being transformed by heat-engines into work, the work obtainable (i.e., the motivity) is

Σ(H)- t0 Σ(H∕t).

The work obtained, however, is simply

2(H).

Thus the waste, or amount needlessly dissipated, is

- t0Σ(H∕t).

This must be essentially a positive quantity, except in the case when perfect engines have been employed in all the operations. In that case (unless indeed the unattainable condition t0 = 0 were fulfilled)

Σ(H∕t = 0,

which is the general expression of reversibility.

17. Works on the Subject.—Carnot’s work has, as we have seen, been reprinted. The scattered papers of Rankine, Thomson, and Clausius have also been issued in collected forms. So have the experimental papers of Joule. The special treatises on Thermo­dynamics are very numerous ; but that of Clerk-Maxwell (Theory of Heat), though in some respects rather formidable to a beginner, is as yet far superior to any of its rivals. (P. G. T. )

THERMOELECTRICITY See Electricity, vol. viii. pp. 94 *sq.*

THERMOMETER, an instrument for detecting and measuring differences in temperature. The name is usu­ally restricted to instruments adapted for use at moderate temperatures; those for measuring high temperatures are termed pyrometers (see Pyrometer). Thermometry has been treated theoretically under Heat (see vol. xi. p. 558 *sqf.* It here remains to trace the history of ther­mometers, and to describe the principal forms in use.

*History.—*The honour of inventing the thermometer has been given to several natural philosophers of the 16th century; the claims of Robert Fludd are more tangible than those of Drebbel and Santorio, but the instrument invented by Galileo before 1597 seems best entitled to be considered the precursor of accurate thermometers. All the early instruments were air thermoscopes, and, until the variations of atmospheric pressure were discovered, their use was only deceptive. Galileo’s thermometer (fig. 1) consisted of a glass bulb containing air, terminating below in a long glass tube which dipped into a vessel containing a coloured fluid. The variations of volume of the enclosed air caused the fluid to fall or rise in the tube, to which an arbitrary scale was attached. The great step in advance of inventing the alcohol thermometer is also due to Galileo, but the date (probably 1611 or 1612) is not precisely known. Rinieri certainly had alcohol thermometers made before 1647, and they are referred to as familiarly known in the oldest memoirs of the Accademia del Cimento (1667). In form they resembled those now in use ; they had large spherical (or, occasionally, cylindrical or helical) bulbs, and the degrees in­tended to represent thousandths of the volume of the reservoir were marked with beads of enamel fused on to the stem (fig. 2). All the Florentine instruments were graduated in the same way, but the scale was arbitrary, and the recorded readings were accordingly supposed for a long time to be useless. In 1829 the fortunate discovery by Antinori of a number of those early Florentine thermometers enabled their scale to be ascer­tained and translated into known degrees. The temperature of melting ice was marked by them as 13⋅5, while 50 corresponded with 55° C. No means of comparing observations made by ther­mometers of different manufacture existed until certain fixed points of universal accessibility were discovered. The thermal conditions of freezing water were studied with great care, but natural congelation was generally supposed to take place at variable tempera­tures, until Fahrenheit proved that, however much water could be cooled down without freezing, the temperature when ice began to form was always the same. Hooke, in 1665 (*Micrographia,* p. 38), describes the manufacture and graduation of comparable spirit thermometers with the freezing point of water as the zero of their scales, and he evidently recognized it as fixed. Halley in 1693 stated that the temperature of boiling water is constant, and this was again proved by Amontons in 1702. In 1694 Renaldeni of Padua proposed to graduate thermometers by taking as standards of temperature mixtures of definite volumes of ice-cold and boiling water. This method, although theoretically admirable (see Heat, vol. xi. p. 559), is defective in practice. Seven years later Newton proposed anonymously (*Phil. Trans.,* 1701, vol. xxii. p. 824) a thermometer scale on which the temperature of freezing water was 0°, and that of the blood of a healthy man 12°. Continuing the graduation of a linseed-oil thermometer above this point, he found that water boiled at 34°. Fahrenheit in 1714 took as fixed points the temperature of the human body and that of a mixture of ice and sal ammoniac or common salt. In 1721 he made a mercury thermometer according to Halley’s suggestion of 1693, and by means of it he proved the dependence of the boiling point on pressure. It was not until after Fahrenheit’s death that the freezing and boiling points of water were universally accepted as fixed points on the thermometric scale. The thermometer has remained un­changed in its main features since the middle of the 18th century. Mercury has been found the most convenient fluid for ordinary use, in spite of the advantages (Heat, vol. xi. p. 561 *sq.)* presented by lighter and more volatile liquids. Graduation of thermometers, by marking off volumes of the stem equal to a given fraction of the capacity of the bulb, although reintroduced by Réaumur in 1730, has now been entirely discontinued.

The idea of a self-registering thermometer early pre­sented itself. Many forms were devised by natural philo­sophers and instrument-makers. That of Sixe, in 1782, a precursor of which, dating from the 17th century, is preserved amongst the instruments of the Florentine Academy, was the most successful.

*Scales.—*The absolute zero of temperature is the logical beginning of a thermometric scale, but some point easy of reference is desirable, and this is found in the tempera­ture at which ice melts and water freezes. The second accepted fixed point is that at which distilled water boils under the pressure of 760 millimetres (29⋅92 in.) of mer­cury. For the division of the space between the two fixed points into degrees of convenient length only three of the innumerable methods proposed have survived, and one of these, the centigrade, is rapidly becoming universal. The oldest system, that of Fahrenheit, dates from 1724. It is used for meteorological purposes, and popularly, in Great Britain, the British colonies, and the United States. The freezing point is marked 32° and the boiling point of water 212°. At first Fahrenheit employed a scale of 180 degrees; the zero was placed at “temperate” (9° C.); 90° at “ blood-heat,” the point to which the alcohol rose when the thermometer was placed under the arm of a healthy man; and - 90° at the temperature of a mixture of ice and salt, then believed to be the greatest possible cold. In 1714 Fahrenheit changed his scale at the suggestion of the Danish astronomer Roemer, placed 0° at his “ absolute zero,” and divided the space between that and the warmth of the human body into 24 degrees. The freezing point of water thus became 8°. For convenience, these long degrees were divided into quarters, which were afterwards termed degrees ; thus the freezing point became 32° and blood heat 96°. A mercury thermometer graduated in