couples 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-

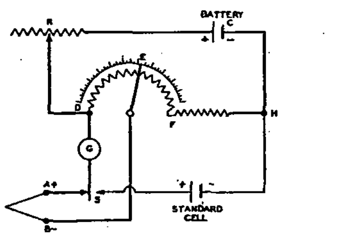

Fig. 1....Basic Circuit and Connections for Thermocouple and Potentiometer

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 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 the use of several thermocouples of different wire sizes, the true temperature being estimated by extrapolation of readings to zero diameter.[8]

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.[7, 8]

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.

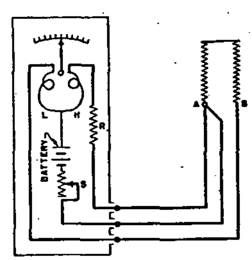

Fig. 2....Typical Resistance Thermometer Circuit and Connections

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 anyone 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 an almost 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. 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. Suction gages and pressure gages with ranges below about 20 psi are ordinarily calibrated against mercury manometers. 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.[8]

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:

1 Standard Atmosphere = 14.696 lb per sq in. = 29.921 in. mercury at 32 F = 33.96 ft water column at 68 F

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

1 Atmosphere = 14.7 lb per sq in. = 29.9 in. mercury = 34.0 ft (408 in.) water column

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 5/16 in. for rough, and ½ in. for more precise, measurements are recommended. Liquids other than water are sometimes used for low-pressure measurement and, when this is done, the readings must be corrected for the density of the fluid.

For measuring pressure differences of a few inches of water, or less, U-gages are often set at an angle for scale amplification. In many gages of this type, commonly termed draft gages or inclined manometers, only one tube of small bore is used and the other leg is replaced by a reservoir. The scale is calibrated to read in inches of water, and it is necessary to use a fluid having the same gravity as that for which the gage was originally calibrated, or to apply a correction if another fluid is used. Such gages may be checked one against another. For more accurate calibration the gage may be checked against a micromanometer or a calibrating device known as a hook gage.[10] The accuracy of a draft gage is dependent on the slope of a tube, and consequently the base of the gage must be leveled carefully. It is not desirable to use a slope of less than 1 in 10. Where pressures are read under extreme conditions of temperature, and calibration is possible only at normal temperature, it is necessary to correct for the change in density of the liquid in the manometer.[11] For measuring low-pressure differences to within 0.001 in. of water, very sensitive micromanometers are available, such as the Illinois or Wahlen,[12] and the Emswiler.[13] Various instrument manufacturers are also prepared to furnish accurate micromanometers.

Barometer

The simplest and earliest type of barometer consists of a glass tube somewhat more than 30 in. long filled with