Table 1 .... Measurement of Temperature

No.	Measurement Means	Application	Range, F	Precision, F	Limitations
1	Glass-stem thermometers				
	Mercury-glass thermometer	Temp of gases and liquids by contact	−38/575	Less than 0.1 to 10	In gases, accuracy affected by radiation
	Alcohol-glass thermometer	"	−100/100	"	"
	Pentane-glass thermometers	"	−200/70	"	"
	Jena or quartz mercury nitrogen thermometers	"	−38/1,000	"	"
2	Gas thermometer	Primary standard	−459/1,000	Less than 0.01	Requires considerable skill to use
3	Resistance thermometers				
	Platinum-resistance thermometer	Precision; remote readings; temp of fluids or solids by contact	−320/1,800	Less than 0.02 to 5	High cost; accuracy affected by radiation in gases
	Nickel-resistance thermometer	Remote readings; temp by contact	−150/300	0.3	Accuracy affected by radiation in gases
4	Thermocouples				
	Pt-Pt-Rh thermocouple	Standard for thermocouples	500/3,000	0.1 to 5	High cost; also, requires expensive measuring device
	Chromel-alumel thermocouple	General testing of high temp; remote rapid readings by direct contact	Up to 2,200	0.1 to 15	Less accurate than above
	Iron-constantan thermocouple		Up to 1,500	0.1 to 15	Subject to oxidation
	Copper constantan thermocouple	Same as above, especially suited for low temp	Up to 600	0.1 to 15	
5	Beckman thermometers (metastatic)	For differential temp in same applications as in glass stem thermometer	5 C diff	0.01 C	Must be set for temp to be measured
6	Bimetallic thermometers	For approx temp	0/1,000	1, usually much more	Time lag; unsuitable for remote use; unreliable
7	Pressure-bulb thermometers				
	Gas-filled bulb	Remote testing	−200/1,000	2	Caution must be exercised so that installation is correct
	Vapor-filled bulb	"	20/500	2	"
	Liquid-filled bulb	"	−50/2,100	2	"
8	Optical pyrometers	For intensity of narrow spectral band of high temp radiation (remote)	1,500 upward	15	
9	Radiation pyrometers	For intensity of total high temp radiation (remote)	Any range		
10	Seger cones (fusion pyrometers)	Approx temp (within temp source)	1,000/3,600	50	
11	Tempil Sticks	Approx temp (on surface)	125/900	±1 percent	
12	Melting and boiling points of materials	Standards	All except extremely high temp	Extremely precise	For laboratory use only

To prevent errors in temperature measurements, ample time should be allowed for the thermometer to attain temperature equilibrium with the surrounding fluid. In reading a thermometer, the eye should be at the same level as the top of the liquid column to avoid parallax.

Thermocouples

When two wires made of dissimilar metals are joined by soldering, welding, or merely by twisting, a thermocouple or thermo-junction is formed. An electromotive force, which depends upon the temperature of the junction, is found to exist between the wires. When the wires are joined at two points a thermocouple circuit is formed. If one junction is kept at a temperature different from the other, an electric current flows through the circuit due to the difference in emf developed by the two junctions. This phenomenon is employed for temperature measurements in thermocouple systems, one junction being ordinarily kept at a constant temperature, as in an ice bath, while the other junction is placed at a point at which it is desired to observe the temperature. In practice it is desirable to utilize emf to indicate temperature because, at small or zero current flow, the resistance of the circuit is unimportant. A high resistance millivolt meter is useful in some cases but the potentiometer yields better results. In the potentiometer the electromotive force generated by the thermocouples is balanced against an electromotive force from the battery so that observations are made with no flow of current through the thermocouple circuit. A conventional arrangement is illustrated in Fig. 1. The thermocouple leads *A-B* are so connected that their polarity opposes that of battery *C*. If the position of *E* on the graduated slide wire rheostat *DF* is adjusted until galvanometer *G* shows no current flowing, resistance *DE* will indicate directly the voltage generated by the thermocouple. In order to calibrate the instrument, switch *S* is thrown over to the standard cell circuit while rheostat *R* is adjusted so that the galvanometer shows zero current. Battery *C* then exerts the known voltage of the standard cell at *DH*.

The act of adjusting rheostat *D-F* (Fig. 1) for zero current flow is known as balancing the potentiometer. Automatic self-balancing instruments of both the indicating and recording types are on the market. They usually contain an automatically compensating cold junction to avoid the use of an ice bath, and special thermocouple wire is furnished with them from the factory.

The choice of materials for thermocouple wire is determined by the temperature to be measured, the protection from corrosion afforded the couple, and the precision and service life required. In general, copper vs. constantan is suitable for temperatures up to 700 F, iron vs. constantan up to 1500 F, and chromel vs. alumel up to 2200 F. Higher temperatures require the use of noble metal thermocouples (platinum vs. platinum-rhodium). In addition to the higher initial

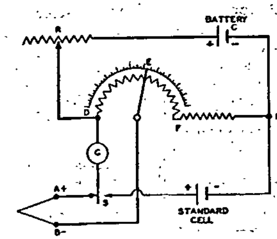

Fig. 1 .... Basic Circuit and Connections for Thermocouple and Potentiometer

cost of a noble metal couple, it does not develop as high an emf as the base metal couples do. Impurities make large differences in the performance of thermocouple wires and for this reason calibration of samples from each spool of wire is essential for precise work. Data on wire can usually be obtained from the manufacturer.

With a suitable potentiometer, small wires serve as well for thermocouples as large ones, and the fineness of the wires is limited only by consideration of mechanical strength and convenience in handling. Small couples respond more promptly to changes in temperature and are less affected by radiation than large ones. Heavy gage couples, however, are necessary for high temperature work where corrosion of the wire is a problem. For use in heated air or gases, thermocouples are often shielded,[*] as are thermometers, and aspirated thermocouples are sometimes used. An arrangement has been described for avoiding error due to radiation. It involves the use of several thermocouples of different wire sizes, the true temperature being estimated by extrapolation of readings to zero diameter.[*]

By the use of thermocouples, temperatures at remote points may be indicated or recorded on conveniently located instruments, and temperatures may be obtained within thin materials, narrow spaces, or otherwise inaccessible locations.

Thermocouples in series, with every alternate junction maintained at a common temperature, will produce an emf which, when divided by the number of couples, gives the average emf corresponding to the true average temperature. This series arrangement of thermocouples, often called a thermopile, can have extreme sensitivity and is useful in detecting very small changes in temperature.

Thermocouples in parallel, having the similar metals of a number of couples connected together and run to a common cold junction, will cause an indication on a potentiometer which is the true average emf only if the electrical resistances of the parallel circuits are the same.[*]

The thermocouple is particularly useful in determining a surface temperature. It may be attached to a metal surface in any of several ways. For permanent installations, soldering, brazing, or peening may be desirable. A small hole is drilled for the peening operation; the thermocouple is inserted and the metal is peened to retain it. The fact that the thermocouple is in electric contact with the surface is unimportant in usual circuits. For temporary arrangements, couples may be attached by means of surgical or cellophane tape. For boiler or furnace surfaces, furnace cement serves very well. To minimize the possibility of error due to heat conduction along the wires, a surface thermocouple should be made of fine wires, and the wires should be held in close contact with the surface for an inch or so from the junction. Electrical insulation between the wires must be perfect except at the junction.

Resistance Thermometers

Resistance thermometers depend for their operation upon the change of electric resistance of metal with change in temperature. The resistance generally increases with rising temperature. Their use largely parallels that of thermocouples, although readings tend to be unstable above 950 F. Two-lead temperature elements are not recommended, since they do not permit correction for lead resistance. Three leads to each resistor are necessary to obtain consistent readings.

A typical circuit used by several manufacturers is shown in Fig. 2. In this design a differential galvanometer is used, in which coils *L* and *H* exert opposing forces on the indicating needle. Coil *L* is in series with the thermometer resistance *AB*, and coil *H* is in series with the constant resistance *R*. As the temperature falls, the resistance of *AB* decreases allowing more current to flow through coil *L* than through coil *H*. This causes an increase in the force exerted by coil *L*, pulling the needle down to a lower reading. Likewise, as the temperature rises the resistance of *AB* increases, causing less current to flow through coil *L* than through coil *H*. This forces the indicating needle to a higher reading. Rheostat *S* must be adjusted occasionally to maintain a constant flow of current.

As compared to the thermocouple, the resistance thermometer does not require a cold junction, and it can be simply scaled for more accurate measurements; but, generally because of its construction it is more costly and is apt to have considerable lag. It gives best results when

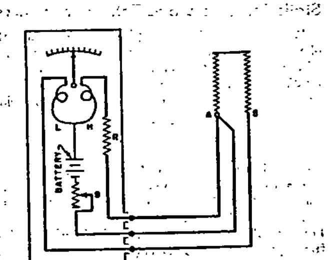

Fig. 2 .... Typical Resistance Thermometer Circuit