*Values of the Corrections.—*If we take for the gas hydrogen the values *c* = 1∙5 c.c. at o° C., *b*=8∙0 c.c., with the index n=1∙5, which satisfy the observations of Joule and Thomson on the cooling effect, and those of Regnault, Amagat and Chappuis on the com­pressibility, the values of the absolute zero *0*0, calculated from Chappuis’s values of the pressure and expansion coefficients at 100 cms. initial pressure, are found to be 273∙10° and 273∙05° respectively, the reciprocals of the coefficients themselves being 273∙03 and 273·22. The corrections are small and of opposite signs. For nitrogen, taking *c*0=1∙58, *b*=l∙14, n=l∙5, we find similarly 273∙10° and 273∙13° for the absolute zero, the correction 00-T0 in this case amounting to nearly 1°. The agreement is very good considering the difficulty of determining the small deviations *c* and *b*, and the possible errors of the expansion and pressure­coefficients. It appears certain that the value of the absolute zero is within a few hundredths of a degree of 273∙10°. Other observa­tions confirm this result within the limits of experimental error. The value of the index *n* has generally been taken as equal to 2 for diatomic gases, but this does not satisfy either the observations on the cooling effect or those on the compressibility so well as n=1∙5, although it makes comparatively little difference to the value of the absolute zero. The value deduced from Travers’s observation of the pressure-coefficient of helium is 273∙13°, taking n=½, which is the probable value of the index for a monatomic gas. The application of the method to the condensible gas carbonic acid is interesting as a test of the method (although the gas itself is not suited for thermometry), because its deviations from the ideal state are so large and have been so carefully studied. The observations of Joule and Thomson on the cooling effect give c0=3∙76 c.c., *b*=0∙58 c.c., n=2, provided that allowance is made for the variation of the specific heat with temperature as determined by Regnault and Wiedemann. Chappuis’s values of the pressure and expansion coefficients agree in giving 273·0$° for the absolute zero, the values of the corrections 00-T0 being 4∙6° and 5∙8° respectively.

The values of the scale correction *dt* deduced from these formulae agree with those experimentally determined by Chappuis in the case of carbonic acid within the limits of agreement of the observa­tions themselves. The calculated values for nitrogen and hydrogen give rather smaller differences than those found experimentally, but the differences themselves are of the same order as the experi­mental errors. The deviations of hydrogen and helium from the absolute scale between 0° and 100° C. are of the order of ∙001° only, and beyond the limits of accuracy of experiment. Even at -250° C. (near the boiling-point of hydrogen) the corrections of the constant volume hydrogen and helium thermometers are only a tenth of a degree, but, as they are of opposite signs, the difference amounts to one-fifth of a degree at this point, which agrees ap­proximately with that observed by Travers. For a fuller discussion of the subject, together with tables of corrections, the reader may refer to papers by Callendar, *Phil. Mag.* v. p. 48 (1903), and D. Berthelot, *Trav. et Mém. Bur. Int. Paris,* xiii. (1903). Berthelot assumes a similar type of equation to that given above, but takes *n* = 2 in all cases, following the so-called law of corresponding states. This assumption is of doubtful validity, and might give rise to relatively large errors in the case of monatomic gases.

19. *Limitations.—*In the application of the gas thermometer to the measurement of high temperatures certain difficulties are encountered which materially limit the range of measure­ment and the degree of accuracy attainable. These may be roughly classified under the heads—(1) changes in the volume of the bulb; (2) leakage, occlusion and porosity; (3) chemical change and dissociation. The difficulties arise partly from defects in the materials available for the bulb, and partly from the small mass of gas enclosed. The troubles due to irregular changes of volume of glass bulbs, which affect the mercury thermometer at ordinary temperatures, become so exaggerated at higher points of the scale as to be a serious source of trouble in gas thermometry in spite of the twentyfold larger expansion. For instance, the volume of a glass bulb will be diminished by from one-quarter to one-half of 1 per cent. the first time it is heated to the temperature of boiling sulphur (445° C.). This would not matter so much if the volume then remained constant. Unfortunately, the volume continues to change, especially in the case of hard glass, each time it is heated, by amounts which cannot be predicted, and which are too large to neglect. The most accurate method of taking account of these variations in a series of observations, without recalibrating and refilling and cleaning the bulb, is to assume the known constant value of the coefficient of expansion of the gas, and to calculate the volume of the bulb at any time by taking observations in ice and steam *(Phil. Trans.* A. 1891, vol. 182, p. 124). Similar changes take place with porcelain at higher temperatures. Metallic bulbs are far more perfect than glass bulbs in this respect. It is probable that silica bulbs would be the most perfect. The writer suggested the use of this material (in the *Journ. Iron and Steel Inst.* for 1892), but failed to construct bulbs of sufficient size. W. A. Shenstone, however, subse­quently succeeded, and there seems to be a good prospect that this difficulty will soon be minimized. The difficulties of leakage and porosity occur chiefly with porcelain bulbs, especially if they are not perfectly glazed inside. A similar difficulty occurs with metallic bulbs of platinum or platinum-iridium, in the case of hydrogen, which passes freely through the metal by occlusion at high temperatures. The difficulty can be avoided by substituting either nitrogen or preferably argon or helium as the thermometric material at high temperatures. With many kinds of glass and porcelain the chemical action of hydrogen begins to be appreciable at temperatures as low as 200° or 300° C. In any case, if metallic bulbs are used, it is absolutely necessary to protect them from furnace gases which may contain hydrogen. This can be effected either by enclosing the bulb in a tube of porcelain, or by using some method of electric heating which cannot give rise to the presence of hydro­gen. At very high temperatures it is probable that the dis­sociation of diatomic gases like nitrogen might begin to be appreciable before the limit of resistance of the bulb itself was reached. It would probably be better, for this reason, to use the monatomic and extremely inert gases argon or helium.

20. *Other Methods.—*Many attempts have been made to over­come the difficulties of gas pyrometry by adopting other methods of measurement. Among the most interesting may be men­tioned: (i.) The variation in the wave-length of sound. The objection to this method is the difficulty of accurately observing the wave-length, and of correcting for the expansion of the material of the tubes in which it is measured. There is the further objection that the velocity varies as the square root of the absolute temperature. (ii.) A similar method, but more promising, is the variation of the refractivity of a gas, which can be measured with great accuracy by an interference method. Here again there is difficulty in determining the exact length of the heated column of gas, and in maintaining the tempera­ture uniform throughout a long column at high temperatures.. These difficulties have been ingeniously met by D. Berthelot *(Comptes Rendus,* 1895, 120, p. 831). But the method is not easy to apply, and the degree of accuracy attainable is prob­ably inferior to the bulb methods. (iii.) Methods depending on the effusion and transpiration of gases through fine orifices and tubes have been put in practice by Barus and by the writer. The method of transpiration, when the resistance of the tube through which the current of gas is passed is measured on the Wheatstone bridge principle *(Nature,* 23rd March 1899), is extremely delicate, and the apparatus may be made very small and sensitive, but the method cannot be used for extrapolation at high temperatures until the law of increase of resistance has been determined with certainty. This may be successfully accomplished in the near future, but the law is apparently not so simple as is usually supposed.

On account of these and similar difficulties, the limit of gas thermometry at the present time must be placed at 1500° C., or even lower, and the accuracy with which temperatures near 1000° C. are known does not probably exceed 2° C. Although measurements can be effected with greater consistency than this by means of electrical pyrometers, the absolute values corresponding to those temperatures must remain uncertain to this extent, inasmuch as they depend on observations made with the gas thermometer.

Electrical Thermometry

21. The convenience of the mercurial thermometer lies in the fact that it is complete in itself, and can be read without sub­sidiary appliances beyond a magnifying glass. Its weakness lies in the very limited range of each single instrument, and in the troublesome and often uncertain corrections which must be applied to its readings in all work of precision. Electrical