Microwave modulation of light by antiferromagnetic resonance in $CoCO_3$

A. S. Borovik-Romanov, V. G. Zhotikov, N. M. Kreines, and A. A. Pankov

Institute of Physics Problems, USSR Academy of Sciences

(Sumbitted May 19, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 12, 705–708 (20 June 1976)

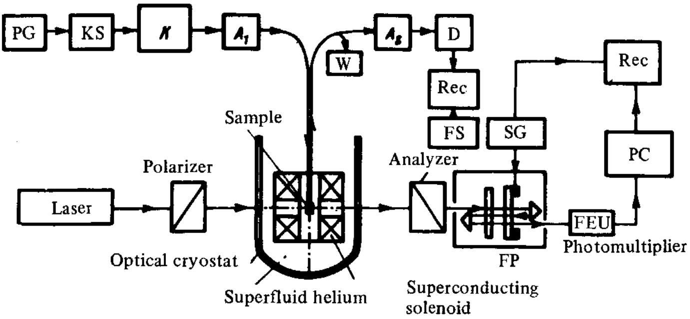
The spectral composition of light passing through a crystal (weakly ferromagnetic $CoCO_3$) is investigated at the instant when the low-frequency AFMR branch, at frequency ~36 GHz, is excited in it. The registered spectrum contains a satellite whose frequency differs from that of the incident light ($\lambda = 0.63\mu$) by an amount equal to the AFMR frequency. This indicates that part of the light passing through the crystal is modulated by the AFMR frequency. The modulation of the light is due to the presence of anisotropic magnetic birefringence in the $CoCO_3$.

PACS numbers: 78.20.Ls, 76.50.+g

An earlier calculation [1] has shown that the presence of anisotropic magnetic birefringence in antiferromagnets should lead to modulation of the light passing through the crystal when homogeneous antiferromagnetic resonance is excited in the latter. We have attempted to observe this effect in a $CoCO_3$ crystal.

The compound1) $CoCO_3$ is a thoroughly investigated antiferromagnet with we ferromagnetism and with easy-plane anisotropy. [2] It has a rather large anisotropic magnetic birefringence in the basal plane, [3] that is, in the antiferromagnetic state there is produced in this crystal a refractive-index difference $n_x - n_y = 27 \cdot 10^{-5}$ for a light beam propagating perpendicular to the basal plane. We have investigated the spectral composition of the light passing through this crystal following excitation of the low-frequency AFMR branch. [4] The spectra instrument was a high-contrast (contrast $\sim 10^7 - 10^8$) three-pass scanning Fabry-Perot interferometer of the American firm "Burleigh." The scanning was with the aid of a piezoceramic. A schematic diagram of the experimental setup is shown in Fig. 1. The light beam from an LG-56 helium-neon laser ($\lambda = 0.63\ \mu$, power ~2 mW) passed in succession through the polarizer, sample, analyzer, Fabry-Perot interferometer, and collimator, and was incident on the photoreceiver. The photoreceiver was a cooled FÉU-79 photomultiplier operating in the photon-counting regime. The signal picked off this multiplier was fed to an photon counter with analog input and was registered with an x-y recorder (the y coordinate). The signal applied to the x-coordinate of the recorder was proportional to the frequency shift of the light emitted by the interferometer and produced in the course of its scanning.

The AFMR was excited in the crystal with a GZ-30 klystron oscillator at a frequency $\nu = 35$—40 GHz. The investigated sample was placed inside a short-circuited plunger waveguide in the antinode of the magnetic component of the microwave field. The absorption signal at microwave power was detected and registered by a second x-y recorder (y coordinate), the x coordinate of which



G. 1. Experimental setup. PG—pulse generator, KS—klystron supply, K—
ystron, A_1,A_2—attenuators, W—wave meter, D—microwave detector, REC—
corder, FS—field scan, SG—scanning generator, PC—photon counter, FP—
bry-Perot Interferometer.

ceived a signal proportional to the magnetic field. At resonance, the sample
sorbed approximately half the power incident on it, that is, ~3—5 mW.

All the experiments were performed in an optical helium cryostat at tem-
ratures 1.5—2.0 °K in superfluid helium (since no light is scattered in it).
e light was applied to the sample through windows in the cryostat and
rough special openings in the waveguide. The magnetic field was produced
a superconducting soledoid and was perpendicular to the light beam. Re-
nance was observed in a field ~1.5—2 kOe as a function of the frequency of
e applied microwave power. The $CoCO_3$ samples were prepared in the form
disks ~0.5—0.8 mm in diameter and 0.1—0.3 mm thick. The plane of the
sk coincided with the basal plane of the crystal. The adjustment of the sam-
es in the cryostat was carried out by means of the conoscopic pattern and
s accurate to within 1°. The AFMR line width in the investigated samples
s ~100—150 Oe. The sample was mounted in such a way that the wave vector
the light was directed along the C_3 axis (the z axis) and the magnetic field
s in the basal plane (the x and y axes were not defined in the plane). The
larization of the incident light coincided with the direction of the magnetic
eld. In the experiment, the polarizer and the analyzer were completely
ossed, so that the light reaching the interferometer was attenuated by a
ctor $\sim 2 \cdot 10^3$ in comparison with the incident light (the maximum degree of
mpensation was $\sim 4-7 \cdot 10^{-2}$ %). The experiment was performed in the follow-
g manner: AFMR was excited in the sample, and the magnetic field corre-
onding to the maximum of the absorption line was recorded. The spectrum
the transmitted light was plotted under these conditions. A typical plot of
is kind is shown in Fig. 2. It is seen that the registered spectrum contains
unshifted component with intensity $\sim(8-10) \cdot 10^6$ counts/sec, and much weak-
components shifted by $\pm\Omega$. Their intensity is 10^3 counts/sec, corresponding
$\sim 5 \cdot 10^{-8}$ of the intensity of the light incident on the crystal. The frequency
the shifted components differed from the frequency of the incident light by
e AFMR frequency. This indicates that a part of the light passing through the
rystal is modulated at AFMR frequency. The presence of a shifted frequency
the spectrum can be regarded as inelastic scattering of light by the homo-
eneous precession of the spins in AFMR, that is, by spin waves with $k=0$.

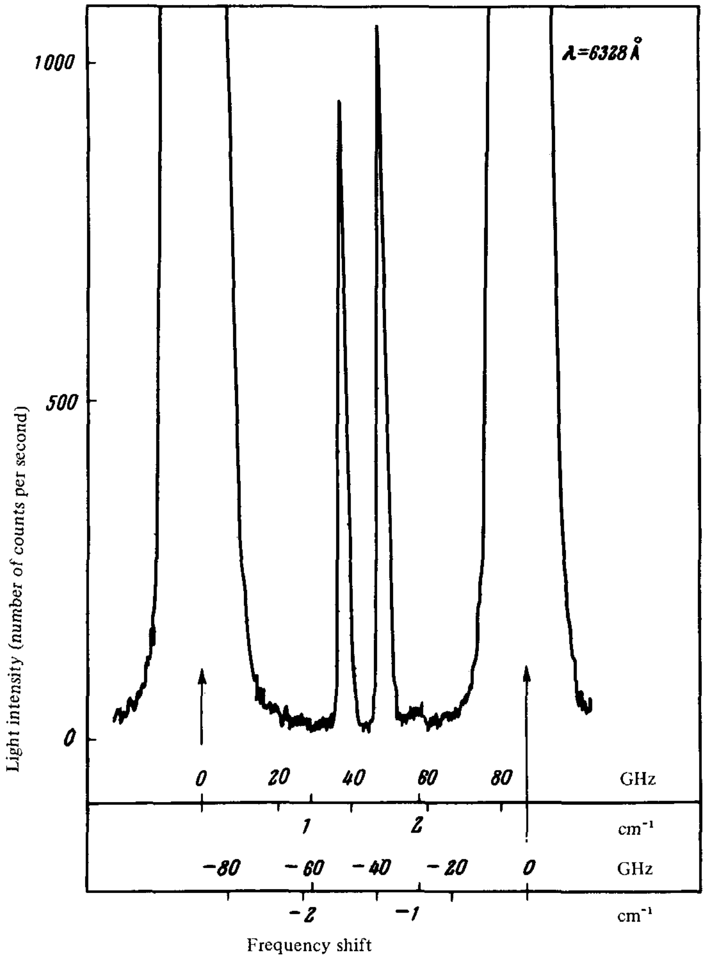


Fig. 2. Spectrum of light passing through crystal. The difference between the intensities of the shifted components is due to misadjustment of the interferometer during the scanning process.

The result described above was obtained by us with two $CoCO_3$ samples. A more detailed investigation of the phenomenon has shown that the shifted components exist in the entire magnetic-field interval at which resonant absorptio of the microwave power is observed (that is, within the limits of the AFMR li width). In addition, it turned out that modulation of the light is observed in a rather wide angle interval ±40 ° between the polarization of the incident light and the direction of the magnetic field. Owing to the presence of anisotropic magnetic birefringence in the basal plane, light in mutually-crossed polaroids is cancelled out to a much worse degree.

The results of the present experiment and of [1] allow us to estimate the ratio of the number of spin waves with $k = 0$ and $k \neq 0$, excited in AFMR.[2)] The umber $n_{k=0}$ of spin waves with $k=0$, according to formula (2) of [1], is proortional to the relative intensity of the satellites observed in the present study $/I_0 \sim 5 \cdot 10^{-8}$). The spin waves with $k \neq 0$, produced in AFMR, cause a change 1 the value of the anisotropic magnetic birefringence, which was observed by s in [1]. The relative change in the light intensity measured in this case $/I_0 = 2 \cdot 10^{-4}$) is proportional to the number $n_{k\neq 0}$ of such spin waves. From the atios I/I_0 determined in two experiments we obtain a value $\sim 2.5 \cdot 10^{-4}$ for $_{k=0}/n_{k\neq 0}$. This estimate does not contradict the value obtained in [1] in a comarison of the intensity of the optical signal and of the microwave power aborbed by the sample.

It should be noted in conclusion that modulation of the light at a frequency 3.5 GHz at ferromagnetic resonance was observed with the aid of a Fabry-erot interferometer by Dillon and Hanlon [5] in the ferromagnetic crystal rBr$_3$. In this case the modulation was due to the presence of a large Faraday ffect in the investigated ferromagnetic crystal.

The authors are sincerely grateful to P. L. Kapitza for interest in the work nd to S. M. Elagin for help with the construction of the apparatus.

)The authors are sincerely grateful to N. Yu. Ikornikova and V. M. Egorov for supplying the CoCO$_3$ crystals.

)The total number of excited spin waves is proportional to the square of the mplitude of the spin oscillations, which is expressed in [1] in terms of the 1ean squared angle of inclination of the spins from the equilibrium position $^2/2$.

A. S. Borovik-Romanov, V. G. Khotikov, N. M. Kreĭnes, and A. A. Pankov, Zh. Eksp. Teor. Fiz. 70, 1924 (1976) [Sov. Phys. JETP 43, No. 5 (1976)].
A. S. Borovik-Romanov and V. I. Okhogin, Zh. Eksp. Teor. Fiz. 39, 27 (1960) [Sov. Phys. JETP 12, 18 (1961)].
A. S. Borovik-Romanov, N. M. Kreĭnes, A. A. Pankov, and M. A. Talalaev, Zh. Eksp. Teor. Fiz. 66, 782 (1974) [Sov. Phys. JETP 39, 375 (1974)].
A. S. Borovik-Romanov, Antiferromagnetiki s anizotropieĭ tipa legkaya ploskost'. Problemy magnetizma (Antiferromagnets with Easy-Plane Anisotropy. Problems of Magnetism), Nauka, 1972.
J. T. Hanlon and J. R. Dillon, Jr., J. Appl. Phys. 36, 1269 (1965).