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EFFECT OF RESONANCE CAPTURE OF SPIN PARTICLES

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Great attention has recently been paid to the problems of motion of spin particles in electromagnetic fields [1-4]. The solution thereto is based on a simultaneous consideration of the spin equation

$$\frac{dS}{dt} = \frac{\mu}{\hbar}[S \times H] \tag{1}$$

and the equation of force acting upon a particle with the intrinsic magnetic moment $\mu = \mu S$

$$F = \mu\nabla(S \cdot H) + F_0 \tag{2}$$

wherein the first term in this form is due to the potential energy $U = -(\mu \cdot H)$, and F_0 is determined by other terms [1, 2].

The presence of magnetic moments significantly affects the motion of particles [1-4]. In particular, Kozorez [3] revealed that the registration of magnetic moments above the dipole one leads to the stability of the orbital motion of one particle around the other (Fig. 1).

The previously observed stable orbital motion of a spherical-shaped sample of an yttrium-iron garnet single-crystal (YIG) under conditions of the ferromagnetic resonance [5, 6] is the particular case of the problems considered, since at the first approximation, the YIG sphere may be considered as a point magnetic dipole. This suggests the possibility of the stable motion of dipole particles in resonant inhomogeneous electromagnetic fields due to the colossal magnitude of the ponderomotive effect in the resonance region [5, 7-9]. Let us evaluate the possibility of this motion.

It is very difficult to find the rigorous solution for the problem of motion of the anisotropic YIG sample under resonance conditions taking into account the inhomogeneities of the magnetic fields. The complexity is due to both the nonlinearity of the equations of magnetization motion and the nonlinearity of the partial differential equations of motion of the sample itself. Therefore, we confine ourselves to the dipole approximation. This approximation is valid for the sample parameters, which are much smaller than the wave length and the radius of its circular orbit, which was done in our case ($d\lambda^{-1}$, $dr_0^{-1} \sim 10^{-2}$ [5, 6]).

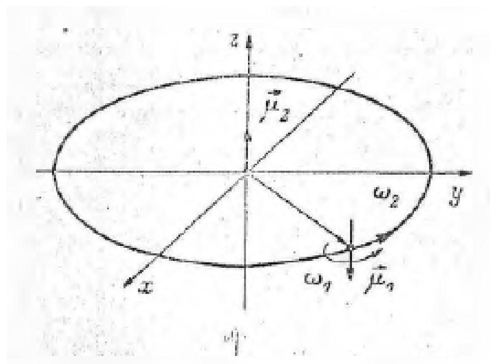
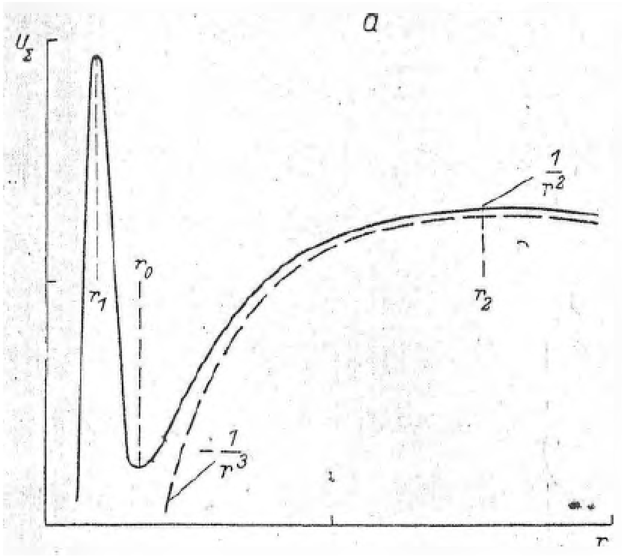


Fig. 1. Stability in the system of two magnets according to Kozorez [3].

We place the dipole having the magnetic moment $\mu_1 \simeq M_1 V$ in the inhomogeneous electromagnetic field with $H \simeq (H_1 \cos\ \omega t, H_1 \sin\ \omega t, H_o(r))$, wherein $r = (x^2 + y^2)^{½}$ and H – is the field at the location of the YIG sample [6] between the pole pieces of the magnet. Using expressions (1), (2) and supplementing them with the dissipative term from the modified Bloch equation for ferromagnets [10], we obtain

$$\frac{d\mu_1}{dt} \simeq \gamma\,[\mu_1 \times H] - \ \omega_r(\mu_1 - \mu_{10}), \tag{3}$$

$$F \simeq \nabla(\mu_1 \cdot H) \tag{4}$$



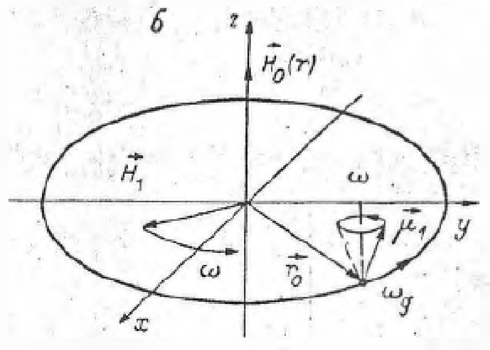


Fig. 2. The average effective energy of the macroscopic spin particle located in the inhomogeneous magnetic field ($\sim\mu_2 r^{-3} i_2$) and in the HF resonant field (the frequency ω = $|\gamma|\ \mu_2 r_1{}^{-3}$) with regard for the dissipation (*a*) and its possible stable motion at the point r_0 during the resonance capture (*b*).

We shall consider the nonrelativistic approximation $\upsilon \ll$ c and $\omega_g \ll \omega_r \ll \omega$, wherein ω_g is the frequency of the orbital motion of the dipole. In this case, we can use the method of separation of variables (fast ω and slow $\omega_{g,\,r}$). Taking the slow variables *x, y* for "frozen", from the equation (3) and its solutions [10, 11] for the mean value (4), we obtain ($H_0 \gg H_1$)

$$\langle F\rangle\,|_{\,t=2\pi\omega^{-1}} \simeq F_1 \ = \nabla(\mu_{1z}H_0). \tag{5}$$

This problem was actually limited to the problem of motion of a point particle in the field of potential energy

$$U_{и} = -\mu_{1z}H_0 = -\mu_{10}H_0\left(1 - \frac{\gamma^2 H_1^2}{\Delta\omega^2 + \omega_r^2 + \gamma^2 H_1^2}\right), \tag{6}$$

wherein $\Delta\omega = \ \omega - \ |\gamma|\ H_0$.

Specifying the inhomogeneity of the field by the dipole field $H_0 \sim \mu_{20} r^{-3}$ for $U_{и}$ we have

$$U_{и} = -\frac{\mu_{10}\mu_{20}}{r^3}\left(1 - \frac{\gamma^2 H_1^2}{(\Delta\omega^2(\mathrm{r}))^2 + \omega_r^2 + \gamma^2 H_1^2}\right). \tag{7}$$

The possibility of emergence of stable states of motion (Fig. 2, *b*), which were noticed previously during the FMR [5, 6], results from the relation $U_\Sigma\,(r) = \ U_{и} + U_{ц}$ (Fig. 2, *a*), with $r_1 < r \lesssim r_2$, wherein $U_{ц}$ is the centrifugal contribution, and r_1 satisfies the equation ω = $|\,\gamma|\ \mu_{20} r_1{}^{-3}$.

Thus, an unstable system with the potential energy of the $\sim r^{-3}$ type can be stabilized by the magnetic resonance interaction. This situation is a particular case for the problems of instability stabilization by means of dissipative and noconservative forces [12]. In principle, it is possible to capture into the resonant state and at multiple frequencies – harmonics 2ω, 3ω, etc., if we take into account the nonlinear terms of interactions in the equations (3), (4). This will lead to obtaining the discrete orbits with respect to r.

The similar resonant capture is apparently possible also for other particles having dipole moments and spins, for example, electric dipoles, nuclear pseudomagnetic dipoles, because the equations of motion [13, 14] in the classical treatment will be similar to the equations (3), (4).

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