

High frequency gravitational waves generation by optical methods

V Pustovoit, V Gladyshev, V Kauts, A Morozov, V Gorelik, I Fomin, D Portnov, E Sharandin and A Kayutenko

Bauman Moscow State Technical University, Moscow, Russia

E-mail: vgladyshev@mail.ru

Abstract. In this paper, various types of sources of gravitational waves are considered. The use of the effect of mutual conversion of electromagnetic and gravitational waves in a nonlinear optical dielectric medium is proposed as a promising method for creating a source of gravitational-wave radiation.

1. Introduction

Gravitational waves are the subject of numerous theoretical studies carried out since the beginning of the twentieth century, and attract attention as a new means of transmitting information and energy over long distances at the speed of light. According to the modern theory, distribution of gravitational waves in space is associated with a change in the space-time metric, i.e. components of the metric tensor, and is caused by oscillations of the quadrupole moment of the mass of physical objects [1].

Another source of gravitational waves, according to the theory of cosmological inflation, are quantum fluctuations of the scalar field at an early stage of the evolution of the Universe [2-4]. Indirect estimation of the effect of relic gravitational waves on the anisotropy and polarization of relic radiation is the basis for experimental verification of theoretical models of the early Universe [5]. It should be noted that relic gravitational waves themselves were not detected and, at present, various methods for their possible detection are proposed [6-10].

Moreover, radiation of gravitational waves can be carried out in astrophysical objects during various dynamic processes, and in this case it is characterized by the frequency which depends on the size of the radiating medium. In 2016, by the method proposed previously in [12] (see also review [13]), the first experiments [11] were carried out to detect gravitational waves from a distant space object whose frequency of gravitational oscillations was in the range of 10-100 Hz.

It should be noted that long ago there was developed a theory [14,15] which predicted the possibility of generating gravitational radiation as a result of the conversion of electromagnetic radiation into gravitational radiation in the presence of a strong magnetic field. In this case, the amplitude of the gravitational wave linearly depends on the square of the static magnetic field value and on the length of the wave interaction path, provided that the so-called synchronism conditions, i.e. the law of conservation of momentum during photon-graviton conversion, are satisfied.



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](#). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

2. Generation of gravitational waves

In addition to gravitational wave radiation from natural sources, the possibilities of their generation and detection in the laboratory are also considered.

Artificial sources imply gravitational radiation of small amplitude and power, and, therefore, weak gravitational waves are considered as small perturbations of Minkovsky space-time $g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$ based on Einstein's linearized theory of gravity.

Gravitational-wave solution of Einstein equations in a linearized approximation [1]:

$$\square \bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu}, \quad (1)$$

where

$$\partial^\mu \bar{h}_{\mu\nu} = 0, \quad \bar{h}_{\mu\nu} = h_{\mu\nu} - \frac{1}{2} \eta_{\mu\nu} h, \quad (2)$$

can be written as follows

$$h_{ij} = \frac{4G}{rc^5} \Lambda_{ij,kl} (\hat{n}) \int_{-\infty}^{\infty} \frac{d\omega}{2\pi} T_{kl} \left(\omega, \frac{\omega \hat{n}}{c} \right) e^{-(i\omega t - r/c)}, \quad (3)$$

where T_{kl} is the energy-momentum tensor of matter, ω is the frequency of gravitational waves, tensor $\Lambda_{ij,kl}$ is determined as follows,

$$\Lambda_{ij,kl} (\hat{n}) = P_{ik} P_{jl} - \frac{1}{2} P_{ij} P_{kl}, \quad P_{ij} (\hat{n}) = \delta_{ij} - n_i n_j,$$

vector n_i determines the direction of propagation of the gravitational wave.

Research literature considers various sources of gravitational waves, which are determined by a different type of the energy-momentum tensor. One such source is crystals excited by an external electric alternating field.

For example, in [16], the component of the energy-momentum tensor of lattice vibrations in the selected direction under the action of the alternating electric field was determined as:

$$T_{11} = d_{131} E_3 \frac{\sin \left(\frac{\omega L - x}{v_s} \right) + \sin \frac{\omega x}{v_s} - \sin \frac{\omega L}{v_s}}{\sin (\omega L/v_s)} \sin (\omega t), \quad (4)$$

where d_{ijk} is the tensor connecting the crystal tension with the electric field, L is the crystal length, v_s is the sound speed provided $L\omega/v_s = \pi/2$ gives the following power of gravitational radiation

$$\mathcal{L}_g \approx \frac{GP_{max}^2 \lambda^4 \pi^2}{120c^3} \quad (5)$$

where P_{max} is the effective tensile force. The power of gravitational radiation of a crystal excited to the level which is extremely close to the point of destruction is estimated as $\mathcal{L}_g \sim 10^{-13}$ erg/sec [16].

The excitation of shock waves arising from the matter irradiation by short pulses of high-power laser radiation [17,18] is also considered among the sources of high-frequency gravitational waves. The power of gravitational radiation, in this case, is determined as follows

$$\mathcal{L}_g = 7 \times 10^{-18} \frac{W_L^2}{\rho_0} \quad (6)$$

where W_L is the laser power, ρ_0 is the medium density. The maximum power of gravitational waves obtained in these processes is estimated as $\mathcal{L}_g \sim 10^{-17} - 10^{-19}$ erg/sec [17,18].

Thus, the considered methods of generating gravitational waves lead to estimates implying the impossibility of their further detection due to the low power of gravitational-wave radiation.

As an alternative mechanism for generating gravitational waves, we consider the parametric processes of interaction between electromagnetic and gravitational waves. The result of this interaction is the conversion of an electromagnetic wave into a gravitational wave, which determines a fundamentally different approach to creating gravitational waves in laboratory conditions.

3. Parametric processes of mutual conversion of electromagnetic and gravitational waves in optical media

In [13,19], the theory of generation of gravitational waves was developed as a result of the so-called parametric processes of interaction between electromagnetic and gravitational waves. If a star has intense electromagnetic radiation at a frequency ω_0 , a gravitational wave with a frequency $2\omega_0$ is formed as a result of the parametric interaction process. Owing to the parametric interaction between a gravitational wave with a frequency $2\omega_0$ and the original electromagnetic wave with a frequency ω_0 , an electromagnetic wave with a frequency $3\omega_0$ should also be formed in the star. Thus, generation of a gravitational wave with a frequency $2\omega_0$ can be inferred by recording the third harmonic of the fundamental frequency in the spectrum of the star. Naturally, such parametric processes can occur only at a high intensity of the initial electromagnetic waves inside the star and a sufficiently large conversion length.

In [20], a method for generation and detection of high-frequency gravitational radiation based on the use of conversion of electromagnetic waves to gravitational waves in an external stationary magnetic field under laboratory conditions is proposed.

The conversion coefficient α of an electromagnetic wave into a gravitational one is determined as follows:

$$\alpha = \frac{GH_0^2 L^2}{c^4} \quad (7)$$

where G is the gravitation constant, H_0 is the static magnetic field strength, L is the conversion length, c is the speed of light. Since for small distances L the conversion coefficient $\alpha \ll 1$, this process with a large value of the coefficient α can be implemented as a result of a nonlinear optical process amplified in a condensed dielectric medium as a result of a large optical nonlinearity of the condensed dielectric and a sharp deceleration of the group speed of light during the interaction of intense laser radiation with matter.

It should be noted that it is possible to carry out laboratory experiments on generation of high-frequency gravitational waves using high-frequency pulsed laser radiation instead of a magnetic field.

4. Conclusion

In this paper, various methods for generating high-frequency gravitational waves in laboratory conditions are considered. The most promising approach is based on the mutual conversion of electromagnetic and gravitational waves in modern nonlinear optical dielectric media.

Acknowledgement

The research by Pustovoit V., Gladyshev V., Kauts V., Morozov A., Gorelik V., Fomin I., Portnov D. was supported by the Russian Science Foundation grant No. 19-12-00242.

References

- [1] Maggiore M 2007 *Gravitational waves* vol 1 (Oxford University Press)
- [2] Baumann D 2009 *Adv. Sci. Lett.* **2** 105
- [3] Mukhanov V F, Feldman H A and Brandenberger R H 1992 *Phys. Rept.* **215** 203

- [4] Fomin I V, Chervon S V and Morozov A N 2018 *Gravitational waves of the early universe* (Bauman Moscow State Technical University) in Russian
- [5] Fomin I V 2016 *Herald of the Bauman Moscow State Technical University, Series Natural Sciences* **4** 65
- [6] Esakov A A et al 2015 *Herald of the Bauman Moscow State Technical University, Series Natural Sciences* **1** 26
- [7] Fomin I V and Morozov A N 2017 *Journal of Physics: Conf. Series* **798** 1
- [8] Nishizawa A et al 2008 *Phys. Rev. D* **77** 022002
- [9] Armano M 2016 *Rev. Lett.* **116** 231101
- [10] Ade P A R et al [PLANCK Scientific Collab.] 2015 *Astron. Astrophys.* **594** A13
- [11] Abbot B P et al [LIGO Scientific Collab.] 2016 *Phys Rev. Lett.* **116** 061102
- [12] Gertsenstein M E and Pustovoit V I 1963 *Sov. Phys. JETP* **16** 433
- [13] Pustovoit V I 2016 *Physics-Uspekhi* **59** 1034
- [14] Zeldovich J B 1973 *Preprint of Applied Mathematics institute of Russian Academy of Sciences* **38** 11
- [15] Gertsenstein M E 1962 *Sov. Phys. JETP* **14** 84
- [16] Weber J 1960 *Phys. Rev.* **117** 306
- [17] Gelfer E, Kadlecová H, Klímo O, Weber S and Korn G 2016 *Phys. Plasmas* **23** 093107
- [18] Kadlecová H, Klímo O, Weber S and Korn G 2017 *Eur. Phys. J. D* **71** 89
- [19] Pustovoit V I and Chernozatonskii L A 1981 *JETP Letters* **34** 229
- [20] Gorelik V S et al 2018 *Journal of Physics: Conf. Series* **1051** 012001