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Some Notes on the Researches of S. G. Salikhov

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SALIKHOV is known as the coauthor of several studies of considerable note, devoted to research of paramagnetic resonance absorption, initiated in 1944 at the Kazan State University. However, a number of serious inconsistencies appear in several of his papers, published over the past few years.

For example, let us examine his paper entitled "Microwave Measurements of Magnetic Permeability and Dielectric Constants of Some Ferrodielectrics"[1] . In this paper the author maintains that "in the case of a ferromagnetic substance, the electric loss, governed by the finite specific resistance of the substance, cannot be distinguished from the magnetic loss". There is no need to attempt to disprove this statement, as the author does so himself, unwittingly, in the second part of the paper, in which $tg\delta_\epsilon$ and $tg\delta_\mu$ are separately identified.

A second statement, presented further on, suffers a similar fate: "It is assumed that μ'' is of prime importance in this process, while the significance of μ' is negligible". However, Table 3, presented at the end of the paper, clearly shows that, without exception, μ' and μ'' have similar values and, moreover, about one half of the substances examined show a value of $\mu' > \mu''$.

A third statement, pertaining to the analysis of samples, fares no better: "Disc-shaped samples, 2 to 3 mm in diameter and 0.1 mm thick, were placed at the bottom of the resonator. The demagnetizing fields were not significant". Unperturbed by this baseless claim, the author in order to compute the g-factor for these samples, makes use of the special case formula of Landau-Lifshitz-Kittel,

$$\omega_{max} = \gamma \{HB\}^{1/2}, \qquad (1)$$

which, as is well known, is based on the assumption that two of the demagnetization factors are equal to zero, while the third is of the highest possible magnitude, equal to 4π[1-4] .

Material presented at the end of the second page of the study under discussion[1] bears no relation to the subject matter at hand, but coincides with statements in the pertinent portion of a paper by Kittel (reference 2, p 22). Equation (1) makes its appearance further on in the text, identified as Eq. (2) and, just eight lines later, it is again presented, this time as Eq. (4). Moreover, the sentence contains an error which renders it meaningless: in place of the "minimum μ_R" used in Kittel's text, the author writes "maximum μ''".

Judging on the basis of its title and factual content, the study under discussion is a purely experimental one; however, it appears fruitless to search for the principal ingredient of such a paper: a description of the procedures employed in conducting the experiment, as well as formulae that would relate the characteristic of the analyzed substance to the system's parameters that are being measured. Only indirectly can one deduce, from one of the sentences quoted above, that the author, in the course of his measurements, did not take into account the displacement of the resonant frequency of the gap, which is dependent upon the magnitude of μ'; therefore, when μ' and μ'' were of equal magnitude, he obtained a strongly distorted curve for $\mu''(H)$.

Let us examine the results of the measurements. These data are presented in a series of curves and in Table 1, which summarizes some of the characteristics of the analyzed substances. It is regrettable that no analysis or discussion of these results is offered, since only a review of this nature could aid in judging the quality of the data obtained. For instance, let us examine several curves and other data in Fig. 4[1] . In the case of two samples of nickel-zinc ferrite, differing slightly in their composition, the author has located anti-resonance minima on the absorption curves. It must be remembered that, while such

[1] S. G. Salikhov, Izv. Akad. Nauk SSSR, Ser. Fiz. 18, 456 (1954)

[2] Ferromagnetic Resonance, Symposium, IIL, 1952

[3] N. N. Malov, J. Exper. Theoret. Phys. USSR 16, 78 (1946)

[4] V. N. Lazukin, Izv. Akad. Nauk SSSR, Ser. Fiz. 16; 510 (1952)

minima have been observed earlier, they normally become noticeable only when the effective permeability $\mu_R = (\mu'^2 + \mu''^2)^{1/2} + \mu''$ can be determined on the logarithmic scale (the so-called μ_R - effect), when their magnitude does not exceed 0.5% of $\mu_{R\,max}$ and, therefore, never reaches the value $\mu_R = 0$ (reference 2, pp 1, 2 , 19). Figure 4 shows the minima on the μ'' curve. Their magnitudes are 10 and 20% of μ''_{max} , and they are all within the range of $\mu'' < 0$. What is the meaning of the negative value of the coefficient that characterizes the absorption? It would appear that not only does the substance not absorb any more energy from a high-frequency electromagnetic field, but, on the contrary, it radiates it!?

A second point, no less curious, is related to these minima. From the Kittel formula,

$$\omega_{min} = \gamma B, \qquad (2)$$

quoted by the author, it follows that the minimum is determined by the magnitude of induction in the substance. We know from Table 1 that, for nickel-zinc ferrite of 17-33-50 composition, the magnitude of the resonance field H = 3100 oersteds, and the induction B = 3100 gauss (curve 1 in Fig. 4). The following three conclusions are made: (1) the given ferrite is paramagnetic; (2) formulae (1) and (2) become identical; and (3) the maximum and the minimum on the absorption curve must coincide. Which, then, is to be believed, the table or the illustrations, theory or the experiment? A second sample of the ferrite, of 20-30-50 composition, produces H = 3100 oersteds and B = 3000 gauss; thus it would appear to be not a ferrite at all, but some sort of super-diamagnetic substance with a magnetic susceptibility of $\chi = 10^{-2}$.

The unexplained influence of the dispersion of susceptibility on the μ'' curve, the composition of the samples, the incorrectly applied induction values, and the unjustified use of Eq. (1) indicate that data in Table 1, pertaining to the value of the g - factors, represent magnitudes obtained by pure coincidence and, naturally, these figures differ from those obtained by other authors (for example, the author shows, for magnetite in the direction (100), that g = 2.34, while Bickford finds that $g = 2.12 \pm 0.04$ (reference 2, p 24).

Let us now turn to the second part of this paper[1]. This portion deals with experiments utilizing the same substances; however, a different procedure has been employed, namely that of measuring on the basis of standing waves in a wave guide, developed in the work of Birks (reference 2, p 37), Malov[3] , and Lazukin[4] . The computation formulae of this method are presented in most complete form in the Lazukin paper [Eqs. (4) and (4a) in reference 4].

Without justification the author "simplifies" these: he eliminates terms containing area tangents; he assigns values of relative input impedances of open and closed circuits, Z_{open} and Z_{closed} , to coefficients A_1 and A_2, which were introduced by Lazukin merely to simplify the expression; the author further places each side of the equations between absolute value signs, and presents the equations in the following form:

$$|\mu| = \left|\frac{\lambda}{2\pi d}(Z_{от}Z_{кз})^{1/2}\right|; \qquad (3)$$

$$|\varepsilon| = \left|\frac{\lambda}{2\pi d}\frac{1}{(Z_{от}Z_{кз})^{1/2}}\right|. \qquad (4)$$

Another curious detail is the fact that an obvious error has been overlooked in Lazukin's paper[4]: The index figure 1 of coefficient K_1 has been placed after an imaginary number, i.e., the coefficient appears as Ki_1 . The author has completely done away with this index in his Z_0 [equation (10) in reference 1] and thus, in place of two, shows three K coefficients.

Furthermore, the Lazukin formulas are applicable to cylindrical coordinates and are valid only for a coaxial line. The author employs the formulas with respect to a right-angled wave guide.

Also, these equations are inconsistent as far as dimensions are concerned. In the following, only one of several possible variants of the author's method of deriving Eqs. (3) and (4) is described. But independent of the method of their derivation, it is not difficult to show that they are incorrect. To accomplish this, it is sufficient to multiply Eqs. (3) and (4) by one another and to extract the the square root. Thus:

$$(|\mu||\varepsilon|)^{1/2} = \lambda / 2\pi d. \qquad (5)$$

As one can see, the refractive index has become a function of the thickness of the layer!? Table 2 serves as a graphic illustration of this relationship: the thicker the sample, the lower its dielectric and magnetic permeability.

Table 2 is followed by Table 3 in which " there are presented data concerning the dielectric constant, magnetic permeability and tangents of magnetic and dielectric losses, computed for the same substances by the method of closing and opening a circuit; these data closely correspond to results obtained by other authors". It is not clear how this table was prepared. Certainly the information presented in this table does not follow from the discussions preceding it. A great many

errors can be found in this table: the effective portion of the dielectric permeability of magnetite-II, $\epsilon' = 0.23$; of nickel-zinc ferrite, $\epsilon' = 0.34$; furthermore, the effective portion of magnetic permeability of magnetite-I, $\mu' = 0.95$; of FeS, $\mu' = 0.71$; of magnetite-II, $\mu' = 0.98$, and of nickel-zinc ferrite, $\mu' = 0.97$. All this, the author claims, "closely parallels results obtained by other authors".

The paper [1], presented at the Second All-Soviet Conference on Ferrites, was subjected to severe criticism; as stated above, the values of moduli $|\epsilon|$ and $|\mu|$, computed from Table 3, did not correspond to values for identical substances presented in Table 2.

Similar errors appear in other independent studies of S. G. Salikhov, published during the same period. Let us examine his papers on the measurement of paramagnetic resonance absorption in metals[5-7]. It is difficult to determine what methods of measurement were employed by the author. For example, he states in one paper[5]: "Measurements were made on standing waves at the point of the exact amplitude minimum". However, only a few lines further down, he states that "The Q-quality of the contour was measured by a special precision method". In a later paper[7], a more detailed, but not at all more comprehensible, description of this method is given. A special paragraph listing the different steps is followed by a statement describing the well-known determination that utilizes a standing wave guide, both ends of which are closed (see reference 8, pages 200 and 201). All this is followed by several sentences bearing no relation to each other and frequently containing incorrect statements. For example: "The decrease in power given off by the generator, ΔW, had no practical effect on the magnitude of measured resonance absorption. This is so because in determining paramagnetic resonance absorption, we used samples that had been specially tested for static susceptibility"!? Another example of the author's inconsistency is contained in the following statements: "Furthermore, because of the difference in refractive indexes, determined by either right-or left-hand polarization of the waves, there occurs oblique elliptical polarization. Rotation of the polarization plane changes the sign in the range of the absorption curve and, therefore, does not affect the position of the resonance absorption maximum. Also, it does not materially effect the form of the curve, since comparatively small samples have been used"!? If this approach, which is outlined in the thesis work of Garif'ianov[9], may be assumed to hold true for measurements of paramagnetic salts, it certainly cannot be applied to the author's experiments. Indeed, no one has ever observed rotation of a polarization plane, either during the passage or during the reflection of waves from the paramagnetic metal; certainly this does not hold true for perpendicular fields and microwaves.

The author devotes only two sentences to a description of his procedure[7]: "A probe is placed at either the maximum or the minimum of the standing waves; as the constant magnetic field intensity is changed, a change, proportional to $\chi''(H)$, is obtained in the amplitude of the standing waves. If the probe is placed at a distance of $\lambda/8$ from the maximum of the standing wave, the changes in amplitude will be proportional to the displacement of the phase which is linearly bound to $\chi'(H)$". This is a new development in the science of microwaves. Hitherto, the standing wave coefficient and the displacement of the wave's minimum position had served as the parameters to be measured; χ' and χ'' can be derived from these only by the use of the complex conversion equations(4).

It is quite obvious that, at the maximum or minimum voltage of the standing waves, with the position of the probe remaining unchanged, changes in voltage will be caused by both the real and the imaginary complex component load; in other words, the changes will be proportional to some arbitrary combination of χ' and χ''. Similar results, though in slightly different proportion, will be observed at a distance of $\lambda/8$ from the maximum point. This is clearly shown in Fig. 1 of the reference 5, in which the dispersion curve of platinum simply represents an inverted absorption curve with a slightly distorted wing in the large fields. This also explains the displacement of the resonance point of this "dispersion" curve by 400 oersteds toward the large fields, a circumstance which has no significance from the physics viewpoint. Incidentally, these dispersion curves which the author "succeeded in obtaining in individual cases" seem to have been largely ignored following the Bloembergen paper [10]. Instead, the earlier

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[5] S. G. Salikhov, Izv. Akad. Nauk SSSR, Ser. Fiz. 16, 748 (1952)

[6] S. G. Salikhov, Dokl. Akad. Nauk. SSSR, 93, 241 (1953)

[7] S. G. Salikhov, J. Exper. Theoret. Phys. USSR 26, 447 (1954)

[8] Methods of Microwave Measurements, Soviet Radio, 1949

[9] N. S. Garif'ianov, Thesis, Kazan State University, 1952

[10] N. Bloembergen, J. Appl. Phys. 23, 1383 (1952)

absorption curves made their appearance as a two-part combination, showing both paramagnetic losses and conductivity losses[6,7].

Turning again to procedure, we note that the curves showing these combined losses are expressed in relative units. However, this does not prevent the author from stating in the introductions to these papers[6,7] that "in order to compare these absorptions that were determined for metals of differing conductivities and shapes, the absorption energy values obtained in the experiment were recomputed on the basis of the following formula:

$$W_{\text{eff}} = \frac{Sd\sqrt{\rho}}{M} W_0, \qquad (6)$$

that is, "an amplitude change, proportional to χ'' is to be converted to W_0, the absorption energy, which was obtained experimentally". The impossibility of obtaining W_0 by this method is only too obvious. The measuring line, the author admits, assures an accuracy no higher than 5%[1], while energy absorbed by the metal, constitutes no more than 0.01-0.001% of the energy drop. Moreover, Eq. (6) is inverted and, therefore, used in the conversion computation. As a matter of fact, the larger the area S, the larger is W_0, and the larger is W_{eff}. Nor does this appear to be a misprint, as this formula appears in each of two separate papers[6,7], published one year apart.

A further analysis indicates that the author does not even make use of Eq. (6), Captions of all illustrations in references 6,7 indicate that the magnitude W_{eff} is plotted along the ordinate axis. In reality, this is not the case at all. It is not W_{eff} that is scaled off along that axis, but some magnitude of unknown origin called "line intensity". This circumstance is easily discovered when one compares information in the Table with the curves in the illustrations. To appear more convincing, the author writes: "Figure 1 shows curves indicating combined losses, at room temperature, for potassium, sodium, and bismuth; W_{eff} is scaled along the ordinate axis, while H_0, the external static field, is plotted along the abscissa. As can be seen from the illustration, the line for potassium is 3.5 times more intensive than that for sodium, and 7 times more intensive than the bismuth line"[7]. However, the tables of this same paper indicate that the reverse is true as far as the relative magnitudes of W_{eff} for these metals are concerned. In addition, it is not at all clear what units were used in the computation of the χ' and χ'' curves.

[11] G. A. J. Hutchison and R. C. Pastor, J. Chem. Phys. 21, 1959 (1953)

Let us turn to the author's low temperature measurements: " A special apparatus for the measurement of paramagnetic absorption at low temperatures consists of an extension of the metal wave guide, made of a dielectric material and having a metallized inner surface" (reference 7, p 449). This sentence is followed by a reference to the Garif'ianov thesis[9]. From it we learn that this portion of the wave guide is made of plexiglass layers having tin foil on one side. Considering that the pole shoes of the electromagnet are 100 × 100 millimeters in dimension, that the wave guide is 28.5 × 12.7 millimeters in size, and the sample is located in the center of the gap, we note that more than 40 cm^2 of the tin foil is in the magnetic field. A baffling question arises: how can one detect the absorption effect on a tin sample of 2.3 cm^2 area when the sample is surrounded by a 40 cm^2 area of the same metal?

It is pointless to look for an evaluation of results in these papers. What conditions cause the effect observed by the author? The statement made above would seem to place some doubt as to the very existence of this effect, particularly since recent studies into the absorption of potassium and sodium[11], as well as researches involving gadolinium and beryllium[12] and several other metals[13], indicate that the effect of resonance absorption in metals can be determined only when exceptionally pure samples are used. Resonance lines obtained in these studies are extremely narrow (half-thickness on the order of several oersteds) and have a g-factor of a magnitude close to that of a free electron. Obviously, such results are in complete disagreement with those obtained by Salikhov. As a matter of fact, he makes no reference to them.

The limitations of a brief review make it impossible to discuss additional shortcomings in these and other studies by the author; however, it is doubtful whether that would serve any purpose since one can arrive at several specific conclusions without such.

1. A primary condition governing experimental work remains unfulfilled in the papers under review: authenticity of the results.

2. No attempt has been made to correct errors that are in contradiction with the most basic precepts of the science of physics in general, and the study of magnetic resonance in particular.

[12] A. F. Kip, Revs. Modern Phys., 25, 229 (1953); A. F. Kip, C. Kittel et al, Phys. Rev. 89, 518 (1953); C. Foher and A. F. Kip, Phys. Rev., 95, 1343 (1954)

[13] N. S. Gutovsky and H. J. Frank, Phys. Rev. 94, 1067 (1954)

Translated by F. Haimson
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