from a stationary mirror. Rather than speculate on other interesting ballistic hypotheses, a new experiment will be suggested later which may provide an experimental indication of the possible nature of an angle-dependent ballistic behavior of light from a moving source, when that light is reflected from a stationary mirror. In a corpuscular ballistic model for the behavior of light, the two factors that can be experimentally examined are the speed and angle of the reflected light for a specific source speed and a specific angle for the incident light.

Tolman's experiment is of doubtful value even if it is uncritically assumed that reflection at grazing incidence will change $c \pm v$ into c. The first-order fringe shift effect to be expected with a Lloyd mirror from such an assumption is relatively negligible and undetectable as will shortly be shown. This will prove quite relevant to other interferometric experiments on the relative speed of light.

Tomaschek's repetition[7] of the Michelson-Morley experiment used sunlight and starlight which were first reflected from heliostats into a telescope and then passed through a laboratory window to finally enter the interferometer. Naturally, the intervening glass predetermined a null result just as in Tolman's experiment.

BECKMANN-MANDICS EXPERIMENT

The same assumption for the change of speed for the reflection of light at grazing incidence was made by Beckmann in the experiment by Beckmann and Mandics.[8] A contradiction with Fermat's principle of least time is also explicitly made in that the angle of reflection r, shown in Fig. 1, is equal to the angle of grazing incidence i, even though the speeds of the incident and reflected light are assumed unequal. Beckmann and Mandics repeated the Tolman experiment in air and in vacuum fifty-four years later in 1964. Their moving light source, without the presence of a slit, was established by means of the reflection of light incident at 15° on a tiny mirror mounted on a rotor at 12.8 cm from the axis of rotation. For the reasons already given, their other null result experiments with a stationary-slit light source are inconclusive, and need not be discussed.

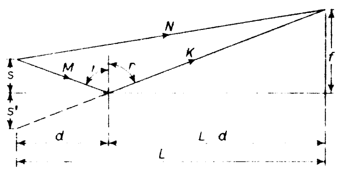

Fig. 1. Lloyd's mirror.

In Fig. 1, f is the perpendicular distance of a particular fringe from the plane of the mirror. The integer number or order of a fringe increases (or decreases) directly with f. The perpendicular distance of the source from the plane of the Lloyd mirror is s, and s' is the equidistant mirror image of s. The plane of observation of the fringe field is at distance L normal to the line ss', and d is the perpendicular distance of the point of reflection, on the Lloyd mirror, from ss'. When the light source is stationary $i = r$, so that

$$\text{ctg}\, i = s/d = f/(L - d) = (f + s)/L \ll 1, \tag{1a}$$

because of the physical condition of grazing incidence and reflection. From (1a) find

$$s/f = d/(L - d), \tag{1b}$$

$$d = Ls/(f + s), \tag{1c}$$

and

$$L - d = Lf/(f + s). \tag{1d}$$

The geometrical path length difference $(M + K - N)$ for a stationary light source $(i=r)$ is equal to some multiple m of the wavelength λ, which can also be expressed in terms of the transit time difference δt_0 of the direct and reflected light rays as

$$c\delta t_0 = M + K - N = m\lambda\ ; \tag{2a}$$

$$M + K = L\sqrt{(1 + (f+s')^2/L^2)} \simeq L(1 + (f+s)^2/2L^2), \tag{2b}$$

and

$$N = L\sqrt{(1 + (f-s)^2/L^2)} \simeq L(1 + (f-s)^2/2L^2), \tag{2c}$$

since $(f \pm s)/L \ll 1$ due to grazing incidence as noted in (1a). From (2a,b,c), find

$$f = m\lambda L/2s \tag{2d}$$

or

$$m = f/\delta f, \tag{2e}$$

where $\delta f = \lambda L/2s$ and is the distance between fringes or the fringe width. From (2d) and (1b) it follows that

$$m = (2s^2/Ld)(L - d)/\lambda. \tag{2f}$$

Assume that light, from a source moving with speed v, travels in vacuum along M and N with speed $c(1 \pm \beta)$; $\beta = v/c$. It was uncritically assumed that the light traveled along K after *grazing* reflection with the speed c, together with the assumption, contradicting Fermat's principle, that $r = i$. Based on these challengeable assumptions, the difference in the time of flight δt of the direct and reflected light rays is expressed as

$$\delta t = [M/c(1 \pm \beta)] + [K/c] - [N/c(1 \pm \beta)] = m'\lambda/c, \qquad (3a)$$

where $m'\lambda$ is the equivalent path difference for light traveling from a stationary source at speed c. To first order in β the multiple m' can be found from (3a) and (2a) as

$$m' = c\delta t/\lambda = m(1 \mp \beta) \pm \beta K/\lambda. \qquad (3b)$$

With $K^2 = f^2 + (L - d)^2$ it follows that

$$K \simeq L - d, \qquad (3c)$$

since $f^2/(L - d)^2 \ll 1$, as previously noted, at grazing incidence in (1a). From (3b) and (3c) it follows, since $\beta \ll 1$, that

$$m' \simeq m \pm \beta(L - d)/\lambda. \qquad (4)$$

The phase change in the transit time difference $\beta K/c \simeq \beta(L - d)/c$ between the direct and reflected light rays is due to the (particular assumed) change in the relative speed of light on reflection. The effective optical-path change $\pm\beta(L - d)$ due to the time phase change modifies the geometrical path difference $m\lambda$ inherent in the Lloyd interferometer. The transit time phase change attendant on the first-order effect for the change of the speed of light due to reflection would be misleadingly interpreted, on the basis of the questionable assumptions, as an apparent shift in the fringe position f.

The angle of reflection r may *not*, as is uncritically assumed, equal the angle of incidence i. The angle r may change due to the change in the relative speed of light on reflection. There would be a change in the geometrical paths K and N because the angle r differs from the angle i, so that there would be a real (geometrical) shift of the fringe position f. The geometrical path changes attendant on the first-order angular-aberration effect (change in r) would be manifest as an actual geometrical shift modifying the inherent fringe position f that corresponded to m. The geometrical fringe shift due to angular aberration could actually diminish the optical phase fringe shift depending on the reflection behavior of the relative speed of light. This would render the experiment inconclusive since the absolute speed of light also leads, as already noted, to a null result because there is no speed or angle change on the reflection of light from a stationary mirror. This suggests a new first-order experiment which for various angles of incidence is sensitive only to a change in the angle of reflection for the relative or absolute speed of light. The optical lever technique as refined by Jones[9] is as sensitive as interferometry and could prove quite effective.

The Beckmann-Mandics experiment, under vacuum conditions, was done with the parameters $L = 425$ cm, $\lambda = 6328$ Å and $\beta = 2.41 \cdot 10^{-7}$. The fringe width δf and therefore s is not given, nor is the measured position f and therefore m. The value of d is not given. It is therefore not possible to fully evaluate this inconclusive experiment.

Beckmann claimed that the distance f "may be measured on the photograph of the fringes (by utilizing the diffraction fringes due to the edge of the Lloyd mirror); . . . ."[8] No diffraction pattern is visible in the published photographs of the uniformly spaced interference fringes. His unsupported assertion that s/f "was of the order of 10^{-4}"[8] is contradicted by the physical facts. It would mean according to (1b) that d was of the order of $L \cdot 10^{-4}$ or about 0.425 mm. This is comparable to or less than any physically reasonable value for s, and contradicts grazing incidence (1a) and the need for clearance between the small rotating mirror source and the Lloyd mirror. It would also mean an f in excess of the 1.5 m diameter of the vacuum chamber; the fringe at f could not be seen. The consequent value of m in (2e) and (2f) would be so huge compared to the fringe change $\beta(L - d)/\lambda$ (of the order of unity) in (4) that the effect would be undetectable even if it were visible; i.e. $m' \simeq m$.

The Lloyd interferometer is most sensitive to change in the relative speed of light on reflection when d in (4) is as small as is consistent with grazing incidence. Ignoring angular aberration, this means large m values in (2d,e,f) for large K so that in agreement with (1b) $f \gg s$; i.e. high-order fringes. Beckmann correctly asserts that for best sensitivity $s \ll f$ (in his notation $x \ll y$). This is oddly contradicted by the subsequent comment, "i.e., for low-order fringers."[8] Apart from aberration effects, sensitivity has to be compromised for resolvability or detectability in the Lloyd mirror when $\beta(L - d)/\lambda$ is of the order of m, which in turn depends on the unspecified quantities s and d in (2f). Erroneous predictions follow from ignoring the effect of aberration due to possible changes in the angle r. The fact that the source is of small but distinct transverse dimension leads to the superposition of fringe patterns from different lateral points of the source. At moderate to large fringe orders the 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 $L \gg d$,

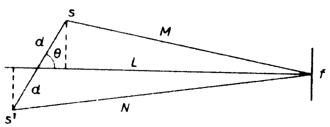

Fig. 2. Interference.

$$M \simeq L - d\cos\theta \tag{5a}$$

and

$$N \simeq L + d\cos\theta. \tag{5b}$$

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

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