CONCERNING THE EFFECTIVE GENERATION AND OBSERVATION OF GRAVITATIONAL WAVES

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Submitted 22 February 1967
ZhETF Pis'ma 5, No. 9, 348-350 (1 May 1967)

The question of effective generation of gravitational waves by an electromagnetic field was recently revived [1]. The source of the gravitational waves in [1] is an energy-momentum tensor, which is quadratic in the electromagnetic field. Mathematically this problem is equivalent to the transformation of light in a quadratically nonlinear medium, and all the deductions of nonlinear optics are applicable to it [2,3]. For an effective transformation it is necessary to satisfy the synchronism conditions and the polarization relations in the entire interaction space. These conditions are not satisfied in [1], and therefore the obtained transformation coefficient η_w is smaller by many orders of magnitude than the synchronism coefficient η_0.

The synchronism condition is satisfied when an electromagnetic wave moves in a constant magnetic field H_0 (wave resonance [4]). For the transformation coefficient we have, apart from a factor on the order of unity,

$$\eta_w \sim \frac{\gamma}{c^5}\frac{H_\sim^2 V}{T_w}, \ [1] \qquad (1)$$

$$\eta_0 \approx \frac{\gamma}{c^4} H_0^2 L^2 = \frac{\gamma H_0^2 T_0^2}{c^2}; \ T_0 = \frac{L}{c}, [4] \qquad (2)$$

where γ is the gravitational constant, $H_\sim$ the field of the electromagnetic wave, V the volume occupied by the wave, T_w the duration of the wave pulse, and T_0 the interaction time.

The ratio η_w/η_0 is equal to

$$\frac{\eta_w}{\eta_0} = \left(\frac{H_\sim}{H_0}\right)^2 \cdot \frac{c^3 T_0^2 T_w}{V}. \qquad (3)$$

The first factor in (3) is equal to the ratio of the alternating and constant fields and the second is connected with the deviation from synchronism [4]. We note that both the second and the first terms are small. For example, when $H_0 = 10^4$ Oe (permanent magnet) the ratio $H_\sim/H_0$ is ≈ 1 at an electromagnetic-wave power $\sim 7 \times 10^{10}$ W/cm^2, which can be attained only in the focus of a powerful laser.

Under laboratory conditions we can expect for a giant laser pulse ($\epsilon = 10^8$ erg, $T_w = 10^{-9}$ sec) an approximate value $\eta_w = 10^{-43}$, and if wave resonance obtains and $H_0 = 10^5$ Oe and $L = 10^3$ cm, then $\eta_0 = 10^{-33}$. For a pulsed magnetic field $H_0 = 3 \times 10^7$ Oe [5] and $L = 10^3$ cm we have $\eta_0 = 10^{-28}$. In spite of the fact that the foregoing estimates of η_0 are much lower than the estimates given in [1] for η_w, the generation of gravitational waves by such methods offers little promise under laboratory conditions. For propagation of light in interstellar fields, $\eta_0 = 10^{-17}$ [4]. For diffusion of radiation inside stars we can use (2), assuming L to be of the order of the radius of a star, which can yield $\eta_0 \sim 10^{-18} - 10^{-25}$, depending on the magnitude of the magnetic field. In collapsing stars, the magnetic fields can be quite large [6] and η_0 can exceed 10^{-18}.

Let us consider another section of the spectrum - low frequencies, to which the results of [1] are not applicable at all. The gravitational radiation of moving bodies (for example, double stars) can be appreciable in the energy balance [7,8] and may even change qualitatively the character of the motion.

Radiation of low-frequency gravitational waves (say from nearby double stars) can be detected from the relative change in the velocity of free nonrelativistic bodies [8,9] by using radio (or optical) interferometers. The amplitude of the periodic component of the relative velocity Δv of two free bodies,* is equal to [7]

$$\Delta v = l\sqrt{\frac{8\pi\gamma t}{c^3}}, \qquad (4)$$

where l is the average distance between the bodies and t the energy flux density of the wave. For two heliocentric stations located at a distance of 100 million kilometers, the gravitational radiation of the star i-Bootes ($t \approx 10^{-10}$ erg/sec-cm^2) produces in accord with (4) a periodic variation of the relative velocity with amplitude $\Delta v = 2.5 \times 10^{-11}$ cm/sec. It is easy to measure such relative velocities with two closely placed bodies under laboratory conditions. A much more complicated problem is the measurement of the periodic components of the relative velocities with a metrological accuracy on the order of 0.1 cm/sec (see, for example, the data on "Mariner-IV" [10,11]).

Since the accuracy with which a narrow-band signal can be measured (such as the gravitational radiation of double stars) usually has an amplitude 6 - 7 orders of magnitude larger than the absolute accuracy of absolute (metrological) measurements of the same quantity, we would be able to measure even now, at the already attained resolution, gravitational-radiation fluxes at the level $10^{-2} - 10^{-4}$ erg/sec-cm^2. There are apparently no grounds for believing that the limit of relative-measurement accuracy has been reached.

In conclusion it should be noted that the pessimistic estimate of the problem of experimentally observing gravitational radiation, expressed by P. J. Westervelt [1], is not sufficiently well founded. It is of undisputed interest to obtain a preliminary theoretical estimate of the astrophysical information that can be obtained by observing low-frequency gravitational radiation.

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*Two heliocentric satellites can be regarded as free if the gravitational-radiation frequency is much higher than the orbital revolution frequency.

ERRATA

In the article by S. A. Al'tshuler and M. A. Teplov, Vol. 5, No. 7, p. 168, the caption of Fig. 1 belongs to Fig. 2.