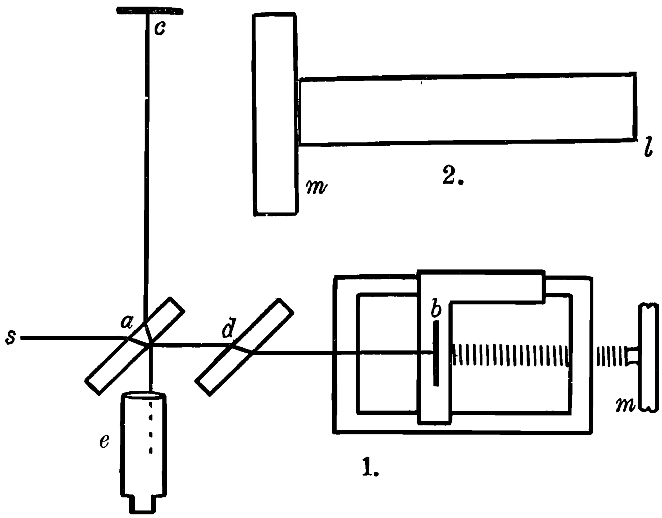
ART. XLVII. — *On a Method of making the Wave-length of Sodium Light the actual and practical standard of length;* by ALBERT A. MICHELSON and EDWARD W. MORLEY.

THE first actual attempt to make the wave-length of sodium light a standard of length was made by Peirce.* This method involves two distinct measurements: first, that of the angular displacement of the image of a slit by a diffraction grating, and second, that of the distance between the lines of the grating. Both of these are subject to errors due to changes of temperature and to instrumental errors. The results of this work have not as yet been published; but it is not probable that the degree of accuracy attained is much greater than one part in fifty or a hundred thousand. More recently, Mr. Bell of the Johns Hopkins University, using Rowland's gratings, has made a determination of the length of the wave of sodium light which is claimed to be accurate to one two hundred thousandth part.† If this claim is justified, it is probably very near the limit of accuracy of which the method admits. A short time before this, another method was proposed by Macé de Lepinay.‡ This consists in the calculation of the number of wave-lengths between two surfaces of a cube of quartz. Besides the spectroscopic observations of Talbot's fringes, the method involves the measurement of the index of refraction and of the density of quartz, and it is not surprising that the degree of accuracy attained was only one in fifty thousand.

Several years ago, a method suggested itself which seemed likely to furnish results much more accurate than either of the foregoing, and some preliminary experiments made in June have confirmed the anticipation. The apparatus for observing the interference phenomena is the same as that used in the experiments on the relative motion of the earth and the luminiferous ether.

* Nature, xx, 99, 1879; this Journal, III, xviii, 51, 1879.
† On the absolute wave-lengths of light, this Journal, III, xxxiii, 167, 1887.
‡ Comptes Rendus, cii, 1153, 1886; Journ. de Phys., II, v, 411, 1886.

Light from the source at *s* (fig. 1), a sodium flame, falls on the plane parallel glass *a*, and is divided, part going to the plane mirror *c*, and part to the plane mirror *b*. These two pencils are returned along *cae* and *bae*, and the interference of the two is observed in the telescope at *e*. If the distances *ac* and *ab* are made equal, the plane *c* made parallel with that of the image of *b*, and the compensating glass *d* interposed, the interference is at once seen. If the adjustment be exact, the whole field will be dark, since one pencil experiences external reflection, and the other internal.



If now *b* be moved parallel with itself a measured distance by means of the micrometer screw, the number of alternations of light and darkness is exactly twice the number of wave-lengths in the measured distance; thus the determination consists absolutely of a measurement of a length and the counting of a number.

The degree of accuracy depends on the number of wave-lengths which it is possible to count. Fizeau was unable to observe interference when the difference of path amounted to 50,000 wave-lengths. It seemed probable that with a smaller density of sodium vapor this number might be increased, and the experiment was tried with metallic sodium in an exhausted tube provided with aluminum electrodes. It was found possible to increase this number to more than 200,000. Now it is very easy to estimate tenths or even twentieths of a wave-length, which implies that it is possible to find the number of wave-lengths in a given fixed distance between two planes with an error less than one part in two millions and probably one in ten millions. But the distance corresponding to 400,000 wave-lengths is roughly a decimeter, and this cannot be determined or reproduced more accurately than say to one part in 500,000. So it would be necessary to increase this distance. This can be done by using the same instrument together with a comparer.

The intermediate standard decimeter lm (fig. 2) is put in place of the mirror b. It consists of a prism of glass one decimeter long with one end l plane, and the other slightly convex, so that when it touches the plane m, Newton's rings appear, and these serve to control any change in the distance lm, which has been previously determined in wave-lengths.

The end l is now adjusted so that colored fringes appear in white light. These can be measured to within one-twentieth of a wave-length, and probably to within one-fiftieth. The piece lm is then moved forward till the fringes again appear at m; then the refractometer is moved in the same direction till the fringes appear again at l, and so on till the whole meter has been stepped off. Supposing that in this operation, the error in the setting of the fringes is always in the same direction, the whole error in stepping off the meter would be one part in two millions. By repetition this could of course be reduced. A microscope rigidly attached to the carriage holding the piece lm would serve to compare, and a diamond attached to the same piece would be used to produce copies. All measurements would be made with the apparatus surrounded by melting ice, so that no temperature corrections would be required.

Probably there would be considerable difficulty in actually counting 400,000 wave-lengths, but this can be avoided by first counting the wave-lengths and fractions in a length of one millimeter and using this to step off a centimeter. This will give the nearest whole number of wave-lengths, and the fractions may be observed directly. The centimeter is then used in the same way to step off a decimeter, which again determines the nearest whole number, the fraction being observed directly as before.

The fractions are determined as follows: the fringes observed in the refractometer under the conditions above mentioned can readily be shown to be concentric circles. The center has the minimum intensity when the difference in the distances ab ac is an exact number of wave-lengths. The diameters of the consecutive circles vary as the square roots of the corresponding number of waves. Therefore, if x is the fraction of a wave-length to be determined, and y the diameter of the first dark ring, d being the diameter of the ring corresponding to one wave-length, then $x = \frac{y^2}{d^2}$.

There is a slight difficulty to be noted in consequence of the fact that there are two series of waves in sodium light. The result of this superposition of these is that as the difference of path increases, the interference becomes less distinct and finally disappears, reappears, and has a maximum of distinctness again, when the difference of path is an exact multiple of both wave-lengths. Thus there is an alternation of distinct interference fringes with uniform illumination. If the length to be measured, the centimeter for instance, is such that the interference does not fall exactly at the maximum—to one side by, say, one-tenth the distance between two maxima, there would be an error of one-twentieth of a wave-length requiring an arithmetical correction.

Among other substances tried in the preliminary experiments, were thallium, lithium, and hydrogen. All of these gave interference up to fifty to one hundred thousand wave-lengths, and could therefore all be used as checks on the determination with sodium. It may be noted, that in case of the red hydrogen line, the interference phenomena disappeared at about 15,000 wave-lengths, and again at about 45,000 wave-lengths: so that the red hydrogen line must be a double line with the components about one-sixtieth as distant as the sodium lines.