sary for accurate measurements, and its magnitude is usually computed by means of the following formula:

$$K = 0.00009\ D\ (t_1 - t_2) \quad (1)$$

where

K = correction to be added, Fahrenheit degrees.
D = number of degrees on the thermometer scale which are not immersed.
t_1 = temperature indicated on the thermometer, Fahrenheit.
t_2 = temperature of the non-immersed mercury column, Fahrenheit.
0.00009 = difference in the coefficient of expansion of the mercury and glass.

When a thermometer is used in a liquid or in air or gas near room temperature, the effects of radiation can often be ignored, but when the temperature of hot air or gas is desired, means are usually provided for minimizing the effect of radiation.[7] These include bright metallic shields around the thermometer bulb, and the use of aspirated thermometers in which a stream of the air or gas is drawn at considerable speed across the bulb and increases the influence of the gas temperature on the thermometer indication. In any case, to prevent errors in temperature measurements, there should be ample circulation so that the thermometer will indicate a true temperature of the medium under observation, and ample time should be allowed for the thermometer to reach the same temperature as the medium. In reading a thermometer the eye should be at the same level as the top of the liquid to avoid parallax.

Industrial-type thermometers are available for permanent installation in pipes or ducts. These instruments are fitted with metal guards to prevent breakage, and are useful for many purposes. However, the considerable heat capacity and conductance of the guards or shields prevent such thermometers from following closely the fluctuations in a medium of varying temperature.

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 range of 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 re-

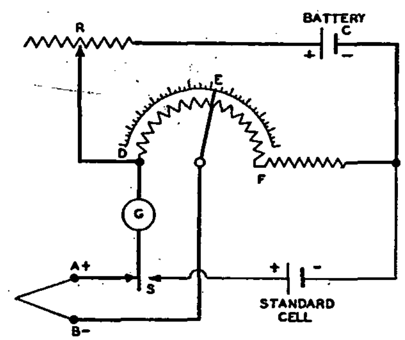

FIG. 1. BASIC CIRCUIT AND CONNECTIONS FOR THERMOCOUPLE AND POTENTIOMETER

quire the use of noble metal thermocouples (platinum *vs.* platinum-rhodium). In addition to the higher initial 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,[8] as are thermometers, and aspirated thermocouples are sometimes used. An arrangement has been described for avoiding error due to radiation. It involves several thermocouples of different sizes, the true temperature being estimated by extrapolation of readings to zero diameter.[9]

By the use of thermocouples, temperatures at remote points may be indi-