12. The limits (37) on α implies that there is a limitation on the radius of the circular orbits we have considered. For, according to equation (49), we must have

$$1 \leq \cosh 2r \leq \sqrt{2} \tag{56}$$

The origin of this upper bound on r becomes apparent when we evaluate (cf. equation (42))

$$d\Sigma^2 = dt^2 + (\sinh^4 r - \sinh^2 r)d\varphi^2 + 2\sqrt{2}\sinh^2 r\, d\varphi dt \tag{57}$$

for the orbit described by equations (49), (52), and (55). We find

$$d\Sigma^2 = (1 - {}^1/_2 \cosh^2 2r)d\sigma^2. \tag{58}$$

Accordingly, when $\cosh 2r$ has its maximum value specified by (56), $d\Sigma^2 = 0$. In other words the *circular orbit of the maximum radius is the null geodesic.*

13. Finally, it is important to remark that for the range of r allowed by (56), the constant of proportionality β between t and σ $(= {}^1/_2\varphi)$ is *always positive.* This last fact seems to be contrary to some statements of Gödel from which he has drawn the conclusion we have quoted earlier.

[1] Gödel, Kurt, "An Example of a New Type of Cosmological Solutions of Einstein's Field Equations of Gravitation," *Rev. Mod. Phys.*, **21**, 447–450 (1949).

[2] Robertson, H. P., "Relativistic Cosmology," *Rev. Mod. Phys.*, **5**, 62–90 (1933), see p. 65.

[3] Gödel, Kurt, "A Remark about the Relationship between Relativity Theory and Idealistic Philosophy," *Albert Einstein: Philosopher-Scientist* (Evanston, Illinois: The Library of Living Philosophers, Inc., 1949), pp. 557–562.

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*ABSENCE OF DISPERSIVE PROPERTIES OF SPACE FOR ELECTROMAGNETIC RADIATION TESTED TO $\pm 14 \times 10^{-5}$; COMMENTS ON A PROPOSAL OF SOFTKY AND SQUIRE**

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In session *I 1* of the Berkeley meeting of December 30, 1960, S. D. Softky and R. K. Squire proposed a test for dispersive properties of space for electromagnetic radiation by detonating a nuclear explosive at a distance of 10^6 miles from the earth and noting the arrival times of different types of radiation at detectors above the atmosphere. In justification of such an experiment (which will no doubt cost the taxpayer several tens of millions of dollars), they assert the following, which I quote directly from their published abstract: "Measurements of c for different frequencies of radiation (radio waves, light, and ratio of esu to emu) have not demonstrated that c is independent of frequency . . . Astronomical tests of the invariability of c with frequency have been done only for optical frequencies . . . In view of the importance of c in many physical theories, it is thought that an accurate comparison for radio, optical, X-ray, and γ-ray frequencies would be worth while."

The purpose of this note is to point out that Softky and Squire have overlooked the fact that a test for the dispersive properties they postulate already exists, covering perhaps not quite as extensive a range of the electromagnetic spectrum as they hope to cover (they claim a factor of 10^{11}) but nevertheless sufficient to render any such effect extremely unlikely over a range of frequencies of a factor of 5×10^9. I refer to a measurement performed in 1950 by means of the bent quartz crystal diffraction spectrometer[1] of the wavelength of the annihilation radiation generated in a block of copper by positrons from the nuclide ^{64}Cu.

The argument is a simple one, as follows. Let us admit for the moment the correctness of the relativistic formula for the rest-mass energy of an electron, $m_0c_1^2$ where c_1 is the velocity of propagation of visible light waves or radio waves. c_1 is now probably known to about 1 ppm.[2, 3] The success of this formula in computing from nuclear reaction energy data masses of many nuclides with results in good agreement with masses measured very accurately by mass spectroscopy is well known.[4] Let us also admit for the moment the correctness of the quantum theory to the extent of equating the above energy, $m_0c_1^2$ to the quantity, $h\nu_a$ in order to compute the frequency, ν_a, of the two equal annihilation radiation photons emitted in the annihilation process. Further let us admit that the relationship between the wavelength, λ_a, of the annihilation radiation and the frequency, ν_a, of that same radiation is $c_2 = \lambda_a\nu_a$ where c_2 is the velocity of propagation of the annihilation radiation whose frequency is certainly of order 5×10^4 times greater than that of visible light and easily 5×10^9 times greater than that of the longest radiowaves. One readily concludes from these three relationships that

$$\lambda_a = (h/m_0c_1)(c_2/c_1). \tag{1}$$

Now the 1951 measurements of Muller, Hoyt, Klein, and DuMond yielded a value for $\lambda_a = h/m_0c_1$ to within the precision of the measurements (± 13.6 parts in 10^5) in excellent agreement with the 1955 least-squares adjusted best values of h, m_0, and c_1, values obtained from a highly overdetermined set of precise input data[5] based on measurements chiefly made at ordinary optical quantum energies and *completely independent of the measurement of the annihilation radiation* which was not used in the 1955 adjustment.

One is therefore forced to the conclusion that either $c_2/c_1 = 1$ to within ± 13.6 parts in 10^5, where c_2 and c_1 are velocities of propagation of electromagnetic radiation differing in frequency or quantum energy by a factor as much as 5×10^9, or else that we must discard one or both of the two relations, $m_0c_1^2 = h\nu_a = hc_2/\lambda_a$, and along with them a great deal of modern physics. The annihilation radiation wavelength measurement has been discussed in a text published three years ago.[6]

* Work performed under the auspices of the U.S. Atomic Energy Commission.

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[2] Bergstrand, Erik, *Ann. franç. Chronom*, **11**, 97 (1957).

[3] Froome, K. D., *Proc. Roy. Soc.*, **A247**, 109 (1958).

[4] Everling, F., L. A. König, and J. H. E. Mattauch, *Nuclear Phys.*, **15**, 342 (1960).

[5] Cohen, E. R., J. W. M. DuMond, T. W. Layton, and J. S. Rollett, *Rev. Mod. Phys.*, **27**, 363 (1955), or in more detail see J. W. M. DuMond, *I.R.E. Trans. on Instrumentation*, **1-7**, Nos. 3 and 4 (Dec., 1958).

[6] Cohen, E. R., K. M. Crowe, and J. W. M. DuMond, *Fundamental Constants of Physics* (New York: Interscience Publishers, 1957), p. 157.