Observation of High-Pressure Phase Transition in Xenon Gas

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Investigating thermal neutron absorption in Xe +3% ^{3}He gas mixture, we have observed a phase transition in the gas at 0.18 g/cm^3 density and at room temperature.

Studies of the low-field mobility of electrons m in gaseous Xe have shown that at densities $n>3\cdot10^{20}$ cm^{-3} the value of (mn) for thermalized electrons is lower than expected from a simple gas phase theory[1]. The phenomenon was attributed to temporary localization of electrons in large atom clusters containing up to 100 atoms[2]. In this model, the high-density xenon was considered as a two phase medium consisting a dense phase (clusters) that can trap electrons and a low density phase surrounding the clusters, which acts as a potential barrier to prevent electron transport from one cluster to another[3]. In optical investigations[4], it was found that the xenon gas is losing its transparency to electroluminescence light due to increasing resonance absorption of excitons trapped into clusters at densities $n>3\cdot10^{20}$ cm^{-3}. Moreover, a relative number of photons originating from excitation luminescence (scintillation) and the scintillation decay time were found to decrease in the same density range[5]. All these facts have been interpreted in terms of steady raising concentration of clusters when the density of xenon is increasing.

In this study we used a large-volume (25-cm length and 9-cm in diameter) gas cylindrical ionization chamber filled with a pressurized Xe +3% ^{3}He gas mixture. Xenon atoms have a relatively large (4.6 barn at 0.5 MeV) cross-section of photoabsorption for gamma radiation, while ^{3}He atoms have an extremely large cross-section for absorption of thermal neutrons (5330 barn). Thus, the selected gas mixture can effectively absorb both gamma rays and neutrons. The absorption of gamma quanta by xenon atoms leads to the generation of electrons with ranges of a few millimeters. Thermal neutrons absorbing in ^{3}He yield a triton and a proton, which share the reaction energy of E_o=764 keV plus the kinetic energy of the incident neutron (actually, negligible for thermal neutrons): $^3\mathrm{He} + \mathrm{n} \rightarrow {}^3\mathrm{H} + \mathrm{p} + 764$ keV, where energy E_t = 191 keV, E_p = 573 keV. The products of the nuclear reaction have small ranges in high density Xe. For example, assuming a uniform distribution of Xe atoms at a density of 0.3 g/cm^3, one can estimate the ranges of a 573 keV proton and a 191 keV triton to be 170 and 50 µm, respectively. Therefore, short-ranged particles can be used as a more precise tool than electrons or photons to probe inhomogeneities of high-density xenon.

To produce thermal neutrons, we used a 30 µCi AmBe source placed in a water moderator shielded with 5-cm thick lead. The source was located at a 50 cm distance from the chamber. Electrical signals originated by radiation absorbing in the gas were measured with a charge-sensitive preamplifier and standard spectrometric equipment (see for example [5,6]). Fig. 1 shows pulse height spectra measured with neutrons at 295 K and 0.047 g/cm^3 (a), 0.11 g/cm^3 (b), 0.17 g/cm^3 (c), and 0.24 g/cm^3 (d) densities of Xe +3% ^{3}He gas mixture. The density of

Xe was determined by measuring the capacitance between the two chamber's electrodes as described in the reference[6]. The net count rate of thermal neutrons was about 8 counts per second, which corresponds to a neutron flux of 0.2 n/sec/cm^2. We found that the shape of the peak corresponding to the thermal neutron absorptions is sensitive to the gas density. The geometrical width of the peak changes rapidly around the density $r_t = 0.18$ g/cm^3 (Fig. 2a). At densities $<r_t$, the peak has a Gaussian shape. At higher densities (measured up to 0.35g/cm^3), the peak has a step-like shape similar to that commonly observed in low-pressure neutron detectors suffering from the wall-effect[7]. The wall-effect dominates when ranges of the ionizing particle clusters is comparable to the detector size. In our case, the ranges of tritons and protons originating from the neutron capture in ^{3}He are less than 0.2 mm at gas densities of >0.18 g/cm^3. This means that the wall-effect associated with collisions of protons and tritons with the detector walls has a negligibly low probability.

For comparison, we measured the gamma ray spectrum of a ^{22}Na gamma ray source. The width of the 511 keV gamma ray peak in the pulse height distribution was found to be practically insensitive to the Xe density in the same density range (Fig. 2b).

We believe that the observed threshold changing the shape of the peak in the pulse height distribution is a direct indication of formation of two phases in high-pressure xenon gas. Indeed, the electron-ion recombination inside a cluster is expected to be much stronger than in the gaseous phase. Therefore, the large clusters may act as walls for the heavily ionizing and short-range particles, and simulate the wall-effect. The rapid changes in the width of the peak at $r_t = 0.18$ g/cm^3 ($n_t = 3 \cdot 10^{20}$ cm^{-3}) is a signature of the phase transition from the homogeneous to structured medium. One can estimate that the average distance between clusters is about 50-μm (the range of tritons at the density r_t).

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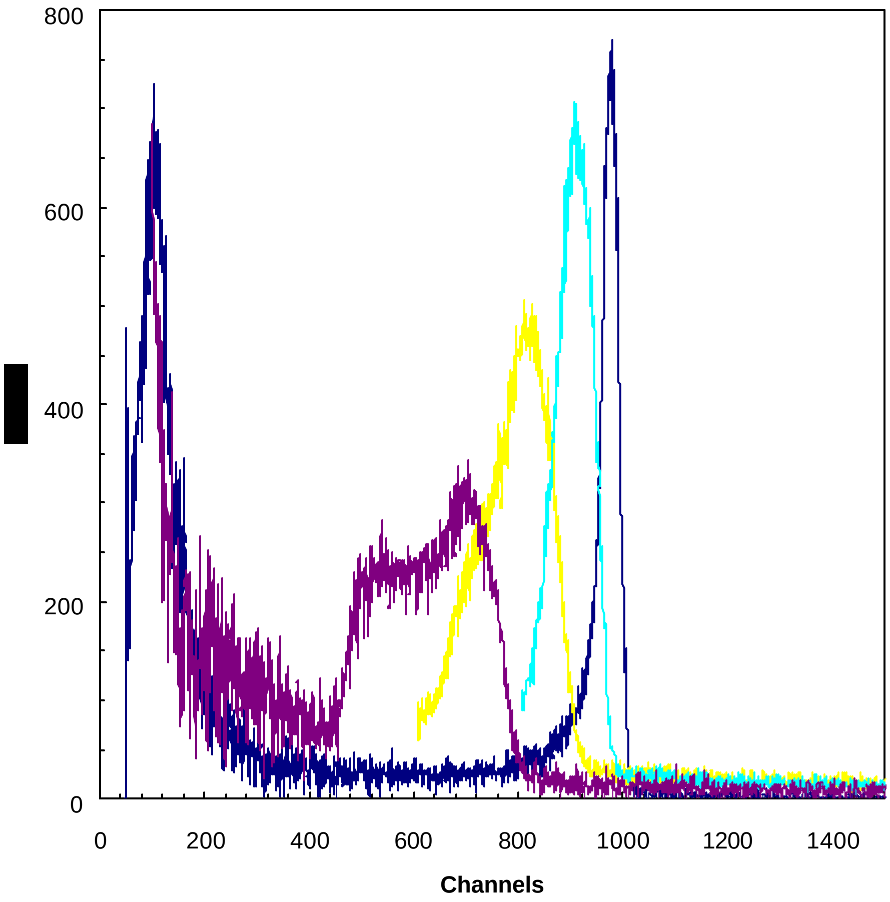
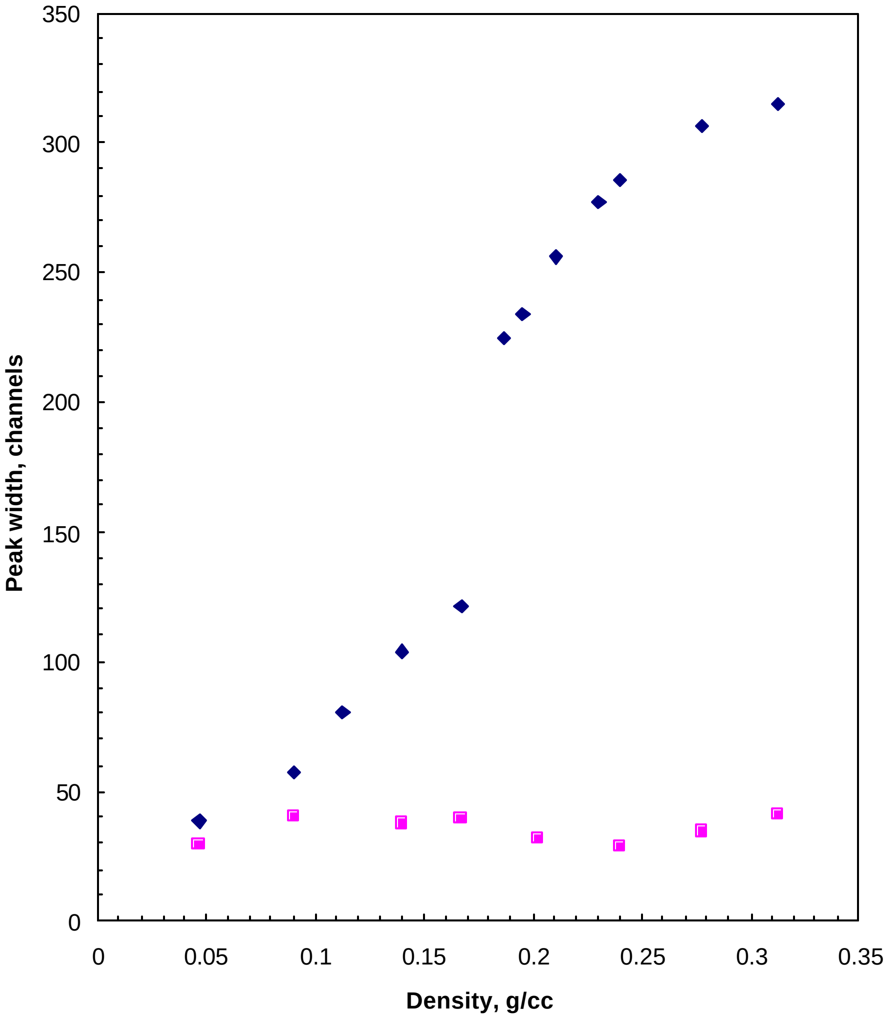


Fig.1. Pulse height spectra measured with thermal neutrons at 295 K and 0.047 g/cm^3 (a), 0.11 g/cm^3 (b), 0.17 g/cm^3 (c), and 0.24 g/cm^3 (d) densities of Xe+3%^{3}He gas mixture. The spectra were measured at the same acquisition time, gamma ray backgrounds has been subtracted in cases (a) and (d).



Fig,2. Geometrical width of pulse height distribution in dependence of the gas density for thermal neutrons (a) and 511 keV gamma rays (b).

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