Letters to the Editor

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Quenching of Afterglow in Gaseous Discharge Plasmas by Low Power Microwaves*

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We have recently described[1] experimental results obtained in the course of a study of interaction of low power very high frequency electromagnetic waves ($\gamma \sim 10^{10}$ cps) simultaneously propagated through gaseous discharge plasmas. The interaction of these waves in the plasma is satisfactorily explained, in a first approximation, on the basis of a theory first proposed by Bailey and Martyn[2] for the similar phenomenon of ionospheric cross modulation of low frequency electromagnetic waves. According to this theory, absorption of the interfering waves increases the temperature of the electron gas above the equilibrium temperature in the appropriate region of the ionosphere and, in our case, in the plasma. This leads to a variation of the mean collision frequency of the electrons, as a result of which the transparency of the medium for these waves is modified.

We have shown that cross modulation is detected even when microwave energy of the order of a few times kT ($T \sim 300$°K and k = Boltzmann constant) is absorbed in the electron gas of the plasma from the "disturbing"[1] wave. It appeared reasonable to assume that phenomena associated with the gas of free electrons in a decaying plasma in thermal equilibrium, phenomena which exhibit (strong) dependence upon the excess temperature of the electron gas, should be affected by the absorption in that plasma of electromagnetic energy even of the order of kT.

The purpose of this note is to report briefly the main experimental results which appear to demonstrate the expected effect on the intensity of the afterglow which is most likely to be associated with the recombination of positive ions with electrons in decaying gaseous discharge plasmas.

These experiments were carried out with helium, neon, argon, xenon, and a mixture of neon and argon gases in the pressure range of 0.1 to 20 mm of Hg. The results reported here, however, concern only neon, where the afterglow has been more conclusively ascribed[3] to the result of the positive ion-electron recombination in the decaying plasma.

The experimental set-up comprised a gaseous discharge tube located in a square wave guide, 2.07 cm on a side. The discharge plasma, the length of which could be varied from 14 to 22 cm, was produced by 1- or 2-microsecond dc voltage pulses. Microwave signals at two different frequencies (8600 and 9400 Mc/sec) were used simultaneously or separately. The 8600-Mc/sec signal was pulse modulated. The duration of these pulses was varied from 2 to 35 microseconds. The maximum peak value of the input power available was 450 milliwatts, of which a certain fraction was absorbed in the decaying plasma. The energy absorbed in the plasma could be varied by attenuating the input power to any desired known value and also by appropriately positioning the microwave pulses in time with respect to the time at which the plasma excitation pulse has been removed. The afterglow light output was observed by means of phototubes. The photosensitive detectors were varied in position along the discharge tube but for most experiments were placed to view the tapered end of the discharge tube through the termination for the microwave pulse (a distance of 50 cm from the tube).

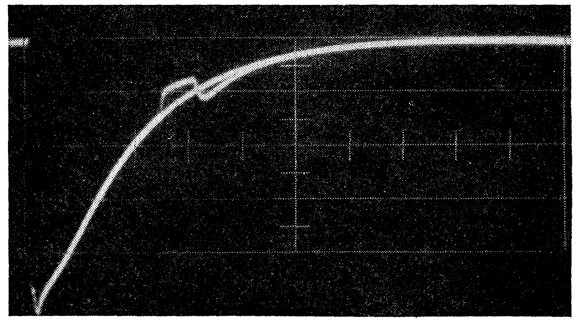

Fig. 1. Quenching by a microwave pulse of the afterglow in a decaying plasma established in neon at 20 mm of Hg pressure. The time scale is 50 μsec per division, a 35-μsec pulse being introduced 125 μsec after a 2-μsec discharge excitation pulse.

Figure 1 shows the amplified photocurrent displayed on an oscilloscope, resulting from the visible afterglow in the decaying neon discharge plasma at 20-mm Hg.

Time scale is 50 microseconds per division and is read from left to right. A 35-microsecond duration microwave pulse (450 milliwatts peak) is introduced 125 μsec after the cessation of the discharge excitation pulse. Downward deflection of the trace indicates higher intensity photocurrent output. It is seen that during the application of the microwave pulse the photocurrent output is decreased. Attempts were made to detect whether this decrease is due to a shift in the spectrum of the light emitted toward a spectral region where the phototube sensitivity is lower or if this is due to an actual decrease in the light intensity. Within the sensitivity of our photodetectors no shift has been observed. The decrease in the light intensity should most probably be ascribed to the reduction of the recombination rate during the application of the microwave signal.

After the pulse the electrons tend to resume recombination at the rate existing immediately before the pulse, since at this pressure few are removed by diffusion.

In Fig. 2 (upper trace) is shown the 10-μsec wide microwave pulse transmitted through the decaying gaseous discharge plasma in nenon at a pressure of 1 mm of Hg. The pulses are positioned at 100, 300, 500, and 800 μsec after the removal of the plasma excitation dc pulse. The lower trace is the displayed photocurrent output produced by the decaying afterglow light intensity. It is seen that for each position of the pulsed microwave signal there is a decrease in the photocurrent. The magnitude of this decrease varies with the absorbed microwave power. The peak

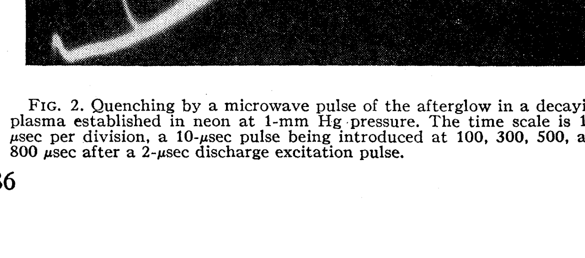

Fig. 2. Quenching by a microwave pulse of the afterglow in a decaying plasma established in neon at 1-mm Hg pressure. The time scale is 100 μsec per division, a 10-μsec pulse being introduced at 100, 300, 500, and 800 μsec after a 2-μsec discharge excitation pulse.

powers absorbed in the plasma at 100, 300, 500, and 800 μsec are 83.5, 12, 4, and 1.3 milliwatts, respectively.

At this low pressure in neon the return to the original trace after removal of the microwave signal is relatively slow, probably caused by the poor thermal contact between the electron gas and the gas of the plasma. Note that since the loss of electrons by diffusion is not negligible here as it was in the high pressure case (Fig. 1), the intensity of the recombination light does not return to the value it had before the beginning of the microwave pulse.

It appears that the phenomenon here described will be applicable to the study of electron-positive ion recombination processes which result directly or indirectly in light emission. In addition, the quenching of afterglow by absorption of low level microwave signals seems to be a valuable new method of detection of electromagnetic energy.

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[1] Goldstein, Anderson, and Clark, Phys. Rev. **90**, 151 (1953).
[2] V. A. Bailey and D. F. Martyn, Phil. Mag. **18**, 369 (1934).
[3] M. A. Biondi and S. C. Brown, Phys. Rev. **76**, 1697 (1949); Holt, Richardson, Howland, and McCline, Phys. Rev. **77**, 239 (1950).
[4] RCA 931-A for the very near ultraviolet and the appropriate blue region of the visible portion of the spectrum and a 1P25 image converter for the red and near infrared portion of the spectrum.

Superconducting Compounds of Nonsuperconducting Elements

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The superconducting molybdenum, tungsten, and bismuth compounds indicate that the metals Mo, W, and Bi themselves are on the borderline of being superconductors.

Thus far the only superconducting compounds of definitely nonsuperconducting elements have been CuS[1] and $CoSi_2$.[2] As such they seemed to be in a rather unique position.

The recent discovery of superconductivity in the (NiAs) and (MnP) crystal structures change this situation entirely. In the (NiAs) structure the following compounds of nonsuperconducting elements become superconducting:

$$\mathrm{PdSb}\sim 1.5^\circ\mathrm{K},\quad \mathrm{PtSb}\sim 2.1^\circ\mathrm{K},\quad \mathrm{PtBi}\sim 1.21^\circ\mathrm{K},\quad \mathrm{PdTe}\sim 2.3^\circ\mathrm{K}.$$

In the (MnP) structure it is

$$\mathrm{IrGe}\sim 4.7^\circ\mathrm{K}.$$

PtBi cannot be considered a typical Bi compound, as $PtBi_2$ should and does not become superconducting.[3]

The underlying working hypothesis will be detailed in a later publication.

[1] W. Meissner, Z. Physik **58**, 570 (1930).
[2] B. T. Matthias, Phys. Rev. **87**, 380 (1952).
[3] N. Alekseyevsky, J. Exptl. Theoret. Phys. (U.S.S.R.) **20**, 863 (1950).

Reversal of Spontaneous Magnetization as a Function of Temperature in LiFeCr Spinels

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(Received March 11, 1953)

The spontaneous magnetization of the ferromagnetic oxides having spinel structure[1] has been explained by Néel's hypothesis[2] of ferrimagnetism, or noncompensated antiferromagnetism. A preponderant exchange interaction between the magnetic moments on tetrahedral (8a)[3] and octahedral (16d)[3] sites, respectively, results in antiparallel alignment of these

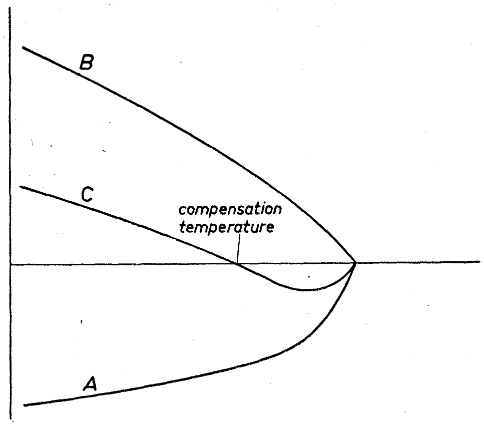


Fig. 1. A. Partial magnetization of tetrahedral sites *vs* temperature; B. partial magnetization of octahedral sites *vs* temperature; C. resulting spontaneous magnetization *vs* temperature. (After Néel, see reference 2.)

moments, and the spontaneous magnetization is thus the difference between the (unequal) partial magnetizations on tetrahedral and octahedral sites, respectively. This assumption has been amply verified by measurements of the saturation magnetization of various ferrites.[4–6]

The application of the neutron diffraction technique[7] has provided direct evidence for the correctness of Néel's hypothesis.

Néel pointed out[2] that the Weiss molecular fields for magnetic ions in the two crystallographic positions will be different because of the difference in numbers and spin orientations of the respective neighboring magnetic ions. Therefore, the curves giving the decrease of the two partial magnetizations with temperature will have different shapes. Thus Néel foresaw the possibility of the existence *inter alia* of a spontaneous magnetization that changes sign at a certain temperature (see Fig. 1).

We have investigated the series of mixed crystal spinels[8] $Li_{0.5}^{+}Fe_{2.5-a}^{3+}Cr_a^{3+}O_4^{2-}$ between $a=0$ and 2.0 and have found that this phenomenon occurs between $a=1.0$ and 1.6.

The saturation magnetization of $Li_{0.5}Fe_{1.25}Cr_{1.25}O_4$ *vs* temperature is shown in Fig. 2, curve I. In order to ascertain whether indeed the spontaneous magnetization changes sign, a rod of the material was saturated at a low temperature: the remanent magnetization was then measured in the absence of a magnetic field ($\perp$ the earth's field) as a function of temperature. Curve II

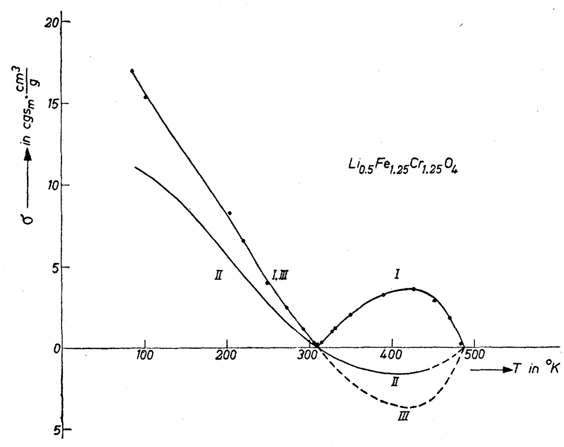
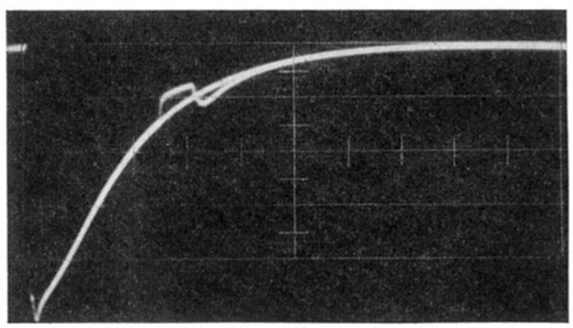


Fig. 2. I. Saturation magnetization of $Li_{0.5}Fe_{1.25}Cr_{1.25}O_4$ *vs* temperature. The points given are measured at 8000 Oe. Points measured at 6000 and 4000 Oe show no greater deviations from the drawn curve; II. residual magnetization of a rod of this material (arbitrary scale); III. spontaneous magnetization.



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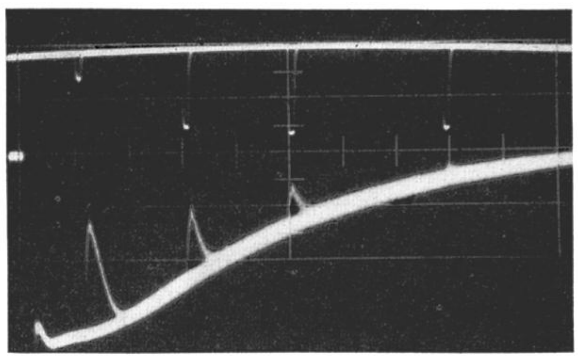

FIG. 2. Quenching by a microwave pulse of the afterglow in a decaying plasma established in neon at 1-mm Hg pressure. The time scale is 100 μsec per division, a 10-μsec pulse being introduced at 100, 300, 500, and 800 μsec after a 2-μsec discharge excitation pulse.