problems of resolvability become formidable even with microdensitometer techniques.

In the absence of critical parameters (d, f, s) the Beckmann-Mandics experiments are altogether of doubtful value. Lloyd interferometer experiments on the relative or absolute speed of light would be expected to lead to null results, and are therefore inconclusive to begin with. *The inherent geometrical path difference $m\lambda$ at high-order fringes renders the sought for fringe shift a negligibly small and undetectable modification.* This provides significant insight on the merits of other interferometric experiments on the relative or absolute speed of light from a moving source.

DETECTABILITY OF FRINGE SHIFTS

The positive *qualitative* result of the Kantor experiment (1962)[10] contradicting the absolute speed of light hypothesis has yet to be duplicated. Three subsequently published attempts have yielded negative results, which were claimed as confirming the Einstein postulate on the absolute speed of light. These negative results were the consequence of a failure to properly adjust and maintain adjustment of the interferometer at its best condition for the detection of a fringe shift. The wrong conclusion, in all of these experiments, that the apparent null results supported the absolute speed of light hypothesis, while seemingly reasonable, has been too hastily embraced.

The problem can best be appreciated by the consideration of the phenomenon of optical interference by a pair of coherent light sources as shown in Fig. 2. Let the mid-point at the distance d from each source s and s' be at the perpendicular distance L from the plane of observation of the fringes at f; when $L >> d$,

$$M \simeq L - d \cos\theta \qquad (5a)$$

and

$$N \simeq L + d \cos\theta. \qquad (5b)$$

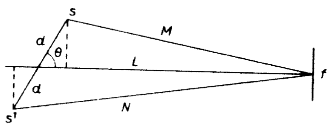

Fig. 2. Interference.

The geometrical path difference $N - M$ can be expressed as some multiple m of the wavelength λ. The transit time difference δt_0 for light traveling at speed c along M and N when emitted simultaneously from s and s' is expressed with the aid of (5a,b) as

$$\delta t_0 = m\lambda/c = (N - M)/c \simeq (2d/c) \cos\theta, \qquad (6a)$$

so that

$$m \simeq (2d/\lambda) \cos \theta \,. \tag{6b}$$

If the sources s and s' are coincident so that d and therefore m in (6b) are zero, the resultant interference will produce uniform illumination everywhere at the plane of observation. Parallel straight fringes, of width $\lambda L/2d$, can then be obtained by adjusting the interferometer so that when d is *not* zero θ equals $\pi/2$ and therefore m is still zero at f; a small separation d will produce wide fringes.

The speed of light emitted from s corresponding to a source moving with speed v, with or against the direction of c, is expressed as the relative speed of light $c(1 \pm \rho\beta)$, where $\beta = v/c$. The coefficient ρ would depend on the nature of the alteration of the relative speed of the light by the medium (air) in which it is propagating, $0 \leqslant \rho \leqslant 1$. There is as yet no experimental knowledge whereby ρ can be determined; theoretical prediction of ρ would be speculative and amount to but inconclusive tentative hypothesis.[11] Let the speed of light emitted from s' correspond to a source moving with speed v in a direction opposite to the source motion corresponding to s. The transit time difference δt for simultaneous emission from s and s' would then be expressed as

$$\delta t = [N/c(1 \pm \rho\beta)] - [M/c(1 \mp \rho\beta)] = m'\lambda/c \,, \tag{6c}$$

where $m'\lambda$ is the equivalent path difference that would yield the same time difference δt, for light traveling at speed c. To first order in β, it follows from (5a), (5b), (6a), and (6c) that

$$m' = m \mp 2\rho\beta L/\lambda, \tag{7a}$$

or, with (6b),

$$m' = (2L/\lambda)[(d/L) \cos \theta \mp \rho\beta] \,. \tag{7b}$$

If θ does not equal $\pi/2$ and d is so large that $(d/L) \cos\theta >> \rho\beta$ in (7b), then $m' \simeq m$, i.e., $\delta t \simeq \delta t_0$. The transit time difference $2\rho\beta L/c$ due to the relative speed of light may be negligible compared to a relatively huge, but avoidable, transit time difference δt_0 that can be inherent in an interferometer by failure to obtain its adjustment for a low or preferably zeroth-order ($\theta = \pi/2$) fringe at the point of observation. The zeroth-order condition becomes mandatory if Nature be such that ρ is rather small. A critique and appreciation of the experiments can now be undertaken.

MICHELSON EXPERIMENT

Three years after the inconclusive Tolman experiment in which light from a moving source was reflected from a stationary Lloyd mirror, Michelson (1913)[12] published a very brief note on the results of his experiment on the speed of light reflected from a moving mirror. His closed-return-path ("folded ring") interferometer arrangement is shown in Fig. 3. The distance *OE* was 608 cm. The distance between centers of the rotating mirrors *D* and *C* was calculated to be 26.5 cm on the basis of the known but unstated distance *AB*, so that *AD* and *BC* cannot be exactly deduced. They probably were about equal to *DC* or slightly more than half of *DC* so that the rotating mirrors could clear *A* and *B*. A light ray from the source *S* partially reflected at the beam splitter *A* was in turn reflected from the rotating mirror *D*. It was then reflected by the stationary concave mirror *E*, the moving mirror *C*, and the stationary mirror *B* to arrive at its starting point *A* where it was reflected into a telescope with a micrometer eyepiece. The transmitted half of the light ray traversed the same loop in the opposite direction to produce interference fringes with the reflected half of the light ray. When the rotor *DC* is stationary and parallel to *AB* the spatially superimposed counterpropagating light rays passed through the exact same optical inhomogeneities that are possible due to density variation in the air path; optical self-compensation was achieved.

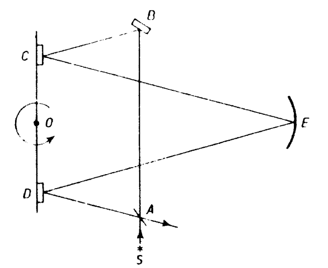

Fig. 3. Michelson experiment.

It was reasonably assumed that a light ray with speed c, incident almost perpendicularly on a moving mirror would have its speed changed to $c \pm kv$ according as it was incident against or with the direction of the mirror's motion. The coefficient k was determined by the specific hypothesis chosen to represent the speed of light reflected from a moving mirror. No consideration was given to the effect of the air on the light speed after the reflection. Michelson's determination of the expression for the fringe shift in addition to being wrong also made the tacit and uncritical assumption that the relative speed of the light $c \pm kv$ is also preserved in that nearly normal reflection from the stationary concave mirror *E* did not change it back to c. By also neglecting or regarding as negligible (compared to *DEC*) the light path increments *CBA* for the reflected ray and *DA* for the transmitted ray Michelson deduced a fringe shift Δ expressed as

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

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

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 Δ 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 Δ' 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 θ 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