The excitation of acoustic emission by a pulsed beam of protons with energy $E_p = 70$ MeV in methanol is investigated. Growth of the acoustic signal at the end of the proton trajectory is observed. The hydrodynamic characteristics of the acoustic emission are calculated on the assumption that the sources of elastic waves in the liquids are "microcavities" formed at the stopping sites of slow ionization electrons, i.e., so-called $\delta$ electrons.

The transmission of pulsed beams of charged particles and gamma quanta through metals is accompanied by the generation of observable elastic waves [1, 2], which are thermoacoustic in origin. Several papers lately have reported the observation of an increase in the acoustic signal induced in metals by beams of charged particles at the end of the trajectory of the latter [3, 4]. This acoustic peaking effect of heavy charged particles can only be explained within the context of the thermoaoustical theory of the origin of elastic waves [5]. A volume thermoelastic force is created by the formation of a temperature field at the place of origin of the charged-particle beam. In materials having a small thermal diffusivity in comparison with metals, typically the majority of liquids, the principal mechanism of the generation of elastic waves is probably emission by "microcavities" and "hot spots" formed at the stopping sites of slow ionization electrons, or $\delta$ electrons, in the substance [6, 7]. Sette and Wanderlingh [8] have investigated the influence of cosmic radiation on the cavitation strength of water, showing that a decrease of the cosmic-ray background increases the cavitation strength of water. It is customarily assumed that cavitation originates at vapor-gas nuclei, or microbubbles. These experiments, coupled with the registration of charged particles in bubble chambers [9], evidence the formation of microbubbles when charged particles are transmitted through stable and metastable liquids. The formation, collapse, and pulsations of microbubbles accompanying the transmission of charged particles through a liquid will necessarily result in the generation of elastic waves. In stable liquids, beams of the usual density do not cause "overlapping" of the energy-release zones of the particles (their tracks), and the acoustic waves comprise a superposition of waves from local sources. Measurement of the acoustic peak in liquids makes it possible to acquire information on the nature of the elastic waves over a wide range of heavy-particle energies. The present experiment was undertaken with this objective in mind.

The measurements were carried out at the ITEF (Institute of Theoretical and Experimental Physics) proton synchrotron, from which a pulsed beam of protons with energy $E_p = 70$ MeV and duration $\tau_b = 10^{-8}$ sec was extracted. A block diagram of the experimental arrangement is given in Fig. 1. The collimated proton beam 1 enters the measurement chamber 5, which is filled with methyl alcohol and has an effective thickness of 0.5 g/cm$^2$. The acoustic signal from the narrowband detector 6 is sent through the amplifier 7 and recorded on the screen of the oscilloscope 8. The pulsed beam current is measured with the transit-time induction loop 3 and, after amplification and shaping, is recorded on the digital voltmeter 9. The slave sweep of the oscilloscope and the digital voltmeter are triggered by a sync pulse from the accelerator 10. The energy is varied by means of the Plexiglas filters 4. The working frequency $f$ of the detector is chosen in accordance with the criterion

$$f \leq f_{\text{max}} = \min \left( \frac{1}{\tau_b}, \frac{s}{r_b} \right),$$

where $\tau_b$ is the duration of the beam, $r_b$ is the beam radius, and $s$ is the sound velocity in the liquid; this criterion permits adjustment for completely coherent reception of acoustic emission, $f = 27.5$ kHz, $\Delta f = 3$ kHz.

The experimental amplitudes of the acoustic emission are given in Fig. 2 as a function of the thickness of the reducing filters, along with the theoretical curve 1, which corresponds to the absorbed beam energy in the chamber on the assumption of monochromaticity of the proton energy after the reducing filters. The left part of the curve represents the specific ionization losses integrated over the thickness of the chamber, the maximum
The experimental dependence obtained here also enables us to determine all the hydrodynamic characteristics of the acoustic emission. Let us examine in closer detail the generation of elastic waves in liquids by beams of charged particles, assuming that the source of emission here comprises "microcavities" and "hot spots" formed at the stopping sites of slow ionization electrons, or $\delta$ electrons. At the end of the $\delta$-electron trajectory, at a distance $r_0$, an energy $\Delta E$ is released, whereupon local superheating takes place, $\Delta T = \varepsilon(v)/\rho C$, along with evaporation of the zone $r_0$, where $\rho$ is the density of the liquid, $\varepsilon(v) = \Delta E / \pi r_0^2$ is the absorbed energy density, $C$ is the heat capacity, and $r_0$ and $\Delta E$ are coupled by the energy-transit time relation. Under the action of the vapor internal energy the cavity nucleus expands to a certain maximum radius $r_f$, at which time its size is in equilibrium with the liquid surrounding the cavity. The expansion of the cavity to $r_f$ must take place in a time $\tau_f$ less than the time of dissipation of thermal energy from the zone $r_f$, i.e., $\tau_f < \tau_x = r_f^2 / 4 \chi$, where $\chi$ is the thermal diffusivity. From the energy balance relation between $\Delta E$ and the vapor internal energy [9] it is possible to determine what the initial vapor pressure $P_0$ in the cavity must be in order for the entire subsequent expansion process and emission of compression waves to be possible:

$$\Delta E = V_0 \cdot L \cdot \rho' + P_0 \cdot V_0 \cdot C_p \cdot \mu / R',$$

where $L$ is the specific heat of vaporization, $V_0$ is the volume of the incipient cavity nucleus, $\rho'$ is the vapor density, $\mu$ is the molecular weight, $R'$ is the gas constant, and $C_p$ is the heat capacity of the vapor. The initial pressure of the expanding cavity varies according to the law $P_t(x) = P_0 \cdot (r_0 / r)^{3 \gamma}$, where $\gamma$ is the polytropy exponent, which characterizes the state of the gas during expansion. Estimates show that the rate of expansion is less than the sound velocity $s$ in the liquid, so that during expansion we can consider the liquid to be incompressible and use the equations of linear acoustics.

The Rayleigh equation for an expanding cavity can be written in the form

$$P_0 \left( \frac{r_0}{r} \right)^{3 \gamma} = P + \frac{2 \sigma}{r} \cdot \frac{3}{2} \rho r^2 + \rho r^2 + 4 \gamma \frac{f^2}{r},$$

where $P$ is the hydrostatic pressure of the liquid, $\sigma$ is the coefficient of surface tension, $\nu$ is the viscosity of the liquid, and $\rho$ is the density of the liquid. From the point of view of thermodynamic behavior, in accordance with the relation between the radius $r$ of the cavity, on the one hand, and the acoustic and thermal wavelengths $\lambda_s$ and $\lambda_x$ in the gas occupying it, on the other, we discern two cases: 1) adiabatic, $\lambda_x < r < \lambda_s$; 2) isothermal, $r < \lambda_x < \lambda_s$. A change in the character of the process causes the elasticity of the gas in the cavity interior to change: $\lambda_x = 2 \pi \delta_x / \omega$, where $\delta_x = \sqrt{2 \chi / \omega}$ is the "penetration depth" of the thermal wave accompanying the acoustic oscillations. It is inferred from the estimates that the processes are isothermal for $r \lesssim 10^{-4}$ cm, with exponent $\gamma = 1$. From Eq. (2) we can determine the maximum radius $r_f$ of expansion of the cavity by allowing for