A means of generating and detecting gravitation waves

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A method of generating gravitational waves under laboratory conditions is considered, and certain vacuum-polarization effects that accompany the interference of the waves in the wave zone are analyzed.

The existence of gravitation waves and the means of generating and detecting them are at present the subject of pure theory.[1] A detector of gravitation waves can be any inertial mass—a quantum oscillator, for example. A quantum oscillator in the state $|0\rangle$ is described by the mean-square momentum $\langle p_0^2\rangle = \int_{-\infty}^{+\infty} \psi^*\hat{p}^2\psi dx = \frac{1}{2}\hbar M\omega_0$, and the mean-square displacement $\langle q_0^2\rangle = \frac{1}{2}(\hbar/M\omega_0)$. The velocity characteristic of the displacement of the oscillator during a period is related to the frequency of the zero-point oscillations by the relation $\langle v_0^2\rangle = \langle p_0^2\rangle/M^2 = \langle q_0^2\rangle\omega_0^2 = \hbar\omega_0/2M$. If the zero-point energy is specified precisely, then the quantity $\langle v_0^2\rangle$ is completely determined.

The change in the energy of the oscillator, $\Delta E = E_2 - E_1$, as a result of its acceleration and the change of its momentum $\Delta\mathbf{p} = \mathbf{p}_2 - \mathbf{p}_1$, (the indices 1 and 2 denote the initial and final states, respectively, $p_1^2 = \langle p_0^2\rangle$; henceforth, we shall omit the symbols that denote the averaging of the dynamic variable p), is determined from the relativistic relation $E^2 = M^2c^4 + \mathbf{p}^2c^2$ in the form

$$\Delta E = \Delta\vec{p}\vec{v}_0, \tag{1}$$

where $v_0^2 = \langle v_0^2\rangle$, Δp is small, and $\Delta p^2 \ll \langle p_0^2\rangle$.

An integral characteristic of the inertial properties of a solid object is the bulk speed of sound $c_0^2 = (\partial P/\partial\rho)_s$, which describes, in addition to the speed of propagation of density perturbations, the setting into motion the centers of mass of the atomic nuclei in an extended body. Considering the solid as an ensemble of coherent quantum oscillators—atomic nuclei, we find that the zero-point energy density $P_0 = E_0/v_a = \frac{1}{2}\hbar\omega_0 1/W_a \equiv K$, where W_a is the volume of an atom, is also the quantity that determines the bulk modulus $K = \rho c_0^2$; i.e., for small perturbations, $\langle v_0^2\rangle \equiv c_0^2$.

The acceleration $\dot{v}_e$ of an electron with a wave vector $\mathbf{k}$, equal to $[(1/\hbar^2)(\partial^2\epsilon(\mathbf{k})/\partial\mathbf{k}\partial\mathbf{k})]^{-1}\dot{v}_e = \Delta\mathbf{p}/\Delta t$, is transferred to the Coulomb center. If $\Delta p \geqslant h/r_a$, where r_a is the radius of the atom, then the interaction between the wave functions of the valence electrons and of the nucleons will be inelastic. The scale of velocities that defines the region of the inelastic interaction can be determined by using the notion of the mean free path of a nucleon in a nucleus, $\bar{\lambda} = 1/n\sigma$, where n is the concentration of nucleons in the nucleus, σ is the cross section for the interaction; the result is $\bar{\lambda} = 0.3\times 10^{-15}$ m. Then the parameter $v^* = \bar{\lambda}/\Delta t_0$, where $(2\Delta t_0)^{-1} = 2Mv_0^2/h$, establishes that a displacement of the Coulomb center by

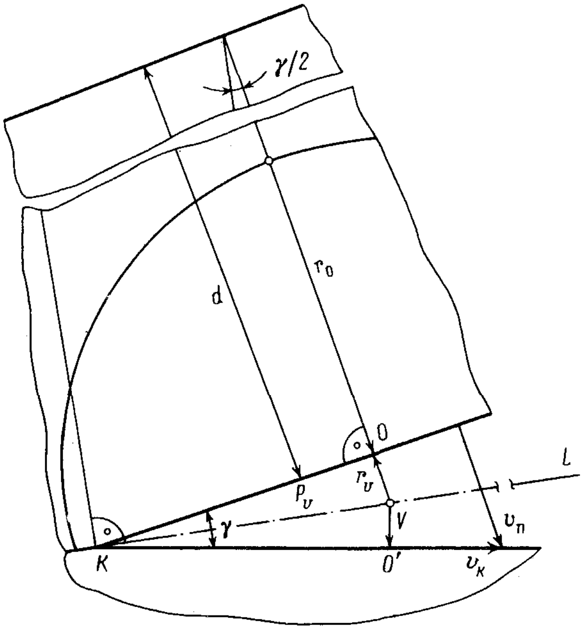

FIG. 1.

$r \gtrsim A\bar{\lambda}$, where A is the atomic weight, will induce an electric dipole moment in the nucleus. In the unperturbed state $|0\rangle$ the probability of inducing an electric dipole moment as a result of a shift of the Coulomb center relative to the center of mass is very small, $\omega \sim \exp[-v_0/(A-N_v)v^*]$, where N_v is the valence of the atom; for Fe^{56}, for example, the probability is $\omega \sim 7\times 10^{-11}$.

One of the simplest schemes for generating and detecting gravitation waves under laboratory conditions is the method of high-velocity oblique collisions. When a plate moving at a velocity v_n collides with a semiinfinite obstacle (Fig. 1), with the point of contact moving at subsonic velocities $v_c < c_0$, various effects are produced.[2] The momentum after contact at point K, acquired as a result of the deceleration, is distributed equally between the moving material of the plate and the stationary half-space. If the colliding objects are made of the same material, the quantity Δv_i, which characterizes the perturbation of the state of motion of the center of mass of the atomic nuclei of the surface layer, is given by $\Delta v_i = (1/2\sqrt{2})v_n$, where the factor 1/2 allows for the equality of the reactions of the elastic forces that arise in the interaction of the atoms with their neighbors by virtue of the binding energy and inertia. The phase velocity of gravitation waves carrying a momentum $\Delta p < 0$, which are generated in the deceleration of the mass (quantum oscillators) in the vicinity of point K, is equal to the velocity of light c. The deceleration of the center of mass of the atoms "organizes" the symmetry of the waves relative to the plane passing through the bisector of the angle γ. The value of $r_v = c\Delta t_v$, with $r_v < 0$ determines the time required for information on the state of motion of the center of mass of the nucleus of an atom at point O on the free surface to arrive at the symmetry plane. It arrives at the same time that information from point O', at the point of reflection symmetry, arrives at the same point on the symmetry plane ($v_p \ll c$). Oscillators located at points O and O' are thus quadrupole sources of gravitation waves. The direction of the vectors reflects the fact that the perturbations are confined to the Coulomb center; i.e., the perturbations that are produced in the deceleration are localized in the neighborhood of the point K. The value of r_v are expressed in units of d; $r_v = d \tan^2(\gamma/2)$. Emission of waves by the center of mass of the nuclei is related to the change in the density of the zero-point energy P_0. This change is due to the change in the atomic volume and the transmission of momentum Δp_i of the center of mass to the symmetry plane.

The characteristic dimension of the region of localization of the perturbation is determined by the formula for the variation of P_0 in the form $-dP/P = dr/r$, so that $P = P_v \exp(-r/r_v)$, where P_v is the density of zero-point energy of the perturbed state at the free boundary. We thus can write $r_0 = -r_v \ln(P_0/P_v)$, and $|2r_0| = 2\ln(P_0/P_v) d \tan^2(\gamma/2)$. For collisions under normal conditions, the value of P_v cannot be less than $\rho_a c_a$, where ρ_a is the density of air. The formula for $|2r_0|$ for small values of γ is identical to the empirical formula for the wavelength $\lambda \approx 26 d \sin^2\gamma/2$ (Ref 2).

The interference of the waves emitted from O and O' causes polarization of the vacuum at points on the symmetry plane and leads to non-cancelling forces and fields (as though a source which attracts the intertial mass existed at point V). The stretching of vacuum at point V is characterized by the quantity $\Delta p_i r_v \sin\gamma/2$, with $\Delta \mathbf{p}_i = M\Delta v_i$, which describes the transverse component of the polarization vector (Fig. 1). This component can interact with matter (the field) in the symmetry plane. The existence of the polarized state is periodic in this scheme, with a period $\tau \approx [d \tan^2(\gamma/2)/v_n]$. If $R_L < c\tau$, then we can observe an amount $\Delta p_L = \Delta p_i (r_v/R_L) \sin\gamma/2$ of momentum at point L. For $R < R_L$ the wave is damped exponentially as $\exp(-R/R_L)$.

We can detect the pressure of the gravitation radiation by placing a planar obstacle at point L. The normal component of the pressure $\Delta E_L/v_a$ is calculated by relation (1), and this pressure is negative, since $\Delta \mathbf{p} < 0$. The action of this pressure on the surface, if $\Delta E_L \pi \xi_e^2/a^2 \gtrsim \Delta \overline{V}_0/n$, where the coherence length is $\xi_e = \pi\hbar v_F/2\Delta E_L$, is determined by the amplitude of the perturbation, the parameters of the Fermi surface, the lattice parameter a, the binding energy per atom $\Delta\overline{V}_0$, and by n, where n is the number of nearest neighbors for each type of lattice, and it causes the atoms to "float" up from the interior to the surface, thus forming a new surface. An analogous process occurs at the free boundaries at $|2r_0|$, but in this case the increase of the surface area during the time τ as a result of the floating up of atoms will occur as a result of the longitudinal component $\Delta \mathbf{p}_i$ of the stretching, and can amount to several hundred percent.

We note that for axisymmetric implosion, with the collision and deceleration involving matter in an excited state (and not in the state $|0\rangle$), the main contribution to the action on the obstacle in the wave zone $R < R_L$ comes from the longitudinal component of the polarization, since the resultant vector $\Delta \mathbf{p}_i$ is oriented at an angle close to π to the symmetry plane.

[1] *Experimental Tests of the Theory of Gravitation* [in Russian], Collection of Papers, State University, Moscow (1989).
[2] A. A. Deribas, *Physics of Strengthening and Welding by Explosion* [in Russian], Nauka, Novosibirsk (1980).

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