Some Mechanisms of “Spontaneous” Polarization of Superfluid He-4

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Abstract Previously, a quantum “tidal” mechanism of polarization of the atoms of He-II was proposed, according to which, as a result of interatomic interaction, each atom of He-II acquires small fluctuating dipole and multipole moments, oriented chaotically on the average. In this work, we show that, in the presence of a temperature or density gradient in He-II, the originally chaotically oriented tidal dipole moments of the atoms become partially ordered, which results in volume polarization of He-II. It is found that the gravitational field of the Earth induces electric induction \( \Delta \varphi \sim 10^{-7} \text{ V} \) in He-II (for vessel dimensions of the order of 10 cm). We study also the connection of polarization and acceleration, and discuss a possible nature of the electric signal \( \Delta \varphi \approx k_B \Delta T / 2e \) observed by A.S. Rybalko in experiments with second sound.

Keywords Helium-4 · Electrical activity · Dipole moment · Acceleration

1 Introduction

In a series of fine experiments, A.S. Rybalko, E.Ya. Rudavskii, S.P. Rubets, et al. obtained a number of interesting results testifying that the atoms of superfluid He\(^4\) possess electric properties [1–4]. In studies of both a standing second-sound half-wave in He-II [1] and torsional oscillations of a film of He-II [2], the alternating electric voltage \( U \) synchronous, respectively, to the second sound and torsional oscillations was observed. This voltage was not related to external electromagnetic fields (in experiments [1], the external voltage was present and is supplied to a heater, but...
its frequency is twice less than that of the observed signal $U$) and can be a consequence of the volume polarization of He-II. The effects [1, 2] were not explained up to now, though the attempts to elucidate the experiment with second sound [1] were made in a number of works [5–9].

Free atoms of He$^4$ create no electric field far from themselves, because they have zero charge and zero dipole and multipole moments. However, an atom of helium, being surrounded by other atoms, can acquire a dipole moment (DM), which follows from the tidal mechanism [8, 10–13], by which a DM is induced by the interaction with neighboring atoms (we call the mechanism “tidal”, since the deformation of electron shells of atoms in this case reminds gravitational tides). In what follows, we will show that a dielectric is polarized due to the gradient of concentration $n$ or temperature $T$. The effect arises at the consideration of the interaction of atoms. Also we will study the connection of polarization and acceleration. The idea of inducing the polarization by the concentration gradient was earlier considered in [6, 12, 14, 15]. Below, we will carry on a more exact analysis and determine the volume polarization of He-II in a second-sound wave.

2 Polarization of He-II Due to a Gravitational Field and the Gradients of Density and Temperature

It is obvious that a single atom freely falling in a gravitational field $g$ is not polarized, since the gravity force causes the same acceleration $g$ of the nucleus and electrons of the atom.

Consider a dielectric (He-II), being at rest in a gravitational field. The gravity force acting on every atom of a dielectric in the equilibrium state, should be balanced by the difference of interatomic forces which act on the given atom from the side of neighboring atoms. This means that, in this case, the concentration gradient must exist in the dielectric. We now evaluate the polarization of He-II induced by the gravitational field. We start from the equations of two-fluid hydrodynamics [16, 17]

$$Dv_s/Dt = -\nabla \mu + g,$$

$$\rho Dv/\rho = -\nabla p + \rho g,$$

$$(3) dp = \rho d\mu + SdT.$$

In the absence of macroscopic motions ($v_n = v_s = 0$), we get

$$\nabla \mu = g, \quad \nabla p = \rho g.$$  (4)

Let us consider that $\rho = \rho(p, T)$, and $\nabla T = 0$ in the stationary case. Then

$$\nabla p = \frac{\partial p}{\partial \rho} \nabla \rho \approx \frac{\partial p}{\partial \rho} \nabla \rho = u_1^2 \nabla \rho.$$  (5)

Relations (4) and (5) allow us to determine $\nabla \rho$ which compensate the gravity force:

$$\nabla \rho = \rho g/u_1^2.$$  (6)