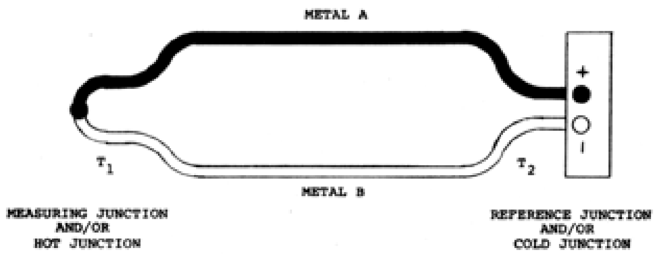
Thermocouple Theory and Development

I- The Thermocouple

A thermocouple is composed of two dissimilar metals, usually in wire form, joined together at one end to form the measuring or "hot" junction, while the other end is known as the reference or "cold" junction.

When there is a temperature difference between these two junctions, a small electromotive force (emf) is developed. An emf will originate not only at the hot junction but there is also the potential of the same wherever there is a temperature gradient between parts of the same wire.



II- Historical Development of the Thermocouple

The theory of thermoelectric effects was not established by one man at one time but is the culmination of various scientists over a span of many years. Here in chronological order are some of the people who developed the elementary principles of thermoelectric thermometry.

1800 - Alessandro Volta concluded that Galvani's frog twitched when contacted by two dissimilar metals.
1821 - Thomas I. Seebeck discovered the existence of thermoelectric currents.
1821 - Jean Baptiste Joseph Fourier published his basic heat conduction formula.
1826 - George S. Ohm discovered his equation for electrical conduction.
1834 - Jean Charles A. Peltier found out that when a current flows across the junction of two metals, it absorbs or releases heat.
1840 - James Prescott Joule found the important I2R heating effect.
1850 - Rudolf Julius Emanuel Clausius introduced the concept of entropy.
1851 - William Thomson (Lord Kelvin) discovered that an electric current produces different thermal effects.

III- Laws of Thermoelectricity

A. **The Law of the Homogeneous Circuit** states that a circuit of a single homogeneous wire cannot maintain a current by means of heat application alone.

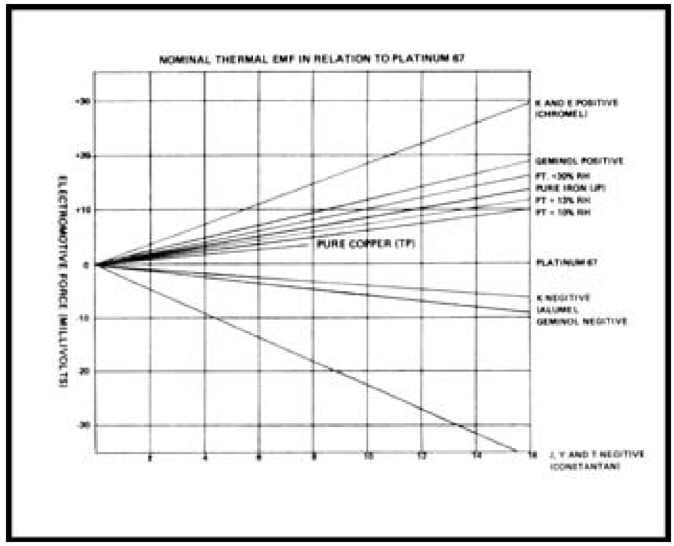
B. **The Law of Intermediate Metals** states that the algebraic sum of the thermo-electromotive forces in a circuit composed of any number of dissimilar materials is zero if all of the circuit is maintained at a uniform temperature.

C. **The Law of Intermediate Temperatures** states if one junction of a circuit of two dissimilar homogeneous wires is maintained at one temperature and the other junction is at another temperature, the thermal emf developed is independent of the temperature gradient along the wires.

D. **The Fundamental Law** of the above three may be stated as the algebraic sum of the thermo-electromotive forces generated in any given circuit containing any number of dissimilar homogeneous metals, is a function only of the temperatures of the junctions.

IV- Polarity of Some Thermocouple Materials

Thermoelectric relationships of the various thermo-elements are charted against platinum 67 as a standard. Each alloy on the chart is thermoelectrically negative in respect to all those above it and positive with respect to all those below it.



Thermocouple Theory and Development

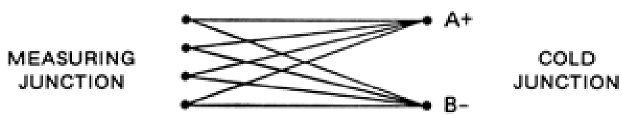
V- Thermocouple Materials

Composition of and practical use are explained in detail on page 150.

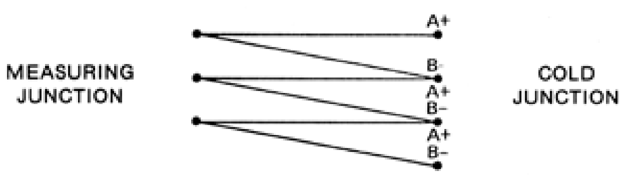
VI- Thermocouple Wiring Arrangements

(1) Standard single thermocouple consisting of two dissimilar wires and a single measuring junction.

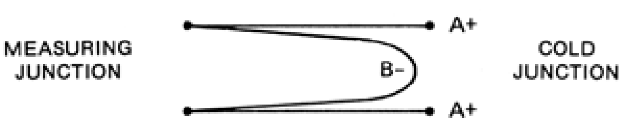
(2) An averaging thermocouple consisting of two or more thermocouples connected in parallel to a common cold junction. The emf generated will correspond to the mean of the temperatures of the individual junctions.



(3) A thermopile consists of two or more thermocouples connected in series. The resultant emf generated will be the aggregate of all individual junctions.



(4) A Delta thermocouple, sometimes known as a differential thermocouple, may consist of two similar wires. "A" joined to a single dissimilar wire "B" with the two measuring junctions normally at different temperatures. The resultant emf will be the difference between the two junctions, usually referred to as the differential temperature.



Care should be taken that there are no grounds in the circuit they will develop thermal emf's.

VII- Thermocouple Protective Materials

Composition of and practical use explained in detail on pages 152-153.

VIII- Installation Principles

A. Thermocouples

1. A sufficient depth of immersion should be provided for so that the measuring junction is entirely into the medium to be measured. This is to prevent heat being conducted away from the measuring junction.
   Basic rule of thumb for minimum immersion depth is 10 times the sheath diameter.
2. Avoid direct flame impingement.
3. A thermocouple reports only what it "feels."
4. In a high temperature environment, install the thermocouple in a vertical position. Otherwise, a support should be provided to prevent sagging of the protection tube.
5. The connecting head and reference junction must be at ambient temperature. Serious errors can occur if this point is overlooked.
6. Preheat refractory protection tubes before installation.
7. Check thermocouples in place - on a regular basis.
8. Replace burned out protection tubes at once.
9. Do not use a type K thermocouple below 1000°F if prior usage was above 1000°F.
10. Do not change the immersion depth of a thermocouple after it has been in service.
11. Select largest wire gauge or sheath diameter possible for longest life, or as small as possible for fastest response.

B. Extension wire

1. Be sure the extension wire is the same calibration as the thermocouple.
2. Select the proper insulation.
3. Observe the color coding - Red is negative.
4. Where possible, install wire in a conduit.
5. Never run electrical wire in the same conduit as thermocouple extension wires.
6. Never run thermocouple wires parallel or across any AC electric line.
7. Do not use extension wire in place of insulated thermocouple wire.
8. If you must splice, solder and tape to avoid grounding or shorting of the splice.
9. Do not contaminate the wires with solvents or oil.
10. If thermocouples are in a series or parallel circuit, check for grounds to avoid stray emf's.
11. Select wire gauge to be compatible with terminal screws yet sufficient size to meet loop resistance requirement.

Thermocouple Application Data

Calibration Code	Conductor & Characteristics		Recommended Temp. Range	Limits of Error			Application Information
	Positive	Negative		Range °F	Standard	Special	
J	Iron (Magnetic)	Constantan® (Non-Mag- netic)	32 to 1400°F (0 to 760°C)	32 to 1400°F (0 to 760°C)	±4.0°F (±2.2°C) or ±0.75%*	±2.0°F (±1.1°C) or ±0.4%*	Suitable for vacuum, reducing, or inert atmospheres. Reduced life in oxidizing atmosphere. Iron oxidizes rapidly above 1000°F so only heavy gauge wire is recommended for high temperature. Bare elements should not be exposed to sulphurous atmospheres above 1000°F.
Jx	White	Red	—	32 to 392°F (0 to 200°C)	±4.0°F (±2.2°C)	±2.0°F (±1.1°C)	Compensating extension wire for "J" calibration.
K	Chromel® (Non-Magnetic)	Alumel® (Magnetic)	32 to 2300°F (0 to 1260°C)	-328 to 32°F (-200 to 0°C) 32 to 2300°F (0 to 1260°C)	±3.96°F (±2.2°C) or ±2.0%* ±4.0°F (±2.2°C) or ±0.75%	±2.0°F (±1.1°C) or ±0.4%	Recommended for continuous oxidizing or neutral atmospheres. Mostly used above 1000°F. Subject to failure if exposed to sulphur. Preferential oxidation of chromium in positive leg at certain low oxygen concentrations causes "green rot" and large negative calibration drifts most serious in the 1500-1900°F temperature range.
Kx	Yellow	Red	—	32 to 392°F (0 to 200°C)	±4.0°F (±2.2°C)	±2.0°F (±1.1°C)	Compensating extension wire for "K" calibration.
T	Copper (Yellow Metal)	Constantan® (Silver Metal)	-328 to 700°F (-200 to 371°C)	-328 to 32°F (-200 to 0°C) 32 to 700°F (0 to 371°C)	±1.8°F (±1.0°C) or ±1.5%* ±1.8°F (±1.0°C) or ±0.75%*	— ±0.9°F (±0.5°C) or ±0.4%*	Usable in oxidizing, reducing, or inert atmospheres, as well as vacuum. Not subject to corrosion in moist atmospheres.
Tx	Blue	Red	—	-75 to 212°F (-60 to 100°C)	±1.8°F (±1.0°C)	±0.9°F (±0.5°C)	Compensating extension wire for "T" calibration.
E	Chromel®	Constantan®	32 to 1600°F (0 to 871°C)	-328 to 32°F (-200 to 0°C) 32 to 1600°F (0 to 871°C)	±3.06°F (±1.7°C) or ±1.0%* ±3.06°F (±1.7°C) or ±0.5%*	±1.8°F (±1.0°C) or ±0.4%*	Recommended for continuous oxidizing or inert atmospheres. Highest thermoelectric output of common calibrations.
Ex	Purple	Red	—	32 to 392°F (0 to 200°C)	±3.06°F (±1.7°C)	±1.8°F (±1.0°C)	Compensating extension wire for "E" calibration.
R	Platinum 13% Rhodium	Platinum	32 to 2700°F (0 to 1482°C)	32 to 2700°F (0 to 1482°C)	±2.7°F (±1.5°C) or ±0.25%*	±1.08°F (±0.6°C) or ±0.1%*	Recommended for high temperature. Requires non-metallic protection tube and ceramic insulators. Long-term high temperature use causes grain growth and mechanical failure. Negative calibration drift caused by rhodium diffusion to pure leg as well as from rhodium volatilization.
S	Platinum 10% Rhodium	Platinum	32 to 2700°F (0 to 1482°C)	32 to 2700°F (0 to 1482°C)	±2.7°F (±1.5°C) or ±0.25%*	±1.08°F (±0.6°C) or ±0.1%*	Same as "R" calibration but output is lower. Also susceptible to grain growth and drift.
RSx	Copper (Black)	Alloy 11 (Red)	—	32 to 392°F (0 to 200°C)	±9°F (±5°C)	—	Compensating extension wire for "R" and "S" calibration.
B	Platinum 30% Rhodium	Platinum 6% Rhodium	1600 to 3100°F (870 to 1705°C)	1600 to 3100°F (870 to 1705°C)	±0.5%*	±0.25%*	Same as "R" calibration but output is lower. Also susceptible to grain growth and drift.
Bx	Gray	Red	—	32 to 392°F (0 to 200°C)	±7.6°F (±4.2°C)	—	Compensating extension wire for "B" calibration.
W5	Tungsten 5% Rhenium	Tungsten 26% Rhenium	32 to 4200°F (0 to 2315°C)	32 to 800°F (0 to 426°C) 800 to 4200°F (426 to 2316°C)	±8.0°F (±4.4°C) ±1%*	— —	For very high temperature applications in inert and vacuum atmospheres.
L	Platinel II® +	Platinel II® -	32 to 2543°F (0 to 1395°C)	392 to 2192°F (200 to 1200°C)	±0.150mv to ±0.315mv	±0.100mv to ±0.158mv	Noble metal combination that approximates the "K" calibration but has much improved oxidation resistance. Should be treated as any noble metal thermocouple.
N	Nicrosil®	Nisil®	32 to 2300°F (0 to 1260°C)	32 to 2300°F (0 to 1260°C)	±4.0°F (±2.2°C) or ±0.75%*	±2.0°F (±1.1°C) or ±0.4%*	Modern nickel based alloy similar to "K" calibration but offering lower drift and longer life at high temperatures.
Nx	Orange	Red	—	32 to 392°F (0 to 200°C)	±4.0°F (±2.2°C)	±2.0°F (±1.1°C)	Compensating extension wire for "N" calibration.
Nickel- Moly	NiMo (Nickel-18% Molybdenum)	Nickel (Nickel-0.8% Cobalt)	32 to 2250°F (0 to 1232°C)	—	—	—	Used in hydrogen applications. Cycling causes excessive grain growth.

Thermocouple Application Data

Temperature Limits for Protected Thermocouples

The suggested temperature limits for continuous duty are shown for both our "**Series 2**" and "**Series 3**" thermocouples which utilize metallic and/or ceramic protection tubes and our **"Series 6"** Naba-Pak® thermocouples.

	Thermocouple in Metallic or Ceramic Protection Tube					Metal Sheathed, Compacted MgO Insulated, Naba-Pak® Thermocouple			
Calibration Code - Thermocouple Type	**8 AWG**	**14 AWG**	**20 AWG**	**24 AWG**	**30 AWG**	**3/8" & 1/2" Sheath OD**	**1/4" & 5/16" Sheath OD**	**3/16" Sheath OD**	**0.02" to 1/8" OD**
J Iron/Constantan®	1400°F (760° C)	1100°F (593°C)	900°F (482°C)	700°F (371°C)	700°F (371°C)	1100°F (593°C)	1000°F (538°C)	900°F (482°C	700°F (371°C)
K Chromel®/Alumel®	2300°F (1260°C)	2000°F (1093°C)	1800°F (982°C)	1600°F (871°C)	1400°F (760°C)	2000°F (871°C)	2000°F (871°C)	2000°F (871°C)	1600°F (871°C)
T Copper/Constantan®	-	-	500°F (260°C)	400°F (204°C)	300°F (149°C)	700°F (371°C)	600°F (316°C)	500°F (260°C)	400°F (204°C)
E Chromel®/ Constantan®	1600°F (871°C)	1200°F (649°C)	1000°F (538°C)	800°F (427°C)	700°F (370°C)	1200°F (649°C)	1100°F (593°C)	1000°F (538°C)	800°F (427°C)
R Plat. 13% Rhodium/ Platinum	-	-	-	2700°F (1482°C)	-	-	-	-	-
S Plat. 10% Rhodium/ Platinum	-	-	-	2700°F (1482°C)	-	-	-	-	-
B Plat. 30% Rhodium/ Plat. 6% Rhodium	-	-	-	3100°F (1705°C)	-	-	-	-	-
W5 Tung. 5% Rhenium/ Tung. 26% Rhenium	-	-	-	4200°F (2316°C)	-	-	-	-	-
N Nicrosil®/Nisil®	2300°F (1260°C)	2000°F (1093°C)	1800°F (982°C)	-	-	2000°F (871°C)	2000°F (871°C)	2000°F (871°C)	1600°F (871°C)
Nickel-Moly Nickel 18% Moly/ Nickel 0.8% Cobalt	-	2250°F (1232°C)	-	-	-	-	-	-	-

Protection Tube Materials

Material	Approximate Composition	Recommended Max. Temp.	NBS Code Number	Application	Remarks
Brass	55%-85% Cu Balance Zn Trace Others	570°F (300°C)	65	Marine Conditions	Good corrosion resistance.
Cast Iron	Fe	1600°F (870°C)	81	Molten Aluminum Die Castings	Needs daily application of white wash solution.
Wrought Iron	0.48% Mn 0.98% Cu Balance Fe	1250°F (675°C)	80	Food Ovens Asphalt Mixers Preheaters Glass Lehrs, Dryers	Non-corrosive atmospheres. Low temperature molten metals.
Carbon Steel	Sae 1018 or Sae 1020	1000°F (540°C)	85	Tinning Galvanizing Petroleum	Non-corrosive gases and liquids. Scales quickly at higher temperatures.
304 Stainless Steel	19% Cr 9% Ni 2% Mn 1% Si Balance Fe	1650°F (900°C)	84	Petroleum Products Mild Acids Steam Lines Food Processing	Good resistance to corrosion. Embrittles in the 900 to 1475°F range.
309 Stainless Steel	23% Cr 13% Ni 2% Mn 1% Si Balance Fe	2000°F (1090°C)	79	Sulfur-Dioxide Mild Acids	High resistance to scaling up to 1900°F. Strong, tough material.
310 Stainless Steel	25% Cr 20% Ni 2% Mn 1.5 % Si Balance Fe	2100°F (1150°C)	76	Chemical Applications Petroleum Products Kiln	High mechanical and creep strength at elevated temperatures. Very good corrosion resistance.
316 Stainless Steel	17% Cr 12% Ni 2% Mn 1% Si 2% Mo, Balance Fe	1700°F (930°C)	83	Chemical Applications Food Products Steam Lines	Higher corrosion resistance than 304. Resists pitting in sulfuric and phosphoric acids.
321 Stainless Steel	18% Cr 10% Ni 2% Mn 1% Si Ti Stabilized, Balance Fe	1700°F (930°C)	72	Petroleum Products Steam Lines	Stability against carbide precipitation. Resists inter-granular corrosion.
330 Stainless Steel	18% Cr 35% Ni 2% Mn 1% Si Balance Fe	2100°F (1150°C)	88	Heat Treating Furnaces Kilns	Good in oxidizing or reducing atmospheres.
347 Stainless Steel	18% Cr 10% Ni 2% Mn 1% Si Cb + Ta Stabilized Balance Fe	1700°F (930°C)	77	Steam Lines Petroleum Products Boiler Tubes	Used for severe stress and corrosion resistance applications.
Alloy-20	34% Ni 20% Cr 2% Mo Cb + Ta Stabilized Balance Fe	2000°F (1090°C)	66	Chemical Applications	Corrosion resistant properties generally superior to 300 series stainless steels. Especially useful against hot sulfuric acid.
Deterheat® (446 Stainless Steel)	25% Cr 1.5% Mn 1% Si Balance Fe	2100°F (1150°C)	82	Neutral Salt Baths Some Molten Metals Furnaces	Highly resistant to sulfur attack. General-purpose alloy.
Inconel® 600	77% Ni 15% Cr 7% Fe	2200°F (1215°C)	86	Salt Baths Furnaces Kilns	Generally used for high temperature. Excellent resistance to oxidation. Should not be used where sulfur is present.
Inconel® 601	60% Ni 23% Cr 14% Fe	2100°F (1150°C)	71	Carburizing Nitriding Heat Treating	Resists scaling to 2100°F. Good resistance to corrosion at high temperature.

Protection Tube Materials

Material	Approximate Composition	Recommended Max. Temp.	NBS Code Number	Application	Remarks
Inconel® 800	34% Ni 22% Cr Balance Fe	2000°F (1100°C)	89	Furnaces Cyanide Baths	Superior to 600 in resistance to green rot. Retains strength at elevated temperature.
Monel®	66% Ni 31% Cu 1% Fe	1000°F (540°C)	75	Marine Conditions Chemical Applications Food Processing	Combines high strength and ductility. Withstands many corrosives.
Nickel	99%+ Ni	2000°F (1100°C)	74	Chemical Applications Food Products Autoclaves	Do not use in the presence of sulfur or reducing atmosphere.
Kanthal®	22% Cr 5% Al Balance Fe	2200°F (1200°C)	87	Molten Copper Furnace Tubes	Has good resistance to sulphides.
HR-160®	37% Ni 29% Co 28% Cr 2.5% Si, 2% Fe	2200°F (1200°C)	60	Boilers & furnaces. Municipal, industrial, and hazardous waste incinerators	Excellent resistance to sulfidation and chloride attack.
Hastelloy® B-2	69% Ni 28% Mo 2% Fe	1000°F (540°C)	78B	Chemical Applications	A nickel-molybdenum alloy with outstanding resistance to hydrochloric and sulfuric acids.
Hastelloy® C-276	57% Ni 16% Mo 16% Cr 5.5% Fe	1000°F (540°C)	78C	Marine Conditions Chemical Applications	Has excellent resistance to a wide variety of chemical process environments.
Hastelloy® X	48% Ni 22% Cr 18.5% Fe 9% Mo	2350°F (1290°C)	78X	Furnace Tubes Chemical Field Nuclear Reactors	Develops an oxide scale. Unusual resistance to oxidizing, reducing and neutral atmospheres.
Titanium	Ti	1000°F (540°C)	67	Power generation Chemical processing Desalination plants	Excellent corrosion resistance, especially in the presence oxidizing acids and chlorides.
Refractory Metals					
Molybdenum	99% Mo Desilicized	3100°F (1700°C)	95	Special Exotic Appl. Inert or Vacuum Atmosphere Only	Sensitive to oxidation above 925°F.
Tantalum	99% Ta Chromalized	4200°F (2300°C)	96	Same as Moly	Extremely sensitive to traces of oxygen above 500°F.
Metal-Ceramic LT-1 (Cermet)	77% Cr 23% Al Oxide	2500°F (1370°C)	97	High Temperature Applications	Good resistance to mechanical and thermal shock.
Ceramic Tube Materials				**Remarks**	
Quartz	Fused Silicon Dioxide	2200°F (1200°C)	94	Can be used in molten silver and gold. Excellent resistance to thermal shock.	
Silica	Silica	2900°F (1600°C)	91	Usually used for glass tank applications.	
Mullite (Porcelain)	63% Al2O3 3 4% SiO2 Other Trace	3100°F (1700°C)	90	Good thermal shock resistance due to low rate of thermal expansion. Some possible contamination of platinum above 2400°F due to silica.	
Alumina	99% + Al2O3	3400°F (1870°C)	99	Impervious to gases at high temperature - Fair resistance to thermal and mechanical shock.	
Carbofrax	90% Silicon-Nitrate 9% Si-Dioxide	3000°F (1650°C)	92	Secondary protection for mullite or alumina tubes. Can take flame impingement. Fair thermal shock resistance.	
Re-crystallized Silicon Carbide	Re-crystallized SiC	3100°F (1700°C)	68	Secondary protection for mullite or alumina tubes.	
Refrax	Silicon-Nitrite bonded Si-Carbide	3150°F (1730°C)	93	Not wetted by molten aluminum. Better resistance to mechanical and thermal shock.	
Beryllium Oxide	99% BeO	4200°F (2300°C)	98	High thermal conductivity. Poor resistance to mechanical shock. Possible reaction with other oxides at high temperature. Should be used with caution as fumes and powders are toxic.	

Protection Tube Materials

Material Selection Guide

Industry Type	Process Application	Suggested Protection Tube Material
Heat Treating	Annealing to 1300°F	304SS Inconel® 601, 446SS
	Annealing over 1300°F	Inconel® 601, 446SS
	Carburizing	Inconel® 601
	Hardening to 1300°F	304SS
	Hardening to 2000°F	Inconel® 601, 446SS
	Hardening over 2000°F	Ceramic
	Lead Hardening	446SS
	Nitriding	Inconel® 601, 446SS
	Salt Bath (Cyanide)	Inconel® 601, 446SS
	Salt Bath (Neutral)	Inconel® 601, 446SS
	Salt Bath (High Speed)	Inc. 600, Infrared
	Quench Oil	Carbon Steel, 304SS
Iron & Steel	Billet & Slab heating to 2000°F	Inconel® 601, 446SS
	Billet & Slab heating over 2000°F	Ceramic, Silicon Carbide
	Blast Furnace	
	Downcomer	Inconel® 601, 446SS
	Stove Dome	Silicon Carbide
	Hot Blast - Main	Inconel® 601
	Stove Trunk	Inconel® 601
	Stove Outlet Flue	Carbon Steel, 304SS
	Bright Annealing (Batch)	Inconel® 601
	Bright Annealing (Cont.)	Inconel® 601, Ceramic
	Forging Furnaces	Ceramic, Silicon Carbide
	Galvanizing	Carbon Steel, Sil. Carbide
	Open Hearths (Flue-stack)	Inconel® 601, LT-1®
	Open Hearths (Checkers)	LT-1®
	Palm Oil	304 SS
	Pickling Tanks	Lead, Sil. Carbide, Teflon®
	Soaking Pits up to 2000°F	Inconel® 601, Sil. Carb.
	Soaking Pits over 2000°F	Ceramic, Silicon Carbide
	Tinning	Carbon Steel, 446SS
	Waste Heat Boilers	Inconel® 601, 446SS

The material recommendations for various service conditions listed are intended as a guide. No guarantee of material suitability can be made since other factors which effect material life may be present.

Industry Type	Process Application	Suggested Protection Tube Material
Non-Ferrous Metals	Aluminum (Molten Die-casting)	Cerite-II & III, Sil. Carbide Vesuvius®, Cast Iron (whitewashed)
	Aluminum (Heat Treating)	Carbon Steel, 304SS
	Aluminum (Annealing)	None or Carbon Steel
	Aluminum (Billet Heating)	Inconel® 601, 446SS
	Babbitt	446SS
	Brass, Bronze (Molten)	LT-1®, Sil. Carb., Hexoloy SA®
	Copper	LT-1®, Sil. Carb., Hexoloy SA®
	Lead	446 SS, Silicon Carbide
	Tin	CS, Silicon Carbide
	Smelting & Ore, Zinc	Inconel® 601, Sil. Carbide
Cement	Exit Flues	Inconel® 601, 446SS
	Kilns	Inconel® 601, Sil. Carbide, Ceramic
Ceramics	Kilns	Ceramic, Silicon Carbide
	Dryers	Ceramic, Silicon Carbide
	Enameling	Silicon Carbide
Chemical	General Applications	304SS, 316SS
	Incineration	LT-1®, Hexoloy SA®
	Reactors	LT-1®, Hexoloy SA®
Food/ Meat	Baking Ovens	304SS, 316SS
	Char. Kilns, Sugar	446SS
	Cooking-Fruits, Vegetables	304SS, 316SS
	Meat, Smokehouses	304SS, 316SS
Gas	Producer Gas	Inconel® 601, 446SS
	Water Gas (Carburetor)	Inconel® 601, 446SS
	Water Gas (Superheater)	Inconel® 601, 446SS
	Tar Stills	Carbon Steel, 304SS
Glass	Forehearth and Feeders	Infrared, Platinum
	Tanks	Ceramic, Silicon Carbide
	Flues and Checkers	Inconel® 60l, 446SS
	Lehrs	304 SS
Incineration	up to 2000°F	Inconel® 601, 446SS
	over 2000°F	LT-1®, Sil. Carbide, Hexoloy SA®
Paper	Digesters	304SS, 316SS
Petroleum	Bridgewall	Inconel® 60l, 446SS
	Dewaxing	304SS, 316SS
	Fractionating Column	304SS, 316SS
	Towers	304SS, 316SS
	Transfer lines	304SS, 316SS
	Sulfur Burners	LT-1®
Power	Boiler Tubes	310SS, 446SS, Inconel® 601
	Flue Gas	446SS
	Preheaters	Carbon Steel, 446SS
	Steam Lines	347SS, 316SS
	Water Lines	304SS
Smelting & Refining	Roasting Sulfur Ovens	Silicon Carbide
	Zinc Retort Preheaters	Ceramic
	Zinc Smelter	Silicon Carbide

Metal Protection Tube Dimensions

Comparison of Pipe Schedules

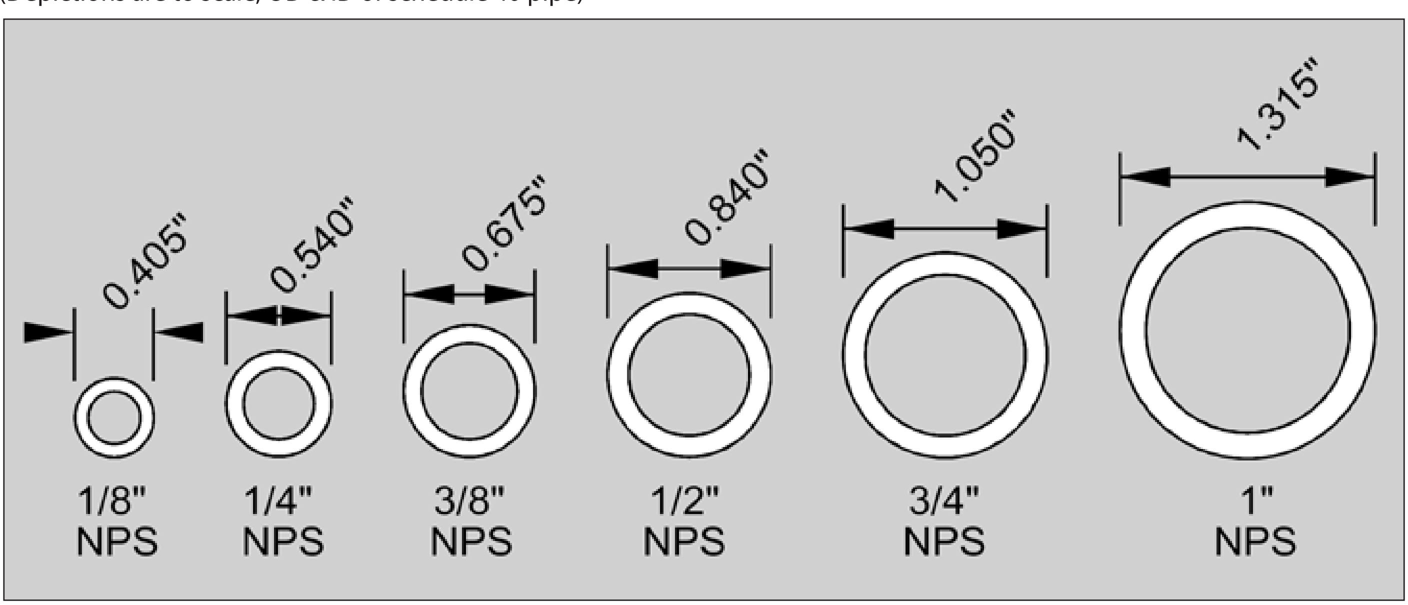
(Standard dimensions and weights)

NPS Pipe Size (DN)	Schedule	Outside Diameter in Inches	Wall Thickness in Inches	Inside Diameter in Inches	Weight Per Ft. in Lbs
1/8″ (6mm)	10	.405	.049	.307	0.186
	40	.405	.068	.269	0.2447
	80	.405	.095	.215	0.3145
1/4″ (8mm)	10	.540	.065	.410	0.330
	40	.540	.088	.364	0.4248
	80	.540	.119	.302	0.5351
3/8″ (10mm)	10	.675	.065	.545	0.424
	40	.675	.091	.493	0.5676
	80	.675	.126	.423	0.7388
1/2″ (15mm)	5	.840	.065	.710	0.5380
	10	.840	.083	.674	0.6710
	40	.840	.109	.622	0.8510
	80	.840	.147	.546	1.088
	160	.840	.187	.466	1.304
3/4″ (20mm)	5	1.050	.065	.920	0.6838
	10	1.050	.083	.884	0.8572
	40	1.050	.113	.824	1.131
	80	1.050	.154	.742	1.474
	160	1.050	218	.614	1.937
1″ (25mm)	5	1.315	.065	1.185	0.8678
	10	1.315	.109	1.097	1.404
	40	1.315	.133	1.049	1.679
	80	1.315	.179	.957	2.172
	160	1.315	.250	.815	2.844
1-1/4″ (32mm)	5	1.660	.065	1.530	1.107
	10	1.660	.109	1.422	1.806
	40	1.660	.140	1.380	2.273
	80	1.660	.191	1.278	2.997
	160	1.660	.250	1.160	3.765

NPS Pipe Size (DN)	Schedule	Outside Diameter in Inches	Wall Thickness in Inches	Inside Diameter in Inches	Weight Per Ft. in Lbs
1-1/2″ (40mm)	5	1.900	.065	1.770	1.274
	10	1.900	.109	1.682	2.085
	40	1.900	.145	1.610	2.718
	80	1.900	.200	1.500	3.631
	160	1.900	.281	1.338	4.859
2″ (50mm)	5	2.375	.065	2.245	1.604
	10	2.375	.109	2.157	2.638
	40	2.375	.154	2.067	3.653
	80	2.375	.218	1.939	5.022
	160	2.375	.343	1.689	7.444
2-1/2″ (65mm)	5	2.875	.083	2.709	2.475
	10	2.875	.120	2.635	3.531
	40	2.875	.203	2.469	5.793
	80	2.875	.276	2.323	7.661
	160	2.875	.375	2.125	10.010
3″ (80mm)	5	3.500	.083	3.334	3.029
	10	3.500	.120	3.260	4.332
	40	3.500	.216	3.068	7.576
	80	3.500	.300	2.900	10.250
	160	3.500	.437	2.626	14.320
3-1/2″ (90mm)	5	4.000	.083	3.834	3.472
	10	4.000	.120	3.760	4.973
	40	4.000	.226	3.548	9.109
	80	4.000	.318	3.364	12.510

Guide to Common Pipe Sizes

(Depictions are to scale, OD & ID of schedule 40 pipe)



Thermocouple and Extension Wire

Thermocouple and Extension Wire Insulation Properties

Material	Temperature Range		Flexibility	Resistance To					
	Continuous	Maximum		Flame Retardance	Abrasion	Acid	Solvent	Base	Moisture
Polyvinyl Chloride	-58 to 212°F (-50 to 105°C)	302°F (150°C)	Excellent	Good	Good	Good	Fair	Good	Good
FEP-Teflon®	-90 to 400°F (-67 to 204°C)	482°F (250°C)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
PFA-Teflon®	-90 to 500°F (-67 to 260°C)	550°F (288°C)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
TFE-Teflon®	-90 to 500°F (-67 to 260°C)	550°F (288°C)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Fiberglass	900°F (482°C)	1000°F (538°C)	Good	Excellent	Good	Good	Excellent	Excellent	Good
High Temp. Fiberglass	1400°F (760°C)	1600°F (871°C)	Good	Excellent	Good	Good	Excellent	Excellent	Good
Refrasil®	1600°F (871°C)	2000°F (1093°C)	Good	Excellent	Fair	Fair	Excellent	Good	Fair
Ceramic Fiber	2200°F (1204°C)	2600°F (1427°C)	Good	Excellent	Fair	Fair	Excellent	Excellent	Fair
Synthetic Fiber	500°F (260°C)	650°F (343°C)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Good
Nylon®	-85 to 248°F (-65 to 120°C)	302°F (150°C)	Good	Poor	Excellent	Excellent	Good	Good	Fair
Kapton®	-450 to 500°F (-267 to 260°C)	800°F (427°C)	Good	Good	Excellent	Good	Good	Good	Good
Silicone Rubber	-100 to 392°F (-73 to 200°C)	500°F (260°C)	Excellent	Good	Fair	Poor	Fair	Good	Good

Thermocouple Wire Weights and Resistances

Stated footages are in pound units, except noble metal calibrations, which are in troy ounce units.
Resistances are nominal for 70°F.

Gauge (AWG)	8		14		16		20		24		28		30		38	
Diameter	.128"		.064"		.051"		.032"		.020"		.012"		.010"		.004"	
Conductor	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb	Res. Ω/Ft	Ft/Lb
Copper	.0006	20	.003	80	.004	128	.010	322	.026	816	.065	2076	.103	3296	.659	20970
Iron	.004	23	.015	91	.003	145	.059	365	.149	926	.376	2356	.598	3741	3.83	23800
Constantan®	.018	20	.072	81	.114	128	.291	324	.725	821	1.85	2090	2.94	3318	18.70	21110
Chromel®	.026	20	.104	82	.165	130	.415	329	1.05	834	2.70	2121	4.03	3368	27.04	21430
Alumel®	.011	21	.043	83	.069	132	.113	334	.438	846	1.11	2153	1.76	3419	11.26	21750
Nicrosil®	.035	21	.142	84	.223	134	.566	337	1.44	854	3.65	2174	5.80	3452	36.25	21960
Nisil®	.013	20	.054	83	.085	131	.215	330	.545	837	1.39	2129	2.20	3380	13.75	21510
Alloy No. 11	.002	20	.007	80	.010	128	.027	322	.070	816	.175	2075	.275	3295	—	20960
	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT	Res. Ω/Ft	Ft/OzT
Platinum	.004	.57	.016	2.29	.025	3.76	.066	9.17	.166	23.49	.240	65.2	.663	93.9	4.15	587
Plat. 6% Rhod.	—	.60	—	2.39	—	3.92	—	9.58	—	24.51	—	68.1	—	98.0	—	613
Plat. 10% Rhod.	.007	.61	.028	2.46	.044	4.03	.119	9.83	.298	25.16	.512	69.9	1.19	100.6	7.45	629
Plat. 13% Rhod.	.008	.63	.031	2.51	.049	4.11	.124	10.04	.312	25.71	.530	71.4	1.25	102.8	7.80	643
Plat. 30% Rhod.	—	.70	—	2.79	—	4.58	—	11.18	—	28.62	—	79.5	—	114.5	—	715

Thermocouple and Extension Wire

Wire Capacities of Conduit

(Approximate number of extension wire cables in conduit for commonly used wire types)

Conduit Size	Polyvinyl or Teflon® insulated wire		Conduit Size	Polyvinyl or Teflon® insulated wire	
	16 AWG	20 AWG		16 AWG	20 AWG
1/2"	3	5	1-1/2"	26	43
3/4"	6	10	2"	42	70
1"	10	16	2-1/2"	61	86
1-1/4"	19	30	3"	93	135

Platinum Wire Weight & Length Relationships

Platinum		
Gauge (AWG)	Diameter	Grams/Inch
26	0.016"	0.07063
24	0.020"	0.11037
—	0.021"	0.12167
—	0.022"	0.13354
20	0.032"	0.28252
Platinum 6% Rhodium		
Gauge (AWG)	Diameter	Grams/Inch
26	0.016"	0.06767
24	0.020"	0.10574
—	0.021"	0.11657
—	0.022"	0.12794
20	0.032"	0.27069
Platinum 10% Rhodium		
Gauge (AWG)	Diameter	Grams/Inch
26	0.016"	0.06583
24	0.020"	0.10352
—	0.021"	0.11341
—	0.022"	0.12447
20	0.032"	0.26334
Platinum 13% Rhodium		
Gauge (AWG)	Diameter	Grams/Inch
26	0.016"	0.06452
24	0.020"	0.10082
—	0.021"	0.11114
—	0.022"	0.12199
20	0.032"	0.25809
Platinum 30% Rhodium		
Gauge (AWG)	Diameter	Grams/Inch
26	0.016"	0.05797
24	0.020"	0.09058
—	0.021"	0.09985
—	0.022"	0.10959
20	0.032"	0.23187

Comparison of Wire Gauges

(Sizes in Inches)

Gauge No.	American or Brown & Sharpe	Birming-ham or Stubs	Wash-burn & Moon	United States Standard (Revised)	United States Standard	Imperial S.W.G
7/0	—	—	.490	—	.50000	.500
6/0	.5800	—	.460	—	.46875	.464
5/0	.5165	—	.430	—	.43750	.432
4/0	.4600	.454	.3938	.4063	.40625	.400
3/0	.4096	.425	.3625	.375	.37500	.372
2/0	.3648	.380	.3310	.3438	.34375	.348
1/0	.3249	.340	.3065	.3125	.31250	.324
1	.2893	.300	.2830	.2813	.28125	.300
2	.2576	.284	.2625	.2625	.26563	.276
3	.2294	.259	.2437	.2391	.25000	.252
4	.2043	.238	.2253	.2242	.23428	.232
5	.1819	.220	.2070	.2092	.21875	.212
6	.1620	.203	.1920	.1943	.20313	.192
7	.1443	.180	.1770	.1793	.18750	.176
8	.1285	.165	.1620	.1644	.17188	.160
9	.1144	.148	.1483	.1495	.15625	.144
10	.1019	.134	.1350	.1345	.14063	.128
11	.09074	.120	.1205	.1196	.12500	.116
12	.08081	.109	.1055	.1046	.10938	.104
13	.07196	.095	.0915	.0897	.09375	.092
14	.06408	.083	.0800	.0747	.07813	.080
15	.05707	.072	.0720	.0673	.07031	.072
16	.05082	.065	.0625	.0598	.06250	.064
17	.04526	.058	.0540	.0538	.05625	.056
18	.04030	.049	.0475	.0478	.05000	.048
19	.03589	.042	.0410	.0418	.04375	.040
20	.03196	.035	.0348	.0359	.03750	.036
21	.02846	.032	.0318	.0329	.03438	.032
22	.02535	.028	.0286	.0299	.03125	.028
23	.02257	.025	.0258	.0269	.02813	.024
24	.02010	.022	.0230	.0239	.02500	.022
25	.01790	.020	.0204	.0209	.02188	.020
26	.01594	.018	.0181	.0179	.01875	.0180
27	.01420	.016	.0173	.0164	.01719	.0164
28	.01264	.014	.0162	.0149	.01563	.0148
29	.01126	.013	.0150	.0135	.01406	.0136
30	.01003	.012	.0140	.0120	.01250	.0124
31	.008928	.010	.0132	.0109	.01094	.0116
32	.007950	.009	.0128	.0102	.01016	.0108
33	.007080	.008	.0118	.0094	.00938	.0100
34	.006305	.007	.0104	.0086	.00859	.0092
35	.005615	.005	.0095	.0078	.00781	.0084
36	.00500	.004	.0090	.0070	.00703	.0076
37	.004453	—	.0085	—	.00664	.0068
38	.003965	—	.008	—	.00625	.0060
39	.003531	—	.0075	—	—	.0052
40	.003145	—	.007	—	—	.0048

NEMA Type Enclosures for use in Non-Hazardous Locations

The following table is based on NEMA 250-1997

Number	Intended Use and Description
1	Indoor use primarily to provide a degree of protection against contact with the enclosed equipment and against a limited amount of falling dirt.
2	Indoor use to provide a degree of protection against limited amounts of falling water and dirt.
3	Outdoor use to provide a degree of protection against wind-blown dust, rain, and sleet; undamaged by the formation of ice on the enclosure.
3R	Outdoor use to provide a degree of protection against falling rain and sleet; undamaged by the formation of ice on the enclosure.
3S	Outdoor use to provide a degree of protection against windblown dust, rain, and sleet; external mechanisms remain operable while ice laden.
4	Indoor or outdoor use to provide a degree of protection against splashing water, windblown dust and rain, and hose-directed water; undamaged by the formation of ice on the enclosure.
4X	Indoor or outdoor use to provide a degree of protection against splashing water, windblown dust and rain, and hose-directed water; undamaged by the formation if ice on the enclosure; resists corrosion.
6	Indoor or outdoor use to provide a degree of protection against the entry of water during temporary submersion at a limited depth; undamaged by the formation of ice on the enclosure.
6P	Indoor or outdoor use to provide a degree of protection against the entry of water during prolonged submersion at a limited depth.
11	Indoor use to provide by oil immersion a degree of protection of the enclosed equipment against the corrosive effects of corrosive liquids and gases.
12, 12K	Indoor use to provide by oil immersion a degree of protection against dust, falling dirt, and dripping non-corrosive liquids.
13	Indoor use to provide by oil immersion a degree of protection against dust and spraying water, oil, and non-corrosive coolants.

NEMA Type Enclosures for use in Hazardous Locations

The following table is based on NEMA 250-1997

Number	Intended Use and Description
7	Enclosures constructed for indoor use in hazardous locations classified as Class I, Division 1, Groups A, B, C, or D as defined in NFPA 70.
8	Enclosures constructed for either indoor or outdoor use in hazardous locations classified as Class I, Division 1, Groups A, B, C, and D as defined in NFPA 70.
9	Enclosures constructed for indoor use in hazardous locations classified as Class II, Division 1, Groups E, F, and G as defined in NFPA 70.
10	Enclosures constructed to meet the requirements of the Mine Safety and Health Administration, 30 CFR, part 18.

Notes: In hazardous locations, when completely and properly installed and maintained, Type 7 and 10 enclosures are designed to contain an internal explosion without causing an external hazard. Type 8 enclosures are designed to prevent combustion through the use of oil-immersed equipment. Type 9 enclosures are designed to prevent the ignition of combustible dust.

Hazardous Locations Reference

The following tables are based on NFPA 497M-1983

Class I - Gases or Vapors

Division 1 - Hazardous vapors present
Division 2 - Hazardous vapors contained, but may be present

Groups for both Division 1 and Division 2:
Group A - Atmospheres containing acetylene
Group B - Atmospheres containing hydrogen or gases or vapors of equivalent hazard such as manufactured gas
Group C - Atmospheres containing ethyl-ether vapors, ethylene or cyclo-propane
Group D - Atmospheres containing gasoline, hexane, naptha, benzene, butane, propane, alcohol, acetone, benzol, lacquer solvent vapors, or natural gas

Class II - Dust

Division 1 - Air suspended
Division 2 - Surface accumulated, non-air suspended

Groups for both Division 1 and Division 2:
Group E - Atmospheres containing metal dust including aluminum, magnesium, their commercial alloys, and other metals of similarly hazardous characteristics
Group F - Atmospheres containing carbon black, coal, or coke dust
Group G - Atmospheres containing flour, starch, or grain dust

Class III - Fibers

Division 1 - Fibers handled, manufactured, or stored
Division 2 - Fibers handled or stored
(no groups)

Group Specifics

Group A - Atmospheres
acetylene

Group B - Atmospheres
acrolein (inhibited) (2)
arsine
butadiene (1)
ethylene oxide (2)
hydrogen
manufactured gases containing more than 30% hydrogen (by volume)
propylene oxide (2)
propylnitrate

Group C - Atmospheres
acetaldehyde
allyl alcohol
n-butyraidehyde
carbon monoxide
crotonaldehyde
cyclopropane
diethyl ether
diethylamine
epichlorohydrin
ethylene
ethylenimine
ethyl mercaptan
ethyl sulfide
hydrogen cyanide
hydrogen sulfide
morpholine
2-nitropropane
tetrahydrofuran
unsymmetrical dimethyl hydrazine (UDMH 1, 1-dimethyl hydrazine)

Group D - Atmospheres
acetic acid (glacial)
acetone
acrylonitrile
ammonia (3)
benzene
butane
1-butanol (butyl alcohol)
2-butanol (secondary butyl alcohol)
n-butyl acetate
isobutyl acetate
di-isobutylene
ethane
ethanol (ethyl alcohol)
ethyl acetate
ethyl acrylate (inhibited)
ethylene diamine (anhydrous)
ethylene dichloride
ethylene glycol monomethyl ether
gasoline
heptanes
hexanes
isoprene
isopropyl ether
mesityl oxide
methane (natural gas)
methanol (methyl alcohol)
3-methyl-1 butanol (isoamyl alcohol)
methyl ethyl ketone
methyl isobutyl ketone
2-methyl-1 -propanol (isobutyl alcohol)

Group D - Atmospheres (contin.)
2-methyl-2-propanol (tertiary butyl alcohol)
petroleum naphtha (4)
pyridine
octanes
pentanes
1-pentanol (amyl alcohol)
propane
1-propanol (propyl alcohol)
2-propanol (isopropyl alcohol)
propylene
styrene
toluene
vinyl acetate
vinyl chloride
xylenes

Group E- Atmospheres
containing metal dust, including aluminum, magnesium, and their commercial alloys, and other metals of similarly hazardous characteristics

Group F- Atmospheres
containing carbon black, coal or coke dust

Group G- Atmospheres
containing flour, starch or grain dust

(1) Group D equipment shall be permitted for this atmosphere if such equipment is isolated in accordance with Section 501-5(a) of National Electric Code by sealing all conduit 1/2 inch size or larger.

(2) Group C equipment shall be permitted for this atmosphere if such equipment is isolated in accordance with Section 501-5(a) of National Electric Code by sealing all conduit 1/2-inch size or larger.

For classification of areas involving ammonia atmosphere,
(3) See Safety Code for Mechanical Refrigeration (ANSI/ASHRAE 15-1978) and Safety Requirements for the Storage and Handling of Anhydrous Ammonia (ANSI/CGA G2.1-1972).

(4) A saturated hydrocarbon mixture boiling in the range 20-135°C (68-275°F). Also known by the synonyms benzine, ligroin, petroleum ether, or naphtha.

Glossary

absolute zero - the lowest possible theoretical temperature. Defined as -273.15°C (0 K).

accuracy - the degree of agreement between a reference value and a measured value.

adiabatic - without loss or gain of heat within a process.

adjusting device (liquid-in-glass thermometer) - a device to adjust the liquid in the bulb and main capillary to that needed for the intended temperature interval.

alpha - (1) the temperature coefficient of resistance of a material. (2) a parameter for a resistance temperature detector.

ambient temperature - the temperature of the surrounding air which is in contact with the measuring devices.

boiling point - the equilibrium temperature is the temperature at which a liquid becomes a vapor. For water this is 100°C (212°F) at standard atmospheric pressure.

bulb (liquid-in-glass thermometer) - the reservoir for the thermometer liquid.

bulb length (liquid-in-glass thermometer) - the distance from the bottom of the bulb to the point where the internal bulb diameter begins to decrease as the bulb merges into the stem.

BTU (British thermal unit) - Defined as the quantity of heat necessary to raise the temperature of one pound of water from 32°F to 33°F (at standard atmospheric pressure).

calibrate - to determine the indication or output of a measuring device with respect to that of a standard.

calibration drift - a change in thermoelectric output due to unwanted environmental stress.

calibration point - a specific value, established by a standard, at which the indication or output of a measuring device is determined.

"Callendar Van Dusen Equation" - a function of temperature which provides resistance values as an interpolation equation for RTD's.

Celsius - the designation of the degree (°C) - on the International Temperature Scale of 1990 (ITS-90). Formerly (prior to 1948) called "centigrade".

certification - to state that a test result is valid and/or a product that is as specified.

color code - the arrangement of standard colors for identifying thermocouple wires.

compensating alloys - a metal alloy which has the same or similar Seebeck coefficient as an actual thermocouple alloy.

connection head - a protective housing enclosing a terminal block for an electrical temperature-sensing device. Usually provided with threaded openings for attachment to a protecting tube and for attachment of conduit.

creep strength - the rate of continuous deformation under stress at a specified temperature. Generally expressed as PSI to produce a 1% elongation in 10,000 hours at the temperature indicated.

corrosion - a variety of environmental conditions which causes deterioration of a metal.

cryogenic - a term that relates to temperatures well below the ice point.

curie point - magnetic transformation point, or the temperature at which a normally magnetic material becomes substantially non-magnetic.

defining fixed points - the reproducible temperatures upon which the International Temperature Scale is based.

degree - the unit of measure on a temperature scale.

deviation - the departure from a standard or known value. Often referred to as "Delta".

DIN 43760 - the standard (obsolete) that defines the characteristics of a 100-ohm platinum resistance temperature detector; established by the European Industrial complex that formulates engineering standards.

drift - the change over a period of time of a set-point value.

ductility - The property of a material which permits deformation without rupture.

duplex - (1) a sensor with two separate elements. (2) A pair of wires made with the conductors insulated from each other.

elastic limit - the maximum stress a material will stand without permanent deformation.

electromotive force (emf) - the electrical potential difference which produces or tends to produce an electric current.

elongation - the amount of permanent stretch after fracture in tension.

endothermic - the absorption of heat.

error - the variant between the value being measured and the correct value.

exothermic - the loss of heat.

exposed junction - a construction in which the measuring function of the sensor protrudes beyond the sheath or a similar tube protecting it.

extension wire - a pair of wires having such temperature-emf characteristics relative to the thermocouple with which the wires are intended to be used that, when properly connected to the thermocouple, the reference junction is transferred to the opposite of the wires.

Fahrenheit - the designation of the degree (°F) and the temperature scale used commonly in public life and engineering circles in English-speaking countries.

fixed point - a reproducible temperature of equilibrium between different phases of a material.

freezing point - the fixed point between the solid and liquid phases of material when approached from the liquid phase under a pressure of one standard atmosphere. For a pure material this is also the melting point.

grounded junction - a construction in which the measuring junction and the sheath material are in electrical contact with each other.

hardness - a resistance of a material to indentation, penetration, scratching or bending.

heat - thermal energy expressed in British thermal units (Btu's).

heater (metal sheathed, electrical resistance) - one consisting of resistance wire or wires, with or without connecting wires, embedded in ceramic insulation compacted within a metal protecting tube.

heat sink - a body where thermal energy is absorbed.

heat transfer - thermal energy is transferred from a body of high energy to a body of low energy.

Glossary

hot junction - the thermocouple measuring junction.

hysteresis - a metallurgical instability or in-homogeneities caused by temperature cycling of elevated temperatures.

ice point - the fixed point between ice and air-saturated water under a pressure of one standard atmosphere. This temperature is 0°C (273.15 K) on the International Temperature Scale of 1990 (ITS-90).

IEC-751 - the current standard that defines the characteristics of a 100-ohm platinum resistance temperature detector; established by the International Electrotechnical Commission (IEC).

International (Practical) Temperature Scales - temperature scales adopted by various conferences on weights and measures are defined in terms of fixed and reproducible equilibrium temperatures. (1) IPTS-48 standard established in the year 1948 (2) IPTS-68 supersedes above scale in 1968 (3) ITS-90 the current reference standard

immersion depth - the length of the sensor which is exposed to the temperature being measured.

impedance - the resistance to electrical flow in alternating current circuits.

insulation resistance - the electrical resistance between isolated conducting materials in a circuit consisting of both conducting and insulating materials.

intrinsically safe - a system or device which inherently poses no risk of causing a spark that could cause ignition of flammable gases.

isothermal - a constant temperature area.

junction - the point at which two dissimilar metals are joined to become the measuring point of a thermocouple.

Kelvin - designates the thermodynamic temperature scale named after Lord Kelvin. Degrees (K) on this scale are of the same magnitude as the Celsius scale.

lag - (1) a delay of time of the signal between the output of the sensor and the measuring device. (2) the "T" dimension of a thermowell which has an extension above the mounting threads.

limits of error - a tolerance for thermoelectric devices as set forth by ANSI specifications.

linearity - the extent to which an instrument or transducer's relative response varies with respect to it's input.

loop resistance - the total electrical resistance of a thermocouple circuit expressed in Ohms.

lower range value - the lowest quantity that an instrument is adjusted to measure.

measuring junction - that junction of a thermocouple which is subjected to the temperature to be measured.

melting point - the fixed point between the solid and liquid phases of a material when approached from the solid phase under a pressure of one standard atmosphere. For a pure material this is also the freezing point.

negative temperature coefficient - a decrease in resistance when the temperature is increased.

noise - an undesirable electrical interface.

NPT - abbreviation for American National Standard taper pipe thread.

parallax - an incorrect reading of a measuring device caused by the viewing edge not being perpendicular to same, causing an optical illusion.

Peltier coefficient - the reversible heat flow, which is absorbed or evolved at a thermocouple junction when unit current passes in unit time.

Peltier emf - synonymous with Peltier coefficient.

platinum 27 - the platinum standard to which the National Bureau of Standards referenced thermoelectric measurements prior to 1972.

platinum 67 - the platinum standard used by the National Bureau of Standards after 1972 as the reference to which thermoelectric measurements are referred.

polarity - an electrical characteristic of a charged current determining a positive and negative flow.

positive temperature coefficient - the increase in resistance with an increase in temperature.

power supply - a device that furnishes separate power to a circuit.

primary standard resistance thermometer - a resistance thermometer that has had its temperature-resistance relationship determined in accordance with methods described in the text establishing the International Temperature Scale.

primary standard thermocouple - a thermocouple that has had its temperature-emf relationship determined in accordance with methods described in the text establishing the International Temperature Scale.

probe - a term used to describe thermocouples and other temperature measuring devices.

PSI - the usual unit of stress in pounds per square inch.

protecting tube - a tube designed to enclose a temperature-sensing device and protect it from the deleterious effects of the environment. It may provide for attachment to a connection head but is not primarily designed for pressure-tight attachment to a vessel.

range - the region between the limits within which a quantity is measured. It is expressed by stating the lower and upper range-values.

reference junction - that junction of a thermocouple which is at a known temperature.

refractory metal thermocouple - a thermocouple whose thermoelements have melting points above that of 60 percent platinum, 40 percent rhodium, 1935°C (3515°F).

repeatability - the action of a sensor to indicate the same reading or output under repeated identical conditions.

resistance - the opposition to the flow of an electrical current.

resistance, insulation (sheathed thermocouple wire) - the measured resistance between wires or between wires and sheath multiplied by the length of the wire expressed in Meg Ohms per foot of length.

response time - the time required for a sensor to reach 63.2% of a step change in temperature.

RFI - the abbreviation for Radio Frequency Interference.

RTD - the abbreviation for a Resistance Temperature Detector.

secondary reference point - reproducible temperatures other than the fixed points; Defined in the ITS, as being useful for calibration purposes.

Glossary

secondary standard thermocouple - a thermocouple that has had its temperature-emf relationship determined by comparison to a primary standard of temperature.

Seebeck coefficient - the rate of change of thermal emf with temperature at a given temperature. Normally expressed as emf per unit of temperature. Synonymous with thermoelectric power.

Seebeck emf - the net emf set up in a thermocouple under open circuit conditions. It represents the algebraic sum of the Peltier and Thomson emf. Synonymous with thermal emf.

sheathed thermocouple - a thermocouple having its thermoelements, and sometimes its measuring junction, embedded in ceramic insulation compacted within a metal protecting tube.

signal - information from a transducer, normally carried electrically. This information can be of either digital or analog form.

span - the algebraic difference between the upper and lower range values.

spark test - a test to detect insulation requirements.

specific gravity - the ratio of the weight of a solid or liquid to the weight of an equal volume of water.

specific heat - the amount of heat necessary to raise the temperature of a substance by 1°F. Expressed as BTU per pound per °F.

specific resistance - the resistance of a material, usually a metal or alloy, to the passage of an electric current.

stability - a sensor's ability to maintain a consistent output when a consistent input is applied.

standard thermoelement - a thermoelement that has been calibrated with reference to pre-determined international standards.

tensile strength - the stress required to rupture in tension (pull). Expressed in PSI.

test thermocouple - a thermoelement that is to be calibrated by comparing its thermal emf with that of a standard thermoelement.

thermal conductivity - the measure of heat a substance will conduct through itself.

thermal electromotive force - the net emf set up in a thermocouple under conditions of zero current. Synonymous with Seebeck emf.

thermal expansion - the increase in length caused by heating. Expressed in inches of increase, per inch of original length, per degrees of temperature.

thermocouple - a device for measuring temperatures by the use of two dissimilar metals in contact; the junction of these metals gives rise to a measurable electrical potential that changes with temperature.

thermocouple assembly - an assembly consisting of a thermocouple element and one or more associated parts such as terminal block, connection head, and protecting tube.

thermocouple element - a pair of bare or insulated thermoelements joined as one end to form a measuring junction and intended for use as a thermocouple or as part of a thermocouple assembly.

thermocouple (letter designated types B, E, J, K, N, R, S, or T) - a thermocouple having an emf-temperature relationship corresponding to the appropriate letter-designated table in ASTM E-230 standard "Temperature Electromotive Force Tables for Thermocouples", within the limits of error specified in that standard.

thermoelectric power - the rate of change of thermal emf with temperature at a given temperature. Synonymous with Seebeck coefficient. Normally expressed as emf per unit of temperature.

thermoelectric pyrometer - an instrument that senses the output of a thermocouple and converts it to equivalent temperature units.

thermoelement - one of the two dissimilar electrical conductors comprising a thermocouple.

thermopile - a number of thermocouples connected in series, arranged so that alternate junctions are at the reference temperature and at the measured temperature. This arrangement serves to increase the output for a given temperature difference between reference and measuring junctions.

thermowell - a tube designed for the insertion of a temperature-sensing element(s), and provided with means for pressure-tight attachment to a vessel.

Thomson coefficient - the rate at which heat is absorbed or evolved reversibly in a thermoelement.

Thomson emf - the product of the Thomson coefficient and the temperature difference across a thermoelement.

transducer - a device which receives and converts energy into another parameter.

transmitter - an externally powered variable resistor which transmits a signal from a transducer via a two wire current loop.

triple point (of water, TPW) - the temperature of equilibrium between ice, water and water vapor. This temperature is to 0.01°C (273.16 K) on the International Temperature Scale of 1990.

ungrounded hot junction - the construction of the measuring junction of a thermocouple which is fully insulated from the enclosing protective material.

upper range value - the highest quantity that an instrument is adjusted to measure.

working standard thermocouple - a thermocouple that has had its temperature - emf relationship determined by reference to a secondary standard of temperature.

yield strength - the stress at which a material exhibits a specified limit. Expressed as PSI.

Measurement and Conversion Table

Fractions to Decimals and Millimeters

1/64	.015625	.39624
1/32	.03125	.79240
3/64	.046875	1.18872
1/16	.0625	1.5875
5/64	.078125	1.9837
3/32	.09375	2.3800
7/64	.109375	2.7788
1/8	.1250	3.1750
9/64	.140625	3.5712
5/32	.15625	3.9675
11/64	.171875	4.3663
3/16	.1875	4.7625
13/64	.203125	5.1587
7/32	.21875	5.5550
15/64	.234375	5.9538
1/4	.2500	6.3500
17/64	.265625	6.7462
9/32	.28125	7.1425
19/64	.296875	7.5412
5/16	.3125	7.9375
21/64	.328125	8.3337
11/32	.34375	8.7300
23/64	.359375	9.1288
3/8	.3750	9.5250
25/64	.390625	9.9212
13/32	.40625	10.317
27/64	.421875	10.716
7/16	.4375	11.113
29/64	.453125	11.509
15/32	.46875	11.905
31/64	.484375	12.304
1/2	.5000	12.700
33/64	.515625	13.100
17/32	.53125	13.492
35/64	.546875	13.891
9/16	.5625	14.288
37/64	.578125	14.684
19/32	.59375	15.080
39/64	.609375	15.479
5/8	.6250	15.875
41/64	.640625	16.271
21/32	.65625	16.667
43/64	.671875	17.066
11/16	.6875	17.463
45/64	.703125	17.859
23/32	.71875	18.255
47/64	.734375	18.654
3/4	.7500	19.050
49/64	.765625	19.446
25/32	.78125	19.842
51/64	.796875	20.241
13/16	.8125	20.637
53/64	.828125	21.034
27/32	.84375	21.430
55/64	.859375	21.828
7/8	.8750	22.225
57/64	.890625	22.62
29/32	.90625	23.017
59/64	.921875	23.416
15/16	.9375	23.81
61/64	.953125	24.208
31/32	.96875	24.605
63/64	.984375	25.001
1	1.0000	25.400

Temperature Conversion Chart

°C	0 to 1000	°F	°C	1000 to 2000	°F	°C	2000 to 3000	°F
-17.8	0	32	538	1000	1832	1093	2000	3632
-12.2	10	50	543	1010	1850	1099	2010	3650
-6.7	20	68	549	1020	1868	1104	2020	3668
-1.11	30	86	554	1030	1886	1110	2030	3686
-4.44	40	104	560	1040	1904	1116	2040	3704
10.0	50	122	566	1050	1922	1121	2050	3722
15.6	60	140	571	1060	1940	1127	2060	3740
21.1	70	158	577	1070	1958	1132	2070	3758
26.7	80	176	582	1080	1976	1138	2080	3776
32.2	90	194	588	1090	1994	1143	2090	3794
37.8	100	212	593	1100	2012	1149	2100	3812
43	110	230	599	1110	2030	1154	2110	3830
49	120	248	604	1120	2048	1160	2120	3848
54	130	266	610	1130	2066	1166	2130	3866
60	140	284	616	1140	2084	1171	2140	3884
66	150	302	621	1150	2102	1177	2150	3902
71	160	320	627	1160	2120	1182	2160	3920
77	170	338	632	1170	2138	1188	2170	3938
82	180	356	638	1180	2156	1193	2180	3956
88	190	374	643	1190	2174	1199	2190	3974
93	200	392	649	1200	2192	1204	2200	3992
99	210	410	654	1210	2210	1210	2210	4010
104	220	428	660	1220	2228	1216	2220	4028
110	230	446	666	1230	2246	1221	2230	4046
116	240	464	671	1240	2264	1227	2240	4064
121	250	482	677	1250	2282	1232	2250	4082
127	260	500	682	1260	2300	1238	2260	4100
132	270	518	688	1270	2318	1243	2270	4118
138	280	536	693	1280	2336	1249	2280	4136
143	290	554	699	1290	2354	1254	2290	4154
149	300	572	704	1300	2372	1260	2300	4172
154	310	590	710	1310	2390	1266	2310	4190
160	320	608	716	1320	2408	1271	2320	4208
166	330	626	721	1330	2426	1277	2330	4226
171	340	644	727	1340	2444	1282	2340	4244
177	350	662	732	1350	2462	1288	2350	4262
182	360	680	738	1360	2480	1293	2360	4280
188	370	698	743	1370	2498	1299	2370	4298
193	380	716	749	1380	2516	1304	2380	4316
199	390	734	754	1390	2534	1310	2390	4334
204	400	752	760	1400	2552	1316	2400	4352
210	410	770	766	1410	2570	1321	2410	4370
216	420	788	771	1420	2588	1327	2420	4388
221	430	806	777	1430	2606	1332	2430	4406
227	440	824	782	1440	2624	1338	2440	4424
232	450	842	788	1450	2642	1343	2450	4442
238	460	860	793	1460	2660	1349	2460	4460
243	470	878	799	1470	2678	1354	2470	4478
249	480	896	804	1480	2696	1360	2480	4496
254	490	914	810	1490	2714	1366	2490	4514
260	500	932	816	1500	2732	1371	2500	4532
266	510	950	821	1510	2750	1377	2510	4550
271	520	968	827	1520	2768	1382	2520	4568
277	530	986	832	1530	2786	1388	2530	4586
282	540	1004	838	1540	2804	1393	2540	4604
288	550	1022	843	1550	2822	1399	2550	4622
293	560	1040	849	1560	2840	1404	2560	4640
299	570	1058	854	1570	2858	1410	2570	4658
304	580	1076	860	1580	2876	1416	2580	4676
310	590	1094	866	1590	2894	1421	2590	4694
316	600	1112	871	1600	2912	1427	2600	4712
321	610	1130	877	1610	2930	1432	2610	4730
327	620	1148	882	1620	2948	1438	2620	4748
332	630	1166	888	1630	2966	1443	2630	4766
338	640	1184	893	1640	2984	1449	2640	4784
343	650	1202	899	1650	3002	1454	2650	4802
349	660	1220	904	1660	3020	1460	2660	4820
354	670	1238	910	1670	3038	1466	2670	4838
360	680	1256	916	1680	3056	1471	2680	4856
366	690	1274	921	1690	3074	1477	2690	4874
371	700	1292	927	1700	3092	1482	2700	4892
377	710	1310	932	1710	3110	1488	2710	4910
382	720	1328	938	1720	3128	1493	2720	4928
388	730	1346	943	1730	3146	1499	2730	4946
393	740	1364	949	1740	3164	1504	2740	4964
399	750	1382	954	1750	3182	1510	2750	4982
404	760	1400	960	1760	3200	1516	2760	5000
410	770	1418	966	1770	3218	1521	2770	5018
416	780	1436	971	1780	3236	1527	2780	5036
421	790	1454	977	1790	3254	1532	2790	5054
427	800	1472	982	1800	3272	1538	2800	5072
432	810	1490	988	1810	3290	1543	2810	5090
438	820	1508	993	1820	3308	1549	2820	5108
443	830	1526	999	1830	3326	1554	2830	5126
449	840	1544	1004	1840	3344	1560	2840	5144
454	850	1562	1010	1850	3362	1566	2850	5162
460	860	1580	1016	1860	3380	1571	2860	5180
466	870	1598	1021	1870	3398	1577	2870	5198
471	880	1616	1027	1880	3416	1582	2880	5216
477	890	1634	1032	1890	3434	1588	2890	5234
482	900	1652	1038	1900	3452	1593	2900	5252
488	910	1670	1043	1910	3470	1599	2910	5270
493	920	1688	1049	1920	3488	1604	2920	5288
499	930	1706	1054	1930	3506	1610	2930	5306
504	940	1724	1060	1940	3524	1616	2940	5324
510	950	1742	1066	1950	3542	1621	2950	5342
516	960	1760	1071	1960	3560	1627	2960	5360
521	970	1778	1077	1970	3578	1632	2970	5378
527	980	1796	1082	1980	3596	1638	2980	5396
532	990	1814	1088	1990	3614	1643	2990	5414
538	1000	1832	1093	2000	3632	1649	3000	5432

°C	0 to 50	°F	°C	50 to 100	°F
-17.78	0	32.0	10.0	050	122.0
-17.22	1	33.8	10.6	051	123.8
-16.67	2	35.6	11.1	052	125.6
-16.11	3	37.4	11.7	053	127.4
-15.56	4	39.2	12.2	054	129.2
-15.00	5	41.0	12.8	055	131.0
-14.44	6	42.8	13.3	056	132.8
-13.89	7	44.6	13.9	057	134.6
-13.33	8	46.4	14.4	058	136.4
-12.78	9	48.2	15.0	059	138.2
-12.22	10	50.0	15.6	060	140.0
-11.67	11	51.8	16.1	061	141.8
-11.11	12	53.6	16.7	062	143.6
-10.56	13	55.4	17.2	063	145.4
-10.00	14	57.2	17.8	064	147.2
-9.44	15	59.0	18.3	065	149.0
-8.89	16	60.8	18.9	066	150.8
-8.33	17	62.6	19.4	067	152.6
-7.78	18	64.4	20.0	068	154.4
-7.22	19	66.2	20.6	069	156.2
-6.67	20	68.0	21.1	070	158.0
-6.11	21	69.8	21.7	071	159.8
-5.56	22	71.6	22.2	072	161.6
-5.00	23	73.4	22.8	073	163.4
-4.44	24	75.2	23.3	074	165.2
-3.89	25	77.0	23.9	075	167.0
-3.33	26	78.8	24.4	076	168.8
-2.78	27	80.6	25.0	077	170.6
-2.22	28	82.4	25.6	078	172.4
-1.67	29	84.2	26.1	079	174.2
-1.11	30	86.0	26.7	080	176.0
-0.56	31	87.8	27.2	081	177.8
0.00	32	89.6	27.8	082	179.6
0.56	33	91.4	28.3	083	181.4
1.11	34	93.2	28.9	084	183.2
1.67	35	95.0	29.4	085	185.0
2.22	36	96.8	30.0	086	186.8
2.78	37	98.6	30.6	087	188.6
3.33	38	100.4	31.1	088	190.4
3.89	39	102.2	31.7	089	192.2
4.44	40	104.0	32.2	090	194.0
5.00	41	105.8	32.8	091	195.8
5.56	42	107.6	33.3	092	197.6
-06.11	43	109.4	33.9	093	199.4
-06.67	44	111.2	34.4	094	201.2
-07.22	45	113.0	35.0	095	203.0
-07.78	46	114.8	35.6	096	204.8
-08.33	47	116.6	36.1	097	206.6
-08.89	48	118.4	36.7	098	208.4
9.44	49	120.2	37.2	099	210.2
10.00	50	122.0	37.8	100	212.0

Explanation of conversion tables

Bold face numbers in the center columns represent temperatures you want to change to either Fahrenheit or Celsius. Left-hand columns are the Celsius equivalent of Fahrenheit and the right-hand columns are the Fahrenheit equivalent of Celsius. Thus a temperature of 100°C is equal to 212°F, and 100°F is equal to 37.8°C.

Interpolation Factors

When bold face numbers are in increments of 10, the following interpolation factors may be applied for specific temperatures.

°C	No.	°F	°C	No.	°F
0.56	**1**	1.8	3.33	**6**	10.8
1.11	**2**	3.6	3.89	**7**	12.6
1.67	**3**	5.4	4.44	**8**	14.4
2.22	**4**	7.2	5.00	**9**	16.2
2.78	**5**	9.0	5.56	**10**	18.0

Conversion Formula

°C = (°F - 32) x 0.5556   °F = (°C x 1.8) + 32