

Temperatures of surfaces below red heat are difficult to determine by any other means than thermocouples. For this purpose, a thermocouple of fine wires is preferable to minimize the possibility of error due to the conduction of heat along the wires. 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 many boiler or furnace surfaces, furnace cement serves very well. The thermocouple may be attached by means of the cement when the surface is cold, and must be treated gently and usually supported until the cement dries, due to heat, and hardens—after which it has ample strength. It is good practice to use as little cement as possible, and also to plaster the wires to the surface for an inch or so from their junction to avoid errors due to heat conduction along the wire. Electric insulation between the wires should be perfect except at the junction since, otherwise, the indicated emf will be between those existing at the junction and at the short circuit.

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 used to measure steady or slowly changing temperature. For accurate results the entire thermometer coil must be exposed to the temperature to be measured.

Pyrometers

The pyrometer is the usual instrument for measuring high temperatures such as those of incandescent bodies or furnace interiors. There are two types. In the radiation pyrometer the radiant energy from an observed surface falls on a thermopile, and the emf generated by the pile, measured by a galvanometer or potentiometer, is an index of the surface temperature. With the optical pyrometer a narrow spectral band, usually red, emitted by the surface, is matched visually with the filament of a special electric

lamp. The emf necessary to cause the filament to match the surface in brightness is the index of the temperature of the surface. Pyrometers are calibrated by means of various metals with known melting or freezing points. Portable as well as laboratory models are manufactured.

Color Indicating Crayons

Crayons are available, the marks of which change color or melt at specified temperatures. Such crayons have been sold in boxes covering the range from about 100 F to about 800 F in 100 deg steps, with a precision of some 10 deg. They are a rough but convenient means of determining temperatures, and of locating isothermal lines on surfaces below red heat.

PRESSURE MEASUREMENT

Pressure Gages

The Bourdon is the most common type of pressure gage, and its appearance probably is familiar to any one having an acquaintance with power plants or laboratories. The essential element of such a gage is the Bourdon tube, a metal tube of oval cross-section curved along its length to form almost a complete circle. One end is closed and the other is connected to the vessel in which the pressure is to be measured. With an increase of pressure, the tube tends to straighten, and vice versa, and the resulting motion of the closed end is communicated by suitable linkages to a needle moving over a graduated dial. If the range is above about 20 psi, such gages are usually calibrated by means of a *dead weight tester*, whereby known pressures are produced in a fluid by imposing known weights on a piston of known area. Gages are commonly set to read accurately at or near the pressure of probable use. Gages of several different types or qualities are available on the market.¹¹ Suction gages and pressure gages with ranges below about 20 psi are ordinarily calibrated against mercury manometers.

Manometers

The manometer is a simple and useful means for measuring partial vacuum and low pressure. It is, moreover, a primary instrument; it does not require calibration, and it is often used as a standard for the calibration of other instruments. It is so universally used that both the inch of water and the inch of mercury have become accepted units of pressure measurement. In its simplest form, the manometer consists of a U-shaped glass tube partially filled with a liquid. A difference in height of the two fluid columns denotes a difference in pressure in the two legs, which is proportional to the difference in height.

For converting manometer readings into other pressure units, certain proposed standard factors are applicable for precise work. These are based on a standard gravitational acceleration of 32.1740 ft per (sec) (sec) and are as follows:

$$\begin{aligned} 1 \text{ Standard Atmosphere} &= 14.696 \text{ lb per sq in.} = 29.921 \text{ in. mercury at } 32 \text{ F} \\ &= 33.96 \text{ ft water column at } 68 \text{ F} \end{aligned}$$

For most ordinary purposes, the following figures are of ample accuracy:

$$\begin{aligned} 1 \text{ Atmosphere} &= 14.7 \text{ lb per sq in.} = 29.9 \text{ in. mercury} \\ &= 34.0 \text{ ft (408 in.) water column} \end{aligned}$$

Manometer tubes should be chemically clean. The bore is not important, except insofar as it affects the meniscus through wetting or surface tension. Bores of at least $\frac{1}{16}$ in. for rough, and $\frac{1}{8}$ in. for more precise, measurements