least two types of instruments based on this fact have been developed. The Dunmore hygrometer was originally designed for use in radio-sondes or small balloons, and means were devised whereby the device transmits humidity data back to earth in the form of a radio signal. In the more usual form, this hygrometer consists of a dual winding of small wire on a non-conducting tube. The whole is coated with an electrolytic film, usually containing a salt such as lithium chloride, which forms an electric connection between the windings. Means are provided for determining the electrical resistance of the film, which is an indication of the humidity. In the radio-sonde, variations in the resistance of the film affect the frequency of an oscillating circuit. These hygrometers are usually calibrated by comparison with a wet- and dry-bulb psychrometer. For calibration for some purposes, particularly for use at sub-zero temperatures, means have been provided for producing atmospheres of known humidity.[42] Advantages of instruments of this type for some scientific and industrial purposes are becoming apparent, and some forms of them are on the market.

The Weaver type hygrometer is particularly useful for determining the humidity of air or other gas in pipes or closed vessels at various pressures and temperatures. It consists of a threaded plug carrying a central electrode insulated from the plug, except for a gelatinous electrolytic film. The film is exposed to the air or gas from the pipe or vessel, and provision is made for determining its electrical resistance. The hygrometer, or detector, is mounted in a manifold equipped with valves whereby the film can be alternately exposed to the test gas, and to a standard gas having a known absolute humidity. The pressure of the standard gas is varied until contact with it establishes the same resistance in the film as the test gas, and the humidity of the test gas is then determined by computation based on the gas laws.

Chemical Hygrometry

The humidity of an atmosphere can be measured directly by extracting and weighing the water vapor from a known sample. For precise laboratory work, powerful desiccants such as sulphuric acid and phosphorus pentoxide are used for the extraction process, while for some purposes, calcium chloride, lithium chloride or silica gel are satisfactory. Freezing the water vapor out of a measured stream of air or gas with solid carbon dioxide, and weighing the resulting ice, is a similar operation. A thermal conductivity method for gas analysis can be used for temperatures above 212 F, or for very low humidities.[43]

HEAT TRANSFER THROUGH BUILDING MATERIALS

Thermal Conductivity

The thermal conductivity (k value) of an insulation, as defined in Chapter 9, is a unit heat transfer factor. Practically universally accepted for the conductivity determination of flat insulation is the guarded hot plate, which is described in *ASTM* test method C-177.[44] In its simplest form it consists of an electrically heated plate and two water cooled plates. Two identical specimens or slabs of a material are required for a test, and one is mounted on each side of the hot plate. A cold plate is then pressed against the outside of each specimen by a clamp screw. The heated plate is divided into two portions: the central or measuring section, and the outer or guard section. During tests the two sections are maintained as nearly as possible at the same temperature. The purpose of the guard section is to minimize errors due to edge effects. The electric energy required to heat the measuring section is carefully observed and, converted to Btu per hour, is divided by the area and the temperature gradient to obtain the conductivity of a material tested. Hot plate apparatus accommodating specimens on the order of one foot square and an inch or more thick, is common. The apparatus at the *National Bureau of Standards* takes specimens 8 in. square, while plates as large as 3 ft square have been used. The thermal conductivity of cylindrical or pipe insulation (Chapter 28) is determined in a similar manner except that an equivalent thickness must be calculated to account for the cylindrical shape.[45]

Recently there has been considerable development of transient state conductivity apparatus utilizing a slender probe.[46, 47, 48, 49] These instruments are commercially available and have the advantages of rapidity and requiring a small test specimen. While useful as research and development tools, the probe has not been generally accepted as have the guarded hot plate and pipe insulation apparatus.

Wall Conductances

The thermal conductances (C values) of many walls can be satisfactorily estimated from the conductivities of their components and their dimensions, but some walls are complicated by the inclusion of metal, for instance, and tests for conductance are required. The apparatus is required to accommodate large specimens representing actual construction. The shielded hot box apparatus was developed for this purpose.[50] Specimens for the apparatus at the *National Bureau of Standards* are 5 ft long and 8 ft high, while others require different sizes, some larger, others smaller.

The guarded hot box is described in the *ASTM* Standard Test Code for Built-up Sections, C-236-54T.[50] The apparatus consists essentially of three boxes: a cold box, cooled by a refrigerating machine; a hot box, heated electrically; and a metering box also heated electrically. Each box has an open side to be placed against the specimen. The cold box is clamped against one side of the specimen, and the hot box against the other. The hot box encloses the metering box and is kept at the same temperature to minimize heat exchanges to or from the metering box, except through the specimen. The electric energy necessary to heat the metering box is measured, converted to Btu per hour, and divided by the area and the temperature difference through the wall, from surface to surface, to yield the conductance of the wall. The transmittance or *U*-value of the wall is then computed by means of the surface coefficients from Chapter 9.

A heat flow meter is sometimes useful for measuring steady heat flow through a wall or other building member.[51, 52, 53] In essence, this meter consists of a plate or slab of material of known thermal resistance having attached thermocouples on both sides. For use, the device is pressed against or cemented to the wall to be tested. At steady state, the temperature difference through the slab, measured with the thermocouples, with the known thermal resistance of the slab, indicates the heat flow through the slab and hence, through the wall covered by it. For best results, such meters are calibrated by means of a guarded hot plate or other suitable apparatus. The chief precaution is to assure that the heat flow is steady at the time of measurement.

EVALUATION OF THE THERMAL ENVIRONMENT

Advocates of radiant heating emphasize the fact that comfort depends on radiant heat exchanges, as well as air temperature. For this reason sev-