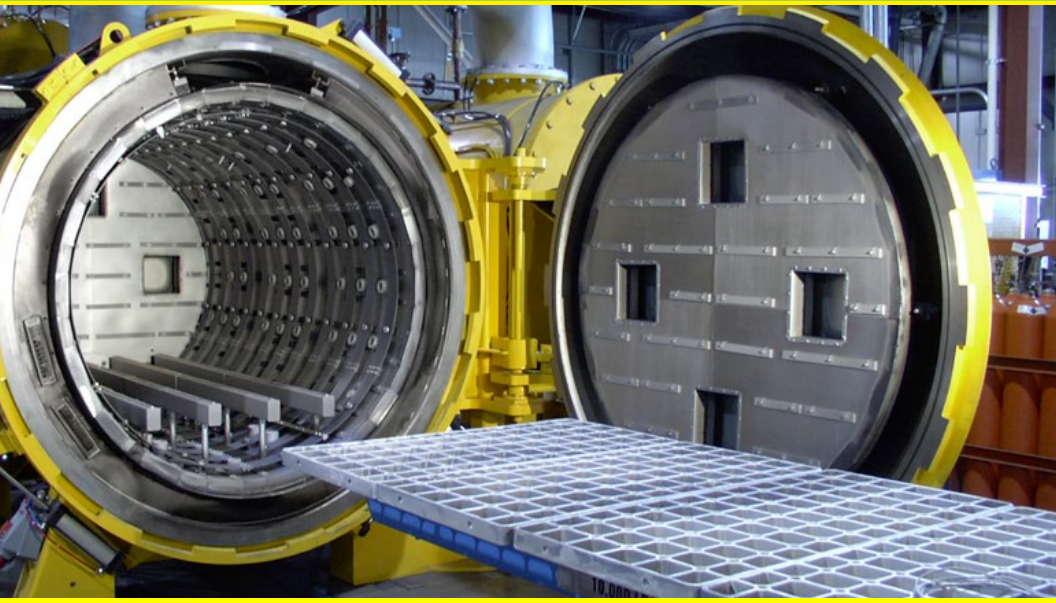


# Critical Melting Points and Reference Data for Vacuum Heat Treating



SOLAR ATMOSPHERES, INC.

# Critical Melting Points and Reference Data for Vacuum Heat Treating

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## **Acknowledgments**

This work is an update of the original reference compilation by the late Charles F. Burns, Jr., Copyright 1997. The current booklet contains revisions to the original work as well as numerous additions. This booklet should serve as a handy reference for people who work in the metals industry.

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## **Limitations**

This data is for reference only. Solar Atmospheres, Inc. will not assume liability for accuracy.

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## DEFINITIONS

### ALLOY

[MET] Any of a large number of substances having metallic properties consisting of two or more elements; at least one component must be a metal.

### EUTECTIC ALLOY

[Met] A material, predominantly one of a specific microstructure, made up of two or more phases formed simultaneously during solidification of two or more elements. A eutectic alloy melts to become a free running liquid at a single temperature, which is lower than the melting point of any of its components.

### EMISSIVITY

The ratio defined by the radiation emitted by a surface to the radiation emitted by a black body at the same temperature.

### MELTING OF PURE SUBSTANCES

[Chem] The temperature, at given pressure, upon which a chemically pure substance changes from a solid state to a liquid state.

### MELTING POINT OF MIXTURES OR ALLOYS

[MET] Unlike pure metals, many alloys do not have a single melting point. Instead, they have a melting range in which the material is a mixture of solid and liquid phases during the melting process. The temperature at which melting begins is called the solidus, and that at which melting is complete is called the liquidus. Special alloys can be designed with a single melting point, however, and these are called eutectic mixtures.

### VAPOR PRESSURE

The vapor pressure of a substance (liquid or solid) is the equilibrium pressure of a vapor above the substance; in other words the vapor (formed from evaporation or sublimation) above the substance when in a closed container.

*When working in vacuum one must recognize that even if the work is not at the boiling point for the substance there is always vapor forming above the surface and excessive heating of a substance under vacuum has the possibility of evaporating the substance. For example at 760 Torr and 50 °C, if water is heated for an extended period in an open container the water will eventually evaporate. Therefore, care must be used when heating under vacuum at high temperatures if one is at or near the known vapor pressure of a substance.*

### SUBLIMATION

A phase change process in which a material passes from a solid state to a gaseous state without becoming a liquid.

**MELTING POINTS OF THE ELEMENTS**  
(atmospheric pressure), (s) = sublimes

<b>ELEMENT</b>	<b>SYMBOL</b>	<b>MELTING POINT °F</b>	<b>MELTING POINT °C</b>
Aluminum	Al	1220	660
Antimony	Sb	1168	631
Arsenic	As	1135 (s)	613 (s)
Barium	Ba	1341	727
Beryllium	Be	2348.6	1287
Bismuth	Bi	520	271.3
Boron	B	3767	2075
Cadmium	Cd	610	321
Calcium	Ca	1544	840
Carbon	C	6588 (s)	3642 (s)
Cerium	Ce	1468	798
Cesium	Cs	83.4	28.4
Chromium	Cr	3465	1907
Cobalt	Co	2723	1495
Copper	Cu	1981	1083
Columbium (Niobium)	Cb	4491	2477
Dysprosium	Dy	2574	1412
Erbium	Er	2784	1529
Europium	Eu	1512	822
Gallium	Ga	86	30
Germanium	Ge	1719	937
Gold	Au	1947	1064
Hafnium	Hf	4051	2233
Indium	In	314	157
Iodine	I	237	114
Iridium	Ir	4435	2446
Iron	Fe	2795	1535
Lanthanum	La	1684	918
Lead	Pb	622	328
Lithium	Li	358	181
Magnesium	Mg	1202	650
Manganese	Mn	2275	1246
Mercury	Hg	-37.97	-38.87
Molybdenum	Mo	4748	2620

**MELTING POINTS OF THE ELEMENTS**  
(atmospheric pressure), (s) = sublimes

<b>ELEMENT</b>	<b>SYMBOL</b>	<b>MELTING POINT °F</b>	<b>MELTING POINT °C</b>
Neodymium	Nd	1870	1021
Nickel	Ni	2647	1453
Niobium (Columbium)	Nb	4491	2477
Osmium	Os	5491	3033
Palladium	Pd	2826	1552
Phosphorus	P	111	44
Platinum	Pt	3214	1768
Potassium	K	147	64
Praseodymium	Pr	1708	931
Rhenium	Re	5756	3180
Rhodium	Rh	3567	1964
Rubidium	Rb	102	39
Ruthenium	Ru	4233	2334
Scandium	Sc	2802	1539
Selenium	Se	422	217
Silicon	Si	2570	1410
Silver	Ag	1764	962
Sodium	Na	208	98
Strontium	Sr	1431	777
Sulfur	S	239	115
Tantalum	Ta	5425	2996
Tellurium	Te	842	450
Thallium	Tl	579	304
Thorium	Th	3182	1750
Tin	Sn	450	232
Titanium	Ti	3034	1668
Tungsten	W	6192	3422
Uranium	U	2070	1132
Vanadium	V	3434	1890
Yttrium	Y	2773	1523
Zinc	Zn	788	420
Zirconium	Zr	3366	1852

**MELTING POINTS**  
Stainless Steels

<b>ALLOY</b>	<b>MELTING RANGE °F</b>	<b>MELTING RANGE °C</b>
301 S/S	2550-2590	1400-1420
302 S/S	2550-2590	1400-1420
302B S/S	2500-2550	1370-1400
303 S/S	2550-2590	1400-1420
304 S/S	2550-2650	1400-1455
305 S/S	2550-2650	1400-1455
308 S/S	2550-2650	1400-1455
309 S/S	2550-2650	1400-1455
310 S/S	2550-2650	1400-1455
314 S/S	2412-2530	1322-1388
316 S/S	2500-2550	1370-1400
317 S/S	2500-2550	1370-1400
321 S/S	2550-2600	1400-1425
330 S/S	2550-2600	1400-1425
347 S/S	2550-2600	1400-1425
384 S/S	2550-2650	1400-1455
403 S/S	2700-2790	1480-1530
405 S/S	2700-2790	1480-1530
409 S/S	2600-2750	1425-1510
410 S/S	2700-2790	1480-1530
416 S/S	2700-2790	1480-1530
420 S/S	2650-2750	1455-1510
430 S/S	2650-2750	1455-1510
430F S/S	2550-2650	1400-1455
431 S/S	2600-2700	1476-1482
440A S/S	2500-2750	1370-1510
440B S/S	2500-2750	1370-1510
440C S/S	2500-2750	1370-1510
442,443,446 S/S	2600-2750	1425-1510
501 S/S	2700-2800	1480-1540
502 S/S	2700-2800	1480-1540



**MELTING POINTS**  
Corrosion-Resistant Steel Castings

<b>ALLOY</b>	<b>MELTING POINT °F</b>	<b>MELTING POINT °C</b>
CA-15	2750	1510
CA-40	2750	1510
CB-30	2725	1496
CC-50	2725	1496
CE-30	2650	1454
CF-8	2600	1427
CF-20	2575	1413
CF-8M	2550	1399
CF-12M	2550	1399
CF-8C	2600	1427
CF-16F	2550	1399
CH-20	2600	1427
CK-20	2600	1427
CN-7M	2650	1454

**MELTING POINTS**  
Heat-Resistant Alloy Castings

<b>ALLOY</b>	<b>MELTING POINT °F</b>	<b>MELTING POINT °C</b>
HA	2750	1510
HC	2725	1496
HD	2700	1482
HE	2650	1454
HF	2550	1399
HH	2500	1371
HI	2550	1399
HK	2550	1399
HL	2600	1427
HN	2500	1371
HP	2450	1343
HT	2450	1343
HU	2450	1343
HW	2350	1288
HX	2350	1288

**MELTING POINTS**  
Aluminum Alloys

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
EC	1215	657
1060	1195-1215	646-657
1100	1190-1215	643-657
2011	1005-1190	541-643
2014	945-1180	507-637
2024	935-1180	507-638
2218	940-1175	504-635
3003	1190-1210	643-654
4032	990-1060	532-571
5005	1170-1210	632-654
5050	1155-1205	624-652
5052	1125-1200	607-649
5056	1055-1180	568-638
5083	1095-1180	591-638
5086	1085-1185	585-641
5154	1100-1190	545-643
5357	1210	654
5456	1055-1180	568-638
6061	1080-1205	582-652
6063	1140-1210	616-654
6101	1150-1210	621-654
6151	1090-1200	588-649
7075	890-1175	477-635
7079	1180	637
7178	890-1165	477-629

**MELTING POINTS**  
**Aluminum Casting Alloys**

<b>ALLOY</b>	<b>MELTING RANGE °F</b>	<b>MELTING RANGE °C</b>
201.0	1060-1200	570-650
206.0	1060-1200	570-650
A206.0	1060-1200	570-650
208.0	970-1170	520-630
222.0	970-1160	520-625
224.0	1020-1190	550-645
238.0	950-1110	510-600
240.0	960-1120	515-605
242.0	990-1180	530-635
295.0	970-1190	520-645
296.0	970-1170	520-630
308.0	970-1140	520-615
319.0	970-1120	520-605
324.0	1010-1120	545-605
332.0	970-1080	520-580
333.0	970-1090	520-585
336.0	1000-1060	540-570
354.0	1000-1110	540-600
355.0	1020-1150	550-620
C355.0	1020-1150	550-620
356.0	1040-1140	560-615
A356.0	1040-1130	560-610
357.0	1040-1140	560-615
A357.0	1030-1130	555-610
358.0	1040-1110	560-600
359.0	1050-1110	565-600
360.0	1060-1090	570-590
A360.0	1060-1090	570-590
364.0	1040-1110	560-600
380.0	970-1090	520-590
A380.0	970-1090	520-590

**MELTING POINTS**  
**Aluminum Casting Alloys**

<b>ALLOY</b>	<b>MELTING RANGE °F</b>	<b>MELTING RANGE °C</b>
384.0	<b>900-1080</b>	480-580
390.0	<b>950-1200</b>	510-650
392.0	<b>1020-1240</b>	550-670
413.0	<b>1070-1090</b>	575-585
A413.0	<b>1070-1090</b>	575-585
443.0	<b>1070-1170</b>	575-630
A444.0	<b>1070-1170</b>	575-630
511.0	<b>1090-1180</b>	590-640
512.0	<b>1090-1170</b>	590-630
513.0	<b>1080-1180</b>	580-640
514.0	<b>1110-1180</b>	600-640
518.0	<b>1000-1150</b>	540-620
520.0	<b>840-1110</b>	450-600
535.0	<b>1020-1170</b>	550-630
A535.0	<b>1020-1150</b>	550-620
B535.0	<b>1020-1170</b>	550-630
705.0	<b>1110-1180</b>	600-640
707.0	<b>1090-1170</b>	585-630
710.0	<b>1110-1200</b>	600-650
711.0	<b>1110-1190</b>	600-645
712.0	<b>1110-1180</b>	600-640
713.0	<b>1100-1170</b>	595-630
850.0	<b>440-1200</b>	225-650
851.0	<b>450-1170</b>	230-630
852.0	<b>410-1180</b>	210-635

**MELTING POINTS****Copper Alloys**

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
C10200 (Oxygen Free)	<b>1950-1980</b>	1065-1083
C11000 (Copper ETP)	<b>1950-1980</b>	1065-1083
C12000 (Copper DLP)	<b>1981</b>	1083
C12200 (Copper DHP)	<b>1981</b>	1083
C14500 (Free Machining [Te])	<b>1924-1967</b>	1051-1075
C17000 (Beryllium Copper)	<b>1590-1800</b>	805-980
C21000 (Gilding)	<b>1920-1950</b>	1050-1066
C22000 (Commercial Bronze [90% Cu])	<b>1870-1910</b>	1020-1043
C22600 (Jewelry Bronze [87.5% Cu])	<b>1840-1890</b>	1005-1035
C23000 (Red Brass [85% Cu])	<b>1810-1880</b>	990-1027
C24000 (Low Brass [80% Cu])	<b>1770-1830</b>	965-1000
C26000 (Cartridge Brass [70% Cu])	<b>1680-1750</b>	915-954
C27000 (Yellow Brass [65% Cu])	<b>1660-1710</b>	905-932
C280000 (Muntz Metal [60% Cu])	<b>1650-1660</b>	900-904
C31400 (Leaded Commercial Bronze)	<b>1850-1900</b>	1010-1038
C33000 Low Leaded Brass [0.5% Pb])	<b>1660-1720</b>	905-938
C34000 (Medium Leaded Brass [1% Pb])	<b>1630-1700</b>	885-927
C35300 (High Leaded Brass [1.6% Pb])	<b>1650-1710</b>	900-932
C34200 (High Leaded Brass [2% Pb])	<b>1630-1670</b>	885-910
C35600 (Extra High Leaded Brass [2.5% Pb])	<b>1630-1660</b>	885-904
C36000 (Free Cutting Brass)	<b>1630-1650</b>	885-900
C36500 (Leaded Muntz Metal)	<b>1630-1650</b>	885-900
C37700 (Forging Brass)	<b>1620-1640</b>	880-893
C38500 (Architectural Bronze)	<b>1610-1630</b>	875-888
C44400 (Inhibited Admiralty)	<b>1650-1720</b>	900-938
C46400 (Naval Brass)	<b>1630-1650</b>	885-900
C50500 (Phosphor Bronze [1.25% Sn])	<b>1890-1970</b>	1035-1077
C51000 (Phosphor Bronze [5% Sn])	<b>1790-1940</b>	975-1060
C52100 (Phosphor Bronze [8% Sn])	<b>1620-1880</b>	880-1027
C52400 (Phosphor Bronze [10% Sn])	<b>1550-1830</b>	845-1000
C54400 (Free Cutting Phosphor Bronze)	<b>1710-1830</b>	930-1000
C60600 (Aluminum Bronze [5% Al])	<b>1920-1950</b>	1050-1065

<b>MELTING POINTS</b>		
<b>Copper Alloys</b>		
<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
C61000 (Aluminum Bronze [7% Al])	<b>1900-1910</b>	1040-1045
C62300 (Aluminum Bronze [11% Al])	<b>1880-1900</b>	1025-1040
C63200 (Aluminum Bronze [9% Al])	<b>1900-1910</b>	1040-1045
C64200 (Aluminum Silicon Bronze)	<b>1800-1840</b>	985-1004
C65500 (High Silicon Bronze [3% Si])	<b>1780-1880</b>	970-1027
Low Silicon Bronze (1.5% Si)	<b>1890-1940</b>	1030-1060
C67500 (Manganese Bronze)	<b>1630-1690</b>	888-920
C70600 (Cupro-Nickel [10% Ni])	<b>2010-2100</b>	1100-1149
C71500 (Cupro-Nickel [30% Ni])	<b>2140-2260</b>	1170-1238
C75200 (Nickel-Silver [65% Cu])	<b>2030</b>	1110
C75700 (Nickel-Silver [65% Cu- 12% Ni])	<b>1900</b>	1038
C77000 (Nickel-Silver [55% Cu])	<b>1930</b>	1054

<b>MELTING POINTS</b>		
<b>Copper Casting Alloys</b>		
<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
Chrome Copper (1% Cr)	<b>1970-1990</b>	1075-1085
Tin Bronze, Alloy 1A	<b>1570-1830</b>	834-1000
Tin Bronze, Alloy 1B	<b>1570-1830</b>	834-1000
Tin Bronze, Alloy SAE 65	<b>1832</b>	1000
Navy M Bronze, Alloy 2A	<b>1520-1810</b>	825-990
Leaded Tin Bronze, Alloy 2B	<b>1570-1830</b>	854-1000
Leaded Tin Bronze, Alloy 2C	<b>1550-1800</b>	845-980
High Leaded Tin Bronze, Alloy 3A	<b>1400-1710</b>	762-930
High Leaded Tin Bronze, Alloy 3B	<b>1570-1790</b>	855-975
High Leaded Tin Bronze, Alloy 3C	<b>1570-1830</b>	855-1000
High Leaded Tin Bronze, Alloy 3D	<b>1570-1730</b>	855-945
High Leaded Tin Bronze, Alloy 3E	<b>1650-1700</b>	900-925
Leaded Red Brass, Alloy 4A	<b>1570-1850</b>	855-1010
Leaded Red Brass, Alloy 4B	<b>1550-1840</b>	845-1005
Leaded Semi Red Brass, Alloy 5A	<b>1540-1840</b>	840-1005
Leaded Semi Red Brass, Alloy 5B	<b>1530-1750</b>	832-955
Leaded Yellow Brass, Alloy 6A	<b>1700-1720</b>	925-940

**MELTING POINTS**  
**Copper Casting Alloys**

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
Leaded Yellow Brass, Alloy 6B	<b>1700-1720</b>	925-940
Manganese Bronze (59% Cu)	<b>1675</b>	913
Manganese Bronze (57.5% Cu)	<b>1616</b>	880
Manganese Bronze (64% Cu)	<b>1700</b>	937
Manganese Bronze (110,000 psi)	<b>1693</b>	923
Aluminum Bronze, Alloy 9A	<b>1900-1910</b>	1040-1045
Aluminum Bronze, Alloy 9B	<b>1900-1910</b>	1040-1045
Aluminum Bronze, Alloy 9C	<b>1880-1900</b>	1027-1040
Aluminum Bronze, Alloy 9D	<b>1900-1930</b>	1038-1055
Nickel Silver (12% Ni)	<b>Max: 1900</b>	Max: 1040
Nickel Silver (15% Ni)	<b>1850-1970</b>	1010-1075
Nickel Silver (18% Ni)	<b>Max: 1930</b>	Max: 1055
Nickel Silver (25% Ni)	<b>2300</b>	1260
Low-Silicon Bronze (1% Si)	<b>1890-1940</b>	1030-1060
High-Silicon Bronze (3% Si)	<b>1780-1880</b>	700-875
Silicon Brass	<b>1510-1680</b>	821-917

**MELTING POINTS**  
**Magnesium Alloys/Casting Alloys**

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
AM100A	<b>1101</b>	594
AZ63A	<b>1130</b>	610
AZ81A	<b>1132</b>	611
AZ91A, B & C Alloys	<b>1105</b>	596
AZ92A	<b>1100</b>	593
HK31A	<b>1090-1200</b>	590-650
HZ32A	<b>1020-1200</b>	550-650
ZH42	<b>1180</b>	638
ZH62A	<b>968-1170</b>	520-630
ZK51A	<b>1020-1180</b>	550-640
ZE41A	<b>977-1190</b>	525-645
EZ33A	<b>1010-1190</b>	545-645
EZ30A	<b>1184</b>	640
EZ41A	<b>1193</b>	645

**MELTING POINTS**  
**Magnesium Alloys/Wrought Alloys**

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
MIA	1200	649
AZ31B	1120-1170	605-632
PE	990-1170	532-632
AZ61A	785-1150	418-620
AZ80A	801-1130	421-610
ZK60A	964-1170	518-635
ZE10A	1195	646
HM21A	1120-1200	605-650
HM31A	900-1200	482-650

**MELTING POINTS**  
**Nickel Alloys**

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
"A" Nickel	2642	1450
"D" Nickel	2600	1427
Duranickel	2550-2620	1400-1440
Cast Nickel	2450	1343
Monel	2370	1299
"K" Monel	2400-2460	1315-1349
Monel (Cast)	2450	1343
"H" Monel (Cast)	2315	1268
"S" Monel (Cast)	2300	1260
Inconel	2470-2580	1354-1413
Inconel (Cast)	2500	1371
Ni-O-Nel	1340-1390	727-754
Hastelloy Alloy "B"	2375-2495	1302-1368
Hastelloy Alloy "C"	2417-2498	1325-1370
Hastelloy Alloy "D"	2050	1121
Hastelloy Alloy "F"	2350	1288
Hastelloy Alloy "N"	2370-2550	1300-1400
Hastelloy Alloy "W"	2400	1316
Hastelloy Alloy "X"	2300-2470	1260-1355



<b>MELTING POINTS</b>		
<b>Superalloys</b>		
<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
Inconel Alloy 600	<b>2470-2575</b>	1354-1413
Inconel Alloy 601	<b>2480-2571</b>	1360-1411
Inconel Alloy 601GC	<b>2374-2494</b>	1301-1368
Inconel Alloy 603XL	<b>2516-2552</b>	1380-1400
Inconel Alloy 617	<b>2430-2510</b>	1332-1380
Inconel Alloy 625	<b>2350-2460</b>	1290-1350
Inconel Alloy 625LCF	<b>2350-2460</b>	1290-1350
Inconel Alloy 686	<b>2440-2516</b>	1338-1380
Inconel Alloy 690	<b>2450-2510</b>	1343-1377
Inconel Alloy 693	<b>2403-2493</b>	1317-1367
Inconel Alloy 706	<b>2434-2499</b>	1334-1371
Inconel Alloy 718	<b>2300-2437</b>	1260-1336
Inconel Alloy 718SPF	<b>2300-2437</b>	1260-1336
Inconel Alloy 725	<b>2320-2449</b>	1271-1343
Inconel Alloy 740	<b>2350-2484</b>	1288-1362
Inconel Alloy X-750	<b>2540-2600</b>	1393-1427
Inconel Alloy 751	<b>2540-2600</b>	1393-1427
Inconel Alloy MA754	<b>2550</b>	1400
Inconel Alloy MA758	<b>2507</b>	1375
Inconel Alloy 783	<b>2437-2565</b>	1336-1407
Inconel Alloy 230	<b>2480-2570</b>	1360-1410
Inconel Alloy C-276	<b>2415-2500</b>	1325-1370
Inconel Alloy G-3	<b>2300-2450</b>	1260-1343
Inconel Alloy HX	<b>2300-2470</b>	1260-1355
Inconel Alloy 22	<b>2464-2529</b>	1351-1387
Incoloy Alloy 800	<b>2475-2525</b>	1357-1385
Incoloy Alloy 800H/800HT	<b>2475-2525</b>	1357-1385
Incoloy Alloy 803	<b>2490-2555</b>	1365-1400
Incoloy Alloy 825	<b>2500-2550</b>	1370-1400
Incoloy Alloy 864	<b>2467-2539</b>	1353-1393

**MELTING POINTS**  
Superalloys

<b>ALLOY</b>	<b>MELTING POINT/RANGE °F</b>	<b>MELTING POINT/RANGE °C</b>
Incoloy Alloy 890	<b>2388-2522</b>	1309-1383
Incoloy Alloy 903	<b>2405-2539</b>	1318-1393
Incoloy Alloy 907	<b>2440-2550</b>	1335-1400
Incoloy Alloy 908	<b>2482-2571</b>	1361-1410
Incoloy Alloy 925	<b>2392-2490</b>	1311-1366
Incoloy Alloy MA956	<b>2700</b>	1482
Incoloy Alloy DS	<b>2426-2552</b>	1330-1400
Incoloy Alloy 330	<b>2520-2590</b>	1380-1420
Incoloy Alloy 25-6MO	<b>2410-2550</b>	1320-1400
Incoloy Alloy A-286	<b>2500-2600</b>	1370-1430
Brightray Alloy B	<b>2550-2590</b>	1400-1420
Brightray Alloy C	<b>2520-2550</b>	1380-1400
Brightray Alloy F	<b>2430-2550</b>	1330-1400
Brightray Alloy S	<b>2550-2590</b>	1400-1420
Brightray Alloy 35	<b>2440-2520</b>	1340-1380
Nimonic Alloy 75	<b>2450-2520</b>	1340-1380
Nimonic Alloy 80A	<b>2410-2490</b>	1320-1365
Nimonic Alloy 81	<b>2381-2507</b>	1305-1375
Nimonic Alloy 90	<b>2390-2500</b>	1310-1370
Nimonic Alloy 91	<b>2372-2462</b>	1300-1350
Nimonic Alloy 105	<b>2354-2453</b>	1290-1345
Nimonic Alloy 115	<b>2300-2399</b>	1260-1315
Nimonic Alloy 263	<b>2372-2471</b>	1300-1355
Nimonic Alloy 901	<b>2336-2453</b>	1280-1345
Nimonic Alloy PE11	<b>2340-2460</b>	1280-1350
Nimonic Alloy PE16	<b>2390-2471</b>	1310-1355
Nimonic Alloy PK33	<b>2372-2453</b>	1300-1345
Udimet Alloy 188	<b>2375-2425</b>	1300-1330
Udimet Alloy L-605	<b>2426-2570</b>	1330-1410
Udimet Alloy 520	<b>2300-2560</b>	1260-1405
Udimet Alloy 720	<b>2180-2440</b>	1194-1338

<b>MELTING POINTS</b> Superalloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> °F	<b>MELTING POINT/RANGE</b> °C
Udimet Alloy D-979	<b>2225-2530</b>	1220-1390
Udimet Alloy R41	<b>2250-2535</b>	1232-1391
Udimet Alloy 250	<b>2600-2650</b>	1427-1454
Udimet Alloy 300	<b>2600-2650</b>	1427-1454
Nilo Alloy 36	<b>2605</b>	1430
Nilo Alloy 42	<b>2615</b>	1435
Nilo Alloy 48	<b>2640</b>	1450
Nilo Alloy K	<b>2640</b>	1450

<b>MELTING POINTS</b> Tin Alloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> °F	<b>MELTING POINT/RANGE</b> °C
Hard Tin (pure tin)	<b>450</b>	232
Antimonial Tin Solder	<b>453-464</b>	234-240
Tin-Silver Solder	<b>430-473</b>	221-245
Soft Solder (70% Sn)	<b>361-378</b>	183-192
Soft Solder (63% Sn)	<b>361</b>	183
Soft Solder (50% Sn)	<b>361-421</b>	183-216
Tin Babbitt Alloy 1	<b>433-700</b>	223-371
Tin Babbitt Alloy 2	<b>466-669</b>	241-354
Tin Babbitt Alloy 3	<b>464-792</b>	240-422
Tin Babbitt Alloy 4	<b>363-583</b>	184-306
Tin Babbitt Alloy 5	<b>358-565</b>	181-296
Tin Die Casting Alloy	<b>700</b>	371
White Metal	<b>475</b>	246
Pewter	<b>471-563</b>	244-295

<b>MELTING POINTS</b> Zinc Alloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> °F	<b>MELTING POINT/RANGE</b> °C
Pure Zinc	<b>787</b>	419.6
AG40A	<b>718-729</b>	381-387
AC41A	<b>716-727</b>	380-386
Zinc-Base Slush-Casting Alloy (4.75% Al)	<b>716-734</b>	380-390
Zinc-Base Slush-Casting Alloy (5.5% Al)	<b>716-743</b>	380-395
Commercial Rolled Zinc (0.08% Pb)	<b>786</b>	419
Commercial Rolled Zinc (0.06% Pb)	<b>786</b>	419
Commercial Rolled Zinc (0.3% Pb)	<b>786</b>	419
Copper Hardened Rolled Zinc	<b>786-792</b>	419-422
Rolled Zinc Alloy (1% Cu)	<b>786-792</b>	419-422

<b>MELTING POINTS</b> Precious Metal Alloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> °F	<b>MELTING POINT/RANGE</b> °C
Silver	<b>1760</b>	962
70% Gold – 30% Platinum	<b>2240-2640</b>	1228-1450
60% Pd – 40% Cu	<b>2180-2240</b>	1196-1224

<b>MELTING POINTS</b> Ni-Cr-Mo-Cu Alloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> °F	<b>MELTING POINT/RANGE</b> °C
Illium "B"	-----	-----
Illium "G"	<b>2300-2440</b>	1260-1338
Illium "R"	<b>2500</b>	1371

<b>MELTING POINTS</b> Electrical Resistance Alloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> <b>°F</b>	<b>MELTING POINT/RANGE</b> <b>°C</b>
80 Ni -20 Cr	<b>2550</b>	1400
60 Ni -24 Fe-16 Cr	<b>2530</b>	1390
35 Ni-45 Fe-20 Cr	<b>2530</b>	1390
Constantan	<b>2230</b>	1220

<b>MELTING POINTS</b> Titanium Alloys		
<b>ALLOY</b>	<b>MELTING POINT/RANGE</b> <b>°F</b>	<b>MELTING POINT/RANGE</b> <b>°C</b>
99.2%	<b>3135</b>	1724
99.0%	<b>3020</b>	1660
Ti- 6 Al - 4V	<b>2920-3020</b>	1604-1660
Ti – 5 Al - 2.5 Sn	<b>Max: 2890</b>	Max: 1590
Ti – 2 Fe – 2 Cr - 2Mo	<b>3010</b>	1654
Ti – 8 Mn	<b>2370-2970</b>	1300-1635
Ti – 4 Al -4 Mn	<b>2820</b>	1549

## EUTECTICS POINTS

ALLOY (Element-Wt. %)	°F	°C
Aluminum-Gold (Au-96)	968	520
Aluminum-Beryllium (Be-0.8)	1191	644
Aluminum-Copper (Cu-33)	1019	548
Aluminum-Iron ( Fe-98)	1211	655
Aluminum-Lithium (Li-93)	351	177
Aluminum-Magnesium (Mg-66)	819	437
Aluminum-Nickel (Ni-5.7)	1182	639
Aluminum-Silicon (Si-12.6)	1071	577
Aluminum-Zinc (Zn-94)	718	381
Aluminum-Zirconium (Zr-57)	2732	1500
Beryllium-Chromium (Cr-13)	2232	122
Beryllium-Copper (Cu-94.7)	1576	858
Beryllium (Fe-22.6)	2219	1215
Beryllium-Nickel (Ni-95)	2102	1150
Beryllium-Silicon (Si-64)	1994	1090
Carbon-Iron (Fe-22.6)	2107	1153
Carbon-Molybdenum	4001	2205
Carbon-Nickel (C-2.5)	2421	1327
Chromium-Carbon (C-3.6)	2793	1534
Chromium-Cobalt (Co-59)	2489	1365
Chromium- Molybdenum (Mo-21)	3308	1820
Chromium-Nickel (Ni-46)	2453	1345
Chromium-Tantalum (Ta-34)	3200	1760
Chromium-Titanium (Ti-53)	2570	1410
Chromium-Zirconium (Zr-86)	2430	1332
Cobalt-Carbon (C-2.6)	2498	1320
Cobalt-Molybdenum (Mo-39)	2435	1335
Cobalt-Tantalum (Ta-21)	2336	1280
Cobalt-Tin (Sn-34)	2034	1112
Cobalt-Titanium (Ti-73)	1868	1020
Cobalt-Vanadium (V-38)	2278	1248
Cobalt-Tungsten (W-45)	2680	1471
Copper-Magnesium(Mg-66)	909	487
Copper-Silicon	1476	802
Copper-Titanium (Ti-12)	1607	875
Iron-Carbon (C-4.2)	2107	1153

## EUTECTICS POINTS

ALLOY (Element-Wt. %)	°F	°C
Iron-Molybdenum (Mo-37)	2640	1449
Iron-Niobium (Nb-19)	2503	1373
Iron-Silicon (Si-20 &Si-53)	2197	1203
Iron-Tin (Sn-49)	2066	1130
Iron-Tantalum(Ta-20))	2606	1430
Iron-Titanium (Ti-67)	1985	1085
Magnesium-Nickel (Mg-24)	946	508
Magnesium-Silicon (Si-1.34)	1180	638
Magnesium-Tin (Sn-98)	399	204
Magnesium-Zinc (Zn-53)	644	340
Manganese-Titanium (Ti-59)	2156	1180
Molybdenum-Nickel (56-Mo)	2388	1309
Molybdenum-Silicon (Si-94)	2577	1414
Nickel-Carbon (C-0.6)	2421	1327
Nickel-Niobium (Nb-23)	2347	1286
Nickel-Silicon (Si-29)	1767	964
Nickel-Tantalum (Ta-63)	2462	1350
Nickel-Tin (Sn-33)	2066	1130
Nickel-Titanium ((Ti-73)	1728	942
Nickel-Vanadium (V-47)	2196	1202
Silicon-Tantalum (Ta-5)	2543	1395
Silicon-Zinc (Zn-99.98)	787	419
Silver-Aluminum (Al-26.5)	1053	567
Silver-Beryllium (Be-0.03)	1616	880
Silver-Calcium (Ca-60)	878	470
Silver-Copper (Cu-28)	1434	779
Silver-Magnesium (Mg-51.4)	882	472
Silver-Tin(Sn-96.5)	430	221
Tantalum-Carbon (C-2)	5149	2843
Tungsten-Carbon (W-1.3)	4919	2715

**ONSET TEMPERATURE FOR ADVERSE REACTIONS BETWEEN  
GRAPHITE OR OXIDES AND FURNACE COMPONENTS**

<b>Surface to Surface Contact</b>	<b>Temperature °F</b>	<b>Temperature °C</b>
<b>Al<sub>2</sub>O<sub>3</sub>-C</b>	<b>&lt;2912</b>	<b>&lt;1600</b>
<b>Al<sub>2</sub>O<sub>3</sub>-Mo</b>	<b>3452</b>	<b>1900</b>
<b>Al<sub>2</sub>O<sub>3</sub>-Ta</b>	<b>3452</b>	<b>1900</b>
<b>Al<sub>2</sub>O<sub>3</sub>-W</b>	<b>3452</b>	<b>1900</b>
<b>BeO-C</b>	<b>4172</b>	<b>2300</b>
<b>BeO-Mo</b>	<b>3452</b>	<b>1900</b>
<b>BeO-MgO</b>	<b>3272</b>	<b>1800</b>
<b>BeO-W</b>	<b>3632</b>	<b>2000</b>
<b>C-Mo</b>	<b>2192</b>	<b>1200*</b>
<b>C-Ta</b>	<b>1832</b>	<b>1000*</b>
<b>C-W</b>	<b>2730</b>	<b>1499*</b>
<b>BeO-ZrO<sub>2</sub></b>	<b>3452</b>	<b>1900</b>
<b>MgO-C</b>	<b>3272</b>	<b>1800</b>
<b>MgO-Mo</b>	<b>2912</b>	<b>1600</b>
<b>MgO-Ta</b>	<b>3272</b>	<b>1800</b>
<b>MgO-W</b>	<b>3632</b>	<b>2000**</b>
<b>MgO-ZrO<sub>2</sub></b>	<b>3632</b>	<b>2000</b>
<b>ZrO<sub>2</sub>-C</b>	<b>2912</b>	<b>1600</b>
<b>ZrO<sub>2</sub>-Mo</b>	<b>3992</b>	<b>2200</b>
<b>ZrO<sub>2</sub>-W</b>	<b>2912</b>	<b>1600</b>

- \*Strong Carbide Formation at higher temperatures.
- \*\* Strong Magnesia evaporation

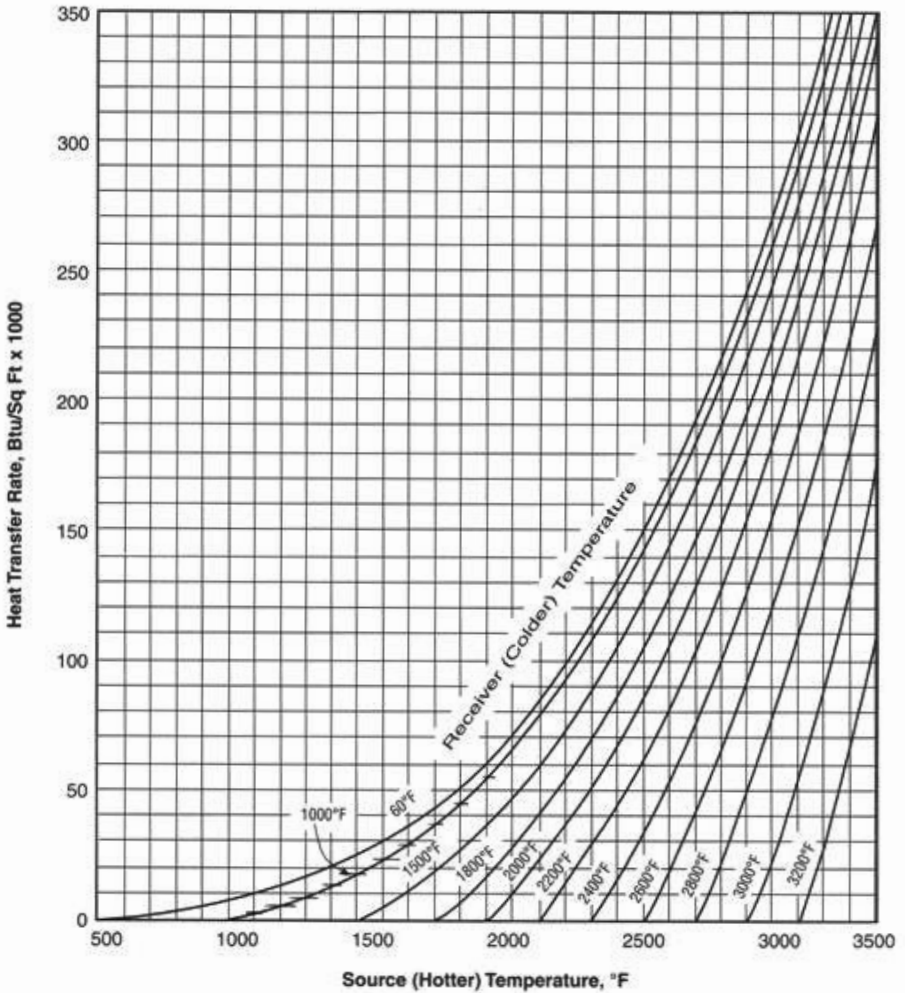


**MELTING POINTS OF CERTAIN SIMPLE AND COMPLEX  
REFRACTORY OXIDES**

Compound	Chemical Formula	Melting Point	
		°F	°C
Alumina	Al <sub>2</sub> O <sub>3</sub>	3762	2072
Aluminum Silicate (mullite)	3Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub>	3326	1830*
Aluminum Titanate	Al <sub>2</sub> O <sub>3</sub> ·TiO <sub>2</sub>	3371	1855
Aluminum Titanate	Al <sub>2</sub> O <sub>3</sub> ·2TiO <sub>2</sub>	3443	1895
Barium Aluminate	BaO·Al <sub>2</sub> O <sub>3</sub>	3632	2000
Barium Aluminate	BaO·6Al <sub>2</sub> O <sub>3</sub>	3380	1860
Barium Orthosilicate	BaO·SiO <sub>2</sub>	3191	1755
Barium Zirconate	BaO·ZrO <sub>2</sub>	4892	2700
Beryllium Oxide	BeO	4649	2565
Chromic Oxide	Cr <sub>2</sub> O <sub>3</sub>	4109	2265
Iron (II) Oxide	FeO	2510	1377
Iron (III) Oxide	Fe <sub>2</sub> O <sub>3</sub>	2851	1566
Iron (IV) Oxide	Fe <sub>3</sub> O <sub>4</sub>	2901	1594
Magnesium Aluminate	MgO·Al <sub>2</sub> O <sub>3</sub>	3875	2135
Magnesium Ferrite	MgO·Fe <sub>2</sub> O <sub>3</sub>	3200	1760
Magnesium Oxide	MgO	5156	2852
Manganese Oxide	Mn <sub>3</sub> O <sub>4</sub>	2849	1565
Niobium Pentoxide	Nb <sub>2</sub> O <sub>5</sub>	2716	1491
Nickel Oxide	NiO	3603	1984
Silicon Dioxide	SiO <sub>2</sub>	3133	1723
Tantalum Pentoxide	Ta <sub>2</sub> O <sub>5</sub>	3402	1872
Titanium Dioxide	TiO <sub>2</sub>	3344	1840
Vanadium Oxide	V <sub>2</sub> O <sub>3</sub>	3578	1970
Zinc Aluminate	ZnO·Al <sub>2</sub> O <sub>3</sub>	3542	1950
Zinc Oxide	ZnO	3576	1969
Zirconium Oxide	ZrO <sub>2</sub>	4825	2663
Zirconium Oxide (stabilized)	ZrO <sub>2</sub> (stabilized)	4500	2482
Zinc Zirconium Silicate	ZnO·ZrO <sub>2</sub> ·SiO <sub>2</sub>	3772	2078
Tungsten Oxide	WO <sub>3</sub>	2683	1473

## BLACK BODY RADIATION

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These curves are plotted from the relationship

$$Q = \frac{AK(T_1^4 - T_2^4)}{\frac{1}{P_1} + \frac{1}{P_2} - 1}$$

where  $P_1$  &  $P_2$  equal 1, that is, the heat source and receiver both have emissivities of 1.0, and they are arranged so there is no barrier to heat transfer between them.

### EMISSIONIVITY OF COMMON MATERIALS

MATERIAL	TEMPERATURE °F	TEMPERATURE °C	EMISSIONIVITY NUMBER
Black Body	75	24	1.0
Black Paint, CuO	75	24	0.96
Carbon, Lamp Black	75	24	0.96
Soot, acetylene	75	24	0.97
Cement	32-392	0-200	0.96
White ceramic, Al <sub>2</sub> O <sub>3</sub>	75	24	0.90
Carbon, unoxidized	75	24	0.81
Water	100	38	0.67

### EMISSIONIVITY OF SELECT METALS

MATERIAL	TEMPERATURE °F	TEMPERATURE °C	EMISSIONIVITY NUMBER
Aluminum unoxidized	75	24	0.02
Aluminum oxidized	390	199	0.11
Aluminum heavily oxidized	200	93	0.20
Brass unoxidized	77	25	0.035
Brass oxidized	392	200	0.61
Bronze polished	122	50	0.10
Chromium unoxidized	212	100	0.08
Chromium oxidized	600	316	0.08
Copper cuprous oxide	100	38	0.87
Copper heavily oxidized, black	100	38	0.78
Copper polished	100	38	0.03
Copper Dow Metal	100	38	0.15
GOLD polished or unoxidized	212	100	0.02
Iconel X	75	24	0.19
Iconel B	75	24	0.21
Iron cast unoxidized	392	200	0.21
Iron cast oxidized	392	200	0.64
Iron cast heavily oxidized	100	38	0.95
Iron unoxidized	212	100	0.05
Iron oxidized	212	100	0.74

## EMISSIVITY OF SELECT METALS

MATERIAL	TEMPERATURE °F	TEMPERATURE °C	EMISSIVITY NUMBER
Iron heavily oxidized (rust)	77	25	0.65
Iron (Wrought)	77	25	0.94
Lead oxidized	100	38	0.43
Magnesium	100	38	0.07
Mercury	77	25	0.10
Molybdenum	100	38	0.06
Molybdenum	2000	1093	0.18
Monel Ni-Cu	392	200	0.41
Monel Ni-Cu, oxidized	77	25	0.43
Nickel unoxidized	77	25	0.05
Nickel oxidized	100	38	0.31
Niobium unoxidized	1500-2000	816-1093	0.19-0.24
Niobium oxidized	1500	816	0.73
Nichrome wire unoxidized	122	50	0.65
Nichrome wire oxidized	122	50	0.95
Nickel unoxidized	77-932	25-500	0.045-0.0.12
Nickel oxidized	392	200	0.37
Platinum	100	38	0.05
Platinum Black	100	38	0.93
Silver polished	100	38	0.01
Steel unoxidized	212	100	0.08
Steel oxidized	77	25	0.80
Steel type 301 polished	75	24	0.27
Steel type 303 oxidized	600	316	0.74
Steel type 316	75	24	0.28
Tantalum unoxidized	2732	1500	0.21
Tin unoxidized	77	25	0.04
Titanium C110M	300	149	0.08
Tungsten unoxidized	77	25	0.02
Zinc Bright galvanized	100	38	0.23
Zinc unoxidized	500	260	0.05
Zinc oxidized	500	260	0.11

## VAPOR PRESSURE OF THE ELEMENTS (s-sublimes)

Element	10 <sup>-4</sup> Torr		10 <sup>-3</sup> Torr		10 <sup>-2</sup> Torr		10 <sup>-1</sup> Torr	
	°C	°F	°C	°F	°C	°F	°C	°F
Aluminum	808	1486	889	1632	996	1825	1123	2053
Beryllium	1029	1884	1130	2066	1246	2275	1395	2543
Boron	1140	2084	1239	2262	1355	2471	1489	2712
Cadmium	180	356	220	428	264	507	321	610
Calcium	463	865	528	982	605	1121	700	1292
Carbon	2290	4150	2471	4480	2681	4858	2926	5299
Cerium	1091	1996	1190	2174	1305	2381	1439	2622
Cesium	74	165	110	230	153	307	207	405
Chromium	992	1818	1090	1994	1205	2201	1342	2448
Cobalt	1362	2484	1494	2721	1649	3000	1833	3331
Copper	1035	1895	1141	2086	1273	2323	1432	2610
Gallium	859	1578	965	1769	1093	1999	1248	2278
Germanium	996	1825	1112	2034	1251	2284	1421	2590
Gold	1190	2174	1316	2401	1465	2669	1646	2995
Hafnium	2037	3698	2218	4024	2446	4434	3049	5520
Iron	1195	2183	1310	2390	1447	2637	1602	2916
Lead	548	1018	620	1148	718	1324	832	1508
Magnesium	331	628	380	716	443	829	515	959
Manganese	791	1456	878	1612	980	1796	1020	1868
Mercury			18	64	48	118	82	180
Molybdenum	2098	3809	2295	4163	2533	4591	2880	5216
Neodymium	1069	1956	1193	2179	1343	2449	1526	2778
Nickel	1257	2295	1371	2500	1510	2750	1679	3054
Niobium	2355	4271	2539	4602				
Palladium	1271	2320	1405	2561	1566	2851	1759	3198
Phosphorus			160	320	190	374	225	437
Platinum	1744	3171	1904	3459	2090	3794	2293	4150
Potassium	123	253	161	322	207	405	265	509
Rhenium	2588	4690	2808	5086	3065	5549	3387	6129
Rhodium	1815	3299	1971	3580	2149	3900	2358	4274
Samarium	574	1065	650	1202	740	1364	849	1560
Selenium			200	392	235	455	280	536
Silicon	1116	2041	1223	2233	1343	2449	1485	2705
Silver	848	1558	920	1688	1047	1917	1184	2163
Sodium	195	383	238	460	291	556	356	673
Sulfur			66	151	97	207	135	275
Tantalum	2599	4710	2820	5108	3074	5565	3370	6098
Tin	922	1692	1042		1189		1373	
Titanium	1250		1384	2523	1546	2815	1742	3168
Tungsten	2767		3016	5461	3309	5988		
Uranium	1585		1730	3146	1898	3448	2098	3808
Vanadium	1586		1725	3137	1888	3430	2079	3774
Ytterbium	359	678	420	788	480	896	552	896
Yttrium	1362	2484	1494	2721	1650	3000	1833	3331
Zinc	248	478	292	558	343	649	405	761
Zirconium	1660	3020	1816	3301	2001	3634	2212	4014

## VAPOR PRESSURE OF THE ELEMENTS (s-sublimes)

Element	1.0 Torr		10 <sup>1</sup> Torr		10 <sup>2</sup> Torr		760 Torr	
	°C	°F	°C	°F	°C	°F	°C	°F
Aluminum	1279	<b>2334</b>	1487	<b>2709</b>	1749	<b>3180</b>	2467	<b>4473</b>
Beryllium	1567	<b>2853</b>	1787	<b>3249</b>	2097	<b>3087</b>	2507	<b>4545</b>
Boron	1648	<b>2998</b>	3030	<b>5486</b>	3460	<b>6260</b>	2527(s)	<b>4581(s)</b>
Cadmium	394	<b>741</b>	484	<b>903</b>	611	<b>1132</b>	765	<b>1409</b>
Calcium	817	<b>1503</b>	983	<b>1801</b>	1207	<b>2205</b>	1487	<b>2709</b>
Carbon	3214	<b>5817</b>	3946	<b>7135</b>	4373	<b>7903</b>	4827	<b>8721</b>
Cerium							3426	<b>6199</b>
Cesium			373	<b>703</b>	513	<b>955</b>	690	<b>1274</b>
Chromium	1504	<b>2739</b>					2222	<b>4031</b>
Cobalt	2056	<b>3732</b>	2380	<b>4316</b>	2720	<b>4928</b>	3097	<b>5607</b>
Copper	1628	<b>2962</b>	1879	<b>3414</b>	2207	<b>4005</b>	2595	<b>4703</b>
Gallium	1443	<b>2629</b>	1541	<b>2806</b>	1784	<b>3243</b>	2427	<b>4400</b>
Germanium	1635	<b>2975</b>	1880	<b>3416</b>	2210	<b>4010</b>	2707	<b>4905</b>
Gold	1867	<b>3393</b>	2154	<b>3909</b>	2521	<b>4570</b>	2966	<b>5371</b>
Hafnium	3049	<b>5520</b>	3463	<b>6265</b>	3995	<b>7223</b>	4603	<b>8317</b>
Iron	1783	<b>3241</b>	2039	<b>3702</b>	2360	<b>4280</b>	2727	<b>4941</b>
Lead	975	<b>1787</b>	1167	<b>2133</b>	1417	<b>2583</b>	1737	<b>3159</b>
Magnesium	605	<b>1121</b>	702	<b>1296</b>	909	<b>1668</b>	1126	<b>2059</b>
Manganese	1251	<b>2284</b>	1505	<b>2741</b>	1792	<b>3257</b>	2097	<b>3807</b>
Mercury	126	<b>259</b>	184	<b>363</b>	216	<b>421</b>	361	<b>682</b>
Molybdenum	3102	<b>5616</b>	3535	<b>6395</b>	4458	<b>7428</b>	4804	<b>8679</b>
Neodymium	1757	<b>3195</b>	2056	<b>3733</b>	2459	<b>4458</b>	2948	<b>5338</b>
Nickel	1757	<b>3195</b>	2056	<b>3733</b>	2364	<b>4287</b>	2837	<b>5139</b>
Niobium							4742	<b>8568</b>
Palladium	2000	<b>3632</b>	2280	<b>4136</b>	2780	<b>5036</b>	3167	<b>5732</b>
Phosphorus	265	<b>509</b>	310	<b>590</b>	370	<b>698</b>	431,	<b>808</b>
Platinum	2582	<b>4680</b>	3146	<b>5695</b>	3714	<b>6717</b>	3827	<b>6921</b>
Potassium	338	<b>640</b>	443	<b>829</b>	581	<b>1078</b>	779	<b>1434</b>
Rhenium	3790	<b>6854</b>	4295	<b>7763</b>	4343	<b>8929</b>	5689	<b>10272</b>
Rhodium	2607	<b>4725</b>	2880	<b>5216</b>	3392	<b>6138</b>	3877	<b>7011</b>
Samarium	985	<b>1805</b>	1174	<b>2145</b>	1446	<b>2635</b>	1787	<b>3249</b>
Selenium	350	<b>662</b>	430	<b>806</b>	550	<b>1022</b>	685	<b>1265</b>
Silicon	1670	<b>3038</b>	1888	<b>3430</b>	2083	<b>3781</b>	2477	<b>4491</b>
Silver	1353	<b>2467</b>	1575	<b>2867</b>	1865	<b>3389</b>	2212	<b>4013</b>
Sodium	437	<b>819</b>	548	<b>1018</b>	696	<b>1285</b>	914	<b>1677</b>
Sulfur	183	<b>361</b>	246	<b>475</b>	333	<b>631</b>	444	<b>831</b>
Tantalum	3740	<b>6764</b>					6027	<b>10881</b>
Tin	1609		1703		1968		2727	
Titanium	1965	<b>3569</b>	2180	<b>3956</b>	2480	<b>4496</b>	3127	<b>5661</b>
Tungsten							5927	<b>10701</b>
Uranium	2338	<b>4240</b>					3527	<b>6381</b>
Vanadium	2207	<b>4005</b>	2570	<b>4665</b>	2950	<b>5342</b>	3380	<b>6116</b>
Yttrium							3338	<b>6040</b>
Ytterbium	657	<b>1215</b>	795	<b>1463</b>	859	<b>1578</b>	1196	<b>2184</b>
Zinc	487	<b>907</b>	593	<b>1099</b>	736	<b>1357</b>	907	<b>1665</b>
Zirconium	2459	<b>4458</b>					3577	<b>6471</b>

## VAPOR PRESSURES OF CERTAIN METAL OXIDES

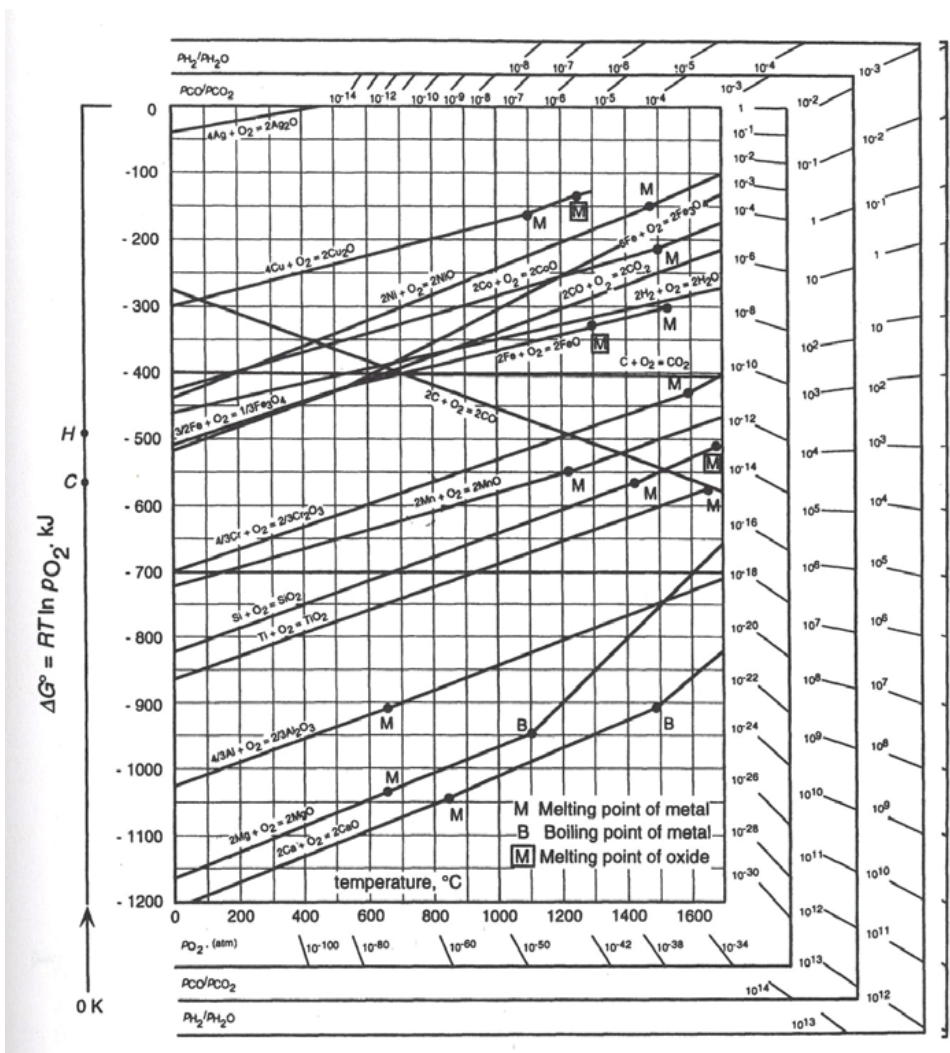
Compound	Formula	10 <sup>-5</sup> Torr (0.01 micron)		10 <sup>-4</sup> Torr (0.1 microns)		10 <sup>-3</sup> Torr (1.0 micron)		10 <sup>-2</sup> Torr (10 microns)		10 <sup>-1</sup> Torr (100 microns)		760 Torr 760,000 microns	
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Aluminum Oxide	Al <sub>2</sub> O <sub>3</sub>			1880	3390	1980	3570	2105	3790	2265	4080	3545	6330
Barium Oxide	BaO			1266	2310	1382	2520	1516	2760			1999	3630
Beryllium Oxide	BeO	1754	3190	1893	3440	2049	3720	2227	4040	2421	4390	4132	7470
Calcium Oxide	CaO	1543	2810	1666	3030	1810	3290	1982	3600	2182	3960	2849	5160
Chromic Oxide	Cr <sub>2</sub> O <sub>3</sub>	1320	2410	1425	2600	1555	2830	1695	3080	1875	3380	3030	5440
Iron (III) Oxide	Fe <sub>2</sub> O <sub>3</sub>								1880				
Magnesium Oxide	MgO	1388	2530	1510	2750	1632	2970	1788	3250	1954	3550	3599	6510
Molybdenum Trioxide	MoO <sub>3</sub>					593	1100	627	1160	699	1290	793	1460
Potassium Oxide	K <sub>2</sub> O	438	820	499	930	577	1070	643	1190	743	1370	1466	2670
Silicon Dioxide	SiO <sub>2</sub>	1366	2490	1482	2700	1604	2920	1738	3160	1893	3440	2232	4050
Sodium Oxide	Na <sub>2</sub> O	554	1031	627	1160	704	1300	799	1470	916	1680	1277	2330
Titanium Oxide	TiO <sub>2</sub>	1577	2870	1704	3100								
Zirconium Oxide	ZrO <sub>2</sub>	1877	3410	2049	3720	2177	3950	2399	4350	2577	4670	4299	7770

# RICHARDSON-ELLINGHAM DIAGRAM

The Richardson-Ellingham Diagram is a graphical representation of the standard Gibbs free energy changes for chemical reactions. It can be used to determine necessary furnace conditions for prevention of unwanted oxidation of metals or the reduction of metal oxides.

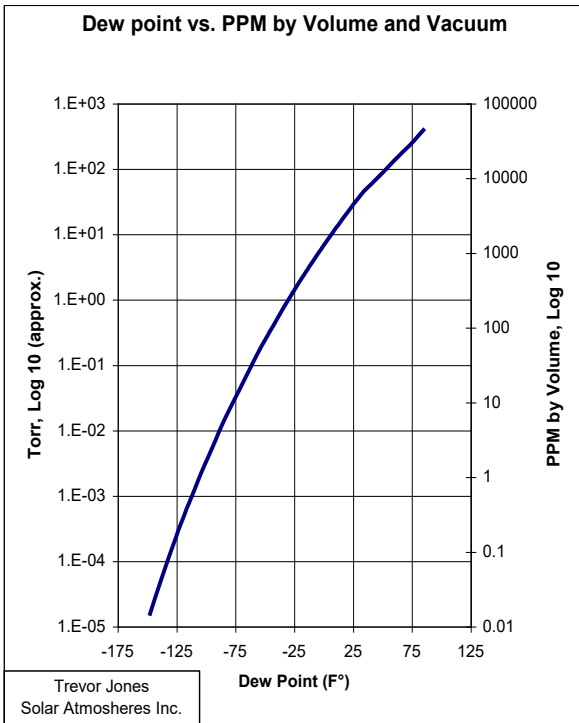
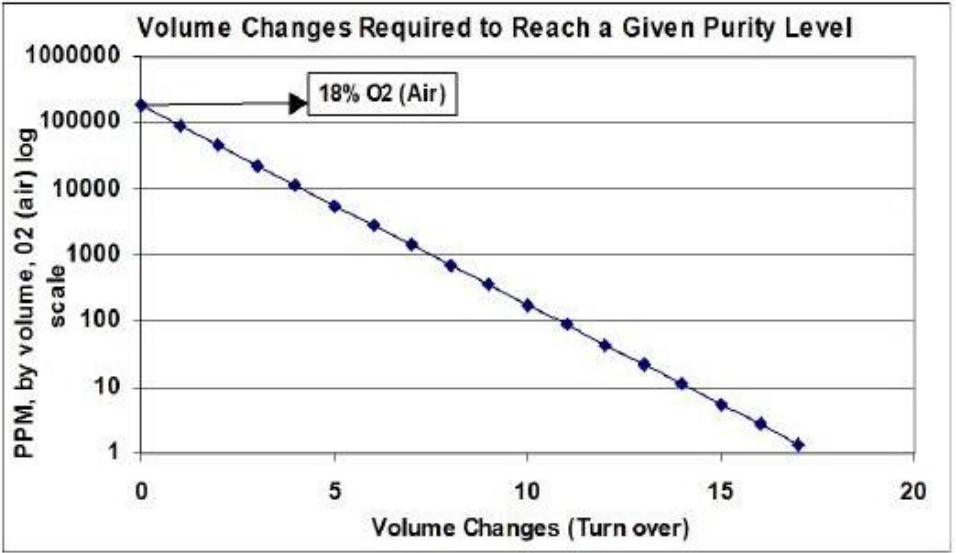
The main uses of this diagram are:

1. Determine the partial pressure of oxygen that is in equilibrium with the metal oxide for a given temperature;
2. Calculate the CO/CO<sub>2</sub> ratio required to reduce an oxide at a given temperature.
3. Determine the ease of oxidation for a given temperature and dew point.
4. Predict the temperatures at which a metal is stable and the temperature that it will readily oxidize.

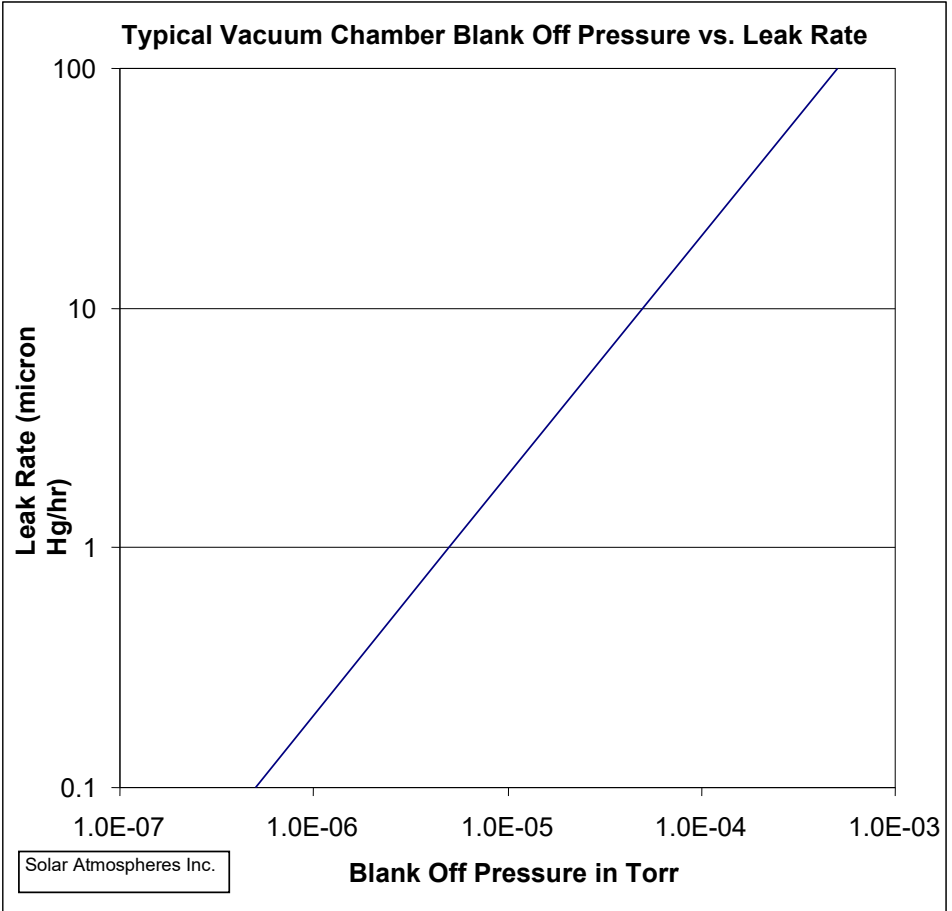




# GAS PURGE CHART



# VACUUM FURNACE BLANK OFF PRESSURE vs. LEAK RATE



## COMMON ENGLISH TO METRIC CONVERSIONS

### Conversion Factors for Common Units of Length

1 inch = 2.54 centimeters (cm) = 25.4 millimeters (mm)

1 foot = 0.305 meters

1 centimeter = 0.394 inches

1 meter = 39.37 inches = 3.28 feet = 1.094 yards

### Conversion Factors for Common Units of Area

1 square inch = 6.45 square centimeters

1 square foot = 0.093 square meter = 930 square centimeters

1 square centimeter = 0.155 square inches

1 square meter = 10.764 square feet = 1550 square inches

### Common Conversion Factors for Units of Volume (Solid and Liquid)

1 cubic inch = 16.4 cubic centimeters (cc)

1 cubic inches = 16.4 milliliters (ml)

1 cubic foot = 0.0283 cubic meters

1 cubic foot = 7.48 U.S. gallons

1 U.S. gallon = 3.78 liters

1 cubic foot = 28.3 liters (L)

1 cubic centimeter (cc) = 0.061 cubic inches

1 milliliters (ml) = 0.061 cubic inches

1 cubic meter = 35.314 cubic feet

1 liter = 35.314 cubic feet

### Common Conversion Factors for Units of Mass (Weight)

1 pound (avoirdupois) lb. = 453.6 gram

1 ounce = 0.0625 lb. = 28.35 grams

1 gram = 0.0022 pounds = 0.0353 ounces

## COMMON PRESSURE CONVERSION FACTORS

Multiply by ↓ to calculate →	Atmosphere (Atm)	Torr	Pascal	Bar	Micron	Psia (lb/in <sup>2</sup> )
<b>Atm</b>	1	760	1.01325X10 <sup>5</sup>	1.01325	7.6X10 <sup>5</sup>	14.696
<b>Torr</b>	1.316X10 <sup>-3</sup>	1	133.322	1.3332X10 <sup>-3</sup>	1000	1.9337X10 <sup>-2</sup>
<b>Pascal</b>	9.8692X10 <sup>-6</sup>	7.5006X10 <sup>-3</sup>	1	1X10 <sup>-5</sup>	7.5006	1.4504X10 <sup>-4</sup>
<b>Bar</b>	9.8692X10 <sup>-1</sup>	750.06	1X10 <sup>5</sup>	1	7.5006X10 <sup>5</sup>	14.504
<b>Micron</b>	1.31579X10 <sup>-6</sup>	1X10 <sup>-3</sup>	1.3332X10 <sup>-1</sup>	1.3332X10 <sup>-6</sup>	1	1.9337X10 <sup>-5</sup>
<b>Psia (Lb/in<sup>2</sup>)</b>	6.8046X10 <sup>-2</sup>	51.7151	6894.757	6.8946X10 <sup>-2</sup>	51715.1	1

To convert from one pressure unit to another, use the left column to locate the old unit and multiply by the conversion factor to obtain the value in the new pressure unit.

*Example:*

To convert Atmospheres to Bar

$$1 \text{ Atm} = 1.01325 \text{ Bar}$$

$$1 \text{ Pascal} = 9.8692 \times 10^{-6} \text{ Atm}$$

## EQUIVALENCE TABLE FOR PRESSURE/VACUUM MEASUREMENTS

(Relating Furnace Vacuum Gauge Readings (Inches Hg) to Absolute Pressure Values)

Micron Hg	Millibar (mbar)	Torr (mmHg)	<i>Inches Hg Vacuum Gauge</i>	Inches Hg Absolute	PSIA (lb/in. <sup>2</sup> absolute)	Atm
760,000	1013	760	<b>0.0</b>	29.92	14.7	1.000
750,000	1000	750	<b>0.42</b>	29.5	14.5	0.987
735,000	981	735.6	<b>1.02</b>	28.9	14.2	0.968
700,000	934	700	<b>2.32</b>	27.6	13.5	0.921
600,000	800	600	<b>6.32</b>	23.6	11.6	0.789
500,000	667	500	<b>10.22</b>	19.7	9.7	0.658
400,000	533	400	<b>14.22</b>	15.7	7.7	0.526
380,000	507	380	<b>14.92</b>	15.0	7.3	0.500
300,000	400	300	<b>18.12</b>	11.8	5.8	0.395
200,000	267	200	<b>22.07</b>	7.85	3.9	0.264
100,000	133.3	100	<b>25.98</b>	3.94	1.93	0.132
90,000	120	90	<b>26.38</b>	3.54	1.74	0.118
80,000	106.8	80	<b>26.77</b>	3.15	1.55	0.105
70,000	93.4	70	<b>27.16</b>	2.76	1.35	0.0921
60,000	80	60	<b>27.56</b>	2.36	1.16	0.0789
51,700	68.8	51.7	<b>27.89</b>	2.03	1.00	0.068
50,000	66.7	50	<b>27.95</b>	1.97	0.97	0.0658
40,000	53.3	40	<b>28.35</b>	1.57	0.77	0.0526
30,000	40.0	30	<b>28.74</b>	1.18	0.58	0.0395
25,400	33.8	25.4	<b>28.92</b>	1.00	0.4912	0.034
20,000	26.7	20	<b>29.14</b>	0.785	0.39	0.0264
10,000	13.33	10	<b>29.53</b>	0.394	0.193	0.0132
7,600	10.13	7.6	<b>29.62</b>	0.299	0.147	0.01
1,000	1.33	1	<b>29.88</b>	0.03937	0.01934	0.00132
750	1.00	0.75	<b>29.89</b>	0.0295	0.0145	0.000987
100	0.133	0.1	<b>29.916</b>	0.00394	0.00193	0.000132
10	0.0133	0.01	<b>29.9196</b>	0.000394	0.000193	0.0000132
1	0.00133	0.001	<b>29.91996</b>	0.0000394	0.0000193	0.0000013
0.1	0.000133	0.0001	<b>29.919996</b>	0.0000039	0.0000019	0.0000001

**EQUIVALENCE TABLE**  
**FURNACE VACUUM GAUGE READINGS (PSIG OR PSIA)**  
**TO ABSOLUTE PRESSURE VALUES**

Bar	Torr	PSIG (Furnace gauge)	PSIA (lb/in. <sup>2</sup> absolute)	Atm
1.01325	760.0	<b>0</b>	14.7	1.00
1.082515	811.8	<b>1</b>	15.7	1.0682
1.358315	1018.7	<b>5</b>	19.7	1.3404
1.703065	1277.4	<b>10</b>	24.7	1.6806
2.047815	1535.8	<b>15</b>	29.7	2.0208
2.392565	1794.3	<b>20</b>	34.7	2.36098
3.082065	2311.4	<b>30</b>	44.7	3.04139
3.771565	2828.5	<b>40</b>	54.7	3.72179
4.461065	3345.6	<b>50</b>	64.7	4.40219
5.150565	3862.7	<b>60</b>	74.7	5.08259
5.840065	4379.8	<b>70</b>	84.7	5.76299
6.529565	4896.9	<b>80</b>	94.7	6.44339
7.219065	5414.0	<b>90</b>	104.7	7.12379
7.908565	5931.1	<b>100</b>	114.7	7.80419
14.80357	11102.1	<b>200</b>	214.7	14.6082
18.25207	13690.2	<b>250</b>	264.7	18.0102
21.69857	16273.1	<b>300</b>	314.7	21.4122
28.59357	21444.1	<b>400</b>	414.7	28.2162
35.48857	26615.1	<b>500</b>	514.7	35.0202
42.38357	31786.1	<b>600</b>	614.7	41.8242
49.27857	36957.1	<b>700</b>	714.7	48.6282
56.17357	42128.1	<b>800</b>	814.7	55.4322
63.06857	47299.1	<b>900</b>	914.7	62.2362
69.96357	52470.1	<b>1000</b>	1014.7	69.0402
104.4386	78325.1	<b>1500</b>	1514.7	103.0602
173.3886	130052.9	<b>2500</b>	2514.7	171.1206
207.8636	155910.2	<b>3000</b>	3014.7	205.1447
242.3386	181769.9	<b>3500</b>	3514.7	239.1688

## TEMPERATURE CONVERSION FAHRENHEIT TO CELSIUS OR KELVIN

°F	°C	K	°F	°C	K	°F	°C	K
<b>-40</b>	-40	233.2	<b>550</b>	287.8	560.9	<b>1700</b>	926.7	1199.8
<b>-32</b>	-35.6	237.6	<b>600</b>	315.6	588.7	<b>1750</b>	954.4	1227.6
<b>-20</b>	-28.9	244.3	<b>650</b>	343.3	616.5	<b>1800</b>	982.2	1255.4
<b>-10</b>	-23.3	249.8	<b>700</b>	371.1	644.3	<b>1850</b>	1010.0	1283.2
<b>0</b>	-17.8	255.4	<b>750</b>	398.9	672.0	<b>1900</b>	1037.8	1310.9
<b>5</b>	-15	258.2	<b>800</b>	426.7	699.8	<b>1950</b>	1065.6	1338.7
<b>10</b>	-12.2	260.9	<b>850</b>	454.4	727.6	<b>2000</b>	1093.3	1366.5
<b>20</b>	-6.7	266.5	<b>900</b>	482.2	755.4	<b>2050</b>	1121.1	1394.3
<b>32</b>	0	273.2	<b>950</b>	510.0	783.2	<b>2100</b>	1148.9	1422.0
<b>40</b>	4.4	277.6	<b>1000</b>	537.8	810.9	<b>2150</b>	1176.7	1449.8
<b>50</b>	10	283.2	<b>1050</b>	565.6	838.7	<b>2200</b>	1204.4	1477.6
<b>70</b>	21.1	294.3	<b>1100</b>	593.3	866.5	<b>2250</b>	1232.2	1505.4
<b>90</b>	32.2	305.4	<b>1150</b>	621.1	894.3	<b>2300</b>	1260.0	1533.2
<b>100</b>	37.8	310.9	<b>1200</b>	648.9	922.0	<b>2350</b>	1287.8	1560.9
<b>120</b>	48.9	322.0	<b>1250</b>	676.7	949.8	<b>2400</b>	1315.6	1588.7
<b>150</b>	65.6	338.7	<b>1300</b>	704.4	977.6	<b>2450</b>	1343.3	1616.5
<b>212</b>	100	373.2	<b>1350</b>	732.2	1005.4	<b>2500</b>	1371.1	1644.3
<b>250</b>	121.1	394.3	<b>1400</b>	760.0	1033.2	<b>2550</b>	1398.9	1672.0
<b>300</b>	148.9	422.0	<b>1450</b>	787.8	1060.9	<b>2600</b>	1426.7	1699.8
<b>350</b>	176.7	449.8	<b>1500</b>	815.6	1088.7	<b>2650</b>	1454.4	1727.6
<b>400</b>	204.4	477.6	<b>1550</b>	843.3	1116.5	<b>2700</b>	1482.2	1755.4
<b>450</b>	232.2	505.4	<b>1600</b>	871.1	1144.3	<b>2750</b>	1510.0	1783.2
<b>500</b>	260	533.2	<b>1650</b>	898.9	1172.0	<b>2800</b>	1537.8	1810.9

Formulas:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$$

$$\text{K} = (^{\circ}\text{F} + 459.67)/1.8$$

$$^{\circ}\text{F} = (1.8 \times \text{K}) - 459.67$$

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

$$^{\circ}\text{C} = \text{K} - 273$$

$$\text{K} = ^{\circ}\text{C} + 273$$

**POWDERED METALS**  
**U.S. MESH TO MICRON CONVERSION CHART**

U.S. Mesh	Microns	Millimeters	Inches	Appearance
5	400	4.0	0.1570	
10	2000	2.0	0.0787	
20	841	0.841	0.0331	
28	700	0.700	0.028	Beach Sand
35	500	0.500	0.0197	
40	400	0.400	0.0165	
50	297	0.297	0.0117	
60	250	0.250	0.0098	Fine Sand
70	210	0.210	0.0083	
80	177	0.177	0.0070	
100	149	0.149	0.0059	
120	125	0.125	0.0049	
140	105	0.105	0.0041	
200	74	0.074	0.0029	Cement
325	44	0.044	0.0017	Silt
400	37	0.037	0.0015	Plant pollen



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