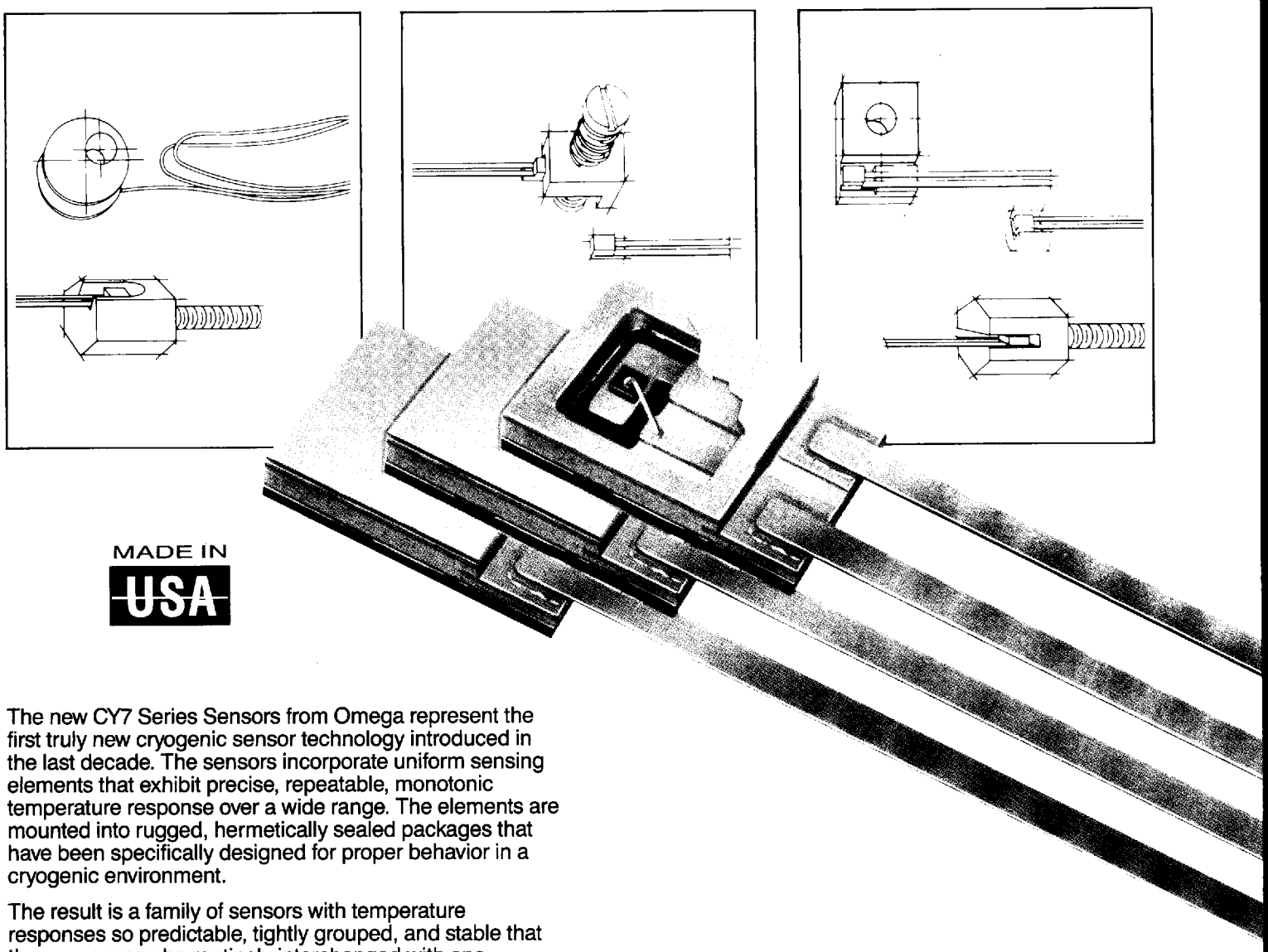
Cryogenic Temperature Sensors

T-65-13

CY7 Series Silicon Diodes



MADE IN USA

The new CY7 Series Sensors from Omega represent the first truly new cryogenic sensor technology introduced in the last decade. The sensors incorporate uniform sensing elements that exhibit precise, repeatable, monotonic temperature response over a wide range. The elements are mounted into rugged, hermetically sealed packages that have been specifically designed for proper behavior in a cryogenic environment.

The result is a family of sensors with temperature responses so predictable, tightly grouped, and stable that the sensors can be routinely interchanged with one another.

A New Proprietary Silicon Diode Chip.

The key to the sensor's temperature response lies with the basic sensing element itself. The small silicon chip in each sensor has a temperature characteristic that is so stable, so predictable, and conforms so well from chip to chip, that the CY7's sensors are the first mass produced, interchangeable cryogenic sensors.

As shown on the graph on page T-11, the temperature response profile of a CY7 is comprised of two distinct elements. With their inherent dual sensitivity, CY7 sensors can cover a wide temperature range (up to 475 Kelvin) and at the same time exhibit high sensitivity for critical low temperature measurement.

Precise thermal response of the sensing element itself becomes of little benefit if thermal errors generated in installing and using the sensor swamp out its capability. It is in minimizing these frequently unsuspected errors that the CY7 excels.

A Sensor Package Designed for Cryogenics.

Sensors for higher temperatures fall far short for cryogenic use. The complex thermal link between the sensing element and its entire environment must be taken into account, as does the effect of any measurement induced self-heating of the sensor itself, to achieve accurate results. In addition, the package must also withstand repeated cycling to low temperatures without mechanical failure.

Cryogenic Temperature Sensors

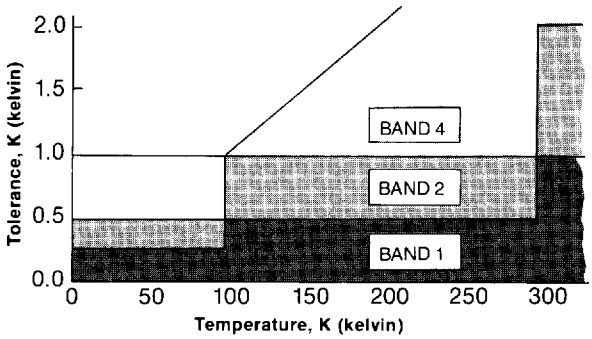
CY7 Series

The development of the CY7 Series has included the design of the unique sensor packages to solve many of the problems encountered in low temperature thermometry. For example, the CY7 hermetic package incorporates a sapphire substrate for high electrical isolation yet good thermal conductivity. The base bottom is metallized for easy anchoring to a sample. Large strong leads form an integral part of the package and are thermally sunk into the substrate. This simplifies making connections to the sensor and at the same time helps reduce measurement errors that could be caused by heat conduction along the leads.

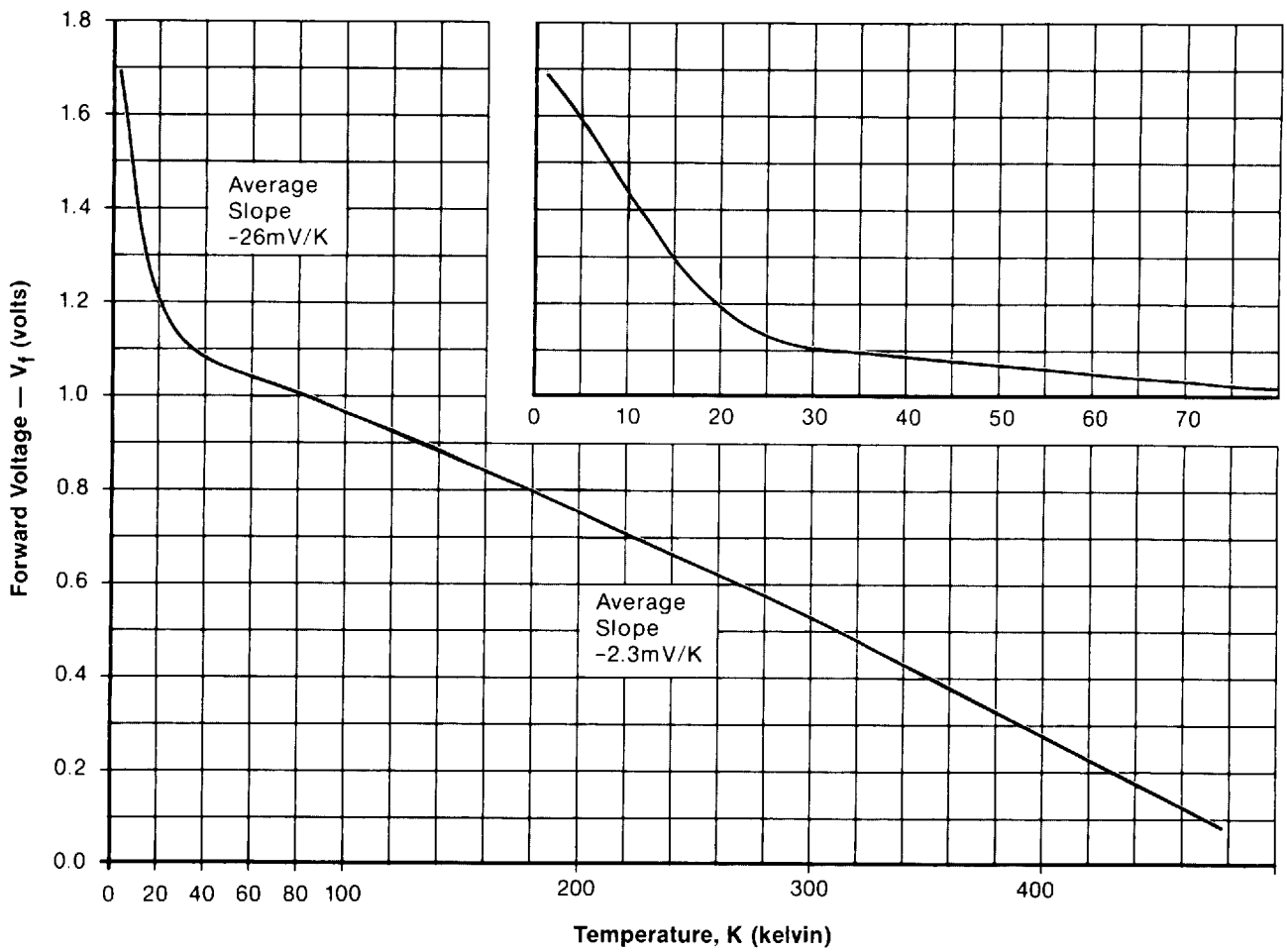
10 Microampere Excitation Current

Key to the achievement of error free measurements is low excitation current. The lower the current, the less power dissipated in the sensor and the less self-heating.

One measure of the effectiveness of a cryogenic sensor's thermal design is the variation in reading obtained between operation in a vacuum at liquid helium temperature and immersion directly in the liquid. In a field where discrepancies of a degree or more have been reported, the Omega CY7 sensors exhibit variations as low as 5 millikelvin.

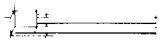


Tolerance Bands for CY7 Series Sensors allow selection of appropriate (and economical) accuracy levels for a given application.

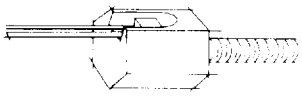


Standard temperature response (Curve 10) for CY7 Series Sensors. All Sensors track this curve within specified tolerance bands.

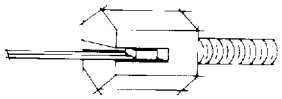
Select the Sensor Configuration Best-Suited to Your Application.



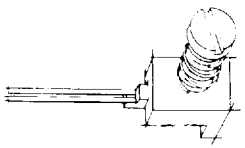
CY7-SD The SD configuration is the smallest package in this series, and is designed primarily for bonding or clamping to a flat surface. Since the sensing element is in best thermal contact with the base (largest surface) of the package, the package should be mounted with that same surface in good contact with the sample. Mounting materials and methods which will not expose the sensor to temperatures above 200°C are required. Low temperature indium-lead-tin based solder or low temperature epoxy is recommended. The SD package style is usable at temperatures up to 475 K.



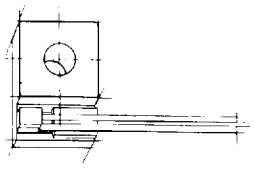
CY7-ET This convenient screw-in package is formed by soldering a basic SD configuration into a recess in one flat of a hexagonal cylinder. The cylinder terminates in a standard 6-32 SAE thread. Thus the sensor can be threaded (finger tight only) into a mounting hole in the sample. A light coating of vacuum grease on the threads further enhances the thermal contact between the sensor package and the sample. The solder used in mounting the SD package to this adapter constrains the upper useful temperature of this configuration to 325 K.



CY7-MT The MT package is similar to the ET version except the SD package is mounted in a slot in the center of the cylinder and the stud is a 3 mm x 0.5 metric thread.



CY7-CO A spring loaded clamp holds a standard SD sensor in contact with the surface of the sample in this configuration. This allows the sensor to be easily changed or replaced. It also enables the sensor to be used over its full operational temperature range of 1.4 to 475 K. Extra clamps are available to accommodate applications where frequent relocation of the sensor is desirable. The 4-40 brass screw used with this clamp has a formed shoulder so that, once the screw is properly seated, the spring applies correct pressure to the clamp.



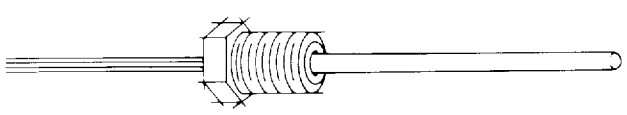
CY7-BO In addition to being soldered to the mounting block, the SD sensor in this design has its leads thermally anchored (without epoxy) to the block via a beryllium oxide insert. Since leads can be a significant heat path to the sensing element, and can lead to measurement errors when incorrectly anchored, this configuration helps maintain the leads at the same temperature as the sensor. Mounting of this block is accomplished with a 4-40 screw (not supplied). Usable temperature range of the CY7-BO sensor is 1.4 to 325 K.

CY7-LR With a CY7-SD sensor mounted on a slightly more than half-round cylinder, this package is designed to be inserted into a 1/8 inch (3.2 mm) diameter hole. Low Temperature epoxy can also be used to install the sensor, although the mounting is much more permanent in that case. As with other soldered down sensors, the temperature range of the CY7-LR extends to 325 K.

CY7-CU In this configuration the SD sensor is epoxied into a flat cylindrical disk and the sensor leads are thermally anchored to that same disk. The unit can be mounted to any flat surface with a 4-40 brass screw (not supplied). The CU style sensor is wired in a four lead configuration with the leads comprised of a 36 inch length of OMEGA color coded cryogenic wire. Temperature range is 1.4 K to 325 K.

CY7-DI This is a two lead version of the the CY7-CU.

CY7-CY Some applications are best served by a relatively large size robust sensor and the CY7-CY fills that bill. It is very similar to the CU style except that the disk has a larger center diameter with the mounting hole directly in the center. The CY sensor has 36 inch heavy duty (30 AWG, PTFE coated) leads. Special attention must be paid to thermally anchoring the leads to prevent heat leak induced measurement error.



Probes The flexibility of the CY7 series sensors makes them ideal candidates for incorporation into various probes and thermowells. However, the individualized nature of these applications usually demands customized designs.

Cryogenic Temperature Sensors

CY7 Series

MADE IN USA

Clean Room Assembly Keeps Out Contaminants

All CY7 sensors are meticulously assembled in semiconductor grade clean rooms on state of the art bonding equipment. special effort is made to keep them free of epoxies, polyimides, fluxes, chlorine, and other contaminants which have a detrimental effect on sensor performance.

Choose the Sensor Style That Best Fits Your Application and Level of Interchangeability You Want.

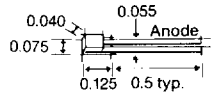
It's easy to pick the CY7 sensor you should use. Omega starts with the same basic sensor style and offers it unmounted or in any of a variety of mounting adapters that will simplify installation in your system. Choose from a simple cylinder that slides into a mounting hole, metric or SAE threaded stud mounts, or bolt-on flat mounts. Probes, thermowells and other mounts can be special ordered.

All CY7 sensors follow the temperature response curve shown on the previous page. Five bands of tracking accuracy are offered to allow sensor selection to be suited to both the technical and economical considerations of any application. Low temperature accuracy ranges from 0.25K for the tightest band (#1) to 1.5K for the loosest (#7).

For the most demanding requirements, CY7 sensors can be individually calibrated to accuracies of better than 50 millikelvin depending on temperature range. Omega offers complete calibration service for virtually any cryogenic sensor on calibration facilities maintained traceable in conformance with MIL-Std-45662.

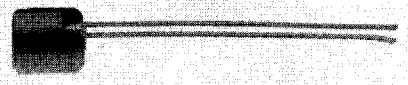
Most Popular Model
Available in Bands 1 thru 7

CY7-SD

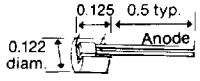


Basic Sensor package style.
Temperature Range: 1.4K to 475K.
Mass: 0.03g

Available in Bands 1 thru 4



CY7-LR



Basic Sensor soldered into cylindrical copper adapter.
Temperature Range: 1.4K to 325K.
Mass: 0.15g

How To Order

Model No.	Price
CY7-SD7	$ 99
CY7-(*)4	160
CY7-(*)3	182
CY7-(*)2	220
CY7-(*)1	435

* *Insert Probe Configuration from Chart Below*

Configuration Type	Add'l. Price
SD	-std-
ET	$27
BO	49
CU	60
DI*	60
LR	27
MT	27
CO	27
CY	71

* *Available as CY7-DI4, $220.*

OMEGA also offers carbon glass, germanium and other low temperature sensors. Contact our Cryogenic Applications Engineers for additional information.

HIGHLIGHTED MODELS STOCKED FOR FAST DELIVERY

Ordering Example: CY7-ET4. Cryogenic sensor with ET configuration and accuracy range 4. $160 + 27 = $187

Band Suffix (Range)	Accuracy (Tolerance) 2K-100K	100K-305K	305K-475K
-1 (1.4 to 475K)	±0.25K	±0.5K	±1K
-2 (1.4 to 475K)	±0.5K	±1.0K	±2.0K
-3 (1.4 to 475K)	±0.5K	±1% of T	±1% of T
-4 (1.4 to 475K)	±1K	±1% of T	±1% of T
-7 (10 to 425K)	±1.5K	±1.5% of T	±1.5% of T

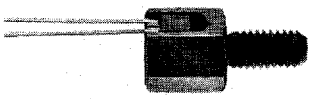
CY7-SD7 has 10-425K range

Model CY7-SD7 Economical Sensor

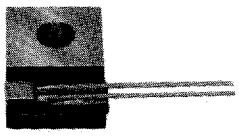
For applications where temperature measurements below 10K are not required, the CY7-SD7 series offers an inexpensive alternative to the other CY7-SD series temperature sensor. The upper operating temperature is limited to 425K for the CY7-SD7. Since the package configuration of the CY7-SD7 is identical to the CY7-SD, the installation and operation of the device follow the same procedures as the CY7-SD.

The CY7-SD7 follows Standard Curve #10 (page T-10) to a tolerance of ±1.5K or 1.5% of temperature, whichever is greater. Due to possible irregularities and non-monotonic behavior below 10K, extrapolations or interpolations outside of the operating temperature range should not be attempted.

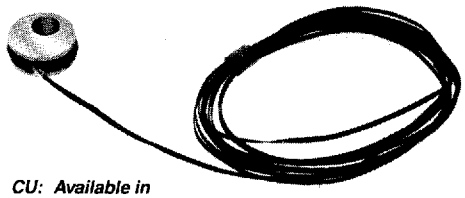
Most Popular Model
Available in Bands 1 thru 4



Available in Bands 1 thru 4

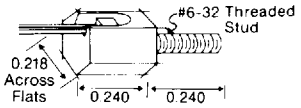


DI: Available in Band 4 Only



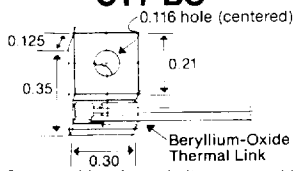
CU: Available in Bands 1 thru 4

CY7-ET



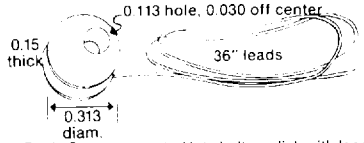
Basic Sensor soldered onto SAE-threaded copper adapter.
Temperature Range: 1.4K to 325K.
Mass: 1.4g

CY7-BO



Basic Sensor soldered onto bolt-on copper block with leads thermally anchored to block.
Temperature Range: 1.4K to 325K.
Mass: 1.5g

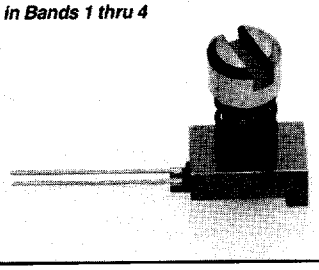
CY7-CU CY7-DI



Basic Sensor mounted into bolt-on disk with leads thermally anchored to disk with low temperature epoxy.
CU version is 4-leaded, DI is 2-leaded.
Temperature Range: 1.4K to 325K.
Mass (excl. leads): 1.0g

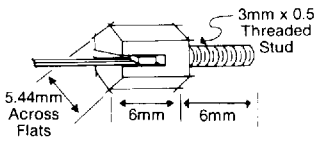
Available in Bands 1 thru 4

Available in Bands 1 thru 4



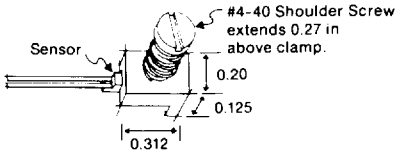
Available in Bands 1 thru 4 **Most Popular Model**

CY7-MT



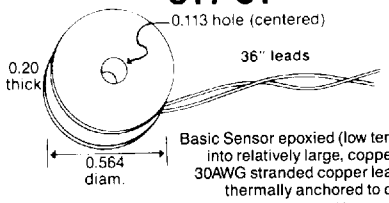
Basic Sensor soldered into metric-threaded copper adapter.
Temperature Range: 1.4K to 325K.
Mass: 1.4g

CY7-CO



Basic Sensor with spring-loaded brass clamp to hold Sensor to sample.
Temperature Range: 1.4K to 475K.
Mass (w/o Sensor): 1.7g

CY7-CY



Basic Sensor epoxied (low temperature) into relatively large, copper disk. 30AWG stranded copper lead pair is thermally anchored to disk.
Temperature Range: 1.4K to 325K.
Mass (excl leads): 4.3g

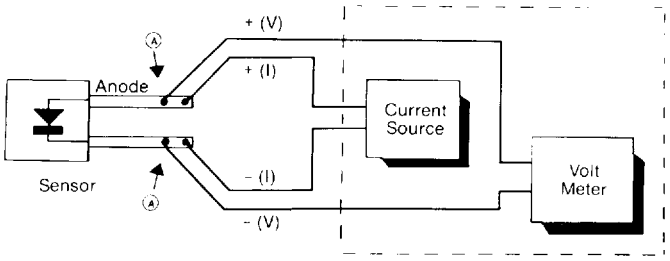
DIMENSIONS IN INCHES UNLESS NOTED

Specifications

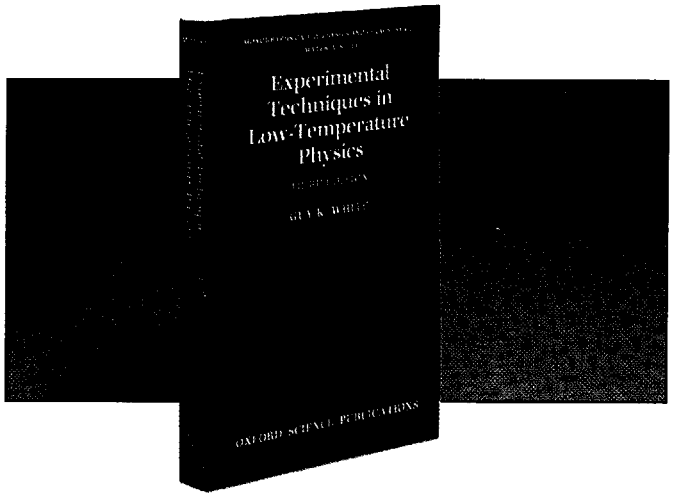
Sensing Element: silicon diode
Temperature Range, CY7-SD or CY7-CO: 1.4 to 475K (10 to 425K for CY7-SD7)
Temperature Range, Other Configurations: 1.4 to 325K
Recommended Excitation Current: 10 microamperes (±0.05% to meet listed specifications)
Temperature response curve: see figure for standard interchangeability curve (curve #10); Nominal output at recommended current is 1.7 V at 1.4K, 0.1 V at 475K.
Repeatability (at 4.2K): typically ±10 millikelvin over multiple thermal cycles
Thermal Time Constants (typical, CY7-SD): 10 ms at 4.2K, 100 ms at 77K, 200 ms at 305K
Accuracy, Interchangeability: sensors track above standard interchangeability curve (curve #10) within the tolerance bands
Temperature Offset, Vacuum to Liquid at 4.2 K: typically 5 to 35 millikelvin depending on configuration
Magnetic Field Use: not recommended
Maximum Recommended Storage Temperature: 60°C
Maximum Installation Temperature, CY7-SD or CY7-CO: 200°C
Maximum Installation Temperature, Other Configurations: 60°C
CY7-SD Construction: sapphire base with alumina body and lid; Molybdenum/manganese metallization on base bottom and lid top with nickel and gold plating; Gold-tin solder as lid seal; Hermeticity: less than 1×10^{-8} std cc/s; Cavity size: < 1 mm^3
Leads: gold plated Kovar, uninsulated; 0.015″ x 0.004″ cross section × approx. 0.5″ long; Designed to withstand at least five right angle bends; Polarity - positive lead on right with package lid up and leads toward user
Configuration Adapters: gold plated OFHC copper except for CO adapter which is brass with steel spring

Silicon Diode Probes and Accessories

MADE IN USA



Typical connection for sensors such as the CY7 series. The connection points (A) are made close to the sensor in the case of 4-lead measurement, and near or at the instrumentation for a 2-lead measurement. Generally, the 4-lead connection is preferred.

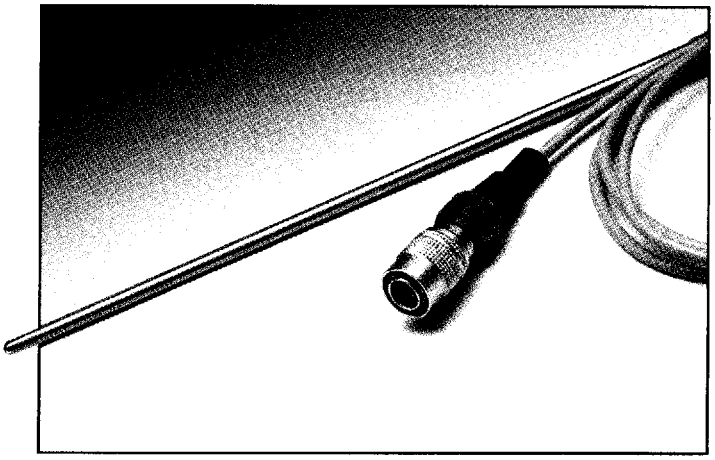


Experimental Techniques in Low-Temperature Physics. 3rd Edition

Guy K. White

This book was written chiefly to help physicists, physical chemists, metallurgists and engineers who need to carry out investigations at low temperatures. It deals with the production and measurement of low temperatures, the handling of liquefied gases on the laboratory scale, the principles and some details of the design of experimental cryostats, including the problems of heat transfer and temperature control. Physical data used in making low-temperature equipment is given. Enough of fundamental principles is included to make the book useful to the advanced university or graduate student. Additional material includes the use of Helium-3 for cooling below 1K by dilution refrigeration and Pomeranchuk cooling, the present status of the IPTS and other thermometry developments, new physical data on materials, and commercial suppliers.

Order No. OP-16
$32.50



CY82-4C Probe/Cable Assembly, $215

4-Wire Probe (Band 4 Sensor) for use with CYD200 Series Indicators

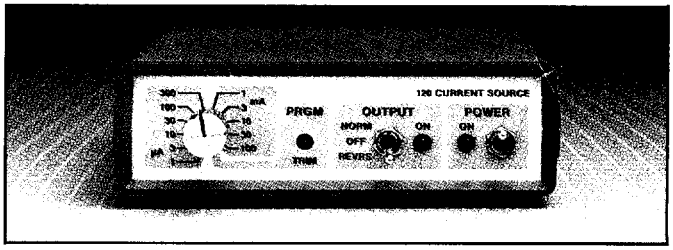
Model No.	Price	Description
CY82-4C	$215	6″ probe/12′ cable, 4-pin connector, 1/8″ SS sheath
CY82-4SL	176	6″ probe/12′ cable, stripped leads, 1/8″ SS sheath
CY10-7P4P	39	4-pin plug

Special Low Thermal Conductivity Extension Wire for CY7 Series Diodes

Model No.	Price	Description
CYW4-32-25	$116	4-lead wire, 32 awg, 25 ft.*
CYW4-32-100	259	4-lead wire, 32 awg, 100 ft.*
CYW4-32-500	869	4- lead wire, 32 awg, 500 ft.*
CYW4-36-25	83	4-lead wire, 36 awg, 25 ft.*
CYW4-36-100	204	4-lead wire, 36 awg, 100 ft.*
CYW4-36-500	688	4-lead wire, 36 awg, 500 ft.*

** Phosphor bronze wire. Insulation is polyimide on 32 AWG wire and formvar (vinyl acetal) on 36 AWG wire. Both types of insulation are rated down to 1.4K*

Constant Current Power Supply		
CY101-PS	$215	9V Battery powered, factory preset at 10μA. Internally selectable 1μA to 1 mA
CY120-PS	605	120 Vac powered, switch selectable 1μA to 100mA.



CY120-PS Power Supply

Cryogenic Temperature Sensors
CY7 Series

STANDARD CURVE #10

Measurement Current = 10μA ±0.05%

T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)
1.40	1.69812	-13.1	16.0	1.28527	-18.6	95.0	0.98564	-2.02
1.60	1.69521	-15.9	16.5	1.27607	-18.2	100.	0.97550	-2.04
1.80	1.69177	-18.4	17.0	1.26702	-18.0	110.	0.95487	-2.08
2.00	1.68786	-20.7	17.5	1.25810	-17.7	120.	0.93383	-2.12
2.20	1.68352	-22.7	18.0	1.24928	-17.6	130.	0.91243	-2.16
2.40	1.67880	-24.4	18.5	1.24053	-17.4	140.	0.89072	-2.19
2.60	1.67376	-25.9	19.0	1.23184	-17.4	150.	0.86873	-2.21
2.80	1.66845	-27.1	19.5	1.22314	-17.4	160.	0.84650	-2.24
3.00	1.66292	-28.1	20.0	1.21440	-17.6	170.	0.82404	-2.26
3.20	1.65721	-29.0	21.0	1.19645	-18.5	180.	0.80138	-2.28
3.40	1.65134	-29.8	22.0	1.17705	-20.6	190.	0.77855	-2.29
3.60	1.64529	-30.7	23.0	1.15558	-21.7	200.	0.75554	-2.31
3.80	1.63905	-31.6	24.0	1.13598	-15.9	210.	0.73238	-2.32
4.00	1.63263	-32.7	25.0	1.12463	-7.72	220.	0.70908	-2.34
4.20	1.62602	-33.6	26.0	1.11896	-4.34	230.	0.68564	-2.35
4.40	1.61920	-34.6	27.0	1.11517	-3.34	240.	0.66208	-2.36
4.60	1.61220	-35.4	28.0	1.11212	-2.82	250.	0.63841	-2.37
4.80	1.60506	-36.0	29.0	1.10945	-2.53	260.	0.61465	-2.38
5.00	1.59782	-36.5	30.0	1.10702	-2.34	270.	0.59080	-2.39
5.50	1.57928	-37.6	32.0	1.10263	-2.08	280.	0.56690	-2.39
6.00	1.56027	-38.4	34.0	1.09864	-1.92	290.	0.54294	-2.40
6.50	1.54097	-38.7	36.0	1.09490	-1.83	300.	0.51892	-2.40
7.00	1.52166	-38.4	38.0	1.09131	-1.77	310.	0.49484	-2.41
7.50	1.50272	-37.3	40.0	1.08781	-1.74	320.	0.47069	-2.42
8.00	1.48443	-35.8	42.0	1.08436	-1.72	330.	0.44647	-2.42
8.50	1.46700	-34.0	44.0	1.08093	-1.72	340.	0.42221	-2.43
9.00	1.45048	-32.1	46.0	1.07748	-1.73	350.	0.39783	-2.44
9.50	1.43488	-30.3	48.0	1.07402	-1.74	360.	0.37337	-2.45
10.0	1.42013	-28.7	50.0	1.07053	-1.75	370.	0.34881	-2.46
10.5	1.40615	-27.2	52.0	1.06700	-1.77	380.	0.32416	-2.47
11.0	1.39287	-25.9	54.0	1.06346	-1.78	390.	0.29941	-2.48
11.5	1.38021	-24.8	56.0	1.05988	-1.79	400.	0.27456	-2.49
12.0	1.36809	-23.7	58.0	1.05629	-1.80	410.	0.24963	-2.50
12.5	1.35647	-22.8	60.0	1.05267	-1.81	420.	0.22463	-2.50
13.0	1.34530	-21.9	65.0	1.04353	-1.84	430.	0.19961	-2.50
13.5	1.33453	-21.2	70.0	1.03425	-1.87	440.	0.17464	-2.49
14.0	1.32412	-20.5	75.0	1.02482	-1.91	450.	0.14985	-2.46
14.5	1.31403	-19.9	80.0	1.01525	-1.93	460.	0.12547	-2.41
15.0	1.30422	-19.4	85.0	1.00552	-1.96	470.	0.10191	-2.30
15.5	1.29464	-18.9	90.0	0.99565	-1.99	475.	0.09062	-2.22

Accessories Used for Mounting CY7 Series Silicon Diode Sensors

Model No.	Price	Description	Temp. Range
OB-CY20-2	$127	Low temperature epoxy for mounting sensor, twenty 2g (approx. 0.1 oz.) packets	1.4 K to 330 K
OB-CY20-5	176	Low temperature epoxy for mounting sensor, twenty 5g (approx. 0.1 oz.) packets	
CYAG	176	General purpose thermal grease, used between sensor and surface (25g tube)	
CYIF	143	Indium foil, high thermal conductivity, highly malleable, used as a mechanical alternative to CYAG grease to mount a sensor. 5 pcs., 0.005″ x 2″ x 2″	
CYAV	83	Adhesive varnish for tacking sensor extension leads, 1 pint can	
CYCO	248	CO Clamps with springs, pkg. of 10	

Cryogenic Temperature Sensors

CY7 Series

Polynomial Representation

Curve #10 can be represented by a polynomial equation based on the Chebychev polynomials which are described below. Four separate ranges are required to accurately describe the curve, with the parameters for these ranges given in Table 1. The polynomials represent Curve #10 on the preceding page with RMS deviations on the order of 10 mK.

The Chebychev equation is of the form

$$T(x) = \sum_{n=0} a_n t_n(x) \qquad (1)$$

where T(x) represents the temperature in kelvin, $t_n(x)$ is a Chebychev polynomial and a_n represents the Chebychev coefficients. The parameter x is a normalized variable given by

$$x = \frac{(V-VL)-(VU-V)}{(VU-VL)} \qquad (2)$$

where V is the voltage and VL and VU designate the lower and upper limit of the voltage over the fit range.

The Chebychev polynomials can be generated from the recursion relation

$$t_{n+1}(x)=2xt_n(x)-t_{n-1}(x),\ t_0(x)=1,\ t_1(x)=x. \quad (3)$$

Alternately, these polynomials are given by

$$t_n(x)=\cos[n*\arccos(x)]. \quad (4)$$

The use of Chebychev polynomials is no more complicated than the use of the regular power series and they offer significant advantages in the actual fitting process. The first step is to transform the measured voltage into the normalized variable using equation (2). Equation (1) is then used in combination with equation (3) or (4) to calculate the temperature. Programs 1 and 2 give sample BASIC subroutines which will take the voltage and return the temperature T calculated from Chebychev fits.The subroutines assume the values VL and VU have been input along with the degree of the fit, Ndegree. The Chebychev coefficients are also assumed to be in an array A(0), A(1), ...,A(Ndegree).

An interesting property of the Chebychev fits is evident in the form of the Chebychev polynomial given in equation (4). No term in equation (1) will be greater than the absolute value of the coefficient. This property makes it easy to determine the contribution of each term to the temperature calculation and where to truncate the series if the full accuracy is not required.

TABLE 1. Chebychev fit coefficients

2.0 to 12.0 K		
A(0) =	7.556358	VL = 1.32412
A(1) =	-5.917261	VU = 1.69812
A(2) =	0.237238	
A(3) =	-0.334636	
A(4) =	-0.058642	
A(5) =	-0.019929	
A(6) =	-0.020715	
A(7) =	-0.014814	
A(8) =	-0.008789	
A(9) =	-0.008554	
12.0 to 24.5 K		
A(0) =	17.304227	VL = 1.11732
A(1) =	-7.894688	VU = 1.42013
A(2) =	0.453442	
A(3) =	0.002243	
A(4) =	0.158036	
A(5) =	-0.193093	
A(6) =	0.155717	
A(7) =	-0.085185	
A(8) =	0.078550	
A(9) =	-0.018312	
A(10) =	0.039255	
24.5 to 100.0 K		
A(0) =	71.818025	VL = 0.923174
A(1) =	-53.799888	VU = 1.13935
A(2) =	1.669931	
A(3) =	2.314228	
A(4) =	1.566635	
A(5) =	0.723026	
A(6) =	-0.149503	
A(7) =	0.046876	
A(8) =	-0.388555	
A(9) =	0.056889	
A(10) =	-0.116823	
A(11) =	0.058580	
100 to 475 K		
A(0) =	287.756797	VL = 0.079767
A(1) =	-194.144823	VU = 0.999614
A(2) =	-3.837903	
A(3) =	-1.318325	
A(4) =	-0.109120	
A(5) =	-0.393265	
A(6) =	0.146911	
A(7) =	-0.111192	
A(8) =	0.028877	
A(9) =	-0.029286	
A(10) =	0.015619	

PROGRAM 1. BASIC subroutine for evaluating the temperature T from the Chebychev series using equations (1) and (3). An array Tc(Ndegree) should be dimensioned.

```
100  REM Evaluation of Chebychev series
110  X=((V-VL)-(VU-V))/(VU-VL)
120  Tc(0) = 1
130  Tc(1) = X
140  T = A(0) + A(1)*X
150  FOR I = 2 to Ndegree
160  Tc(I) = 2*X*Tc(I-1)-Tc(I-2)
170  T = T + A(I)*Tc(I)
180  NEXT I
190  RETURN
```

PROGRAM 2. BASIC subroutine for evaluating the temperature T from the Chebychev series equations (1) and (4). ACS is used to represent the arccosine function.

```
100  REM Evaluation of Chebychev series
110  X = ((V-VL)-(VU-V))/(VU-VL)
120  T = 0
130  FOR I = 0 to Ndegree
140  T = T + A(I)*COS(I*ACS(X))
150  NEXT I
160  RETURN
```