[3] K. Brecher and Ph. Morrison, Phys. Rev. Lett. 23, 802 (1969).
[4] O.F. Prilutskii and I.L. Rozental', Preprint 22, Institute of Space Research, USSR Academy of Sciences, 1970.
[5] K.C. Anand, R.R. Daniel, and S.A. Stephens, Phys. Rev. Lett. 20, 764 (1968).
[6] I.A.M. Bleeker, I.I. Burger, A.I.M. Deerenberg, A. Scheepmaker, B.N. Swanenburg, and Y. Tanaka, Can. J. Phys. 46, S522 (1968).
[7] A.Z. Dolginov and I.N. Toptygin, Proceedings, Fifth Conference of Winter School on Cosmophysics, Apatity, 1968; Icarus 8, 54 (1968).
[8] E.J. Low, D.E. Kleimann, F.F. Forbes, and H.H. Aumann, Astrophys. J. 157, L97 (1969).
[9] E.E. Becklin, J.A. Frogel, A.R. Hyland, J. Kristian, and G. Neugebauer, Astrophys. J. 158, L133 (1969).

METASTABLE "OVERTURNED" STATE OF FERROMAGNET AS A SOURCE OF AMPLIFICATION OF ELECTROMAGNETIC OR ACOUSTIC WAVES

A.M. Kosevich
Khar'kov State University
Submitted 21 April 1970
ZhETF Pis. Red. 11, No. 11, 537 - 540 (5 June 1970)

It is known [1] that a uniaxial ferromagnet in a magnetic field parallel to the easy magnetization axis has two equilibrium states if $H < \beta M_0$, where H is the intensity of the magnetic field in the magnet, M_0 is the value of the spontaneous magnetic moment, and β is the anisotropy constant ($\beta > 0$). In one of these states (thermodynamically stable), the vector of the magnetic moment $\vec{M}$ is directed along the field $\vec{H}$, and in the other (thermodynamically metastable) it is directed against the field $\vec{H}$. If $H > \beta M_0$, then only one stable direction of $\vec{M}$ along the field $\vec{H}$ remains.

We wish to call attention to the fact that a metastable "overturned" state of a ferromagnet (a ferrodielectric) can be readily used for amplification (to a considerable degree, coherent) of electromagnetic waves or acoustic oscillations. Two methods of such a utilization of the "overturned" state can be indicated.

1. Let the z axis be the easy magnetization axis, and let the magnetic moment of the crystal $\vec{M}$ be parallel to this axis: $\vec{M} = -M_0\vec{n}$ ($M_0 > 0$), where $\vec{n}$ is the unit vector along the z axis. We assume that the external constant magnetic field is directed opposite to $\vec{M}$ ($\vec{H} = H_0\vec{n}$, $H_0 > 0$) and is such that $H_0 - \beta M_0 = H_1 < 0$ and $|H_1| \ll H_0 \simeq \beta M_0$. In the region of low temperatures, the stability of the "overturned" state relative to thermal fluctuations will be conserved also at very small H_1.

We now turn on a weak magnetic field $\vec{h}$, parallel to the z axis and increasing slowly with time. Assume that at the instant of time when the condition $H_1 + h(t) = 0$ is satisfied, the "overturned" state becomes unstable and the ferromagnet goes over, after a suitable relaxation time τ, into a stable equilibrium state with a vector $\vec{M}$ directed along $\vec{H}$. If $g\beta M_0\tau \gg 1$, where g is the gyromagnetic ratio, then the magnetic moment $\vec{M}$ will precess during the course of such a transition about the direction $\vec{n}$ with increasing frequency, approaching the resonant frequency $\omega_0 = g(H + \beta M_0) = 2g\beta M_0$. It is clear that this will be accompanied by electromagnetic radiation and amplification of the high-frequency electromagnetic wave with the required circular polarization and the frequency $\omega \leq \omega_0$, satisfying the condition $\omega\tau \gg 1$, is possible. The spectral characteristics of the radiation or of the amplification can be analyzed in analogy with the description given in [2]. The maximum amplification should occur when $\omega = \omega_0$. We note that the resonant frequency ω_0 can be varied by changing the inclination of the magnetic field $\vec{H}$ to the easy-magnetization axis.

Owing to the magnetoacoustic coupling under resonant conditions, application of acoustic waves is also possible.

We call attention to the fact that in the scheme proposed by us there is no need for the "instantaneous" and very difficultly realizable switching off of a magnetic field of large intensity, proposed in [2] (the same difficulty arose in the discussion of the realization of the "kogetron" scheme proposed in [3]).

2. Let us assume now that $H_1 > 0$ and $H_1 << H_0$ as before. Then the "overturned" state in a constant magnetic field will be unstable. It can be stabilized, however, by a high-frequency circularly polarized electromagnetic wave traveling along the z axis. Indeed, we write the magnetic field and the magnetic moment in the form

$$\mathbf{H} = H_0 \mathbf{n} + \mathbf{h}, \quad \mathbf{M} = -M_0 \mathbf{n} + m + \xi,$$

where $\vec{h}$ is the high-frequency field of the wave

$$h_x = h_1 \cos \omega t, \quad h_y = h_2 \sin \omega t, \quad |h_1| = |h_2| = h_0 \tag{1}$$

$\vec{m}$ is the small addition to the magnetic moment, describing its precession around the direction of $\vec{n}$ with frequency on the order of gH_1, and ξ is a rapidly oscillating component of the magnetic moment (with frequency $\omega >> gH_1$).

Writing down the Landau and Lifshitz equations for the motion of the magnetic moment and suing the method of analyzing oscillations in a rapidly oscillating field, well known from mechanics [4, 5], we obtain the following equation for the "slowly" varying quantity $\vec{m}$:

$$\dot{m}_x + \Omega m_y = 0, \quad \dot{m}_y - \Omega m_x = 0, \quad \dot{m}_z = 0, \tag{2}$$

$$\Omega = gH_1 - (g^2/2\omega)[h_1 h_2 - (g\beta M_0/\omega) h_0^2]. \tag{3}$$

The total energy of the ferromagnet at small deviations from the "overturned" state is

$$W = W_0 - \frac{1}{2} M_0 \Omega (\theta - \pi)^2, \quad W_0 = \text{const},$$

where θ is the angle of inclination of the vector $\vec{M}$ to the direction $\vec{n}$.

We see that stable oscillations (2) correspond to $\Omega < 0$. It follows from (3) that this is possible if, first, the wave (5) is right-hand polarized: $h_1 h_2 = h_0^2$, and second if $\omega > g\beta M_0 \simeq gH_0$. Since the field intensities in the electromagnetic wave are usually small, the most favorable is the choice of the frequency from the conditions

$$\omega > g\beta M_0, \quad 1 - (g\beta M_0/\omega) = 2\gamma \sim 1,$$

at which the following limitations are obtained on ω:

$$g\beta M_0 < \omega < \gamma g h_0 (h_0/H_1). \tag{4}$$

It follows from (4) that the limitations on ω and h_0 become less stringent with decreasing βM_0. If it is assumed that $\beta M_0 \sim 100$ G and $H_1 \sim 1$ Oe, then it is necessary to have in the wave $h_0 \sim 10$ Oe and $\omega \sim 10^9$ sec^{-1}.

If the amplitude of the electromagnetic wave decreases slowly with time, then the reorientation of the vector $\vec{M}$, described in Sec. 1, occurs at the instant of time at which $\Omega = 0$, and the amplification process becomes possible.

It would be most interesting to realize a condition $\omega = 2gH_0 + gH_1 = 2g\beta M_0 + gH_1$, at which the frequency of the wave that stabilizes the "overturned" state is resonant for ordinary orientation of the vector $\vec{M}$ along the field $\vec{H}$. In this case, while the amplitude of the wave h_0 decreases at the "input", it increases at a certain instant of time very sharply "at the output."

It am grateful to V.M. Tsukernik for constant interest in the work, and also to I.M. Lifshitz and M.I. Kaganov for useful discussions.

[1] L.D. Landau and E.M. Lifshitz, Elektrodinamika spolshnykh sred (Electrodynamics of Continuous Media), Gostekhizdat, 1957, Sec. 37. [Addison-Wesley, 1959].
[2] V.G. Bar'yakhtar and A.G. Kvirikadze, Fiz. Tverd. Tela 9, 3264 (1967) [Sov. Phys.-Solid State 9, 2569 (1968)].
[3] V.M. Fain, Izv. vuzov. Radiofizika 1, 75 (1958).
[4] L.D. Landau and E.M. Lifshitz, Mekhanika (Mechanics), Gostekhizdat, 1958, Sec. 30 [Addison-Wesley, 1960].
[5] A.I. Akhiezer and S.V. Peletminskii, Fiz. Tverd. Tela 10, 3301 (1968) [Sov. Phys.-Solid State 10, 2609 (1969)].

SECOND-ORDER PHASE TRANSITIONS WITHOUT DIVERGENCES IN THE SECOND DERIVATIVES OF THE THERMODYNAMIC POTENTIAL

A.P. Levanyuk and A.A. Sobyanin
Institute of High Pressure Physics, USSR Academy of Sciences
Submitted 21 April 1970
ZhETF Pis. Red. 11, No. 11, 540 - 543 (5 June 1970)

It is known that the Landau theory of second-order phase transitions does not hold in the immediate vicinity of the transition point, owing to the strong increase of the long-wave fluctuations of the characteristic parameters of the transition [1, 2]. On the other hand, if the fluctuations are accompanied by the appearance of long-range fields (electric, magnetic, elastic), then their character changes significantly [3]. As a result, not all fluctuation waves increase in sufficiently anisotropic crystals near the transition point, but only waves with definite wave-vector directions. This leads to a strong decrease of the phase volume connected with the large fluctuations. An example of this type are uniaxial ferroelectrics [4, 6], in which, owing to the occurrence of the electric field, only fluctuations with wave vectors lying in the plane perpendicular to the ferroelectric axis increase. Therefore, for example, the specific heat increases on approaching the transition point in accordance with a law that differs from that in the isotropic substance.

In this article we consider another example, when the fluctuations of the characteristic parameters are even more suppressed. It turns out that if the transition parameter η and the elastic deformation u_{ik} are linearly connected in the symmetrical phase, then only fluctuations of the wave vectors parallel to definite crystallographic axes increase, i.e., the phase volume corresponding to large fluctuations decreases even more strongly than in the preceeding case. Consequently, at $T \to T_c$ (T_c is the transition temperature) the specific heat remains finite, and the thermodynamic potential can be expanded in a