A WAVE-LENGTH COMPARATOR.*

STANDARD MEASUREMENT IN WAVE-LENGTHS OF LIGHT.

BY A. E. H. TUTTON.

THE employment of the principle of the interference of two rays of monochromatic light, derived from the same source, one retarded behind the other by having to traverse a longer path, for the production of rectilinear interference bands constituting a scale of half-wave-lengths, has now been brought to such perfection that this highly refined scale may be used for the measurement of short distances or small movements of any description whatsoever. The accuracy is absolute to the tenth part of a scale division, the twentieth part of a wave-length of light, and is actually measurable with the most ordinary micrometer to the one-hundredth of a scale division, corresponding to the two-hundredth part of a wave-length. Now a wave-length of even the grossest radiations employed, those of red light, derived from either cadmium vapor (0.0006438 millimeter) or hydrogen (0.0006562 millimeter) is a forty-thousandth of an inch, so that the measurable unit is an eight-millionth part of an inch.

The finest trustworthy measurement by mechanical means (such as the Whitworth machine) or micrometric devices (such as the most refined thickness measurer) is the one-thousandth of a millimeter, or the twenty-five-thousandth of an inch. Moreover, the amount of possible error with either of these mechanical methods of measurement or the interference method is from one to two units of the respective scales. Hence the interference method is only subject to a possible error of one three-hundred-and-twentieth the magnitude of that to which the mechanical mode of measurement is liable.

The interference method was first seriously employed by Fizeau, who utilized it for the determination of the thermal expansion of crystals and other small bodies. It was materially improved by Abbe and Pulfrich, and more recently both for the same crystallographic purpose and for general purposes by the writer, who has also extended its use to the measurement of the modulus of elasticity of crystals and small bodies or small quantities of substances in general.

It will be remembered also that Prof. Michelson, of Chicago, has recently adapted his entirely different mode of producing interference fringes, in this case circular, to the determination of the number of wave-lengths of red cadmium light, which he has proved to be the most homogenous of all radiations yet known to us, in the French meter. By employing a graduated series of glass-plate *etalons* or intermediate standards, each double of the preceding one, commencing with a basal one of half a millimeter in which the actual number (1.212) of half-wave-lengths was counted, the number of wave-lengths of red cadmium light in the meter was eventually found to be 1,553,163. This number has since been confirmed by the independent method of Fabry and Perot, in which circular fringes are also produced.

Three years ago the writer was invited by the Standards Department of the Board of Trade to adapt his interferometer to the purposes of a wave-length comparator of measures of length, and a memoir recently published in the Philosophical Transactions of the Royal Society (Phil. Trans. A, 1910, vol. ccx., p. 1), with the consent of the President of the Board of Trade, describes the instrument, which has now been installed in the Standards Office. The memoir also comprises an appendix concerning the possible employment of wave-length rulings on metal as defining lines on standard bars, with suggestions for their use along with the interference bands of the interferometer, in an original method of determining the total number of wave-lengths in the British yard.

A general view of the interferometer and one of the duplicate microscopes of the comparator, together with sufficient of the bar-carriage to enable some idea of the whole apparatus to be gained, is given in the accompanying illustration.

The whole instrument is mounted on a large stone block, resting on isolated concrete foundations. On a small stone pedestal, similarly isolated, in front of the large block, rests the pedestal of the auto-collimating telescope and attached Geissler tube of the interferometer. In the common focal plane of the telescope objective and eyepiece, opposite the junction of this main optical tube with the rectangularly attached side tube carrying the Geissler tube, a small totally reflecting prism is arranged, half covering the focal aperture. A still smaller rectangular stop or opening in a plate in front of and almost touching

that one of the perpendicular prism faces which is directed toward the objective, and lies in the focal plane very close to the edge dividing the closed half from the open half, is the effective source of the interfering light; the rays from the Geissler tube, received on the other face of the right-angled prism, are arranged to fill this stop after reflection from the hypotenuse of the prism. The rays proceed from the stop to the objective, which they are arranged to fill with light, and thence pass out of the telescope as parallel rays, in the path of which the dispersion and interference apparatus is placed. The rays return to the telescope from the latter along practically the same path, but after re-entering the telescope, instead of returning to the little rectangular stop, their origin, they are deflected just sufficiently to one side to form an image of the stop, the same size as the original, in the open semi-circular aperture of the focal plane, within a couple of millimeters of the real stop. This closeness to identity of path of the outgoing and the incoming rays, and consequent normal incidence on the reflecting glass surfaces of the interference ap-

length, if desired, and has numerous adjustments. Such calibration is not essential, however, as the particular image of the origin-stop in the color corresponding to the spectrum bright line of cadmium or hydrogen can be adjusted visually on removal of the front lenses of the Ramsden eyepiece.

The interference apparatus consists of three circular and thick glass disks, the third of which is of black glass polished on an absolutely true plane on its outer surface, which is one of the two important surfaces concerned in the production of the interfering light. It is ground on the black surface, by which it is attached in an adjustable manner to the right microscope of the comparator, the movement of which it is to record. The other two are larger disks of colorless glass, identically similar, the two truly plane surfaces of each disk not being strictly parallel, but inclined at the minute angle of 35 minutes. The left surface of that one nearest to the black glass disk is the second surface concerned in the interference, and approaches the black glass within a millimeter; the second is a duplicate one, merely introduced on

CENTRAL PART OF COMPARATOR, SHOWING INTERFEROMETER.

paratus, is largely responsible for the magnificent field of parallel straight-lined interference bands which the author's interferometer affords, for it fulfills an essential condition for perfect interference.

With the ordinary eyepiece in position, the images of the stop reflected from the various surfaces of the interference apparatus can be focused, adequately magnified, and viewed during their adjustment to the theoretically ideal positions. But when this eyepiece is replaced by a special one consisting of a Ramsden micrometer combined with an additional lens between the latter and the focal plane, the telescope is converted into a low-power microscope, which focuses simultaneously the interference bands, a little silvered reference ring in the center of one of the two surfaces reflecting the interfering light, and the micrometer spider lines. There are two parallel vertical spider lines; one is adjustable by the left drum head of the micrometer, so as to be able to set it at any convenient distance from the other in order to include a single band and most of the reference ring between them; and both are moved together by the other (right) measuring drum, in order to be able to determine the band width and any fraction of a band which may have passed the reference center.

The dispersion apparatus consists of a Hilger constant-deviation prism, which enables the desired spectrum ray to be isolated from all others, and that alone delivered to the interference apparatus. The rays are deviated exactly at right angles by this prism toward the interference apparatus, the surfaces of which they strike at normal incidence, after which they return through the constant-deviation prism (thus securing double dispersion) to the telescope. The prism is mounted on a divided circle, so that it may be calibrated for the delivery of light of any desired wave-

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The apparatus as described up to this point is the interferometer.

The comparator consists of two V-and-plane beds, nearly 7 feet long, of specially homogeneous cast iron, and worked truly plane with consummate care, together with their contents; they are arranged stepwise, one on the top of the stone block, and the other 7½ inches below and in front. On the upper one slide the two duplicate microscopes, and on the lower one the standard-bar carriage and accessory fine-adjustment fittings. The carriage is given a longitudinal motion, a transverse motion, adequate to bring either of the two bars to be compared under the microscopes, as well as fine adjustments for azimuth, height and level, thus enabling the defining marks on the bars to be readily focused without touching the microscopes if it is so desired.

Each microscope is carried on a solidly constructed slider on the V-and-plane bed, by which its coarse adjustment for position is effected. The microscope-bearing bracket is not, however, fixed directly to this slider, but to a second one sliding over the first, also with V-and-plane contact, and with the further control of the movement of a cylinder within a cylinder-

* Nature.