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Leybold Apparatus for Measuring the Velocity of Light by Means of a Rotating Mirror

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Leybold Apparatus for Measuring the Velocity of Light by Means of a Rotating Mirror

Written at the request of the AAPT Committee on Apparatus

Apparatus is manufactured by Leybold and is distributed in the U.S.A. and Canada by J. Klinger, 82–87 160th Street, Jamaica 32, New York for the measurement of the velocity of light, following a slight modification of the experiment originally performed by Foucault. The apparatus has been installed in the sophomore physics laboratory at M.I.T. for the use of the more advanced students. No special maintenance of the apparatus has been required during its one term of operation, and students have been able to measure the velocity of light in air with an uncertainty of less than 5%. With some minor modifications, moreover, the uncertainty can be reduced to 1–2%.

This experiment affords the student the opportunity to measure directly the velocity of light using a concept which is familiar to him—the time it takes a light beam to go from one point to a second point. This experiment, when combined with the measurement of the wavelength of standing electromagnetic waves, the resonant frequency of an electromagnetic cavity, or the inductance and capacitance of an inductor and capacitor of known geometrical configuration, allows the student to verify the equivalence of the speed of light and the speed of propagation of electromagnetic waves as predicted by Maxwell. With an improved accuracy of 1–2%, it is also possible for the students to observe the difference between phase velocity, as determined from an index of refraction experiment, and group velocity in a medium such as carbon disulfide. The student, in addition to obtaining the above objectives, gains a knowledge of the geometric optics involved and the experience of adjusting a critical optical experiment.

The experiment is discussed in detail in a book by Michelson[1]; the arrangement of the optical elements is shown in Fig. 1 for reference. The major elements are a revolving mirror, catalog number 47640, priced at $122.15; a surface mirror, number 46320, priced at $40.70; and a lens of 5-meter focal length, number 46012a, priced at $38.70. Catalog numbers and prices are quoted from Klinger's Bulletin No. 14, January, 1957. In addition to the above apparatus, an intense light source, a glass scale and ocular, an adjustable slit, and various mounting clamps and optical benches are required which can also be obtained from Klinger. Although two plane mirrors are shown in Fig. 1, only one is necessary. The purpose of mirror M_2 is to fold the optical path to conserve laboratory space. The apparatus has been mounted on one wall of the laboratory in plywood boxes for protection from dust and minimization of stray light and uses about 7.5 meters of wall space. To avoid a direct reflection from the rotating mirror and to conserve floor space, mirror M_1 is mounted vertically above the rotating mirror, lens L vertically above the slit, and the rotating mirror rotates about an almost vertical axis.

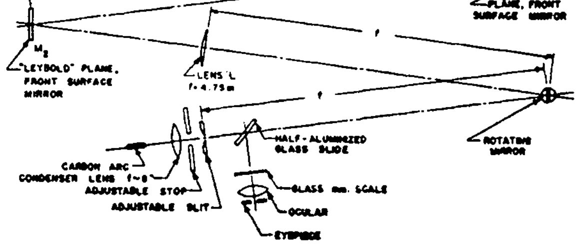

Fig. 1. Schematic layout of Leybold apparatus.

Leybold manufactures a 6-volt, 30-watt lamp as a light source but it does not supply sufficient light intensity to conveniently align the apparatus except in a darkened laboratory. We are using a small carbon arc drawing 8 amperes current and a condensing lens of 8 in. focal length as a light source.

The revolving mirror (Fig. 2) consists of two optically flat mirrors, 1 cm wide and 2 cm high, mounted back to back on the shaft of a 220-volt, universal ac-dc, high-speed (30 000 rpm) motor. The revolving mirror and motor is well-constructed, is easily mounted, can withstand continuous operation without any significant temperature rise, and has a constant speed within 60 rpm after a 10-minute warmup period. Any vibration of the mirror has no noticeable effect on the slit image.

The revolving mirror may be improved in several respects. The first is to provide an interlock to prevent

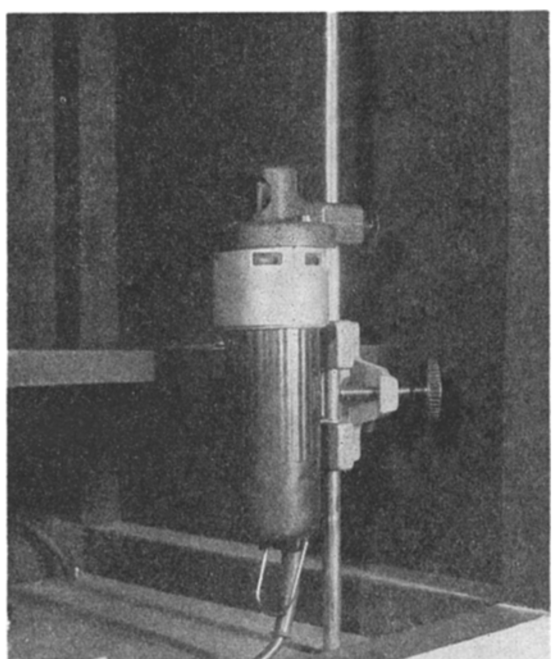

Fig. 2. Revolving mirror of Leybold apparatus.

operation of the motor when the key is inserted for manual rotation of the mirror. The second respect is to use a reversible motor which effectively doubles the speed and hence the image displacement. The third is to use a motor with a speed-voltage curve which saturates at full voltage. The motor now used shows a 1% change in speed for a 2% change in voltage.

The speed of the revolving mirror is measured with a strobotac which has been carefully calibrated using the 60 cycle-per-second power line as reference. Speed measurement can be made within 60 rpm and is a negligible source of experimental error. Leybold suggests adjustment of the speed of the motor for zero beat frequency between a standard tuning fork and the sound of the rotating mirror. (The sound is quite annoying if one is exposed to it for any length of time.) This method has not been tried in our laboratory.

The focusing lens is a single element, plano-convex, nonachromatic lens of 12-cm diameter and 4.75-meter focal length. Aberrations broaden the slit image from 0.5 mm to 1.0 mm width. The aberrations may be reduced by a limiting aperture, but this causes a reduction in image intensity.

The plane mirrors are aluminized, optically flat within about 10 wavelengths. Screw adjustments are used to provide angular alignment of the mirrors. No aberration of the image is found to be due to the mirrors.

The number of elements in the system could be reduced by one if the lens is removed and mirror M_2 is made concave. The use of a focusing mirror, while having the advantage of reducing the number of elements, has the disadvantage that alignment of the apparatus may be slightly more difficult.

An image of the slit is observed directly with an ocular of magnifying power 5 on a glass scale calibrated in millimeters. The measurement of the image displacement is the limiting factor in the experiment. The slit must be about 0.5 mm wide for sufficient light intensity for observation, and the slit image displacement can be measured within an accuracy of 0.2 mm. The displacement has been measured with an accuracy of 0.03 mm by careful measurements on a photographic exposure. Photographic techniques are more involved than is warranted in a sophomore laboratory and the direct observation of the displacement is not precise enough for measurement of group velocity. It is felt that a more desirable method of measurement is to align a set of cross-hairs with the image before and during rotation of the mirror and measure the displacement of the cross-hairs with a micrometer. This method should yield results which are accurate to within 0.1 mm.

A larger image displacement is obtained by increasing the distance from the revolving mirror to the scale, but the decrease in the image intensity and the increase in the difficulty of the alignment of the apparatus make this method not feasible for increasing the accuracy of the experiment for laboratory use.

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[1] A. A. Michelson, *Studies in Optics* (University of Chicago Press, Chicago, 1927).

Book Reviews

Physical Science for Liberal Arts Students. HUGO N. SWENSON AND J. EDMUND WOODS. Pp. 333+vi, 25.3×19 cm. John Wiley & Sons, Inc., New York, 1957. Price $6.50.

This text is written for the liberal arts physics course, taken usually by the nonscientist in the interest of gaining scientific literacy and an appreciation of the nature of the scientific process. There are still not many good texts for this type of course, which has evolved fairly recently as part of the general education movement and which differs significantly from both the science survey course and the preprofessional physics course.

The liberal arts course might be characterized by saying that it combines two aims: developing appreciation for science as an autonomous but interacting segment of culture, and imparting literacy in scientific terminology and command of scientific facts and ideas. Both these aims are implicit in a statement by the authors in the preface, in which they propose to concern themselves with "descriptions and illustrations of the special methods and disciplines, experimental and logical, that have been found useful in the physical sciences."

The text is in three parts: a two-chapter introduction, presenting an encapsulated history of science and formulating some philosophical themes, a major section on "The Macrocosm" (astronomy and mechanics), and a still longer concluding section on "The Microcosm" (heat, chemistry, electricity, optics, and atomic and nuclear physics). In the first major section, a plentitude of descriptive astronomical material is introduced, combined with an analysis of the geometry, arithmetic, algebra, and technology constituting the measurement base for our knowledge of astronomical fact. This leads to an account of the successful replacement of the Ptolemaic theory by the Copernican; evidence is marshalled for each theory and emphasis is given to the crucial role played by experiment and the advance of experimental technique. Thus the invention of the telescope, making possible the direct observation of the phases of Mercury and Venus, is exhibited as contributing a decisive point to Galileo's argument.

After a full chapter devoted to the astronomy of time measurement and a one-chapter abridgement of Newtonian mechanics, Newton's theory of universal gravitation, is presented and used to explain other astronomical measurements, such as the masses of the moon and the planets. At the end of the section, after a chapter on work and energy, is a detailed description of an inductive laboratory investigation of the motion of a simple pendulum, a case study illustrating the experimental method, which has served as the integrating theme of the section.

The integrating theme of the second section is the development of the theory of the nuclear atom. This is presented in a sequence of expositions, each at a deeper level, interspersed by blocks of more didactic material on heat, chemistry, electricity, optics, and quantum theory, to enable the student to handle the thematic material as it develops. The steps in the sequence are relatively