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A Paradox in the Interaction of the Gravitational and Electromagnetic Fields ?

RECENTLY Woodward and Yourgrau[1] put forward the hypothesis that the influence of gravitation on the propagation of electromagnetic waves depends on the frequency of the radiation. Their starting point is that the light deflexion by the Sun's gravitational field, as found from optical determinations at solar eclipses, appears somewhat larger[2,3] than the value predicted by Einstein's theory of gravitation. Lately Muhleman *et al.*[4] and Seielstad *et al.*[5] succeeded in measuring the light deflexion by the Sun at 2.388 GHz and 9.602 GHz. Their results ($1.82'' \pm 0.2''$ and $1.77'' \pm 0.2''$) are in close agreement with the predictions of general relativity. The uncertainty introduced by our limited knowledge of the coronal plasma amounts to about 10 per cent of the relativistic light deflexion[4], which, being sufficient to prevent a decision between Einstein's theory and the Brans-Dicke theory, is not enough to make these measurements compatible with the predictions of Woodward and Yourgrau. Their hypothesis (according to formula (2), or (1) and (3))[1] gives at 2.388 GHz and 9.602 GHz the tremendous values of 15′ 39″ and 7′ 45″ respectively for the light deflexion (that is, more than 500 times and 200 times the experimental results).

This is not astonishing, as Woodward and Yourgrau[1] derived the coefficients determining the wavelength dependence of the light deflexion chiefly from the experiments of Sadeh *et al.*[6,7]. Sadeh *et al.*[6] found a frequency shift of the 21 cm line in Tau A near an occultation by the Sun, which was orders of magnitude higher than the general relativistic value. Yet such an anomalous frequency shift (or time delay) was not confirmed, either by the radar measurements of Shapiro and co-workers[8,9] or by the recent Mariner VI and VII results[10], all of which yielded the general relativistic values with an uncertainty of about 10 per cent[8,9] or better[10]. Thus the suspicion arises that there was an unknown source of error in the experiment of Sadeh *et al.*[6]. The clock experiment of Sadeh and coworkers[7] has not yet been repeated (to my knowledge) and one should await further measurements before drawing far reaching conclusions.

It seems that the recent experiments[4,5,8–10] preclude the possibility of a frequency dependence of the interaction of gravitational and electromagnetic fields, at least at the strength assumed by Woodward and Yourgrau. To cite the authors[1] (and replacing an "if" by an "as"): As the "observed deflexion corresponds to that predicted by the general theory . . . the assumption of frequency dependence is unnecessary and unjustified".

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Drs Woodward and Yourgrau write :

DR REINHARDT is correct in saying that the time delay and quasar deflexion results flatly contradict the frequency dependence hypothesis presented in our first paper[1]. We do not take exception to the reported results that Dr Reinhardt quotes. We only note below some interesting features of those results. We would like to mention that it is possible, following a suggestion of Treder[2], to formulate a plausible theory of the electromagnetic–gravitational field interaction that easily explains all of the empirical data, including internal anomalies in the observations that indicate frequency dependence. A paper describing this theory is now in preparation.

Though there is a difference by a factor of three in the density of the r^{-6} component of the plasma density if one demands the same deflexion for both Seielstad's and Muhleman's observations[3,4], we do not feel that the reported results of the quasar deflexion experiments are significantly in error.

In the results of the interplanetary time delay experiments, we accept the general validity of the stated conclusions, but we should like to point out two anomalies that would be expected if some frequency dependence, albeit far smaller than would be expected on the basis of our first paper[1], were operative. Orbits determined using radar data are somewhat spurious, and prediction and observation at later epochs disagree. According to Ash *et al.*[5], ". . . the predictions based on our fitted orbits were compared with Earth–Venus and Earth–Mercury time delay measurements obtained from about one month to six weeks after the last datum included in the analysis. The differences (O–C) ranged from 50 to 80 μs. No completely satisfactory explanation has been found for these discrepancies; less than one quarter can be accounted for solely by errors in the parameter estimates of magnitudes comparable to the standard errors of those estimates". A plasma hypothesis, tentatively advanced by the authors as an explanation, was conclusively ruled out by Smith *et al.*[6].

Another anomaly is that simultaneous ranging at different frequencies, at least in some circumstances, gives different time delays. In fact, ". . . a programme undertaken in the spring and summer of 1967 to make simultaneous interplanetary time delay measurements at Cornell's Arecibo Ionospheric Observatory ($\lambda = 70$ cm) and Haystack disclosed slowly varying, systematic differences in the delays—about 20 μs on average. These differences disappeared at the close approaches between the Earth and the target planet but increased gradually as the interplanetary distance increased. No satisfactory explanation for these discrepancies has yet been found; neither plausible errors in timing nor effects of interplanetary plasma can account for them[7]". Even if the above cited anomalies are totally physically insignificant, it is still possible within the formalism of the theory now in preparation to account for null results at the frequencies used in the time delay and quasar