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The authors congratulate Academician V.I. Ovcharenko on the occasion of his 70th jubilee

Breakdown Voltage in Argon, Nitrogen, and Sulfur Hexafluoride Gases as a Function of Temperature

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Abstract—The maximum intensity of the electrostatic field used in the study of its influence on the properties of magnetoactive coordination compounds is limited by the breakdown phenomenon. The breakdown of the gas medium is developed, as a rule, in the region of location of the studied sample and results in its destruction. The determination of optimum intensities of the electrostatic field is very important for successful accomplishment. The breakdown voltage in argon, nitrogen, and sulfur hexafluoride is studied in a temperature range of 80–300 K. The theory of breakdown appearance in gases makes it possible to assume an increase in the breakdown voltage with a decrease in the temperature of the studied gas. The following data are obtained by measuring the breakdown voltage under atmospheric pressure in the gas media between the planar electrodes remote at 0.7 mm: for nitrogen with decreasing temperature from 300 to 80 K, the breakdown voltage averaged over several measurements increases from 2.8 kV (field intensity $E \approx 40$ kV/cm) to 5.6 kV ($E \approx 80$ kV/cm); for argon with decreasing temperature from 300 to 90 K, this value increases from 1.4 kV (20 kV/cm) to 2.2 kV (31 kV/cm); and for elegas in the temperature range from 300 to 210 K, the average breakdown voltage increases from 5 kV (71 kV/cm) to 7.9 kV (113 kV/cm).

Keywords: electrostatic field, breakdown in gas medium, temperature dependence of breakdown voltage, IR microscopy, coordination compounds

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INTRODUCTION

Magnetoactive coordination compounds represent a broad class of substances studied in the area of molecular magnetism. One of the promising features of these systems is magnetic bistability: a possibility of molecules of the compound to exist in one of two magnetically nonequivalent states. Particularly, the compounds demonstrating phenomena of spin crossover [1–3] and nonclassical spin transition [4–6], valence-tautomeric complexes [7, 8], and other systems based on transition metal ions [9, 10] are among such systems. Significant changes in the magnetic, optical, and mechanical properties of the compound during the phase transition provide wide possibilities for their practical use in the production of new devices of superdense data storage. The external electrical field action is the most practical and convenient method for controlling spin states of isolated molecules.

The treatment of a sample with a high-intensity field (higher than 10 kV/cm) with the determination of the spin state of the complex by IR microscopy is one of the variants of studying the electrical field effect on the spin state of the magnetoactive molecular systems [11]. A breakdown between electrodes results in the destruction of the sample and forced halt of experiment. Therefore, preliminary studies on the determination of a temperature dependence of the breakdown voltage in various gases are necessary before experiments of this type. The choice of the gas optimum for the study makes it possible to beforehand determine maximum admissible intensities of the electrical field available in the required temperature range.

Breakdown in the gas medium is an avalanche-like ionization of the gas under the action of the external electrical field. Breakdown (gas discharge without external ionization radiation) occurs due to knock out electrons from the cathode by the working gas ions, further acceleration of the electrons in the electrical field, and subsequent impact ionization of atoms and

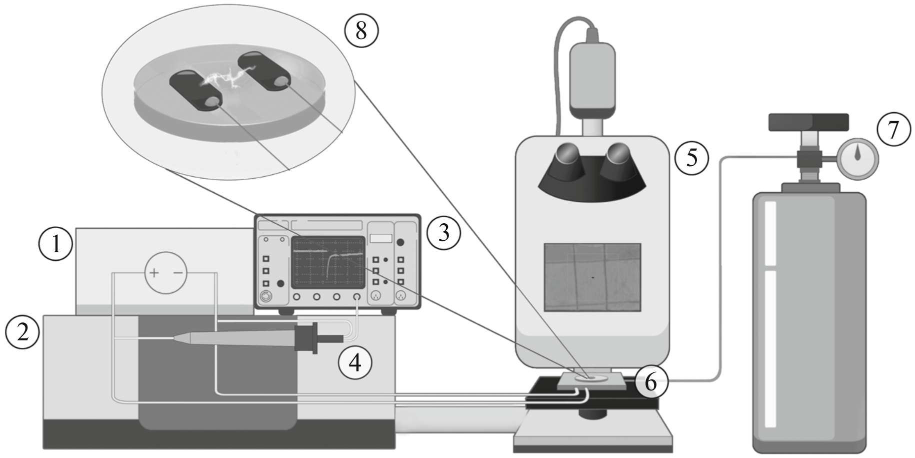

Fig. 1. Scheme of the experimental setup: (1) high-voltage source, (2) IR spectrometer, (3) oscillograph, (4) potential divider, (5) IR microscope, (6) modified sample stage of IR microscope, (7) high-pressure cylinder with working gas, and (8) object-plate of temperature stage with mounted electrodes.

molecules of the working gas [12, 13]. According to the theory of discharge appearance, the breakdown condition depends on both the gas itself and such its parameters as temperature and pressure.

In this work, we studied the temperature dependences of the breakdown voltage for three gases (argon Ar, nitrogen N_2, and sulfur hexafluoride SF_6 (elegas)) in the temperature range from 300 K to the temperature of condensation of each gas. Among the listed gases, elegas is most promising for the generation of high-intensity electrostatic fields. Elegas SF_6 represents a heavy inert gas and is a favorable medium for arc blowout. The high arc blowout properties of elegas are explained by the capability of SF_6 molecules of capturing free electrons to form poorly mobile heavy ions preventing the formation of electron avalanches [14]. A drawback of elegas as applied to the problem discussed is its high condensation temperature (~209 K), which does not allow this gas to be used at temperatures lower than the indicated one.

The character of the temperature dependence of the breakdown voltage in the gas can be evaluated from the conditions of the appearance of an independent discharge including the free path length λ [12]:

$$U = \frac{\Delta W_u d}{q\lambda \ln \dfrac{d}{\lambda\left(\ln\left(\dfrac{1}{\gamma}+1\right)\right)}}, \qquad (1)$$

where U is the breakdown voltage, d is the distance between the electrodes, ΔW_u is the ionization energy, q is the electron charge, and γ is the second Townsend coefficient reflecting the number of electrons knocked out from the cathode (unchanged for each gas) by one ion of the given gas [12].

At $d \gg \lambda$, the number of collisions in the gas is sufficient for the fulfillment of the dependence $\lambda \sim T^{1/2}$ obtained from the statistical concepts taking into account collisions of particles in the gas. Thus, the free path length increases with temperature and, hence, Eq. (1) allows one to assume that the breakdown voltage in the gas increases with decreasing temperature.

EXPERIMENTAL

A HYPERION 2000 IR microscope equipped with a Linkam FTIR600 temperature-controlled sample stage that makes it possible to change the temperature of the studied sample from 77 to 600 K was used to monitor breakdown in gases under an external electrical field. In this case, the temperature of the gas and electrodes located inside the stage changes. Temperature control was performed with a T95 System Controller instrument (Linkam Scientific Instruments, Great Britain).

Parallel-plane plates mounted in a BaF_2 object-plate of the temperature stage served as electrodes to which the voltage from a high-voltage source was supplied. A Sh0105 high-voltage power unit (Nauel, Russia) providing a potential difference at its outlets to 30 kV was used as a high-voltage source. The distance between the electrodes was 0.7 ± 0.1 mm. The scheme of the setup is shown in Fig. 1.

A resistive capacity high-voltage potential divider with the division factor 1 : 10000 and an oscillograph operating in the single launching mode were used to detect breakdown. The breakdown was detected on the oscillograph display with an increase in the voltage at the source outlet, which made it possible to determine the voltage preceding the breakdown. The superposition of the characteristic oscillograms obtained by the breakdowns of the studied gases makes it possible

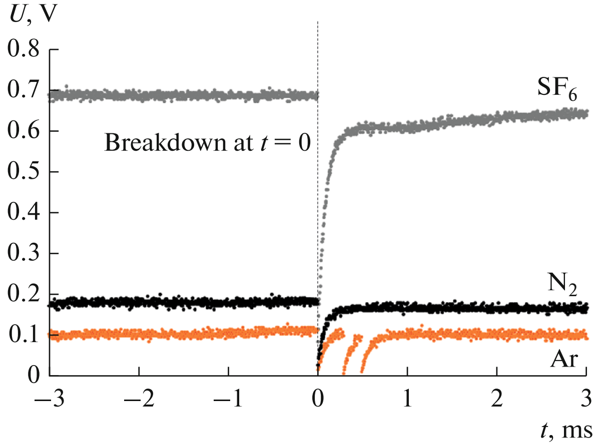

Fig. 2. Breakdown oscillograms of the studied gases detected at room temperature. The voltage at the divider outlet with the division factor 1 : 10000 is indicated at the ordinate.

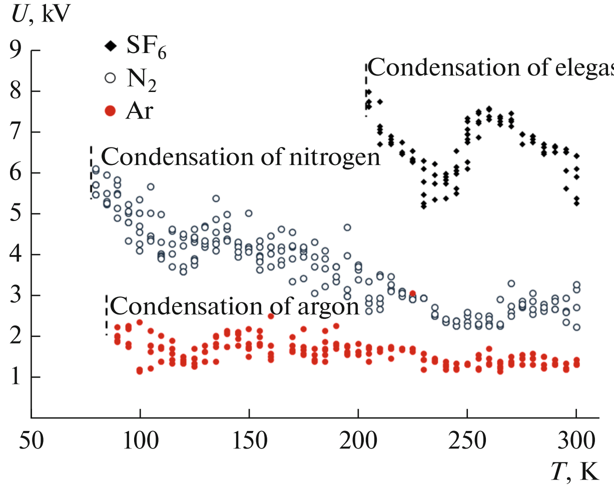

Fig. 3. Temperature dependences of the breakdown voltage in the studied gases: Ar, N_2, and elegas SF_6.

to clearly show distinctions of their insulation properties (Fig. 2).

The following temperature dependences of the breakdown voltage of the studied gases were obtained in the experiments: for argon Ar in the temperature range from 90 to 300 K, for nitrogen N_2 in the temperature range from 80 to 300 K, and elegas SF_6 in a temperature range of 210–300 K. An atmospheric pressure was maintained in the medium between the electrodes. A temperature increment was 5 K. Numerous measurements of the breakdown voltage of the gas were carried out for each temperature point in order to determine the maximum, minimum, and average values of the breakdown voltage.

RESULTS AND DISCUSSION

The final temperature dependences of the breakdown voltage of the studied gases are shown in Fig. 3. The data obtained for all gases are consistent with the evaluation of the character of the temperature dependence of the breakdown voltage reflected by Eq. (1), that is, the breakdown voltage increased with decreasing temperature. The experimental average breakdown voltage in nitrogen increased from 2.8 kV (corresponds to an electrical field intensity of 40.1 kV/cm) to 5.6 kV (80.7 kV/cm) with decreasing temperature from 300 to 80 K. In argon the average measured breakdown voltage increased from 1.4 kV (20 kV/cm) to 2.2 kV (31 kV/cm) with decreasing temperature from 300 to 90 K. However, in the case of elegas, a gradual increase in the breakdown voltage with decreasing temperature does not occur in the whole temperature range. A decrease in the temperature of the gas from 250 to 230 K is accompanied by a sharp decrease in the breakdown voltage of elegas. The breakdown voltage increases with the further temperature decrease from 230 to 200 K. In elegas the average breakdown voltages at the ultimate points were 7.9 kV (113 kV/cm) at 210 K and 5.9 kV (84 kV/cm) at 300 K.

The following conclusions can be drawn on the basis of the data obtained. As expected, the highest breakdown voltage was obtained for elegas and, hence, this gas is optimal for experimental studies of the electrostatic field effect on the properties of magnetoactive compounds in the temperature range from 210 K and higher. In similar experiments, elegas makes it possible to develop the electrical field intensity up to 80 kV/cm. If the studied features of the magnetoactive compounds (e.g., magnetic structural transitions) lie in the temperature range below 210 K, then nitrogen is the optimum gas for experiments: nitrogen makes it possible to operate in the temperature range from 80 K and higher but with lower limiting values of the electrical field intensity (to 40 kV/cm). In the case of changing the sample stage structure (e.g., increasing the distance between the plates with a high voltage), it is not necessary to obtain the full temperature dependence of the breakdown voltage but it is enough to determine the breakdown voltage at room temperature, since the breakdown voltage increases at lower temperatures. This work will be useful for researchers involved in studying the electrical field effect on the properties of various chemical objects, including coordination compounds.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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