679.88	15.038	143.71
-264	-6245.49	2.900	267.34	-234	-6048.69	10.056	212.73	-204	-5664.77	15.181	142.79
-263	-6242.45	3.163	259.25	-233	-6038.53	10.267	209.49	-203	-5649.52	15.323	141.95
-262	-6239.17	3.419	253.16	-232	-6028.16	10.475	206.21	-202	-5634.13	15.465	141.18
-261	-6235.62	3.670	248.73	-231	-6017.58	10.680	202.91	-201	-5618.59	15.605	140.47
-260	-6231.83	3.917	245.63	-230	-6006.80	10.881	199.61	-200	-5602.92	15.746	139.82
-259	-6227.79	4.162	243.58	-229	-5995.82	11.079	196.31	-199	-5587.10	15.885	139.23
-258	-6223.51	4.405	242.34	-228	-5984.64	11.274	193.05	-198	-5571.15	16.024	138.68
-257	-6218.98	4.646	241.72	-227	-5973.27	11.465	189.83	-197	-5555.05	16.163	138.18
-256	-6214.21	4.888	241.53	-226	-5961.71	11.653	186.66	-196	-5538.82	16.301	137.72
-255	-6209.20	5.130	241.63	-225	-5949.97	11.838	183.56	-195	-5522.45	16.438	137.29
-254	-6203.95	5.371	241.90	-224	-5938.04	12.020	180.54	-194	-5505.95	16.575	136.90
-253	-6198.46	5.614	242.21	-223	-5925.93	12.199	177.62	-193	-5489.30	16.712	136.53
-252	-6192.72	5.856	242.49	-222	-5913.64	12.376	174.78	-192	-5472.52	16.848	136.18
-251	-6186.75	6.098	242.68	-221	-5901.18	12.549	172.05	-191	-5455.61	16.984	135.85
-250	-6180.53	6.341	242.71	-220	-5888.54	12.720	169.43	-190	-5438.55	17.120	135.54
-249	-6174.07	6.584	242.54	-219	-5875.74	12.888	166.92	-189	-5421.37	17.255	135.25
-248	-6167.36	6.826	242.16	-218	-5862.77	13.054	164.53	-188	-5404.04	17.390	134.96
-247	-6160.41	7.068	241.52	-217	-5849.63	13.217	162.25	-187	-5386.59	17.525	134.68
-246	-6153.22	7.309	240.63	-216	-5836.33	13.378	160.09	-186	-5368.99	17.660	134.41
-245	-6145.80	7.549	239.48	-215	-5822.88	13.537	158.06	-185	-5351.27	17.794	134.14
-244	-6138.13	7.788	238.08	-214	-5809.26	13.694	156.14	-184	-5333.40	17.928	133.88
-243	-6130.22	8.025	236.41	-213	-5795.49	13.850	154.33	-183	-5315.41	18.062	133.61
-242	-6122.08	8.261	234.52	-212	-5781.56	14.003	152.64	-182	-5297.28	18.195	133.35
-241	-6113.70	8.494	232.38	-211	-5767.48	14.155	151.06	-181	-5279.02	18.328	133.09
-240	-6105.09	8.726	230.04	-210	-5753.25	14.305	149.59	-180	-5260.62	18.461	132.82

Table 8.3.2 *Type T thermocouples—thermoelectric voltages,* E(T), *Seebeck coefficients,* S(T), *and first derivative of the Seebeck coefficients,* dS/dT, *reference junctions at 0 °C—Continued*

T °C	E μV	S μV/°C	dS/dT nV/°C²	T °C	E μV	S μV/°C	dS/dT nV/°C²	T °C	E μV	S μV/°C	dS/dT nV/°C²
-180	-5260.62	18.461	132.82	-120	-3922.62	26.026	120.94	-60	-2152.41	32.840	106.55
-179	-5242.10	18.594	132.55	-119	-3896.54	26.147	120.72	-59	-2119.52	32.946	106.25
-178	-5223.44	18.727	132.29	-118	-3870.33	26.268	120.49	-58	-2086.52	33.052	105.94
-177	-5204.64	18.859	132.01	-117	-3844.00	26.388	120.26	-57	-2053.42	33.158	105.63
-176	-5185.72	18.991	131.74	-116	-3817.56	26.508	120.02	-56	-2020.21	33.264	105.31
-175	-5166.66	19.122	131.47	-115	-3790.99	26.628	119.77	-55	-1986.89	33.369	104.98
-174	-5147.47	19.254	131.19	-114	-3764.30	26.748	119.52	-54	-1953.47	33.474	104.66
-173	-5128.16	19.385	130.91	-113	-3737.49	26.867	119.26	-53	-1919.94	33.578	104.32
-172	-5108.71	19.515	130.63	-112	-3710.57	26.986	119.00	-52	-1886.31	33.682	103.99
-171	-5089.12	19.646	130.35	-111	-3683.52	27.105	118.73	-51	-1852.58	33.786	103.66
-170	-5069.41	19.776	130.07	-110	-3656.36	27.224	118.46	-50	-1818.74	33.889	103.33
-169	-5049.57	19.906	129.79	-109	-3629.07	27.342	118.19	-49	-1784.80	33.993	103.00
-168	-5029.60	20.036	129.51	-108	-3601.67	27.460	117.91	-48	-1750.75	34.095	102.68
-167	-5009.50	20.165	129.24	-107	-3574.15	27.578	117.64	-47	-1716.61	34.198	102.36
-166	-4989.27	20.294	128.96	-106	-3546.52	27.695	117.36	-46	-1682.36	34.300	102.05
-165	-4968.91	20.423	128.70	-105	-3518.76	27.812	117.08	-45	-1648.01	34.402	101.75
-164	-4948.43	20.551	128.43	-104	-3490.89	27.929	116.80	-44	-1613.55	34.504	101.46
-163	-4927.81	20.680	128.17	-103	-3462.90	28.046	116.52	-43	-1579.00	34.605	101.18
-162	-4907.07	20.808	127.91	-102	-3434.80	28.162	116.24	-42	-1544.34	34.706	100.92
-161	-4886.20	20.936	127.67	-101	-3406.58	28.278	115.96	-41	-1509.59	34.807	100.67
-160	-4865.20	21.063	127.42	-100	-3378.24	28.394	115.69	-40	-1474.73	34.907	100.43
-159	-4844.07	21.190	127.19	-99	-3349.79	28.510	115.42	-39	-1439.77	35.008	100.22
-158	-4822.81	21.318	126.96	-98	-3321.22	28.625	115.15	-38	-1404.72	35.108	100.01
-157	-4801.43	21.444	126.74	-97	-3292.54	28.740	114.88	-37	-1369.56	35.208	99.83
-156	-4779.93	21.571	126.52	-96	-3263.74	28.855	114.62	-36	-1334.30	35.308	99.66
-155	-4758.29	21.697	126.31	-95	-3234.83	28.969	114.37	-35	-1298.94	35.407	99.52
-154	-4736.53	21.824	126.12	-94	-3205.80	29.084	114.12	-34	-1263.49	35.507	99.38
-153	-4714.64	21.950	125.92	-93	-3176.66	29.198	113.87	-33	-1227.93	35.606	99.26
-152	-4692.63	22.075	125.74	-92	-3147.41	29.311	113.63	-32	-1192.27	35.705	99.16
-151	-4670.49	22.201	125.57	-91	-3118.04	29.425	113.40	-31	-1156.52	35.804	99.07
-150	-4648.23	22.327	125.40	-90	-3088.56	29.538	113.17	-30	-1120.67	35.903	98.99
-149	-4625.84	22.452	125.23	-89	-3058.96	29.651	112.95	-29	-1084.71	36.002	98.91
-148	-4603.33	22.577	125.08	-88	-3029.26	29.764	112.73	-28	-1048.66	36.101	98.84
-147	-4580.69	22.702	124.93	-87	-2999.44	29.877	112.51	-27	-1012.51	36.200	98.76
-146	-4557.92	22.827	124.79	-86	-2969.50	29.989	112.30	-26	-976.26	36.299	98.69
-145	-4535.03	22.952	124.65	-85	-2939.46	30.101	112.10	-25	-939.91	36.397	98.60
-144	-4512.02	23.076	124.51	-84	-2909.30	30.213	111.89	-24	-903.47	36.496	98.50
-143	-4488.88	23.201	124.38	-83	-2879.03	30.325	111.70	-23	-866.92	36.594	98.37
-142	-4465.62	23.325	124.26	-82	-2848.65	30.437	111.50	-22	-830.28	36.693	98.23
-141	-4442.23	23.449	124.13	-81	-2818.16	30.548	111.31	-21	-793.54	36.791	98.05
-140	-4418.72	23.573	124.01	-80	-2787.55	30.659	111.11	-20	-756.70	36.889	97.83
-139	-4395.08	23.697	123.89	-79	-2756.84	30.770	110.92	-19	-719.76	36.986	97.58
-138	-4371.32	23.821	123.77	-78	-2726.01	30.881	110.73	-18	-682.73	37.084	97.27
-137	-4347.44	23.945	123.65	-77	-2695.08	30.992	110.54	-17	-645.59	37.181	96.91
-136	-4323.43	24.068	123.52	-76	-2664.03	31.102	110.35	-16	-608.36	37.278	96.50
-135	-4299.30	24.192	123.40	-75	-2632.87	31.213	110.15	-15	-571.04	37.374	96.03
-134	-4275.05	24.315	123.27	-74	-2601.61	31.323	109.96	-14	-533.62	37.470	95.49
-133	-4250.67	24.438	123.14	-73	-2570.23	31.432	109.76	-13	-496.10	37.565	94.90
-132	-4226.17	24.561	123.01	-72	-2538.74	31.542	109.55	-12	-458.49	37.659	94.25
-131	-4201.55	24.684	122.87	-71	-2507.14	31.652	109.34	-11	-420.78	37.753	93.54
-130	-4176.81	24.807	122.73	-70	-2475.44	31.761	109.12	-10	-382.98	37.846	92.79
-129	-4151.94	24.930	122.58	-69	-2443.62	31.870	108.90	-9	-345.09	37.939	92.01
-128	-4126.95	25.052	122.42	-68	-2411.70	31.979	108.67	-8	-307.10	38.030	91.20
-127	-4101.83	25.175	122.26	-67	-2379.67	32.087	108.43	-7	-269.03	38.121	90.41
-126	-4076.60	25.297	122.09	-66	-2347.52	32.195	108.19	-6	-230.86	38.211	89.64
-125	-4051.24	25.419	121.92	-65	-2315.27	32.303	107.94	-5	-192.61	38.301	88.94
-124	-4025.76	25.541	121.74	-64	-2282.92	32.411	107.68	-4	-154.26	38.389	88.35
-123	-4000.16	25.662	121.55	-63	-2250.45	32.519	107.41	-3	-115.83	38.477	87.92
-122	-3974.43	25.784	121.35	-62	-2217.88	32.626	107.13	-2	-77.31	38.565	87.70
-121	-3948.59	25.905	121.15	-61	-2185.20	32.733	106.85	-1	-38.70	38.653	87.79
-120	-3922.62	26.026	120.94	-60	-2152.41	32.840	106.55	0	0.00	38.741	66.38

Table 8.3.2 *Type T thermocouples—thermoelectric voltages,* E(T), *Seebeck coefficients,* S(T), *and first derivative of the Seebeck coefficients,* dS/dT, *reference junctions at 0 °C—Continued*

T °C	E μV	S μV/°C	dS/dT nV/°C²	T °C	E μV	S μV/°C	dS/dT nV/°C²	T °C	E μV	S μV/°C	dS/dT nV/°C²
0	0.0	38.741	66.38	60	2467.5	43.649	83.20	120	5227.0	48.181	68.26
1	38.8	38.808	67.60	61	2511.2	43.733	82.98	121	5275.3	48.250	68.06
2	77.6	38.876	68.76	62	2555.0	43.815	82.75	122	5323.5	48.318	67.86
3	116.5	38.945	69.88	63	2598.8	43.898	82.52	123	5371.9	48.385	67.67
4	155.5	39.016	70.94	64	2642.8	43.980	82.28	124	5420.3	48.453	67.47
5	194.6	39.087	71.96	65	2686.8	44.063	82.04	125	5468.8	48.520	67.28
6	233.7	39.160	72.94	66	2730.9	44.145	81.79	126	5517.3	48.587	67.09
7	272.9	39.233	73.86	67	2775.1	44.226	81.55	127	5566.0	48.654	66.91
8	312.1	39.307	74.75	68	2819.3	44.308	81.29	128	5614.7	48.721	66.72
9	351.5	39.382	75.59	69	2863.7	44.389	81.04	129	5663.4	48.788	66.54
10	390.9	39.458	76.39	70	2908.1	44.470	80.78	130	5712.2	48.854	66.36
11	430.4	39.535	77.15	71	2952.6	44.550	80.52	131	5761.1	48.921	66.19
12	470.0	39.613	77.86	72	2997.2	44.631	80.26	132	5810.1	48.987	66.01
13	509.6	39.691	78.55	73	3041.9	44.711	79.99	133	5859.1	49.053	65.84
14	549.4	39.770	79.19	74	3086.6	44.791	79.73	134	5908.2	49.118	65.67
15	589.2	39.849	79.80	75	3131.5	44.870	79.46	135	5957.3	49.184	65.50
16	629.1	39.929	80.37	76	3176.4	44.950	79.19	136	6006.5	49.249	65.33
17	669.0	40.010	80.91	77	3221.4	45.029	78.92	137	6055.8	49.315	65.17
18	709.1	40.091	81.41	78	3266.4	45.107	78.65	138	6105.2	49.380	65.01
19	749.2	40.173	81.88	79	3311.6	45.186	78.38	139	6154.6	49.445	64.85
20	789.4	40.255	82.33	80	3356.8	45.264	78.10	140	6204.1	49.509	64.69
21	829.7	40.338	82.74	81	3402.1	45.342	77.83	141	6253.6	49.574	64.53
22	870.1	40.420	83.12	82	3447.5	45.420	77.56	142	6303.2	49.639	64.38
23	910.6	40.504	83.47	83	3492.9	45.497	77.29	143	6352.9	49.703	64.23
24	951.1	40.587	83.80	84	3538.5	45.574	77.01	144	6402.6	49.767	64.07
25	991.7	40.671	84.10	85	3584.1	45.651	76.74	145	6452.4	49.831	63.93
26	1032.5	40.756	84.37	86	3629.8	45.728	76.47	146	6502.3	49.895	63.78
27	1073.3	40.840	84.62	87	3675.5	45.804	76.20	147	6552.2	49.959	63.63
28	1114.1	40.925	84.84	88	3721.4	45.880	75.93	148	6602.2	50.022	63.49
29	1155.1	41.010	85.04	89	3767.3	45.956	75.66	149	6652.2	50.086	63.34
30	1196.2	41.095	85.22	90	3813.3	46.032	75.39	150	6702.4	50.149	63.20
31	1237.3	41.180	85.37	91	3859.4	46.107	75.13	151	6752.5	50.212	63.06
32	1278.5	41.266	85.50	92	3905.5	46.182	74.86	152	6802.8	50.275	62.92
33	1319.8	41.351	85.62	93	3951.7	46.257	74.60	153	6853.1	50.338	62.78
34	1361.2	41.437	85.71	94	3998.0	46.331	74.34	154	6903.5	50.400	62.65
35	1402.7	41.523	85.79	95	4044.4	46.405	74.08	155	6953.9	50.463	62.51
36	1444.3	41.608	85.84	96	4090.8	46.479	73.82	156	7004.4	50.526	62.37
37	1485.9	41.694	85.88	97	4137.4	46.553	73.56	157	7054.9	50.588	62.24
38	1527.7	41.780	85.90	98	4183.9	46.626	73.30	158	7105.6	50.650	62.11
39	1569.5	41.866	85.91	99	4230.6	46.700	73.05	159	7156.2	50.712	61.98
40	1611.4	41.952	85.89	100	4277.3	46.773	72.80	160	7207.0	50.774	61.84
41	1653.4	42.038	85.87	101	4324.2	46.845	72.55	161	7257.8	50.836	61.71
42	1695.5	42.124	85.83	102	4371.0	46.918	72.30	162	7308.7	50.897	61.58
43	1737.6	42.209	85.77	103	4418.0	46.990	72.06	163	7359.6	50.959	61.46
44	1779.9	42.295	85.70	104	4465.0	47.062	71.81	164	7410.6	51.020	61.33
45	1822.2	42.381	85.62	105	4512.1	47.133	71.57	165	7461.6	51.082	61.20
46	1864.6	42.466	85.53	106	4559.3	47.205	71.34	166	7512.7	51.143	61.07
47	1907.1	42.552	85.42	107	4606.5	47.276	71.10	167	7563.9	51.204	60.94
48	1949.7	42.637	85.31	108	4653.8	47.347	70.87	168	7615.2	51.265	60.82
49	1992.4	42.723	85.18	109	4701.2	47.418	70.64	169	7666.4	51.325	60.69
50	2035.2	42.808	85.04	110	4748.7	47.488	70.41	170	7717.8	51.386	60.57
51	2078.0	42.893	84.89	111	4796.2	47.559	70.18	171	7769.2	51.446	60.44
52	2121.0	42.977	84.74	112	4843.8	47.629	69.96	172	7820.7	51.507	60.32
53	2164.0	43.062	84.57	113	4891.4	47.699	69.74	173	7872.2	51.567	60.19
54	2207.1	43.147	84.40	114	4939.2	47.768	69.52	174	7923.8	51.627	60.07
55	2250.3	43.231	84.21	115	4987.0	47.838	69.30	175	7975.5	51.687	59.94
56	2293.6	43.315	84.02	116	5034.9	47.907	69.09	176	8027.2	51.747	59.82
57	2336.9	43.399	83.83	117	5082.8	47.976	68.88	177	8079.0	51.807	59.69
58	2380.4	43.483	83.62	118	5130.8	48.045	68.67	178	8130.8	51.866	59.57
59	2423.9	43.566	83.41	119	5178.9	48.113	68.46	179	8182.7	51.926	59.44
60	2467.5	43.649	83.20	120	5227.0	48.181	68.26	180	8234.7	51.985	59.32

TABLE 8.3.2 *Type T thermocouples—thermoelectric voltages,* E(T), *Seebeck coefficients,* S(T), *and first derivative of the Seebeck coefficients,* dS/dT, *reference junctions at 0 °C—Continued*

T °C	E μV	S μV/°C	dS/dT nV/°C²	T °C	E μV	S μV/°C	dS/dT nV/°C²	T °C	E μV	S μV/°C	dS/dT nV/°C²
180	8234.7	51.985	59.32	240	11455.8	55.300	50.80	300	14859.8	58.086	42.86
181	8286.7	52.045	59.19	241	11511.1	55.351	50.64	301	14917.9	58.129	42.78
182	8338.8	52.104	59.07	242	11566.5	55.401	50.48	302	14976.1	58.172	42.69
183	8390.9	52.163	58.94	243	11621.9	55.452	50.32	303	15034.3	58.215	42.62
184	8443.1	52.222	58.81	244	11677.4	55.502	50.17	304	15092.5	58.257	42.54
185	8495.3	52.280	58.69	245	11732.9	55.552	50.01	305	15150.8	58.300	42.46
186	8547.6	52.339	58.56	246	11788.5	55.602	49.85	306	15209.1	58.342	42.39
187	8600.0	52.397	58.43	247	11844.1	55.652	49.69	307	15267.5	58.385	42.32
188	8652.4	52.456	58.31	248	11899.8	55.701	49.54	308	15325.9	58.427	42.25
189	8704.9	52.514	58.18	249	11955.5	55.751	49.38	309	15384.3	58.469	42.19
190	8757.5	52.572	58.05	250	12011.3	55.800	49.22	310	15442.8	58.511	42.12
191	8810.1	52.630	57.92	251	12067.1	55.849	49.07	311	15501.3	58.553	42.06
192	8862.7	52.688	57.79	252	12123.0	55.898	48.91	312	15559.9	58.595	41.99
193	8915.4	52.746	57.66	253	12178.9	55.947	48.76	313	15618.5	58.637	41.93
194	8968.2	52.803	57.53	254	12234.9	55.996	48.60	314	15677.2	58.679	41.88
195	9021.1	52.861	57.40	255	12290.9	56.044	48.45	315	15735.9	58.721	41.82
196	9073.9	52.918	57.27	256	12347.0	56.093	48.30	316	15794.6	58.763	41.76
197	9126.9	52.975	57.13	257	12403.1	56.141	48.14	317	15853.4	58.805	41.71
198	9179.9	53.032	57.00	258	12459.3	56.189	47.99	318	15912.2	58.846	41.65
199	9233.0	53.089	56.87	259	12515.5	56.237	47.84	319	15971.1	58.888	41.60
200	9286.1	53.146	56.73	260	12571.7	56.285	47.69	320	16030.0	58.929	41.55
201	9339.2	53.203	56.60	261	12628.0	56.332	47.54	321	16089.0	58.971	41.50
202	9392.5	53.259	56.46	262	12684.4	56.380	47.39	322	16148.0	59.012	41.45
203	9445.8	53.316	56.32	263	12740.8	56.427	47.25	323	16207.0	59.054	41.40
204	9499.1	53.372	56.19	264	12797.3	56.474	47.10	324	16266.1	59.095	41.35
205	9552.5	53.428	56.05	265	12853.8	56.521	46.95	325	16325.2	59.137	41.31
206	9606.0	53.484	55.91	266	12910.3	56.568	46.81	326	16384.3	59.178	41.26
207	9659.5	53.540	55.77	267	12966.9	56.615	46.67	327	16443.5	59.219	41.21
208	9713.0	53.596	55.63	268	13023.5	56.661	46.52	328	16502.8	59.260	41.17
209	9766.7	53.651	55.49	269	13080.2	56.708	46.38	329	16562.1	59.301	41.12
210	9820.3	53.707	55.35	270	13136.9	56.754	46.24	330	16621.4	59.343	41.07
211	9874.1	53.762	55.20	271	13193.7	56.800	46.11	331	16680.7	59.384	41.02
212	9927.9	53.817	55.06	272	13250.5	56.846	45.97	332	16740.1	59.425	40.98
213	9981.7	53.872	54.92	273	13307.4	56.892	45.84	333	16799.6	59.466	40.93
214	10035.6	53.927	54.77	274	13364.3	56.938	45.70	334	16859.1	59.506	40.88
215	10089.6	53.982	54.63	275	13421.3	56.984	45.57	335	16918.6	59.547	40.83
216	10143.6	54.036	54.48	276	13478.3	57.029	45.44	336	16978.2	59.588	40.77
217	10197.6	54.091	54.33	277	13535.3	57.075	45.31	337	17037.8	59.629	40.72
218	10251.8	54.145	54.18	278	13592.4	57.120	45.18	338	17097.4	59.670	40.67
219	10305.9	54.199	54.04	279	13649.6	57.165	45.06	339	17157.1	59.710	40.61
220	10360.2	54.253	53.89	280	13706.8	57.210	44.93	340	17216.8	59.751	40.55
221	10414.4	54.307	53.74	281	13764.0	57.255	44.81	341	17276.6	59.791	40.49
222	10468.8	54.360	53.59	282	13821.3	57.300	44.69	342	17336.4	59.832	40.42
223	10523.2	54.414	53.44	283	13878.6	57.344	44.57	343	17396.3	59.872	40.35
224	10577.6	54.467	53.28	284	13936.0	57.389	44.46	344	17456.2	59.912	40.28
225	10632.1	54.520	53.13	285	13993.4	57.433	44.34	345	17516.1	59.953	40.21
226	10686.6	54.573	52.98	286	14050.8	57.477	44.23	346	17576.1	59.993	40.13
227	10741.2	54.626	52.82	287	14108.3	57.522	44.12	347	17636.1	60.033	40.05
228	10795.9	54.679	52.67	288	14165.9	57.566	44.01	348	17696.1	60.073	39.97
229	10850.6	54.732	52.52	289	14223.5	57.610	43.90	349	17756.2	60.113	39.87
230	10905.4	54.784	52.36	290	14281.1	57.653	43.80	350	17816.4	60.153	39.78
231	10960.2	54.836	52.21	291	14338.8	57.697	43.69	351	17876.5	60.192	39.68
232	11015.0	54.889	52.05	292	14396.5	57.741	43.59	352	17936.8	60.232	39.57
233	11069.9	54.941	51.89	293	14454.3	57.784	43.49	353	17997.0	60.272	39.46
234	11124.9	54.992	51.74	294	14512.1	57.828	43.40	354	18057.3	60.311	39.34
235	11179.9	55.044	51.58	295	14569.9	57.871	43.30	355	18117.6	60.350	39.22
236	11235.0	55.096	51.42	296	14627.8	57.914	43.21	356	18178.0	60.389	39.08
237	11290.1	55.147	51.27	297	14685.7	57.958	43.12	357	18238.4	60.428	38.94
238	11345.3	55.198	51.11	298	14743.7	58.001	43.03	358	18298.9	60.467	38.80
239	11400.5	55.249	50.95	299	14801.7	58.044	42.94	359	18359.3	60.506	38.64
240	11455.8	55.300	50.80	300	14859.8	58.086	42.86	360	18419.9	60.545	38.47

TABLE 8.3.2 ***Type T thermocouples**—thermoelectric voltages,* E(T)*, Seebeck coefficients,* S(T)*, and first derivative of the Seebeck coefficients,* dS/dT*, reference junctions at 0 °C—Continued*

T °C	E µV	S µV/°C	dS/dT nV/°C²	T °C	E µV	S µV/°C	dS/dT nV/°C²	T °C	E µV	S µV/°C	dS/dT nV/°C²
360	18419.9	60.545	38.47	375	19332.2	61.096	34.64	390	20252.3	61.564	26.88
361	18480.4	60.583	38.30	376	19393.4	61.131	34.26	391	20313.9	61.591	26.16
362	18541.0	60.621	38.12	377	19454.5	61.165	33.88	392	20375.5	61.616	25.42
363	18601.7	60.659	37.92	378	19515.7	61.199	33.47	393	20437.2	61.641	24.65
364	18662.3	60.697	37.72	379	19576.9	61.232	33.04	394	20498.8	61.666	23.84
365	18723.1	60.735	37.50	380	19638.2	61.265	32.59	395	20560.5	61.689	23.01
366	18783.8	60.772	37.28	381	19699.4	61.297	32.13	396	20622.2	61.712	22.14
367	18844.6	60.809	37.04	382	19760.7	61.329	31.64	397	20683.9	61.733	21.23
368	18905.4	60.846	36.79	383	19822.1	61.360	31.13	398	20745.7	61.754	20.29
369	18966.3	60.883	36.52	384	19883.5	61.391	30.60	399	20807.4	61.774	19.32
370	19027.2	60.919	36.25	385	19944.9	61.422	30.04	400	20869.2	61.793	18.31
371	19088.1	60.955	35.96	386	20006.3	61.451	29.46				
372	19149.1	60.991	35.65	387	20067.8	61.480	28.85				
373	19210.1	61.027	35.33	388	20129.3	61.509	28.22				
374	19271.2	61.062	34.99	389	20190.8	61.537	27.56				
375	19332.2	61.096	34.64	390	20252.3	61.564	26.88				