Physical Discharge Initiation (Ignition) Mechanisms

A great volume of experimental data on the electric breakdown of liquids that have been accumulated by the present time confirms repeated statements that there are several different breakdown mechanisms that cannot be described in the context of a unified theory.

For the discharge ignition stage, at least four mechanisms of discharge initiation can be identified: 1) bubble, 2) microexplosive, 3) ionization, and 4) electrothermal.

In the first case, the main role in discharge ignition is played by the gas that has already existed on the electrodes and in the liquid before field application. Ionization inside of gas bubbles results in their deformation and initiation of primary plasma channels. This discharge initiation mechanism is most probably realized in nondegassed liquids for voltage exposure times ranging from units to hundreds of microseconds and at standard or reduced hydrostatic pressure.

For the microexplosive discharge initiation, the events develop in the following sequence: electron emission into the liquid (the discharge from cathode) or ionization of liquid molecules (the discharge from anode) – fast local heating of the liquid by the current of induced charge carriers – shock wave generation and propagation – explosive vaporization behind the shock wave front – ionization of gas-vapor bubbles – initiation of a plasma channel. The main condition for realization of this discharge initiation mechanism is the high field strength near the electrode that can be achieved for nanosecond voltage pulse durations. Among the factors favorable for the realization of this discharge initiation mechanism are also a small tip radius of the initiating electrode (from units to tens of microns) and small (submillimeter) interelectrode distance.

The ionization discharge initiation mechanism implies the origin of the plasma channel due to autoionization of liquid molecules (anode initiation) or collision ionization (cathode initiation). In this case, energy liberation, first-order phase transition, and shock wave generation are among the secondary processes. The conditions for realization of this discharge initiation mechanism
are even more stringent than in the previous case: extremely high electric field strengths (more than $10^7$ V/cm) and very short voltage pulses ($10^{-8}$ s and shorter). In this case, the field strength is sufficient for ionization of liquid molecules, but the exposure time is insufficient for the first-order phase transition. The realization of this discharge type is favored by the increased hydrostatic pressure.

By the electrothermal discharge initiation mechanism is meant the following sequence of phenomena: high-voltage conduction current running under the effect of the electric field – heating up of the liquid in the near-electrode regions with maximum field strength – boiling up of the liquid – ionization of vapor-gas cavities – formation of a plasma channel.

This mechanism can be realized at large values of the product of the electrical conductivity of the liquid ($\gamma$) into the voltage pulse duration ($\tau$). Since for pulsed voltages $\tau$ does not exceed several hundreds of microseconds, this initiation mechanism is most probable for liquids with large $\gamma$ values, primarily for electrolytes.

According to the above-described classification and the logic prompted by the nature of the phenomenon itself, we now try to describe quantitatively the pre-discharge and discharge processes (some insight into which have already been gained by us or other researchers) or restrict ourselves to their physical interpretation. Exception is the electrothermal mechanism of the discharge ignition and propagation for which we only estimate the conditions of realization in Sect. 8.5. We have already presented experimental data on the electrothermal discharge in high-conducting liquids (in Sect. 4.2.4) and on the liquid electric strengths (Sect. 6.5.2).

This is explained by the fact that the authors of the monograph virtually did not investigate the electrothermal breakdown of liquids. We are not aware of the corresponding publications over the last 15–20 years. The computational models and experimental data were published previously (see References to the Foreword and Chaps. 4 and 6).

### 7.1 Bubble Discharge Initiation Mechanism

The significant dependence of the electric strength on the external pressure observed under a certain combination of breakdown conditions (see Chap. 6) gave us grounds to assume the important role of gases in liquid breakdowns. Physical models have been developed based on the processes describing the evolution of the gas already existed in the liquid or produced under the effect of the electric field. They considered the liquid breakdown under long-term exposure to dc or ac voltages. This approach to the pulsed breakdown caused serious objections mainly for three reasons:

1) Pulsed electric strength for a wide range of experimental conditions was independent of the pressure (Chap. 6).