MAXIMUM TEMPERATURE RANGE

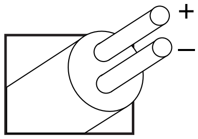
Thermocouple Grade
32 to 2642°F
0 to 1450°C

Extension Grade
32 to 300°F
0 to 150°C

LIMITS OF ERROR
(whichever is greater)
Standard: 1.5°C or 0.25%
Special: 0.6°C or 0.1%

COMMENTS, BARE WIRE ENVIRONMENT:
Oxidizing or Inert; Do Not Insert in Metal Tubes; Beware of Contamination; High Temperature

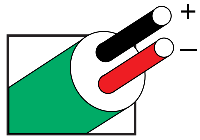
TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C



Thermocouple Grade

NONE ESTABLISHED

Platinum-10% Rhodium vs. Platinum



Extension Grade

Revised Thermocouple Reference Tables

TYPE S

Reference Tables
N.I.S.T.
Monograph 175
Revised to ITS-90

Z

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-40	-0.236	-0.232	-0.228	-0.224	-0.219	-0.215	-0.211	-0.207	-0.203	-0.199	-0.194	-40
-30	-0.194	-0.190	-0.186	-0.181	-0.177	-0.173	-0.168	-0.164	-0.159	-0.155	-0.150	-30
-20	-0.150	-0.146	-0.141	-0.136	-0.132	-0.127	-0.122	-0.117	-0.113	-0.108	-0.103	-20
-10	-0.103	-0.098	-0.093	-0.088	-0.083	-0.078	-0.073	-0.068	-0.063	-0.058	-0.053	-10
0	-0.053	-0.048	-0.042	-0.037	-0.032	-0.027	-0.021	-0.016	-0.011	-0.005	0.000	0

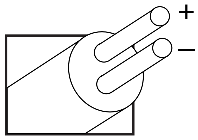
°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.005	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.050	0.055	0
10	0.055	0.061	0.067	0.072	0.078	0.084	0.090	0.095	0.101	0.107	0.113	10
20	0.113	0.119	0.125	0.131	0.137	0.143	0.149	0.155	0.161	0.167	0.173	20
30	0.173	0.179	0.185	0.191	0.197	0.204	0.210	0.216	0.222	0.229	0.235	30
40	0.235	0.241	0.248	0.254	0.260	0.267	0.273	0.280	0.286	0.292	0.299	40
50	0.299	0.305	0.312	0.319	0.325	0.332	0.338	0.345	0.352	0.358	0.365	50
60	0.365	0.372	0.378	0.385	0.392	0.399	0.405	0.412	0.419	0.426	0.433	60
70	0.433	0.440	0.446	0.453	0.460	0.467	0.474	0.481	0.488	0.495	0.502	70
80	0.502	0.509	0.516	0.523	0.530	0.538	0.545	0.552	0.559	0.566	0.573	80
90	0.573	0.580	0.588	0.595	0.602	0.609	0.617	0.624	0.631	0.639	0.646	90
100	0.646	0.653	0.661	0.668	0.675	0.683	0.690	0.698	0.705	0.713	0.720	100
110	0.720	0.727	0.735	0.743	0.750	0.758	0.765	0.773	0.780	0.788	0.795	110
120	0.795	0.803	0.811	0.818	0.826	0.834	0.841	0.849	0.857	0.865	0.872	120
130	0.872	0.880	0.888	0.896	0.903	0.911	0.919	0.927	0.935	0.942	0.950	130
140	0.950	0.958	0.966	0.974	0.982	0.990	0.998	1.006	1.013	1.021	1.029	140
150	1.029	1.037	1.045	1.053	1.061	1.069	1.077	1.085	1.094	1.102	1.110	150
160	1.110	1.118	1.126	1.134	1.142	1.150	1.158	1.167	1.175	1.183	1.191	160
170	1.191	1.199	1.207	1.216	1.224	1.232	1.240	1.249	1.257	1.265	1.273	170
180	1.273	1.282	1.290	1.298	1.307	1.315	1.323	1.332	1.340	1.348	1.357	180
190	1.357	1.365	1.373	1.382	1.390	1.399	1.407	1.415	1.424	1.432	1.441	190
200	1.441	1.449	1.458	1.466	1.475	1.483	1.492	1.500	1.509	1.517	1.526	200
210	1.526	1.534	1.543	1.551	1.560	1.569	1.577	1.586	1.594	1.603	1.612	210
220	1.612	1.620	1.629	1.638	1.646	1.655	1.663	1.672	1.681	1.690	1.698	220
230	1.698	1.707	1.716	1.724	1.733	1.742	1.751	1.759	1.768	1.777	1.786	230
240	1.786	1.794	1.803	1.812	1.821	1.829	1.838	1.847	1.856	1.865	1.874	240
250	1.874	1.882	1.891	1.900	1.909	1.918	1.927	1.936	1.944	1.953	1.962	250
260	1.962	1.971	1.980	1.989	1.998	2.007	2.016	2.025	2.034	2.043	2.052	260
270	2.052	2.061	2.070	2.078	2.087	2.096	2.105	2.114	2.123	2.132	2.141	270
280	2.141	2.151	2.160	2.169	2.178	2.187	2.196	2.205	2.214	2.223	2.232	280
290	2.232	2.241	2.250	2.259	2.268	2.277	2.287	2.296	2.305	2.314	2.323	290
300	2.323	2.332	2.341	2.350	2.360	2.369	2.378	2.387	2.396	2.405	2.415	300
310	2.415	2.424	2.433	2.442	2.451	2.461	2.470	2.479	2.488	2.497	2.507	310
320	2.507	2.516	2.525	2.534	2.544	2.553	2.562	2.571	2.581	2.590	2.599	320
330	2.599	2.609	2.618	2.627	2.636	2.646	2.655	2.664	2.674	2.683	2.692	330
340	2.692	2.702	2.711	2.720	2.730	2.739	2.748	2.758	2.767	2.776	2.786	340
350	2.786	2.795	2.805	2.814	2.823	2.833	2.842	2.851	2.861	2.870	2.880	350
360	2.880	2.889	2.899	2.908	2.917	2.927	2.936	2.946	2.955	2.965	2.974	360
370	2.974	2.983	2.993	3.002	3.012	3.021	3.031	3.040	3.050	3.059	3.069	370
380	3.069	3.078	3.088	3.097	3.107	3.116	3.126	3.135	3.145	3.154	3.164	380
390	3.164	3.173	3.183	3.192	3.202	3.212	3.221	3.231	3.240	3.250	3.259	390
400	3.259	3.269	3.279	3.288	3.298	3.307	3.317	3.326	3.336	3.346	3.355	400
410	3.355	3.365	3.374	3.384	3.394	3.403	3.413	3.423	3.432	3.442	3.451	410
420	3.451	3.461	3.471	3.480	3.490	3.500	3.509	3.519	3.529	3.538	3.548	420
430	3.548	3.558	3.567	3.577	3.587	3.596	3.606	3.616	3.626	3.635	3.645	430
440	3.645	3.655	3.664	3.674	3.684	3.694	3.703	3.713	3.723	3.732	3.742	440
450	3.742	3.752	3.762	3.771	3.781	3.791	3.801	3.810	3.820	3.830	3.840	450
460	3.840	3.850	3.859	3.869	3.879	3.889	3.898	3.908	3.918	3.928	3.938	460
470	3.938	3.947	3.957	3.967	3.977	3.987	3.997	4.006	4.016	4.026	4.036	470
480	4.036	4.046	4.056	4.065	4.075	4.085	4.095	4.105	4.115	4.125	4.134	480
490	4.134	4.144	4.154	4.164	4.174	4.184	4.194	4.204	4.213	4.223	4.233	490
500	4.233	4.243	4.253	4.263	4.273	4.283	4.293	4.303	4.313	4.323	4.332	500
510	4.332	4.342	4.352	4.362	4.372	4.382	4.392	4.402	4.412	4.422	4.432	510
520	4.432	4.442	4.452	4.462	4.472	4.482	4.492	4.502	4.512	4.522	4.532	520
530	4.532	4.542	4.552	4.562	4.572	4.582	4.592	4.602	4.612	4.622	4.632	530
540	4.632	4.642	4.652	4.662	4.672	4.682	4.692	4.702	4.712	4.722	4.732	540
°C	0	1	2	3	4	5	6	7	8	9	10	°C

°C	0	1	2	3	4	5	6	7	8	9	10	°C
550	4.732	4.742	4.752	4.762	4.772	4.782	4.793	4.803	4.813	4.823	4.833	550
560	4.833	4.843	4.853	4.863	4.873	4.883	4.893	4.904	4.914	4.924	4.934	560
570	4.934	4.944	4.954	4.964	4.974	4.984	4.995	5.005	5.015	5.025	5.035	570
580	5.035	5.045	5.055	5.066	5.076	5.086	5.096	5.106	5.116	5.127	5.137	580
590	5.137	5.147	5.157	5.167	5.178	5.188	5.198	5.208	5.218	5.228	5.239	590
600	5.239	5.249	5.259	5.269	5.280	5.290	5.300	5.310	5.320	5.331	5.341	600
610	5.341	5.351	5.361	5.372	5.382	5.392	5.402	5.413	5.423	5.433	5.443	610
620	5.443	5.454	5.464	5.474	5.485	5.495	5.505	5.515	5.526	5.536	5.546	620
630	5.546	5.557	5.567	5.577	5.588	5.598	5.608	5.618	5.629	5.639	5.649	630
640	5.649	5.660	5.670	5.680	5.691	5.701	5.712	5.722	5.732	5.743	5.753	640
650	5.753	5.763	5.774	5.784	5.794	5.805	5.815	5.826	5.836	5.846	5.857	650
660	5.857	5.867	5.878	5.888	5.898	5.909	5.919	5.930	5.940	5.950	5.961	660
670	5.961	5.971	5.982	5.992	6.003	6.013	6.024	6.034	6.044	6.055	6.065	670
680	6.065	6.076	6.086	6.097	6.107	6.118	6.128	6.139	6.149	6.160	6.170	680
690	6.170	6.181	6.191	6.202	6.212	6.223	6.233	6.244	6.254	6.265	6.275	690
700	6.275	6.286	6.296	6.307	6.317	6.328	6.338	6.349	6.360	6.370	6.381	700
710	6.381	6.391	6.402	6.412	6.423	6.434	6.444	6.455	6.465	6.476	6.486	710
720	6.486	6.497	6.508	6.518	6.529	6.539	6.550	6.561	6.571	6.582	6.593	720
730	6.593	6.603	6.614	6.624	6.635	6.646	6.656	6.667	6.678	6.688	6.699	730
740	6.699	6.710	6.720	6.731	6.742	6.752	6.763	6.774	6.784	6.795	6.806	740
750	6.806	6.817	6.827	6.838	6.849	6.859	6.870	6.881	6.892	6.902	6.913	750
760	6.913	6.924	6.934	6.945	6.956	6.967	6.977	6.988	6.999	7.010	7.020	760
770	7.020	7.031	7.042	7.053	7.064	7.074	7.085	7.096	7.107	7.117	7.128	770
780	7.128	7.139	7.150	7.161	7.172	7.182	7.193	7.204	7.215	7.226	7.236	780
790	7.236	7.247	7.258	7.269	7.280	7.291	7.302	7.312	7.323	7.334	7.345	790
800	7.345	7.356	7.367	7.378	7.388	7.399	7.410	7.421	7.432	7.443	7.454	800
810	7.454	7.465	7.476	7.487	7.497	7.508	7.519	7.530	7.541	7.552	7.563	810
820	7.563	7.574	7.585	7.596	7.607	7.618	7.629	7.640	7.651	7.662	7.673	820
830	7.673	7.684	7.695	7.706	7.717	7.728	7.739	7.750	7.761	7.772	7.783	830
840	7.783	7.794	7.805	7.816	7.827	7.838	7.849	7.860	7.871	7.882	7.893	840
850	7.893	7.904	7.915	7.926	7.937	7.948	7.959	7.970	7.981	7.992	8.003	850
860	8.003	8.014	8.026	8.037	8.048	8.059	8.070	8.081	8.092	8.103	8.114	860
870	8.114	8.125	8.137	8.148	8.159	8.170	8.181	8.192	8.203	8.214	8.226	870
880	8.226	8.237	8.248	8.259	8.270	8.281	8.293	8.304	8.315	8.326	8.337	880
890	8.337	8.348	8.360	8.371	8.382	8.393	8.404	8.416	8.427	8.438	8.449	890
900	8.449	8.460	8.472	8.483	8.494	8.505	8.517	8.528	8.539	8.550	8.562	900
910	8.562	8.573	8.584	8.595	8.607	8.618	8.629	8.640	8.652	8.663	8.674	910
920	8.674	8.685	8.697	8.708	8.719	8.731	8.742	8.753	8.765	8.776	8.787	920
930	8.787	8.798	8.810	8.821	8.832	8.844	8.855	8.866	8.878	8.889	8.900	930
940	8.900	8.912	8.923	8.935	8.946	8.957	8.969	8.980	8.991	9.003	9.014	940
950	9.014	9.025	9.037	9.048	9.060	9.071	9.082	9.094	9.105	9.117	9.128	950
960	9.128	9.139	9.151	9.162	9.174	9.185	9.197	9.208	9.219	9.231	9.242	960
970	9.242	9.254	9.265	9.277	9.288	9.300	9.311	9.323	9.334	9.345	9.357	970
980	9.357	9.368	9.380	9.391	9.403	9.414	9.426	9.437	9.449	9.460	9.472	980
990	9.472	9.483	9.495	9.506	9.518	9.529	9.541	9.552	9.564	9.576	9.587	990
1000	9.587	9.599	9.610	9.622	9.633	9.645	9.656	9.668	9.680	9.691	9.703	1000
1010	9.703	9.714	9.726	9.737	9.749	9.761	9.772	9.784	9.795	9.807	9.819	1010
1020	9.819	9.830	9.842	9.853	9.865	9.877	9.888	9.900	9.911	9.923	9.935	1020
1030	9.935	9.946	9.958	9.970	9.981	9.993	10.005	10.016	10.028	10.040	10.051	1030
1040	10.051	10.063	10.075	10.086	10.098	10.110	10.121	10.133	10.145	10.156	10.168	1040
1050	10.168	10.180	10.191	10.203	10.215	10.227	10.238	10.250	10.262	10.273	10.285	1050
1060	10.285	10.297	10.309	10.320	10.332	10.344	10.356	10.367	10.379	10.391	10.403	1060
1070	10.403	10.414	10.426	10.438	10.450	10.461	10.473	10.485	10.497	10.509	10.520	1070
1080	10.520	10.532	10.544	10.556	10.567	10.579	10.591	10.603	10.615	10.626	10.638	1080
1090	10.638	10.650	10.662	10.674	10.686	10.697	10.709	10.721	10.733	10.745	10.757	1090
1100	10.757	10.768	10.780	10.792	10.804	10.816	10.828	10.839	10.851	10.863	10.875	1100
1110	10.875	10.887	10.899	10.911	10.922	10.934	10.946	10.958	10.970	10.982	10.994	1110
1120	10.994	11.006	11.017	11.029	11.041	11.053	11.065	11.077	11.089	11.101	11.113	1120
1130	11.113	11.125	11.136	11.148	11.160	11.172	11.184	11.196	11.208	11.220	11.232	1130
1140	11.232	11.244	11.256	11.268	11.280	11.291	11.303	11.315	11.327	11.339	11.351	1140
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Revised Thermocouple Reference Tables

TYPE S

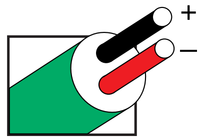
Reference Tables N.I.S.T. Monograph 175 Revised to ITS-90



Thermocouple Grade

NONE ESTABLISHED

Platinum-10% Rhodium vs. Platinum



Extension Grade

MAXIMUM TEMPERATURE RANGE

Thermocouple Grade
32 to 2642°F
0 to 1450°C

Extension Grade
32 to 300°F
0 to 150°C

LIMITS OF ERROR
(whichever is greater)
Standard: 1.5°C or 0.25%
Special: 0.6°C or 0.1%

COMMENTS, BARE WIRE ENVIRONMENT:
Oxidizing or Inert; Do Not Insert in Metal Tubes; Beware of Contamination; High Temperature

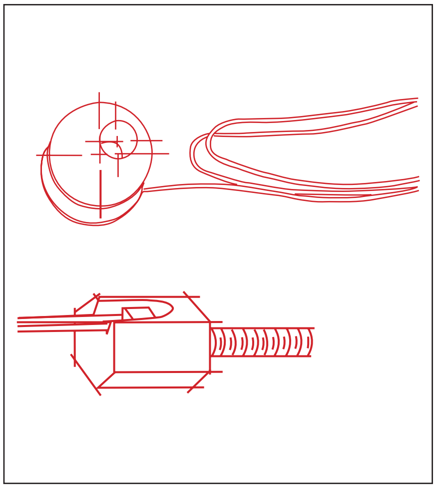
TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

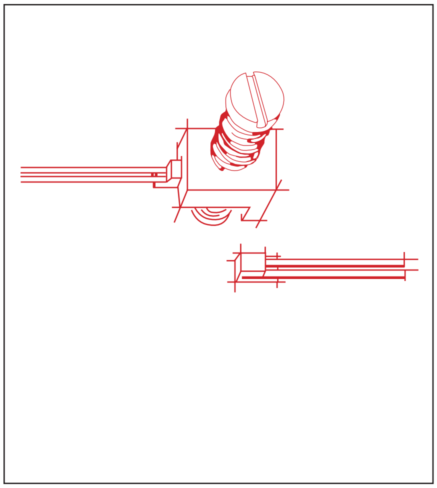
Thermoelectric Voltage in Millivolts

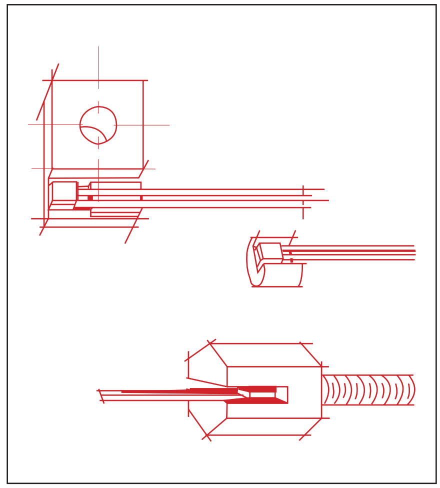
°C	0	1	2	3	4	5	6	7	8	9	10	°C
1150	11.351	11.363	11.375	11.387	11.399	11.411	11.423	11.435	11.447	11.459	11.471	1150
1160	11.471	11.483	11.495	11.507	11.519	11.531	11.542	11.554	11.566	11.578	11.590	1160
1170	11.590	11.602	11.614	11.626	11.638	11.650	11.662	11.674	11.686	11.698	11.710	1170
1180	11.710	11.722	11.734	11.746	11.758	11.770	11.782	11.794	11.806	11.818	11.830	1180
1190	11.830	11.842	11.854	11.866	11.878	11.890	11.902	11.914	11.926	11.939	11.951	1190
1200	11.951	11.963	11.975	11.987	11.999	12.011	12.023	12.035	12.047	12.059	12.071	1200
1210	12.071	12.083	12.095	12.107	12.119	12.131	12.143	12.155	12.167	12.179	12.191	1210
1220	12.191	12.203	12.216	12.228	12.240	12.252	12.264	12.276	12.288	12.300	12.312	1220
1230	12.312	12.324	12.336	12.348	12.360	12.372	12.384	12.397	12.409	12.421	12.433	1230
1240	12.433	12.445	12.457	12.469	12.481	12.493	12.505	12.517	12.529	12.542	12.554	1240
1250	12.554	12.566	12.578	12.590	12.602	12.614	12.626	12.638	12.650	12.662	12.675	1250
1260	12.675	12.687	12.699	12.711	12.723	12.735	12.747	12.759	12.771	12.783	12.796	1260
1270	12.796	12.808	12.820	12.832	12.844	12.856	12.868	12.880	12.892	12.905	12.917	1270
1280	12.917	12.929	12.941	12.953	12.965	12.977	12.989	13.001	13.014	13.026	13.038	1280
1290	13.038	13.050	13.062	13.074	13.086	13.098	13.111	13.123	13.135	13.147	13.159	1290
1300	13.159	13.171	13.183	13.195	13.208	13.220	13.232	13.244	13.256	13.268	13.280	1300
1310	13.280	13.292	13.305	13.317	13.329	13.341	13.353	13.365	13.377	13.390	13.402	1310
1320	13.402	13.414	13.426	13.438	13.450	13.462	13.474	13.487	13.499	13.511	13.523	1320
1330	13.523	13.535	13.547	13.559	13.572	13.584	13.596	13.608	13.620	13.632	13.644	1330
1340	13.644	13.657	13.669	13.681	13.693	13.705	13.717	13.729	13.742	13.754	13.766	1340
1350	13.766	13.778	13.790	13.802	13.814	13.826	13.839	13.851	13.863	13.875	13.887	1350
1360	13.887	13.899	13.911	13.924	13.936	13.948	13.960	13.972	13.984	13.996	14.009	1360
1370	14.009	14.021	14.033	14.045	14.057	14.069	14.081	14.094	14.106	14.118	14.130	1370
1380	14.130	14.142	14.154	14.166	14.178	14.191	14.203	14.215	14.227	14.239	14.251	1380
1390	14.251	14.263	14.276	14.288	14.300	14.312	14.324	14.336	14.348	14.360	14.373	1390
1400	14.373	14.385	14.397	14.409	14.421	14.433	14.445	14.457	14.470	14.482	14.494	1400
1410	14.494	14.506	14.518	14.530	14.542	14.554	14.567	14.579	14.591	14.603	14.615	1410
1420	14.615	14.627	14.639	14.651	14.664	14.676	14.688	14.700	14.712	14.724	14.736	1420
1430	14.736	14.748	14.760	14.773	14.785	14.797	14.809	14.821	14.833	14.845	14.857	1430
1440	14.857	14.869	14.881	14.894	14.906	14.918	14.930	14.942	14.954	14.966	14.978	1440
1450	14.978	14.990	15.002	15.015	15.027	15.039	15.051	15.063	15.075	15.087	15.099	1450
1460	15.099	15.111	15.123	15.135	15.148	15.160	15.172	15.184	15.196	15.208	15.220	1460
1470	15.220	15.232	15.244	15.256	15.268	15.280	15.292	15.304	15.317	15.329	15.341	1470
1480	15.341	15.353	15.365	15.377	15.389	15.401	15.413	15.425	15.437	15.449	15.461	1480
1490	15.461	15.473	15.485	15.497	15.509	15.521	15.534	15.546	15.558	15.570	15.582	1490
°C	0	1	2	3	4	5	6	7	8	9	10	°C

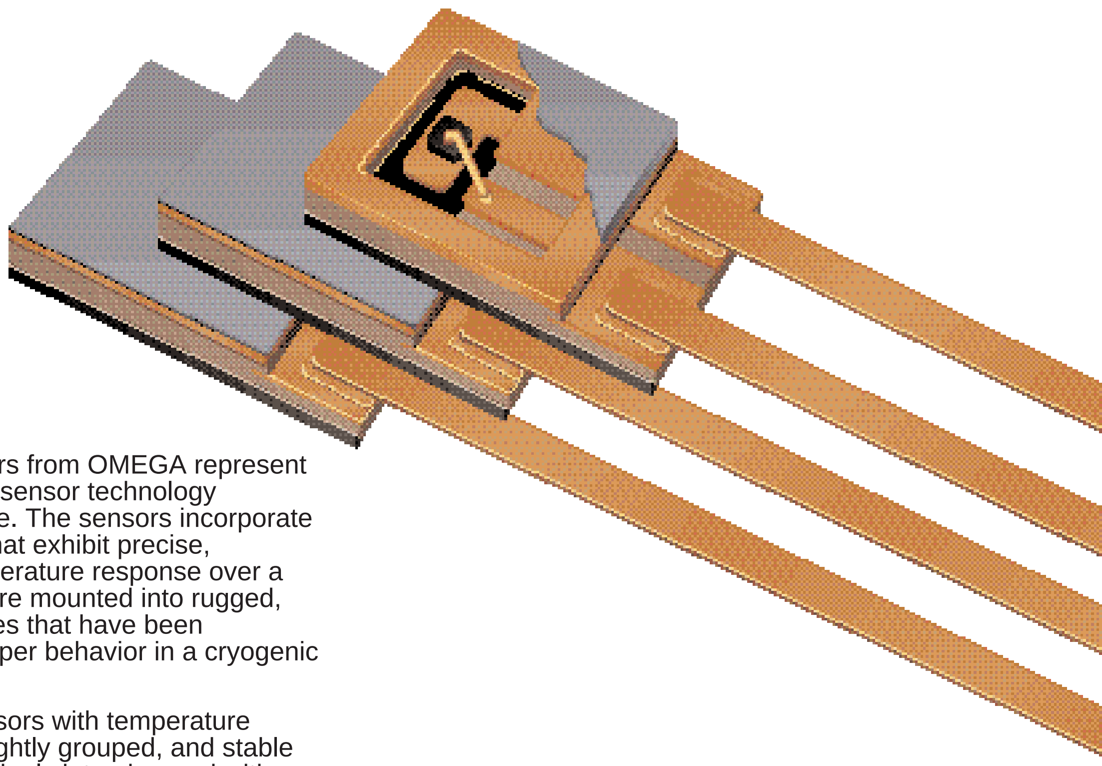
°C	0	1	2	3	4	5	6	7	8	9	10	°C
1500	15.582	15.594	15.606	15.618	15.630	15.642	15.654	15.666	15.678	15.690	15.702	1500
1510	15.702	15.714	15.726	15.738	15.750	15.762	15.774	15.786	15.798	15.810	15.822	1510
1520	15.822	15.834	15.846	15.858	15.870	15.882	15.894	15.906	15.918	15.930	15.942	1520
1530	15.942	15.954	15.966	15.978	15.990	16.002	16.014	16.026	16.038	16.050	16.062	1530
1540	16.062	16.074	16.086	16.098	16.110	16.122	16.134	16.146	16.158	16.170	16.182	1540
1550	16.182	16.194	16.205	16.217	16.229	16.241	16.253	16.265	16.277	16.289	16.301	1550
1560	16.301	16.313	16.325	16.337	16.349	16.361	16.373	16.385	16.396	16.408	16.420	1560
1570	16.420	16.432	16.444	16.456	16.468	16.480	16.492	16.504	16.516	16.527	16.539	1570
1580	16.539	16.551	16.563	16.575	16.587	16.599	16.611	16.623	16.634	16.646	16.658	1580
1590	16.658	16.670	16.682	16.694	16.706	16.718	16.729	16.741	16.753	16.765	16.777	1590
1600	16.777	16.789	16.801	16.812	16.824	16.836	16.848	16.860	16.872	16.883	16.895	1600
1610	16.895	16.907	16.919	16.931	16.943	16.954	16.966	16.978	16.990	17.002	17.013	1610
1620	17.013	17.025	17.037	17.049	17.061	17.072	17.084	17.096	17.108	17.120	17.131	1620
1630	17.131	17.143	17.155	17.167	17.178	17.190	17.202	17.214	17.225	17.237	17.249	1630
1640	17.249	17.261	17.272	17.284	17.296	17.308	17.319	17.331	17.343	17.355	17.366	1640
1650	17.366	17.378	17.390	17.401	17.413	17.425	17.437	17.448	17.460	17.472	17.483	1650
1660	17.483	17.495	17.507	17.518	17.530	17.542	17.553	17.565	17.577	17.588	17.600	1660
1670	17.600	17.612	17.623	17.635	17.647	17.658	17.670	17.682	17.693	17.705	17.717	1670
1680	17.717	17.728	17.740	17.751	17.763	17.775	17.786	17.798	17.809	17.821	17.832	1680
1690	17.832	17.844	17.855	17.867	17.878	17.890	17.901	17.913	17.924	17.936	17.947	1690
1700	17.947	17.959	17.970	17.982	17.993	18.004	18.016	18.027	18.039	18.050	18.061	1700
1710	18.061	18.073	18.084	18.095	18.107	18.118	18.129	18.140	18.152	18.163	18.174	1710
1720	18.174	18.185	18.196	18.208	18.219	18.230	18.241	18.252	18.263	18.274	18.285	1720
1730	18.285	18.297	18.308	18.319	18.330	18.341	18.352	18.362	18.373	18.384	18.395	1730
1740	18.395	18.406	18.417	18.428	18.439	18.449	18.460	18.471	18.482	18.493	18.503	1740
1750	18.503	18.514	18.525	18.535	18.546	18.557	18.567	18.578	18.588	18.599	18.609	1750
1760	18.609	18.620	18.630	18.641	18.651	18.661	18.672	18.682	18.693			1760
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Cryogenic Temperature Sensors
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 Z-93, 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 is 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 must the effect of any measurement-induced self-heating of the sensor, if one is to achieve accurate results. In addition, the package must also withstand repeated cycling to low temperatures without mechanical failure.

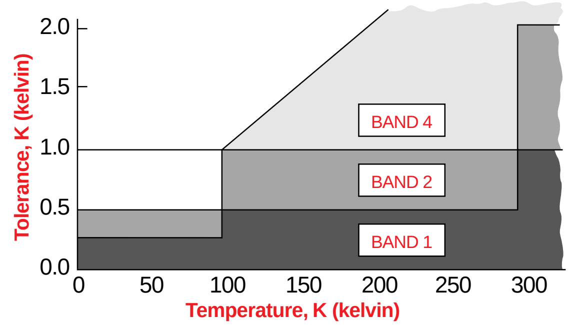
Cryogenic Temperature Sensors
CY7 Series

The development of the CY7 Series has included the design of 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.

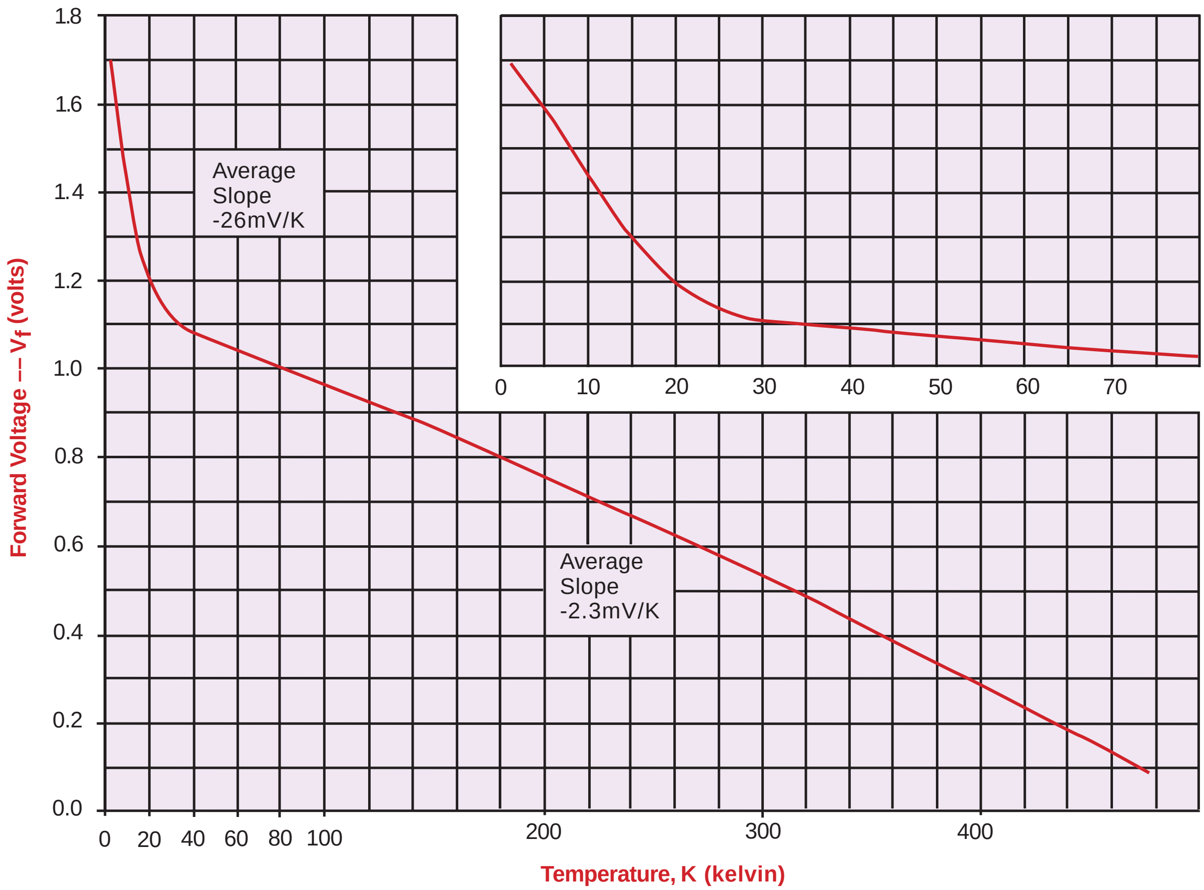
10 Microampere Excitation Current

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

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, OMEGA® CY7 sensors exhibit variations as low as 5 millikelvin.



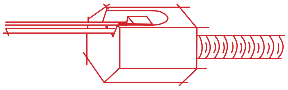
Tolerance Bands for CY7 Series Sensors allow selection of appropriate (and economical) accuracy levels for a given application.



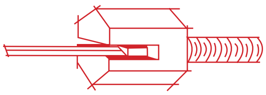
Standard Temperature Response (Curve 10) for CY7 Series Sensors. All Sensors Track this Curve Within Specified Tolerance Bands.

Select the Sensor Configuration Best Suited to Your Application

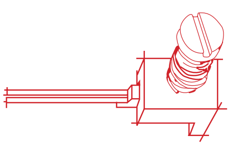
CY7-SD The SD configuration is the smallest package in this series, and is designed primarily for bonding or clamping to a flat surface. Since the sensing element is in best thermal contact with the base (largest surface) of the package, the package should be mounted with that same surface in good contact with the sample. Mounting materials and methods which will not expose the sensor to temperatures above 200ºC 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.



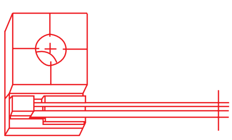
CY7-ET This convenient screw-in package is formed by soldering a basic SD configuration into a recess in one flat of a hexagonal cylinder. The cylinder terminates in a standard 6-32 SAE thread. Thus the sensor can be threaded (finger tight only) into a mounting hole in the sample. A light coating of 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 adaptor 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.

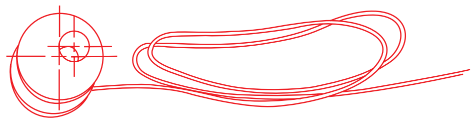


CY7-CO A spring-loaded clamp holds a standard SD sensor in contact with the surface of the sample in this configuration. This allows the sensor to be easily changed or replaced. It also enables the sensor to be used over its full operational temperature range of 1.4 to 475 K. Extra clamps are available 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.

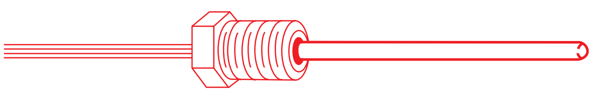
CY7-LR With a CY7-SD sensor mounted on a slightly more than half-round cylinder, this package is designed to be inserted into a 1/8 inch (3.2 mm) diameter hole. Low temperature epoxy can also be used to install the sensor, although the mounting is much more permanent in that case. As with other soldered 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's color coded cryogenic wire. Temperature range is 1.4 to 325 K.

CY7-D1 This is a two-lead version of the the CY7-CU.

CY7-CY Some applications are best served by a relatively large, 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

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

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

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

The Chebychev polynomials can be generated from the recursion relation

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

Alternately, these polynomials are given by

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

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 that 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 1
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
```

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