Some of radiation regularities of the hydrogen in the gas discharge with water-solution cathode

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Abstract. The radiation of hydrogen in gas discharge, which ignited between a liquid electrolyte and copper electrode in the current range of 1–15 A was studied. As the liquid electrolyte, solutions of sodium chloride in distilled water with concentrations in the range of 2-10 g/l were used. Spectral studies were carried out in the visible region of radiation.

1. Introduction
When using water solutions as a cathode, the plasma is formed mainly from the components of the liquid-phase substance. One of them is hydrogen, which is part of the water. In the case of using an water solution of sodium chloride, hydrogen is released due to electrolysis processes at the cathode. Inside the aqueous solution, the sodium ions drift toward the negative electrode. On the surface of this electrode, they are reduced to form metallic sodium. Metallic sodium reacts instantly with water. This produces sodium hydroxide and hydrogen. Gaseous hydrogen floats up and enters the discharge zone. There are other possible mechanisms of the appearance of hydrogen in gas discharge. Plasma gas discharge with a water-solution cathode is enriched with hydrogen. Such plasma is promising for use in the processes of producing synthesis gas from carbon-containing waste by the plasma-chemical method [1-6]. The release of gases on electrodes contributes to appearance of various physical effects [7-8].

The spectral lines of hydrogen, in particular, the Balmer lines Hα and Hβ are studied in detail and are widely used in experimental practice. Using them, the parameters of arc plasma and spark discharge in various burning conditions are determined with sufficiently high accuracy [9–11]. The purpose of this work was to study the properties of a gas discharge with a water-solution cathode by hydrogen emission.

2. Experiment
The scheme of the experimental setup is shown in Figure 1. The electric discharge was ignited above the water solution I, which flowed upward from the cylindrical channel 2. The water solution served as a cathode. The negative electrode 3 was located inside the water solution, and the positive electrode 4 – above the water solution. In the experiments, sodium chloride solutions in distilled water with mass concentrations within 2-10 g/l were used.

Electric power was supplied from a two-half-wave rectifier. The studies were conducted in the range of currents of 1-15 A. The Voltage applied to the electrodes was varied in the range of 1500-2500 V.
The emission spectrum of gas discharge was studied using AvaSpec-3648 fiber-optic spectrometer in the wavelength range of 484-724 nm with a resolution of 0.15 nm (diffraction grating of 1200 lines/mm, input optical slit 10 μm).

Radiation of gas discharge was projected on the entrance of spectrometer 5 through node 6, consisting of the collecting lens and the optical gap. This optical node 6 was moved in three mutually perpendicular directions (along the X, Y and Z axes) by means of a coordinate device. Spectrometer 5 was functionally linked to computer 7.

To determine the hardware half-width of the spectrometer, a hydrogen lamp TBC-15 with a thin capillary channel in which a glow discharge was ignited was used. The lamp is filled with hydrogen at a pressure of 10^{-2} mm Hg. The lamp practically did not heat up when the discharge was burning. Under such conditions, the broadening of the spectral lines of hydrogen is insignificant. Therefore, the half-width of spectral line of hydrogen in spectrum of hydrogen lamp was adopted as the instrumental half-width of spectrometer. For the H\textsubscript{α} line, it was within 0.30–0.35 nm.

3. Experimental results and their analysis
Hydrogen radiation in cathode discharge region was detected. A thin radiating layer adjoined the water-solution cathode (Figure 1). Its thickness δ was in the range of 2.0-3.0 mm. With distance from water-soluble cathode, the intensity of spectral lines of hydrogen sharply decreased.

Figure 2. Spectral lines of hydrogen in survey spectrum of gas discharge. Concentration of water solution is 4 g/l. Discharge current is 10 A. Distance from the upper edge of cylindrical channel is 2 mm. Optical gap 1 mm. Integration time 400 ms.
For the registration of spectral lines of hydrogen H_α and H_β it took prolonged integration of spectrum. In this case, a significant number of pixels of the CCD detector were saturated in the overview spectrum (Figure 2). The saturation region was near the yellow D-sodium line, which is a doublet of lines 3^2P_{1/2} \rightarrow 3^2S_{1/2} (\lambda = 589.6 \text{ nm}) and 3^2P_{3/2} \rightarrow 3^2S_{1/2} (\lambda = 590.0 \text{ nm}).

The Balmer hydrogen line H_α (656.3 nm) corresponds to the radiative transition from level with excitation potential of 12.088 eV [12]. Therefore, the presence of the H_α line in the spectrum suggests the presence of high-energy electrons in the cathode region, capable of transferring hydrogen atoms from the ground state to the excited state with the 3d electron configuration.

The presence of H_α and H_β spectral lines in the spectrum made it possible to calculate the electron temperature T_e according to the method of relative intensities. The data necessary for calculation were taken from [13]. As example, Table 1 shows the numerical values of T_e, obtained from the emission spectrum of gas discharge at different currents. The cathode was water solution of sodium chloride with concentration 4 g/l.

Table 1. Temperature of electron gas.

| Discharge current (A) | Temperature of electron gas (K) |
|-----------------------|---------------------------------|
| 6                     | 4860                            |
| 10                    | 5040                            |
| 14                    | 4980                            |

Figure 3 shows profiles of spectral lines H_α, registered in hydrogen lamp radiation spectra TVS-15 and gas discharge. Discharge current was 12 A. Water solution of sodium chloride with concentration of 4 g/l was used as the cathode. The spectra of hydrogen lamp and gas discharge were recorded at the same integration time – 650 ms.

![Figure 3](image-url)
As can be seen, the contours of Hα spectral line of the gas discharge and hydrogen lamp practically coincide (Figure 3c). Only in the wings of profile does spectral Hα line of gas discharge receive a noticeable expansion. On the half-width of the spectral line expansion is absent. This result indicates the similarity of conditions for excitation of hydrogen atoms. It can be assumed that in the cathode region of gas discharge with water-solution cathode the concentration of electrons is almost the same as in a low-pressure glow discharge. As is known, it does not exceed 10^{11} cm^{-3} [14]. In gas discharge with water electrodes, the electron concentration obtained by absorbing microwave radiation is in the range (4-7)·10^{11} cm^{-3} [15].

4. Conclusions
The radiation of hydrogen atoms is present near water-solution cathode in a thin layer (2-3) mm thick. In the visible radiation region, the most intense are the Balmer lines Hα and Hβ. According to calculations using spectral lines Hα and Hβ the electron gas in the near-cathode region has a temperature of 5000±150 K. Spectral line Hα is subjected to a small broadening on the wings. The concentration of electrons in the hydrogen glow zone is almost the same as in the glow discharge of low pressure.

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