it. Phillips’s maximum, claimed also by Walferdin, has a por­tion of the mercury thread separated from the rest by a minute bubble of air. It is placed horizontally, and, as temperature increases, the detached portion of mercury is pushed forward and is not withdrawn when the main column retreats toward the bulb on cooling. It is set for a new observation by bringing it into a vertical position and tapping it slightly. By reducing the length of the index and the bore of the stem this thermometer may be made suitable for use in any position without altering its register. Walferdin’s outflow maximum thermometer is a modification of that of Lord Charles Cavendish@@1 and the type of a number of similar instruments. It is set by filling the stem entirely with mercury from a lateral chamber at the top (fig. 4). The instrument is placed vertically, and as temperature rises mercury overflows into the reservoir. To be read, the thermometer is brought back to its original tempera­ture, then the number of degree spaces left vacant at the top of the tube shows the excess of maximum tempera­ture above that at the time of setting.

The minimum thermometer in most frequent use is that of John Rutherford, invented in 1790. It is a spirit thermometer, preferably filled with amyl alcohol to reduce risk of distillation, in the column of which a small porce­lain index is included. The instrument is hung hori­zontally, and, as temperature falls, the index is drawn back by the surface tension of the fluid. When tempera­ture rises, the liquid flows past the index easily, leaving it at the lowest point attained. Baudin invented a modification called the thermomètre à marteau in 1862 ; it acts vertically, the index being fixed by a spring, as in Sixe’s thermometer, and set by a long glass needle included in the stem, which, when the instrument is inverted, falls on the index and drives it to the surface of the alcohol. The mercurial minimum of Casella is an instrument of great delicacy and beauty, extremely difficult to make, and requir­ing careful handling in its use. A side tube of wide bore ac (fig. 5) is joined to the stem of an ordi­nary mercurial thermo­meter near the bulb. This tube terminates in a small chamber ab, cut off by a perpendicular glass diaphragm which is perforated by a hole of greater diameter than the thermometer stem. When set, the mercury in the stem indicates the actual temperature, and the chamber is empty. On the principle of Balfour Stewart’s fluctua­tion thermometer,@@2 when the instrument is heated the mercury remains stationary in the stem but expands into the chamber ab. When cooled, the mercury passes out of the chamber ; when this is empty, the temperature has returned to that at which the instru­ment was set, the surface attraction of glass and mercury prevents the fluid leaving the diaphragm b, and all subsequent contraction takes place from the stem. The position of the mercury column in the stem marks the minimum temperature since last setting. The instrument is set by raising the bulb end and allowing all the mercury to flow from the chamber.

Thermometers which record the actual temperature at any required time, by a change of position produced by a clock, were employed by Blackadder@@3 in 1826. His process was complicated and uncertain. Negretti & Zambra have a simpler arrangement that works well. Several of their reversing thermometers (see under Deep-Sea Thermometers) are pivoted on a frame, and held upright by catches which are withdrawn in turn at definite intervals by an electrical arrangement regulated by a clock. Each instru­ment, when it reverses, preserves the record of temperature at that moment until it is set again.

No thoroughly satisfactory self-registering maximum or minimum thermometer has yet been produced. In all existing forms the indications are liable to be disturbed by shaking. Where alcohol is the fluid used, it is apt to volatilize and accumulate at the top of the tube, so registering a much lower temperature than actually occurs. It is extremely difficult also to free alcohol thermometers from air, which gradually escapes from solution in the fluid and renders the instrument untrustworthy or even useless.

Radiation Thermometers.—The intensity of solar radiation is measured by the pyrheliometer, which usually consists of a body heated by the sun’s rays and a thermometer to measure the rise of temperature. In meteorology radiation is measured by thermo­meters simply exposed with blackened bulbs. Results of the utmost diversity are given by different methods. As there is no means of determining the true measure of radiation, all that can be done is to have the instruments whose indications are to be compared constructed and exposed in the same way. The usual

form, as suggested by Herschel, is a maximum thermometer with a spherical bulb half an inch in diameter coated with lamp- black and placed in the centre of a spherical vessel of clear glass, 2½ inches in diameter, and exhausted of air. The state of the vacuum may be shown by including a small mercurial manometer, or a radiometer, or by soldering in platinum electrodes through which a discharge can be made in the interior. It is not essential that the vacuum be very perfect ; some observers prefer to employ a globe filled with dry air. For separate instruments to be com­parable, Whipple@@4 and Ferrel@@5 have shown that the bulbs must be truly spherical, of equal thickness and size (a difference of 8 per cent. in diameter produces variations of several degrees), blackened sufficiently to absorb all radiation falling on them, and placed accu­rately in the centre of perfectly spherical enclosures, which must also be of equal diameter. The stem should be as small as possible in proportion to the bulb ; and before being used for comparative purposes all radiation thermometers should be compared with an arbitrary standard by daily exposure for several weeks to sunshine.

Minimum radiation thermometers, intended to measure radiation from the earth at night, are usually filled with alcohol, and much ingenuity has been expended on increasing their delicacy. The bulbs are made very large relatively to the bore, and constructed so as to expose a great surface, the reservoir being often helical, lenticular, annular, spoon-shaped, forked, or even like a gridiron.

Earth Thermometers.—Saussure introduced the use of sluggish thermometers packed in non-conducting material for taking the temperature of the soil at different depths. Symon’s earth thermo­meter on this principle is a slow-action instrument cased in felt, and is lowered by a chain into an iron tube which has previously been sunk to the required depth. It may be withdrawn and read with­out changing its record. The underground temperature committee of the British Association have used both slow-action and self-regis­tering thermometers for their observations in mines and shafts.@@6

Thermometers with very long stems, which can be read above ground, fitted in deep borings in the rock, are used at the observa­tories of Greenwich and Edinburgh for investigating earth tem­perature. Those at present established at the Royal Observatory, Edinburgh,@@7 are the successors of a set fixed in the rock in 1837, and broken accidentally in 1876. They are placed with their bulbs at depths of 25, 12, 6, 3 feet beneath the surface respectively, and one has its bulb just covered. The readings of the intermediate thermometers supply data for correcting the long columns of alcohol in the deeper ones for the different temperatures of their different parts. Allowance may be made for this effect without calculation by utilizing the principle applied by Sainte-Claire Deville to pyrometers. A second stem, similar in every way to that of the thermometer, nearly filled with the same fluid, but hermetically sealed at the lower end, is fixed beside the thermo­meter stem. The fluctuations it shows are due solely to causes affecting the stem and not the bulb of the thermometer, and they are eliminated from the readings of the latter by taking account only of the difference of level of the fluid in the two tubes.

Deep-Sea Thermometers.—The earliest ob­servations of warmth beneath the surface were made by raising samples of water in a valved box and noting the temperature when it was brought on board. Saussure, in addi­tion to this, used sluggish thermometers, which he left immersed for several hours before reading. His latest thermometer for sea-work was filled with alcohol, and had a bulb more than an inch in diameter, which was imbedded in a mass of wax and enclosed in a stout wooden case. It attained the tem­perature of its surroundings very slowly, pre­served it for a long time, and gave, in his hands, thoroughly trustworthy results. On the introduction of registering thermometers these were used, but the unsuspected magni­tude of the effect of pressure at great depths made the earlier records entirely misleading.

A modification of Sixe’s thermometer, pro­tected from pressure by the addition of an outer bulb partially filled with a liquid, is now usually employed on deep-sea expeditions. Those used on the “Challenger,” under the name of Miller-Casella thermometers, were of the form shown in fig. 6. The tube is U-shaped, the bend and part of each limb filled with mercury, the rest of the tube, the bulb, and part of the expansion on the other side with alcohol. A steel index, held in its place by the pressure of a hair, is immersed

@@@1 *Phil. Trant ,* i., 1757, p. 300. Henry Cavendish’s register thermometer is on another principle and a much less practical instrument (see Wilson’s *Life of Cavendish,* p. 477).

@@@2 *Proc. R. S.,* viii. 195.

*@@@3Trans. R. S. E.,* 1826, x. 337, 440.

@@@4 *Quart. J. R. Met. Soc.,* 1879, v. 142 ; 1884. x. 45.

@@@5 *Signal Service Prof. Papers,* No. xiii., 1884, p. 34.

@@@6 For a résumé of the methods and work of the committee, see *Brit. Assoc. Reports,* 1882, p. 74.

@@@7 *Trans. R. S. E.,* 1880, xxix. p. 637.