this way, with divisions of equal length continued above blood heat, registered 212° in boiling water. Thus the Fahrenheit scale came from a duodecimal reckoning.

De Lisle, in 1724, introduced a scale in which the boiling point of water was marked 0° and the temperature of the cellars of the Paris Observatory 100°. He after­wards adopted the freezing point of water as his upper fixed point, and called it 150°. This scale was used for many years in Russia, but is now obsolete.

In 1730 Réaumur made alcohol thermometers with their zero at the freezing point of water, and degrees of one- thousandth of the volume of the bulb. On some of these the boiling point of water was 80° ; but the instruments were defective in principle and very unequal in their indications. Deluc introduced mercury thermometers graduated from 0° in melting ice to 80° in boiling water, and these, with Réaumur’s name attached, are in use for popular purposes in Germany, Holland, and other parts of the Continent.

Celsius adopted a centesimal scale in 1742. The boiling point was marked 0° and the freezing point of water 100°. Linnæus introduced the mode of reckoning from 0° in melting ice to 100° in boiling water, which is now known as the centigrade, and is used universally in laboratories, and in all except English-speaking countries for every scientific purpose.

Fahrenheit’s scale is convenient for meteorological work on account of its short degrees, admitting of great accuracy in reading and compactness in recording, and on account of its low zero, which makes it possible in temperate climates to dispense with negative quantities. On the other hand, the centigrade scale is on the whole so con­venient, its use is so nearly universal, and the advantage of a uniform system is so great that it must ultimately be adopted for all purposes.@@1

Air Thermometer.—Under constant pressure gases expand equally for equal increments of heat. Hence, when an air thermo­meter is graduated between two fixed points the graduation may be continued above and below these points in degrees of the same length ; and any number of air thermometers so made will agree amongst themselves at every temperature. The principle of air thermometers is treated of in Heat (ut sup.), and examples of special forms are described in that article and in Pyrometer. The air thermometer is the ultimate standard of reference to which all other thermometers are referred.

Alcohol Thermometer.—Alcohol, the first liquid used for thermometric purposes, possesses numerous advantages, and on account of its low freezing point it is always used for observations in polar regions. Alcohol thermometers are graduated by fixing the freezing point in melting ice and by comparison with a mer­cury or air thermometer at several higher and lower temperatures. Recently low-temperature thermometers have been verified at Kew in melting mercury at the temperature of - 40. The law of expan­sion of alcohol in glass at low temperatures is not known with such precision as to make the minimum indications of Arctic expedi­tions entirely trustworthy. The graduation of ordinary minimum alcohol thermometers used for meteorological purposes is effected by comparison with mercury standards, and their indications, so far as this source of uncertainty is concerned, may consequently be relied on.

Mercury in Glass Thermometer. —The simplest form is the Weight Thermometer, a large glass bulb terminating in a capillary tube, and filled with a known weight of mercury at 0° C. The weight of mercury that escapes when the apparatus is heated to

100o is determined, and the temperature of any enclosure is then ascertained by placing in it the thermometer filled at zero, and weighing the liquid that runs out. Thermometers on this principle were used by Regnault in his celebrated researches on steam.

Standard Thermometers.—The tube is sometimes made with elliptical bore to ensure visibility of the mercury column, but it is usually circular in section. The internal diameter must be as nearly as possible uniform. This is tested by a preliminary calibration in which a short thread of mercury is measured in different parts of the tube. The length of stem and the range of the thermometer having been decided upon, the size of the bulb is calculated from the known expansibility of mercury and the section of the bore. The bulb is made as nearly as possible the required size, either by blowing it from a tube or preferably by forming it of a glass cylinder, and attached to the stem. The bulb is usually cylindrical in form and it must be uniform in thickness. The utmost care requires to be exercised to keep the bulb and stem dry and clean and to fill them with pure mercury recently distilled. The mercury is boiled in the thermometer for some time to drive out all traces of air and moisture, and the point of the stem is sealed off. If the thermometer is not intended to measure tem­peratures up to the boiling point of mercury, an expansion should be made at the top of the tube to prevent bursting from accidental overheating. Under Heat (vol. xi. p. 561) the changes of volume which thermometer bulbs undergo in cooling and for a long time afterwards are discussed. The process of annealing by heating to a temperature exceeding 400° C. for some hours as originally pro­posed by Person,@@2 or in vapour of mercury for several days as recently practised at Kew, renders the thermometer much less liable to suffer change of zero by the lapse of time or by heating to any lower temperature. All instruments of precision should be treated in this way, or kept for several years after they have been filled and sealed before they are graduated.

The first fixed point on the scale is marked at the place where the mercury stands when the thermometer is buried in melting ice from which the water is allowed to drain away, the second at the place where the mercury stands when the thermometer is immersed in steam of water boiling freely under the pressure of 760 mm. (29⋅92 inches) of mercury corrected to 0o C. The space between these may be graduated either in arbitrary equidistant divisions, as it is best to do in delicate instruments, or in degrees of any scale. Each degree centigrade is 1/100 of the volume of the tube between the freezing and boiling points ; if the tube is quite uniform in bore the degrees will be of equal length and may be marked off correctly by a dividing engine. If the preliminary calibration showed the tube to vary in diameter, the degree marks are often adjusted to correspond to intervals of equal volume. It is better in all cases, whether degrees or arbitrary divisions are adopted, to have them of equal length and correct the readings by the calibration curve. The scale may be continued above and beneath the fixed points in degrees or divisions of the same length.

Calibration consists in measuring the internal volume of the thermometer tube by means of a thread of mercury detached from the main column. There are several ways of doing this, for parti­culars of which reference may be made to the British Association Report on the subject (1882, pp. 145-204), where references to original memoirs are given. The best and simplest is Gay Lussac’s “ step by step ” method.

The most recent and approved processes of manufacturing, testing, and using standard thermometers of great delicacy and high pre­cision are described by Guillaume in his “Etudes Thermométriques” ( Travaux et Mémoires du Bureau International des Poids et Mesures, v., 1886) ;@@3 for additional information the work of Pickering cited below may also be consulted.

Comparison of Thermometers.—As the apparent expansion of mercury in glass from -39° to 100o C.@@4 is very nearly proportional to the amount of heat imparted to it, a thermometer made and divided as indicated above is a natural standard. But the apparent expansion with different kinds of glass differs (see Heat, vol. xi. pp. 563-4),@@5 and, except at the fixed points or near them, mercury thermometers of different construction will only fortuitously agree absolutely among themselves or with the air thermometer. Bosscha@@6 states that at 50° C. the mercury thermometer shows an error of 0o⋅5, other experimenters place it as high as 1o, but Mascart found it to amount only to 0°⋅06.@@7 For purposes of ordi­nary experiment thermometers are compared at several tempera­tures with some standard instrument of known value—that of the Kew observatory for Great Britain,—and all results are stated in terms of the standard. The methods of comparison at Kew are

@@@1 The process of converting readings of any one of the three existing scales into those of any other is a simple matter of proportion. They stand in the ratio of 80 : 100 : 180 (32 being subtracted from Fahren­heit temperatures before the calculation is made, and added to the result when converting from Reaumur or centigrade into Fahrenheit). An easy rule for changing centigrade readings into Fahrenheit mentally is—multiply the centigrade temperature by 2, subtract one-tenth of the product, and add 32 : e.g., 10o C. =20-2 + 32 = 50° F. These rules are only to be applied to thermometers made with all modern precautions. When the boiling point was determined by immersing the bulb of the thermometer in boiling water or in steam at any pressure other than 760 mm. appropriate corrections have to be applied. For a detailed historical account, see Renou, “Histoire du Thermomètre,” Annuaire Soc. Mét. de France, 1876.

@@@2 Comptes Rendus, xix., 1844, p. 1314.

@@@3 Abstract by Guillaume in the Séances de la Soc. Française de Physique, 1886, p. 219.

@@@4 Ayrton and Perry, Phil. Mag. [5], xxii. 1886, p. 325.

@@@5 See also Kraffts, Comptes Rendus, xcv. 836.

@@@6 Comptes Rendus, lxix. 875. See Note by Regnault, ibid., 879.

@@@7 Berthelot. Mécanique Chémique. i. 158.