thermometers have the disadvantage of requiring auxiliary apparatus, such as galvanometers and resistances, the use of which involves some electrical training. But they far surpass the mercurial thermometer in point of range, delicacy and adaptability, and can be applied to many investigations in which ordinary thermometers are quite useless.

There are two kinds of electrical thermometers, which depend on different effects of heat on the electrical properties of metals: (1) The *Thermocouple,* or *Thermopile,* which depends on the production of a thermoelectric force when the junctions of different metals in an electric circuit are at different tempera­tures; and (2) the *Electrical Resistance Thermometer,* the action of which depends on the fact that the resistance of a pure metal to the passage of an electric current increases very con­siderably when the temperature is raised. The theory of the thermocouple is discussed in the article Thermoelectricity, as it possesses many points of interest, and has been studied by many skilful experimentalists. The electrical resistance ther­mometer is of more recent origin; but although the theory has been less fully developed, the practice of the method bids fair to surpass all others in the variety and accuracy of its applica­tions. In order to secure the widest possible range and the greatest constancy, in either variety of electrical thermometer, advantage is taken of the great stability and infusibility charac­teristic of the metals of the platinum group. Other metals are occasionally used in work at low temperatures with thermo­couples for the sake of obtaining a larger electromotive force, but the substitution is attended with loss of constancy and uncertainty of reduction, unless the range is greatly restricted.

22. *Applications of the Thermocouple.—*The principal uses of the thermocouple in thermometry are for measuring high temperatures, and for measuring small differences of tempera­ture, more particularly when the temperature is required to be measured *at a point,* or in a very small space. The electro­motive force of the couple depends only on the temperature at the plane of junction of the two metals, which can be very exactly located. A typical instance of a measurement to which the thermocouple is peculiarly suited, is the determination of the cyclical variations of temperature at accurately measured depths from one-tenth to one-hundredth of an inch in the metal of the cylinder of a heat engine, the interior surface of which is exposed to cyclical variations of temperature in the working of the engine.@@1 The exact depth of the plane of junction can be measured without difficulty to the thousandth of an inch. The insertion of the wire makes the least possible disturbance of the continuity of the metal. There is no lag, as the thermometer itself is part of the metal. The instantaneous value of the temperature at any particular point of the stroke can be measured separately by setting a periodic contact to close the circuit of the galvanometer at the desired point. A further advantage is gained by measuring only the difference of tem­perature between two junctions of a thermocouple at different depths, instead of the whole interval from some fixed point. None of these advantages could be secured by the use of any ordinary thermometer; some depend on the fact that the method is electrical, but some are peculiar to the thermocouple, and could not be otherwise attained.

On the other hand, the thermocouple is not well suited for thermometry of precision on account of the smallness of the electromotive force, which is of the order of ten microvolts only per degree for the most constant couples. By the use of very delicate galvanometers it is possible to read to the hundredth or even in special cases to the thousandth of a degree on this small difference, but unfortunately it is not possible to eliminate accidental thermal effects in other parts of the circuit due to small differences of temperature and material. These acci­dental effects seldom amount to less than one or two microvolts even in the best work, and limit the accuracy attainable in temperature measurement to about the tenth of a degree with a single platinum thermocouple. This limit can be surpassed

by using couples of greater thermoelectric power and less permanence, or by using a pile or series of couples, but in either case it is doubtful whether the advantage gained in power is not balanced by loss of simplicity and constancy. A method of avoiding these effects, which the writer has found to be of great use in delicate thermoelectric researches, is to make the whole circuit, including all the terminals and even the slide­wire itself, of pure copper. Platinoid, german silver, constantan and other alloys most commonly used for resistances and slide­wires, are particularly to be avoided, on account of their great thermoelectric power when connected to copper. Manganin and platinum-silver are the least objectionable, but the improve­ment effected by substituting copper is very marked. It is clear that this objection to the use of the couple does not apply so strongly to high temperatures, because the electromotive force of the couple itself is greater, and the accuracy attainable is limited by other considerations.

23. *The Resistance Thermometer.—*In practice the resistance thermometer is almost invariably made of platinum, since there is very seldom any advantage to be gained by the substitution of baser metals. The instrument is for this reason often re­ferred to simply as the “ platinum thermometer.” It is im­portant that the platinum should be pure, both for the sake of uniformity and also because the change of electrical resistance with temperature is greatly diminished by impurities. The observation of the fundamental coefficient, which is ∙00390 (or rather larger than the coefficient of expansion of a gas) for the purest metal hitherto obtained, is one of the most delicate tests of the purity of the metal. In addition to the constancy and infusibility of the metal, a special advantage which is secured by the use of platinum is the close agreement of the thermo­dynamical scale with the platinum scale of temperature, as defined by the formula

*pt=* 100(R-R0)/(R1-R0), (24)

in which the symbol *pt* stands for the temperature on the platinum scale centigrade, and R, R1 and R0 are the observed resistances of the thermometer at the temperatures *pt,* 100° and 0° C. respectively. A platinum thermometer is generally arranged to read directly in degrees of temperature on the platinum scale, just as a mercury thermometer is graduated in degrees of the mercury scale. The reduction to the scale of the gas thermometer is most conveniently effected by the difference formula

*t—pt=dt(t-*100)/10,000, (25)

in which *d* is a constant, called the difference-coefficient, the value of which for pure platinum is about 1·50, but varies slightly for different specimens. This formula was first given by the writer as the result of a series of comparisons of different platinum wires with each other and with other metals, and also with an air thermometer over the range 0° to 625° C. The platinum wire in these comparisons was enclosed inside the bulb of the air thermometer itself, and disposed in such a manner as to be at the mean temperature of the bulb in case the temperature was not quite uniform throughout (*Phil. Trans.* A. 1887, p. 161). The formula was subsequently verified by C. T. Heycock and F. H. Neville ( *Journ. Chem. Soc.* February 1895), by the observation of a number of higher points up to the freezing-point of copper at 1082° C., which they showed to agree with the most probable mean of all the best determinations by various methods of gas thermometry. At still higher temperatures, beyond the present range of the gas thermometer, the writer has succeeded in obtaining pre­sumptive evidence of the validity of the same formula by comparison with the scales of the expansion and the specific heat of platinum, which appear to follow similar laws *(Phil. Mag.* December 1899). If we assume that the coefficient of expansion of platinum, the coefficient of increase of resistance, and the specific heat are all three linear functions of the tem­perature, we obtain results which are in agreement within the limits of error of observation up to the fusing-point of platinum itself. The same formula has been independently verified by

@@@1 Hall, *Trans. Amer. Inst. Elect. Eng.* 1891, vol. viii. p. 226; Callendar and Nicolson, *Proc. Inst. C. E.* vol. cxxxi. p. 1.