INFLUENCE OF AN EXTERNAL ELECTRIC FIELD ON THE EPR SIGNALS OF PAIRS OF EXCHANGE-COUPLED CHROMIUM IONS IN RUBY

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The linear pseudo-Stark splitting of EPR signals of individual chromium ions in corundum was observed in several investigations [1,2]. On the other hand, in addition to the signals of the individual ions in ruby, there were observed [3] many weaker supplementary signals, due to pairs of exchange-coupled chromium ions. The theory of the spectrum of such pairs was considered in [3-5]. A study of the EPR spectrum of exchange pairs in magnetically-dilute crystals is of interest to the theory of exchange (super-exchange) interaction in such substances. However, to study the exchange interactions by radiospectroscopic means [7,8] it is essential to have first of all effective methods for interpreting the EPR spectra of the exchange pairs. An investigation of the temperature dependence of the intensities and the angular dependence of the positions of the pair signals [3] does not always make it possible to interpret the spectrum uniquely.

We propose here an additional method of interpreting the spectrum of exchange pairs, based on an effect observed by us, namely the nonlinear splitting of EPR signals of pairs of exchange-coupled chromium ions (Cr^{3+}) in corundum.

This effect was predicted theoretically in [6], where it was shown that a noticeable splitting of the signals is to be expected for pairs of neighbors of the 4th, 6th, and 7th configuration spheres. In the case when H || E || C_3 (H and E are the intensities of the electric and magnetic fields and C_3 is the optical axis of the corundum), the nonzero splittings are those for the transitions

a) $E^{(3)}_{2g}, \pm 2 \longleftrightarrow E^{(3)}_{3g}, \pm 3 \quad (1)$ b) $E^{(3)}_{2g}, \pm 2 \longleftrightarrow E^{(3)}_{1g}, \pm 1 \quad (\frac{3}{5})$

c) $A^{(1)}_{2g}, 0 \longleftrightarrow E^{(3)}_{1g}, \pm 1 \quad (\frac{1}{5})$ d) $A^{(1)}_{2g}, 0 \longleftrightarrow E^{(1)}_{1g}, \pm 1 \quad (\frac{6}{5})$

(we use the notation of [5]). The parentheses after each transition contain the magnitude of the expected splitting, assuming as unity splitting the 3/2 ⟷ 3/2 signal of an individual Cr^{3+} ion.

We investigated experimentally the spectral regions from 480 to 680 G and from 850 to 1200 G, i.e., on both sides of the 3/2 ⟷ 3/2 signal of the Cr^{3+} ion, observed for 802 G at a resonant frequency of 9.27 Gcs. A corundum crystal containing 0.05% chromium (by weight) was investigated with the RE 1301 apparatus.

With H || E || C_3 the influence of the electric field was observed in five signals, which we denote α (525 G), β (590 G), γ (926 G), δ (994 G), and σ (1093 G). Figure 1 shows a plot of the derivative of the absorption signal σ at E = 0 kV/cm and E = 100 kV/cm. Figure 2 shows

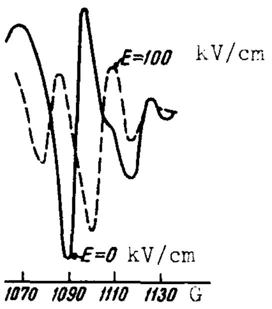

Fig. 1

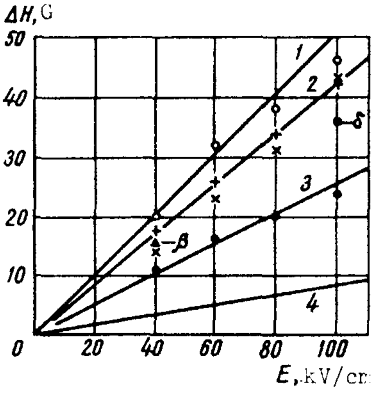

Fig. 2

the theoretical dependence of the splittings of the EPR signals on the values of the external electric field E for transitions of type d, a, b, and c (the lines 1, 2, 3, and 4 respectively), and the results of the experimental measurements for the signals α, γ, and σ (×, o, and • respectively). + denotes the results of the experiment for an individual Cr^{3+} ion ($3/2 \longleftrightarrow 3/2$ transition). The lack of exact data for β and δ is due to the weak intensity of these signals and the proximity of other signals.

Investigations by J. J. Krebs [7] convince us that the observed signals cannot be ascribed to Fe^{3+} and Mn^{2+} impurities. That these signals are due to pairs was further confirmed by the angular dependence of the signal positions.

It is seen from Fig. 2 that the signals σ, α, and γ can be ascribed to transitions b, a, and d, respectively.

A combination of the method of measuring the signal splitting in an electric field (which determines the type of the transition) and the methods involving temperature and angle measurements [3] will make it possible, in our opinion, to assign the signals to concrete pairs. We note, in particular, that signals with observable splitting should appear in the investigated region of the spectrum, according to theoretical calculations [5].

An investigation of the observed effect in magnetically dilute crystals in a wide range of magnetic fields will yield more complete information on the exchange interaction of paramagnetic ions.

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ELECTRIC BREAKDOWN THROUGH A FLAME

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An investigation of electric breakdown through a flame is of interest for gas-discharge physics, for shock-wave production under laboratory conditions, and for production of intense flashes, cumulative collapses, pinches, etc. at atmospheric pressures without surrounding the discharge with chamber walls and limiting the passage of radiation from the discharge or limiting the intensity of the resultant shock wave. (In this respect the investigated types of discharge are similar to discharges initiated by exploding wires [1,2].)

The plasma of the flame facilitates the cascade breakdown in the electric field, owing to the decrease in the density of the heated gas (the density is approximately one order of magnitude lower at a temperature of several thousand degrees than at normal temperature) as a result of thermal ionization and thermal excitation of the gas and of various emission effects on the electrodes. This decrease in the breakdown voltage makes it possible to produce breakdown in large discharge gaps with relatively low voltages.

The apparatus used for the research consisted of a battery and five capacitors of 150 μF each, charged to 5 - 10 kV and discharged through a vacuum discharge gap into the flame plasma. The discharge development was recorded by a high-speed camera (SFR). The flash of light was recorded with a photomultiplier and its energy measured with a special calorimeter. The current flowing through the plasma was measured with a Rogowski loop and reached several hundred kA.

A vertical flame jet was produced by a burner using a mixture of illuminating gas and oxygen. The temperature of such a flame usually does not exceed 2000°. One electrode was the body of the burner, and the other was a high-melting-point metal rod. To reduce heating, the electrode was placed in a stream of air which deflected the flame. The air stream was turned off prior to the discharge.

The experiment has shown that the initial breakdown voltage in the plasma is close to 1 kV/cm, which is several dozen times smaller than the breakdown voltage under normal conditions. A flame jet 10 cm long broke down regularly at 10 kV, and the flame was not extinguished after the breakdown. Figure 1 shows a series of photographs of the channel of the discharge through the flame, taken at 8 μsec intervals. The photographs show that the length of the intense-glow interval was approximately 150 μsec. Figure 2 shows a time sweep of the central part of the discharge.