working levels [4]. Inasmuch as the reaction rate (the rate of population of the levels during the course of the reaction) and the relaxation times depend on the temperature and on the other parameters of the mixture, and are different for different levels, the generation spectrum can vary with these parameters. It is therefore of great interest to study the distribution of the generation energy over the spectrum and the time evolution of the dynamics of the spectrum as functions of the mixture parameters.

If the rate of relaxation from the lower working level exceeds its population from the higher level as a result of relaxation processes, then the reaction should be accompanied by inversion in the entire ignition region. It is possible that this is precisely the situation in the $H_2 + F_2$ mixture with respect to the (2 - 1) transition in HF, owing to the depletion of level 1 in collisions between HF and H_2. This gives grounds for hoping to obtain a lasing regime without external triggering of the reaction and in the continuous regime.

The authors thank V. L. Tal'roze for useful discussions, and B. L. Dyatkin and L. S. German for supplying chemically pure fluorine.

[1] N. N. Semenov and A. E. Shilov, Kinetika i kataliz 6, 3 (1965).
[2] N. Semenoff, Chem. Rev. 6, 374 (1929).
[3] O. M. Batovskii, T. K. Vasil'ev, E. F. Makarov, and V. L. Tal'roze, ZhETF Pis. Red. 9, 341 (1969) [JETP Lett. 9, 200 (1969)].
[4] A. N. Oraevskii, Zh. Eksp. Teor. Fiz. 55, 1423 (1968) [Sov. Phys.-JETP 28, 744 (1969)].
[5] I. L. Dunham, Phys. Rev. 41, 721 (1932).
[6] D. E. Mann, B. A. Thrush, D. R. Lide, J. J. Ball, and N. Acquista, J. Chem. Phys. 34, 420 (1961).
[7] K. L. Kompa and G. C. Pimentel, ibid. 47, 857 (1967).
[8] J. H. Parker and G. C. Pimentel, ibid. 48, 5273 (1968).
[9] R. W. F. Gross, N. Cohen, and T. A. Jacobs, ibid. 48, 3821 (1968).
[10] T. F. Deutsch, Appl. Phys. Lett. 10, 234 (1967).
[11] R. W. Terhune and C. W. Peters, J. Mol. Spectroscopy 3, 138 (1959).

PASSAGE OF ELECTROMAGNETIC WAVE THROUGH A FERROMAGNETIC METAL IN THE ANTIRESONANCE REGION

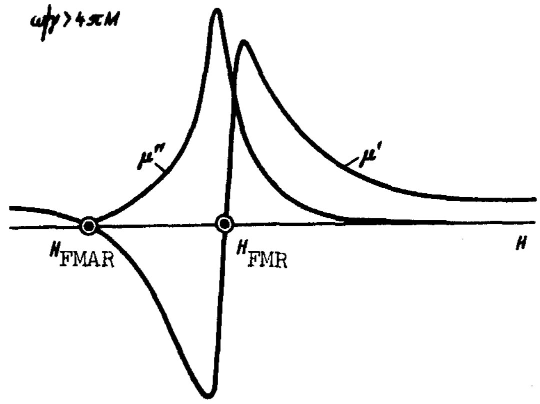
B Heinrich[1)] and V. F. Meshcheryakov
Institute of Physics Problems, USSR Academy of Sciences
Submitted 21 April 1969
ZhETF Pis. Red. 9, No. 11, 618 - 622 (5 June 1969)

It is known that the propagation of an electromagnetic wave inside a metal is determined principally by the presence of the conduction electrons. The magnetic system acts on the conduction electrons via the Lorentz force $\vec{F} = (e/c)\vec{v} \times \vec{H}$, whence it follows that the singularities of the high-frequency magnetic susceptibility should affect the propagation of an electromagnetic wave inside a ferromagnetic metal. The reciprocal of the depth of penetration in a ferromagnetic metal is

$$\mathrm{Re}(k) \sim [(\mu'^2 + \mu''^2)^{1/2} + \mu'']^{1/2} ,$$

1) Physics Institute, Czechoslovak Academy of Sciences

Fig. 1



where μ' and μ'' are the real and imaginary parts of the high-frequency susceptibilities. Figure 1 shows the variation of μ' and μ'' as functions of the external magnetic field when $\omega/\gamma > 4\pi M$, from which it is seen that there exist two points near which the depth of penetration of the electromagnetic wave inside the metal has singularities. At the ferromagnetic-resonance (FMR) point the depth of penetration of the electromagnetic wave decreases strongly, owing to the large value of μ''. In addition to this point, there exist a point of ferromagnetic antiresonance (FMAR) [1 - 4], where $\mu' \to 0$. If the damping is so strong that the group velocity of the wave is smaller than the velocity of light[2)] (as is always the case for ferromagnetic metals), then the picture of the skin layer remains the same as before. In this case the depth of the skin layer should increase strongly at the FMAR point and the transparency of the ferromagnetic metal should increase. This question was considered by Kaganov for the case of precession of magnetization without exchange of forces [4].

We investigated the transparency of ferromagnetic permalloy plates (90% Ni) ∿ 10μ thick at a frequency 36 GHz as a function of the magnetic field. The plate thickness was chosen such that the depth of penetration of the microwave field at $\mu = 1$ was much smaller than the thickness of the sample. In our case the attenuation in the plate was approximately 160 dB at $\mu = 1$, and the intensity of the transmitted wave far from the FMAR region was much smaller than the sensitivity of the superheterodyne receiver.

The power was incident of the sample from a resonator, in the wall of which a coupling aperture of 3 mm diameter was cut in the region of the maximum of the magnetic component of the microwave field. The samples were attached to this wall from the outside by means of a conducting silver adhesive. The wall of the receiving waveguide, with a similar aperture, was pressed against the sample from above. The power passing into the waveguide was fed directly to the mixing diode of a superheterodyne receiver with sensitivity 10^{-12} W. The decoupling between the resonator and the waveguide was such that when the resonator was fed with a klystron rated 10^{-2}W the receiver did not sense the signal.

The measurements were made at two orientations of the external magnetic field relative to the plane of the film. In one of the experiments the magnetic field was directed along

[2)] This condition reduces to the inequality $\Delta H > (4c^2/\delta_0^2\sigma^2)4\pi M$, which yields in our case $\Delta H > 0.2$ Oe.

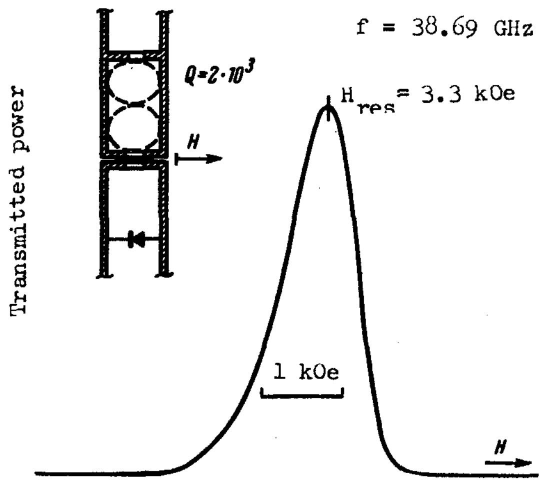


Fig. 2a

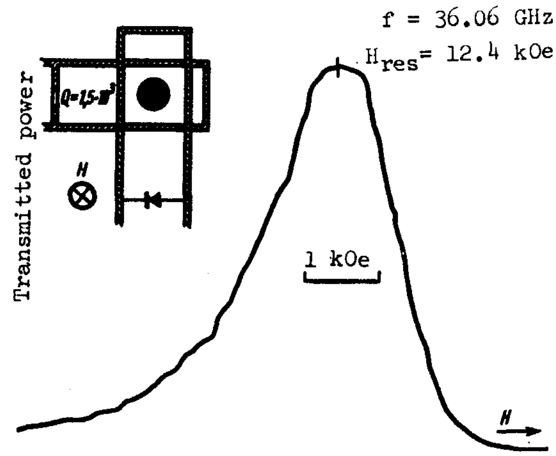


Fig. 2b

the plane of the plate and the passage of the microwave power was observed when the polarization of the incident and transmitted waves were identical. Figure 2a shows the experimental conditions and the obtained results. The damping of the microwave power in this case ranged from 160 dB at $\mu = 1$ to 80 dB at $H = H_{FMAR}$. The fact that the change of the transparency of the film at the FMAR point is connected with the gyroscopic effect of the magnetized d electrons was confirmed by an experiment with mutually perpendicular polarizations of the microwaves in the resonator and in the waveguide. The magnetic field was then applied perpendicular to the plane of the plate, leading to a shift of the FMAR pint by $4\pi M$. Figure 2b shows the experimental conditions and the results.

The FMAR condition [1] has the following form: $\omega/\gamma = B_{intern}$, i.e., $(\omega/\gamma) = H + 4\pi M$ for a parallel orientation, and $(\omega/\gamma) = H$ for a perpendicular orientation. From a comparison of these formulas with the experimental results we obtain $4\pi M = 9400$ Oe and $\gamma = 1.83$, corresponding to $g = 2.08 \pm 0.01$. These quantities are in good agreement with the observed value of the resonant FMR field, the position and width of which were measured for the case of a parallel configuration (see Fig. 3).

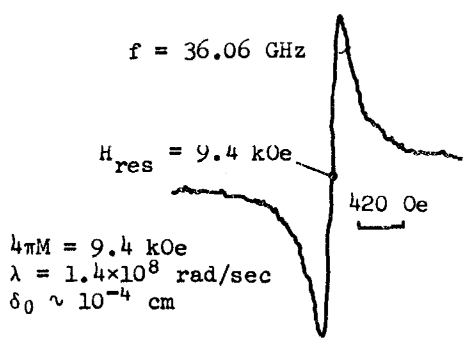


Fig. 3

The presence of exchange interaction leads to excitation inside the metal, besides the ordinary electromagnetic wave, also of an exchange wave with a wave vector, say for the perpendicular configuration of the external field, given by $|k| = \sqrt{2\pi/A}\, M \approx 10^6\ cm^{-1}$ (A is the exchange constant). Inasmuch as the high-frequency susceptibility is 10^5 times larger than for the ordinary wave, the boundary conditions can be satisfied only if its amplitude is smaller than the amplitude of the ordinary electromagnetic wave by the same factor. Consequently the transparency of the ferromagnetic metal in the FMAR region is determined by the ordinary wave. Since the amplitude of the transmitted wave in the FMAR is

$$h \sim \frac{k}{\mathrm{sh}(kd)},$$

where d is the thickness of the plate, and

$$k_{\parallel} = \frac{2}{\delta_0}\sqrt{\frac{\Delta H_{\gamma}}{\omega}}, \quad k_{\perp} = \frac{1}{\delta_0}\sqrt{\frac{\Delta H}{2\pi M}},$$

it follows that in the case of samples for which $d \geq k^{-1}_{FMAR}$ the shape and intensity of the FMAR is determined by the attenuation. The values of the Landau-Lifshitz relaxation constant λ, calculated from the results of our FMAR and FMR measurements, are the same; $\lambda_{exp} \approx 1.4 \times 10^8$ rad/sec.

In conclusion, we wish to thank P. L. Kapitza for making it possible to perform this work, and A. S. Borovik-Romanov for stimulating interest in the work, valuable advice, and discussions. We are grateful to A. I. Shal'nikov for great help in the preparation of the experiments, and Doctors Kaganov, Blank, Frait, and Kamberskii for useful discussions.

[1] J. H. Van Vleck, Physica 17, 234 (1951).
[2] W. A. Yager and F. R. Merrit, Phys. Rev. 75, 318 (1949).
[3] L. L. Hirst, Phys. Rev. Lett. 18, 229 (1967).
[4] M. I. Kaganov, Fiz. Met. Metallov. 7, 288 (1959).

TWO-PHONON PROCESSES IN INELASTIC ELECTRON SCATTERING IN n-InSb

M. M. Aksel'rod and I. M. Tsidil'kovskii
Institute of Metal Physics, USSR Academy of Sciences
Submitted 28 April 1969
ZhETF Pis. Red. 9, No. 11, 622 - 626 (5 June 1969)

When the condition for magnetophonon resonance (MPR)

$$\epsilon_{N,S} - \epsilon_{L,S'} = \hbar\omega_0, \ (N, L = 0, 1, 2, \ldots; S = S' = \pm\frac{1}{2}) \tag{1}$$

is satisfied, a number of extrema should appear on the curves of longitudinal ($\rho_{\parallel}$) and transverse ($\rho_{\perp}$) magnetoresistance. In formula (1), $\epsilon_{N,S}$ is the energy of the N-th Landau level with given orientation of the spin S, and ω_0 is the limiting frequency of the optical phonons. Experimental investigations have shown that, in accord with the theory, the transverse magnetoresistance of the n-InSb samples has maxima at magnetic field values