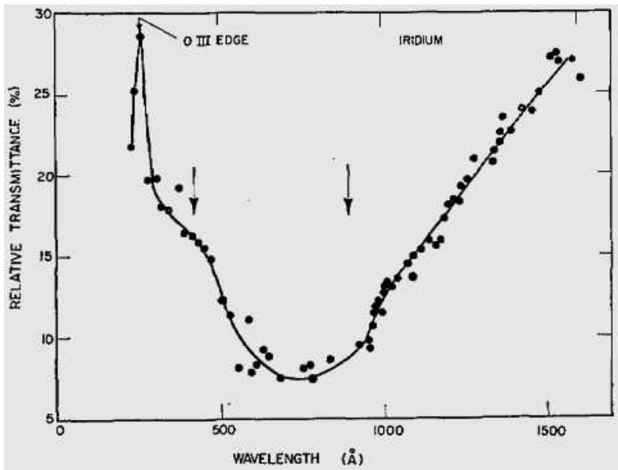

FIG. 2. Relative transmittance of iridium between 237 and 1600 Å. The vertical arrows at 890 and 420 Å represent the plasma frequencies assuming the number of active electrons to be two or nine, respectively.

the reflectance and relative transmittance of Ir and to illustrate that thin films of high-melting-point materials can be evaporated by the focused beam of a laser. Films several hundred angstroms thick can be produced by a single laser pulse in a few microseconds. Smith and Turner[1] have applied this technique to the evaporation of compounds and elements whose melting points were less than 1240°C.

In this preliminary investigation of laser-deposited thin films, Al (melting point 660°C), Ir (melting point 2454°C), and W (melting point 3410°C) were equally well evaporated using a ruby laser operating in the normal mode. The energy per pulse was about 100 J; the laser action lasted about 500 μsec. In addition to producing a mirror-like coating, the laser also caused some sputtering of the metal.

The reflectance of Ir produced by a single laser pulse is shown in Fig. 1. Unpublished data by Hass *et al.*[2] on the reflectance of Ir films produced by electron-beam heating techniques are also shown in Fig. 1 for wavelengths shorter than 600 Å. To longer wavelengths, their results are similar to those in Fig. 1.

The relative transmittance of an Ir film approximately 400-Å thick is shown in Fig. 2. In order to obtain the variation of transmittance of Ir as a function of wavelength without producing a self-supporting film, the Ir was evaporated directly onto a plastic scintillator (NE 102). The fluorescent radiation produced by the incident vacuum uv was detected by a photomultiplier. Only one half of the scintillator was coated. Thus, by measuring the ratio of the photomultiplier signals when the radiation was incident on the uncoated portion of the scintillator and then on the coated portion, the relative transmittance of the film was obtained.[3]

The frequency ν_p at which a metal changes from being a reflecting to a transmitting medium is given by[4,6]

$$\nu_p = (ne^2/\pi m)^{\frac{1}{2}}, \qquad (1)$$

where m and e represent the electronic mass and charge, respectively, and n is the number of electrons/cm³ interacting with the incident radiation. Generally, n is taken to be the density of the valence electrons. If the electrons in the outermost 6*s* shell are the only ones operative, Eq. (1) gives a transmission onset of 890 Å while, if in addition to those electrons the seven 5*d* electrons participate, the onset wavelength is 420 Å. These wavelengths are indicated in the figure by the vertical arrows. The data, however, indicate that the transmission onset occurs at about 650 Å.

Critical-absorption edges in Ir are expected at 263 Å (O III edge), 221 Å (N VII edge), and 207 Å (O II edge).[6] In Fig. 2, a sudden decrease of the transmittance at 260 Å can be correlated with the O III absorption edge.

The use of a laser to produce thin films for optical studies in the vacuum uv has several advantages over conventional evaporation techniques. Namely, the speed of deposition of the films, the simplicity of evaporating films in an ultrahigh-vacuum system, the lack of contamination from hot filaments or crucibles, and the ability to evaporate materials with high melting points. The major disadvantage is the possibility of sputtering material onto the reflecting surfaces. Investigations are currently underway to solve this problem.

* This work was supported by the National Aeronautics and Space Administration.
[1] H. M. Smith and A. F. Turner, Appl. Opt. 4, 147 (1965).
[2] G. Hass, G. F. Jacobus, and W. R. Hunter, J. Opt. Soc. Am. 56, 1435A (1966); and private communication with W. R. Hunter.
[3] J. A. R. Samson and R. B. Cairns, Appl. Opt. 4, 915 (1965).
[4] F. Seitz, *Modern Theory of Solids* (McGraw-Hill Book Company, New York, 1940), Ch. 17.
[5] D. Pines, in *Solid State Physics*, S. F. Seitz and D. Turnbull, Eds. (Academic Press Inc., New York, 1955), Vol. 1, p. 367.
[6] A. E. Sandström, in *Handbuch der Physik*, S. Flugge, Ed. (Julius Springer-Verlag, Berlin, 1957), Vol. 30, p. 78.

Constancy of the Velocity of Light

J. G. Fox
Department of Physics, Carnegie Institute of Technology
Pittsburgh, Pennsylvania 15213

INDEX HEADING: Velocity of light; Absorption; Scattering.

THIS note is prompted by certain recent articles [1–3] on this subject which ignore an important aspect of the propagation of light through matter. Because of this omission, the conclusions of these authors are of little or no value. The aspect involved, which is the extinction of the primary radiation and its replacement by secondary radiation scattered in the forward direction by the electrons of the medium, is vital to any experimental argument for or against the constancy of the velocity of light.

We are not concerned here with experiments of the Michelson-Morley type, which have conclusively disposed of the ether.[4] We are concerned rather with experiments which are meant to decide between Einstein's special theory of relativity (c is independent of the relative velocity of source and observer) and Ritz's emission theory (c is additive with the relative velocity of the source with respect to the observer). I have discussed[5] the arguments in favor of the former and against the latter. The number of decisive experiments is not large. Of these, one of the most important types is the measurement of the velocity of radiation from a moving source.

In interpreting experiments of this sort, the question immediately arises: what happens to the velocity of radiation from a moving source if the radiation traverses intervening matter which is stationary relative to the observer? According to our basic ideas of dispersion theory it suffers repeated forward scattering. Then if Ritz's theory is accepted for the sake of argument, there are two possibilities: (1) The velocity of the radiation is unchanged when it is scattered, or (2) The velocity of the scattered radiation is c relative to the scattering medium. (Intermediate possibilities seem unattractive and have not been seriously proposed). On the first assumption, which was that of Ritz, the well-known argument of DeSitter about the observed zero eccentricities of the orbits of many distant binary stars gives a conclusive verdict against the emission theory. There is no need to consider it further. On the second assumption, a modified Ritz theory which seems more natural,[5,6] we must then ask whether the amount of matter traversed is enough to reduce the velocity of *all* the radiation to c with respect to the medium.

This brings us to the extinction theorem of Ewald and Oseen[7] and the problem of estimating the extinction distance. Strong theoretical[8,9] and experimental[8] arguments have been adduced which show that the $1/e$ distance for the transformation of the amplitude is $\lambda/(n-1)$ where λ is the wavelength and n the index of refraction. The corresponding distance for transformation of the energy is then $\lambda/2(n-1)$. For visible light in air at sea-level pressure this distance is about 0.2 mm. Thus the experiment of Záhejsky and Kolesnikov[1] proves nothing about the modified emission theory (assumption 2 above) since it was done in air at atmospheric pressure. In the experiment of Waddoups *et al.*[3] the residual pressure in the evacuated equipment was 2.6×10^{-4} atm. Therefore the extinction distance for 7000-Å light was 77 cm. The significant light path in the experiment was 1 m. Thus the flux of the primary wave was reduced to $e^{-1/0.77}$ or about $\frac{1}{4}$ of its initial value while the remaining 75% was forward-scattered flux which traveled part of its path at the speed c. This strongly affected the fringe shift expected on the emission theory but its effect was not calculated (indeed it is difficult to do) so this experiment is of little value in deciding between Einstein and Ritz.

The extinction distance in interstellar space is about one light year[5] so, on the modified emission theory, light from distant stars has, during most of its travel, a velocity of c with respect to the interstellar medium and not with respect to the star. Thus the argument of Aleksandrov[2] breaks down for the same reason as the argument of DeSitter.[5]

It is, apparently, not always realized[1,10] that very serious doubt was cast on the experiment of Kantor[11] (who claimed an effect of a moving solid medium on the speed of light in air) by White and Alpher.[12] They applied extinction arguments of the type outlined above even before the repetition of Kantor's experiment by Babcock and Bergman[13] in both air and vacuum yielded a negative result.

It should also be clear that the phenomenon of extinction and the associated extinction distance make irrelevant other experiments done in air or in an insufficient vacuum such as the experiment of James and Sternberg.[14]

There is one fairly recent experiment with light in a vacuum with negligible extinction whose result is significant: Beckmann and Mandics[15] obtained a null result for the fringe shift from a Lloyd interferometer using light which had been reflected from a moving mirror. Unfortunately a fixed slit was located between the moving mirror and the Lloyd mirror for an unspecified fraction of their data. This arrangement suffers from the same criticism[5] as that of Ritz. However, all of their data contradicted the emission theory and some of it was free from this criticism, so the results are meaningful.

The whole history of this matter of proving the constancy of c has involved an unusually large number of errors. There may be more but it seems that at least we now understand the role of extinction. Good evidence, all of recent date, now exists.[8,9,13,15] It is to be hoped that time will not be wasted in future on additional experiments or arguments which are nullified by extinction.

[1] J. Záhejský, and V. Kolesnikov, Nature 212, 1227 (1966).
[2] E. B. Aleksandrov, Soviet Astronomy 9, 519 (1965).
[3] R. O. Waddoups, W. F. Edwards, and J. J. Merrill, J. Opt. Soc. Am. 55, 142 (1965).
[4] T. C. Jaseja, A. Javan, J. Murray, and C. H. Townes, Phys. Rev. 133, A1221 (1964).
[5] J. G. Fox, Am. J. Phys. 33, 1 (1965).
[6] W. Pauli, *Theory of Relativity* (Pergamon Press, New York, 1958), p. 6.
[7] M. Born and E. Wolf, *Principles of Optics* (Pergamon Press, New York, 1959), pp. 70 and 100.
[8] T. A. Filippas and J. G. Fox, Phys. Rev. 135, B1071 (1964).
[9] T. Alväger, J. M. Bailey, F. J. M. Farley, J. Kjellman, and I. Wallin, Arkiv. Fys. 31, 145 (1966). Alternatively for an abbreviated account, see same authors, Phys. Letters 12, 260 (1964).
[10] V. Výsín, Phys. Letters 8, 36 (1964).
[11] W. Kantor, J. Opt. Soc. Am. 52, 978 (1962).
[12] D. R. White and R. A. Alpher, J. Opt. Soc. Am. 53, 760 (1963).
[13] G. C. Babcock and T. G. Bergman, J. Opt. Soc. Am. 54, 147 (1964).
[14] J. F. James and T. S. Sternberg, Nature 197, 1192 (1963).
[15] P. Beckmann and P. Mandics, J. Res. Natl. Bur. Stds. (U. S.) 69D, 623 (1965).

Modification of Phase-Compensated Corner Cube for Interferometry

PAUL B. MAUER

Apparatus and Optical Division Research Laboratory, Eastman Kodak Company, Rochester, New York 14650

(Received 31 March 1967)

INDEX HEADINGS; Polarization; Interferometry; Reflection; Film.

A TECHNIQUE for phase-compensating a corner cube with a 3-layer film was recently described.[1] The utility of such a compensated cube is still limited owing to the differences of rotation of the plane of polarization of light incident on different sextants.

A convenient means for increasing the utility of such a compensated cube is to introduce a quarter-wave plate ahead of the cube, oriented so as to produce circularly polarized light. If the cube is properly phase-compensated, the return light is all still circularly polarized, and is restored to plane polarization on its return passage through the quarter-wave plate. The final plane of polarization is parallel to the incident plane, since a corner cube does not produce left–right reversal as does a flat mirror.

Unfortunately, a new problem now arises. The effective path length for circularly polarized light is sensitive to the sextant in which the light is incident. Although rotation of the plane of polarization by the cube does not alter the circular-polarization state of the return beam, it does affect its phase.

A simple means for further correction of the cube is to coat adjacent sextants with thin films which effectively add or subtract 120° phase relative to their neighbors. This could be done by coating one sextant with material of index n, to a physical thickness $t=(\frac{1}{3})\lambda/(n-1)$, where λ is the vacuum wavelength. An adjacent sextant should then be coated with a film of twice the thickness, to provide $(\frac{2}{3})\ \lambda$ of added path. Depending on which adjacent sextant is given the double-thickness coating, the cube is corrected for right-handed or left-handed circular polarization. An optional procedure would be to coat diametrically opposite sextants with films of $\frac{1}{2}$ the above thickness, to give the necessary total phase correction.

This combination of a quarter-wave plate and a phase-compensated corner cube with additional phase-correcting coatings makes a versatile beam-returning component for interferometers. The full aperture is useable and the unit is relatively insensitive to angular motion. The only restriction is that plane-polarized light must be used. If the additional phase-correcting coatings are omitted, the direction of motion of the cube is indicated by the sequence of blanking of the cube sextants. Using left-circular polarization, motion toward the observer causes the blanking sequence to be clockwise, and motion away from the observer produces a counterclockwise blanking sequence. If the quarter-wave plate is oriented to produce right-circular polarization, the relation between direction of motion and blanking sequence is reversed.

[1] P. Mauer, J. Opt. Soc. Am. 56, 1219 (1966).

Frequency Doubling

ROSALIND B. MARIMONT

National Institute of Neurological Diseases and Blindness, and Mathematical Research Branch, National Institute of Arthritis and Metabolic Diseases, National Institutes of Health, Bethesda, Maryland, 20014

(Received 2 March 1967)

INDEX HEADING: Vision.

IN his recent article[1] Kelly presents a very interesting new phenomenon, that of spatial-frequency doubling in a flickering target. However, his model and discussion raise a number of questions. His analysis leads to a spatial-frequency doubling dependent only on temporal frequency, which would lead to a