a fringe shift $\Delta$ expressed as

$$\Delta = (8\beta R/\lambda)(1 - k/2), \tag{8a}$$

where $R = OE \simeq DEC/2$. The filtered wavelength $\lambda$ was 6000 A.

The observed fringe shifts "reduced" to their equivalent value at a rotor speed of 1000 r.p.m. ranged from 3.1 to 4.3 with a weighted mean of 3.81 compared to the value of $\Delta$ of 3.76 computed with $k$ equal to zero. Michelson's reasonable but incorrect conclusion was that "the velocity of a moving mirror is without influence on the velocity of light reflected from its surface."[5]

A determination of the fringe shift $\Delta'$ based on the change of $c \pm kv$ to $c$ on nearly normal reflection from the stationary mirror $E$ and nonnormally at $B$ yields, to sufficient approximation,

$$\Delta' = (8\beta R/\lambda)(1 - \rho k/4). \tag{8b}$$

The excessively broad variation in the fringe shifts obtained by Michelson is as consistent with $\rho \leqslant 0.7$ for $k$ equal to unity as it is for $k$ equal to zero. The excessive range of the "observed" fringe shifts renders the experiment inconclusive as a check on an absolute or any of several possible relative speed of light hypotheses.

It is doubtful if the unmodified Michelson arrangement can ever be made to yield definitive results. The static rotation of the mirrors $C$ and $D$ has the effect of changing both the separation $d$ and the angle $\theta$ of the equivalent virtual sources in Fig. 2. This is due to the unequal angles of incidence on the mirrors $C$ and $D$ of the light rays reflected and transmitted from the beam splitter. Optical self-compensation is not maintained and the path difference $m\lambda$ is no longer zero. The result of dynamic rotation of the mirrors $C$ and $D$ manifests itself in the wide fringe shift range obtained. There is the additional problem of resolving the possible ambiguity of reading fringe shifts such as 3.76 from a shift that may have been 0.76, or 1.76, or 2.76, etc.

## BECKMANN-MANDICS CLOSED PATH EXPERIMENT

Light reflected from a rotating mirror was used in the related Beckmann-Mandics (1964)[13] experiment shown in Fig. 4. The experiment was done in air. Some of the apparatus (mirrors and mirror mounts) in this experiment can be recognized from photographs as that used in the Kantor[10] experiment. Except for differences in mechanical implementation, the experiment is essentially the same in concept as the Kantor experiment with one notable exception. Instead of stroboscopic microsecond light flashes admitted at the moments when the rotating windows *W* were normal to the light path, Beckmann caused light to be reflected from a rotating mirror *RM* mounted at the axis of rotation of the windows.

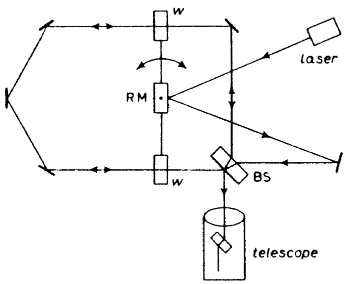


*Fig. 4. Beckmann-Mandics arrangement.*

It was stated that "if the rotor was off the perpendicular position by more than 0.5°, the chopping mirror *RM* diverted the incoming ray from its path into the interferometer and nothing could be seen in the telescope." An opportunity to witness the experiment was provided this author and the intense laser light was seen for nearly 360° rotation due to its reflection not only from the *RM* mirror surface but also, and with seemingly comparable intensity, by diffuse reflection, from the smooth and unpainted side and back surfaces of its aluminum mount.

It was stated that "a zero fringe (uniform illumination throughout the field of view) was obtained and the beam splitter *BS* was then very slightly rotated about its vertical axis, thus very slightly displacing the reflected from the transmitted loop and giving rise to low-order fringes." The surveyor's telescope used in this experiment to view the fringes was fitted internally with a rotatable optically flat glass plate. The calibrated external dial whereby this image-displacing plate could be rotated is visible in one of the photographs that shows the telescope. It was demonstrable that the fringes produced by Beckmann were dependent on the angular position of the image-displacing plate. The fringes from the internal reflections in the plate were mistakenly assumed to be interferometer fringes.

The rotating windows when viewed in collimated light exhibited many nonlinear fringes across their one-centimeter dimension indicating poor optical form and variable thickness especially near an edge.

Just as with the Michelson arrangement, the Beckmann-Mandics arrangement even without its experimental shortcomings would not be expected to produce reliable results. If the arrangement were indeed properly adjusted to the zeroth-order fringe a slight static rotation of the axially mounted rotatable mirror *RM* would have the effect of destroying the zeroth-order condition. There would be a change in path length difference between the opposite light paths; $d$ and $\theta$ for the effective virtual sources would change and there would be a loss of optical self-compensation. Dynamic rotation would produce, in addition to an angular variation of the injected light beam, an obvious continual lateral displacement of the light beam entering the interferometer. One possible result would be an effective lateral displacement of the equivalent virtual sources in Fig. 2, giving rise to a spurious shift of blurred fringes. The null result of the Beckmann-Mandics experiment is not productive of conclusive or significant conclusions concerning the relative or the absolute speed of light.

## BABCOCK-BERGMAN EXPERIMENTS

The Kantor[10] experimental apparatus was taken to the U.S. Naval Weapons Center at China Lake, California, where it was hoped to repeat the experiment in a large vacuum chamber there. This hope was not realized with the Kantor apparatus due to certain technical difficulties. Babcock published an internal report[14] in 1962 on the absence of any fringe shift obtained with certain modifications of the Kantor apparatus. This author did, on more than one occasion, adjust the interferometer correctly at China Lake so that a fringe shift was visible. Babcock has confirmed by his own word, as recorded by Ockert[15] in a footnote, that he witnessed the experimental effect of a fringe shift first obtained by this author in San Diego.

Babcock and Bergman (1964)[16] published the results of their experimental repetition in vacuum of the Kantor experiment with a completely different apparatus. They found no fringe shift. They regarded this as confirming Einstein's absolute speed of light postulate. Their arrangement is shown in Fig. 5.

The rotating windows in their experiment were relatively thick (0.34 cm) plate glass without optical surface or plane parallelism. They were cemented to the rotor without due regard to being mounted parallel to each other and perpendicular to the plane of rotation. It was asserted that: "It must not be supposed that the slight nonparallelism of the windows spoils the experiment, . . ."[16] On the next page it was noted that "taking the windows out of the path of the interfering beams changed the appearance of the fringes by rotating and narrowing them."[16] The rotation of the vertical fringe field as seen by this writer at China Lake was a rotation to a horizontal field when the windows were removed from the flight path. "An aperture of black cardboard was placed in the interferometer to mask any light not coming through the windows."[16] With this *aperture* removed it was found that the fringes seen above

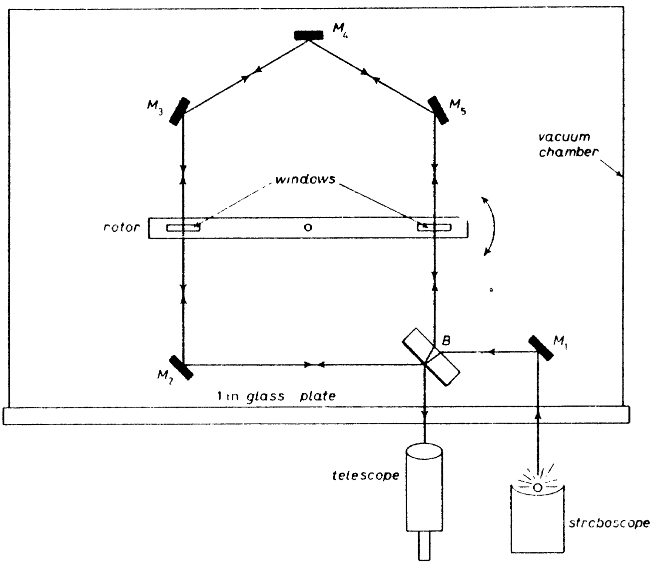


*Fig. 5. Babcock-Bergman arrangement.*

the windows were horizontal, while those seen through the windows were vertical. It is obvious from this that the interferometer was not correctly arranged. The use of a broad uncollimated light source in this experiment makes a zeroth-order fringe condition unattainable over any physically significant area of the field of view. Optical self-compensation with the nonparallel light rays from an uncollimated source is impossible.

"The adjustable mirror mounts and the base of the beam splitter were bolted to a 0.5-in aluminum plate which was in turn bolted to the vacuum tank.... The motor for the window rotor was bolted to a piece of copper plate, .... The copper plate and motor rested on a 1-in.-thick piece of plastic foam."[16] The interferometer was therefore isolated to some degree from motor vibration but it was directly subject to all other laboratory vibrations transmitted through the vacuum chamber steel shell. The gross insensitivity of the improperly arranged and adjusted interferometer was demonstrated by pounding on the vacuum chamber cylindrical tank with negligible effect on the fringe field. A closed-loop interferometer when adjusted to a zeroth-order fringe condition is, as a matter of known experience, excruciatingly sensitive to minute displacements of any of its component mirror surfaces due to vibration.

The enormous static optical-path differences and rotations for the effective virtual sources in the Babcock-Bergman experiment renders the experiment inconclusive as a test of the relative or the absolute speed of light.

The one way uncompensated Jamin interferometer experiment by Waddoups, Edwards and Merrill (1965)[17] is so briefly reported that it is almost exempt from evaluation. The conclusion that the speed of light is absolute was based on measurements on a chosen set of rotated fringes superimposed on several other fringe patterns. An experimental report of like quality purporting to establish the relative speed of light would rightly have been received with considerable diffidence. The observed rotation of fringe patterns, in this experiment and that by Babcock and Bergman, corresponds to a rotation of the virtual sources $s$ and $s'$ about their mid-point in a plane normal to $L$ in Fig. 2.

## KANTOR EXPERIMENT

The *quantitative* formulation for the fringe shift in the Kantor[10] experiment is based on two implicit *uncritical* assumptions that are most likely wrong. One is that the relative speed of light $c \pm \rho v$ is changed to $c$ on *nonnormal* reflection from the mirrors $A$, $B$, $D$ and $E$ shown in Fig. 6. The second is the uncritical assumption that the angle of reflection is equal to the angle of incidence even though the reflected-light speed differs from the incident-light speed.

The assumption that the relative speed of the light $c \pm \rho v$, incident *normally*, is altered to $c$ on *normal* reflection is based upon the supposition that the photon is re-emitted with speed $c$ from a point of *normal* incidence on the stationary mirror acting as a "new" source; *normal* reflection is assumed for the reason that there is no tangential component of motion in the *normally* incident light. Empirically, the speed on reflection for other angles of incidence could be found to be dependent on the angle of reflection in some manner reminiscent of the angle dependence of the intensity and polarization of light reflected from a smooth surface. Or it might be experimentally observed that, for a given incident relative speed $c \pm \rho v$ at a

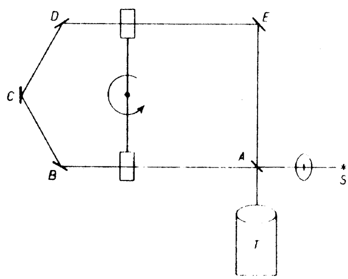


*Fig. 6. Kantor arrangement.*