Institute of Solid State Physics of the Russian Academy of Sciences

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NONLINEAR WAVE AND VORTEX MOTIONS ON THE WATER SURFACE

PhD Dissertation Summary

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DISSERTATION TOPIC

A turbulent system is a highly excited system with many freedom degrees and a directed energy flow in the space of freedom degrees. Along with vortex turbulence, wave turbulence plays a crucial role in many processes that occur both on Earth and in the Universe. It is the object of intensive researches in many phenomena: wave and vortex processes on the ocean surface, in the atmosphere, in plasma, etc. Turbulent vortex processes play a key role in the determination of weather and climate events.

Although turbulent wave and vortex systems have been studied by many researchers for the past few decades, the complexity of the objects under study and the variety of arising effects leave open a lot of questions, in particular, questions regarding system interaction, energy transfer and dissipation. The present dissertation provides the study of energy dissipation in the weakly turbulent system of capillary waves on the surfaces of water and liquid hydrogen, as well as the study of vortex motion which arises as a result of the weakly nonlinear wave interaction on the water surface.

The **goals** of the present dissertation have been:

1. To study the peculiarities of energy distribution over the dissipative region of stationary turbulent spectra in a wave system on the liquid surface.
2. To study the position of the end of the inertial interval of a turbulent cascade in a wave system on the liquid surface.
3. To study the processes of the generation of vortex motion by waves on the surface and in the bulk of a liquid.

To achieve the stated goals it has been necessary to solve the following **tasks**:

1. To construct experimental setups to study the generation of vortex motion in the system of capillary waves and in the system of gravity waves.
2. To study energy distribution over the high-frequency region of a turbulent cascade in the system of capillary waves on the liquid hydrogen surface at different characteristics of wave excitation.
3. To study energy distribution over the high-frequency region of a turbulent cascade in the system of capillary waves on the water surface at different spectral characteristics of wave excitation.
4. To study energy distribution over the high-frequency region of a turbulent cascade in the system of capillary waves on the water surface in experimental cells with different geometries.
5. To study the conditions of the formation of vortex motion by a wave system on the water surface.
6. To study the formation of a vortex system under different conditions of the excitation of surface waves.

Scientific novelty

1. The “quasi-Planck” spectrum in the system of capillary waves on the liquid hydrogen surface has been observed experimentally for the first time.
2. A new mechanism of the formation of vortex motion by nonlinear waves on the liquid surface has been observed experimentally for the first time.
3. The formation of vortex motion by waves on the liquid surface has been studied experimentally under different conditions of excitation.

Practical significance

In the present dissertation, we have studied experimentally energy distribution over the dissipative region of a turbulent cascade in a wave system on the water surface and the charged surface of liquid hydrogen, and we have experimentally discovered and studied a new mechanism of the generation of vortex motion by the nonlinear interaction between noncollinear waves on the liquid surface. Knowledge of the mechanisms of energy dissipation in turbulence, as well as of energy transfer from a wave system to a vortex system, is important for the understanding of many applied and fundamental problems, in particular, for the understanding of nonlinear energy transfer on the surface of the Global ocean and the dynamics of large-scale planetary atmospheric vortices.

KEY RESULTS AND CONCLUSIONS

Key aspects to be defended

1. The “quasi-Planck” spectrum in a turbulent energy cascade in the system of capillary waves on the liquid hydrogen surface has been observed experimentally for the first time.
2. The power dependence of the characteristic frequency of exponential energy decay in the dissipative region of a turbulent cascade in the system of capillary waves on the liquid hydrogen surface on the amplitude of broad-band pumping has been observed experimentally.
3. It has been shown experimentally that under the excitation of a turbulent state on the water surface by monochromatic or broad-band pumping, the characteristic frequency of the high-frequency end of the inertial interval and the characteristic frequency of exponential energy decay in the dissipative region increase with an increase in the pump amplitude by the power law.
4. It has been shown experimentally that vortex motion arises on the liquid surface as a result of the interaction between nonlinear waves propagating at an angle to each other.
5. The process of the formation of vortex motion by two perpendicular standing waves has been studied experimentally in the case of both capillary and gravity waves on the water surface.
6. The dependence of the amplitude of vortex motion on the amplitude and relative phase of two perpendicular standing waves has been measured experimentally.

Personal contribution. All the experimental data presented in the dissertation have been obtained with the author’s direct participation. The dissertation has been prepared in the Laboratory of Quantum Crystals, Institute of Solid State Physics of the Russian Academy of Sciences, from 2009 to 2019.

PUBLICATIONS AND APPROBATION OF THE RESEARCH

The first author is Filatov Sergey, except JETP Letters 2011, JETP Letters 2012, UFN 2012

First-tier publications

1. S.V. Filatov, V.M. Parfenyev, S.S. Vergeles, M.Yu. Brazhnikov, A.A. Levchenko, V.V. Lebedev, "Nonlinear Generation of Vorticity by Surface Waves", Physical Review Letters, **116**, 054501 (2016), doi: 10.1103/PhysRevLett.116.054501

Second-tier publications

1. M.Yu. Brazhnikov, L.V. Abdurakhimov, S.V. Filatov, A.A. Levchenko, "Quasi-Planck" spectra of capillary turbulence on the surface of liquid hydrogen, JETP Lett. 2011.V. 93. P. 34., doi: 10.1134/S0021364011010024
2. L.V. Abdurakhimov, M.Yu. Brazhnikov, A.A. Levchenko, I.A. Remizov, S.V. Filatov, Turbulent Capillary Cascade near the Edge of the Inertial Rangeon the Surface of a Quantum Liquid, JETP Letters, Vol. **95**, No. 12, pp. 670–679. (2012) doi:10.1134/S0021364012120028
3. L.V. Abdurakhimov, M.Yu. Brazhnikov, A.A. Levchenko, I.A. Remizov, S.V. Filatov, Kinetic and discrete turbulence on the surface of quantum liquids, UFN, **55**, 8, pp. 818-825 (2012), doi: 10.3367/ufne.0182.201208i.0879
4. S.V. Filatov, M.Yu. Brazhnikov, A.A. Levchenko, A Method for Spatial Recording of Waves on the Surface of a Transparent Liquid, Instruments and Experimental Techniques, Vol. **56**, No. 6, pp. 731–735 (2013), doi: 10.1134/S0020441214010199
5. S.V. Filatov, M.Yu. Brazhnikov, A.A. Levchenko, Generation of a Vortex Flow by Waves on the Surface of a Liquid, JETP Letters, Vol. **102**, No. 7, pp. 432–436 (2015), doi: 10.1134/S0021364015190054
6. S.V. Filatov, M.Yu. Brazhnikov, A.A. Levchenko, A. M. Lihter, Turbulence in the System of Capillary Waves on the Surface of Water, Journal of Surface Investigation: X-ray, Synchrotron and Neutron Techniques, Vol. **10**, No. 5, pp. 1060–1066 (2016), doi: 10.1134/S102745101605027X

7. S.V. Filatov, S.A. Aliev, A.A. Levchenko, D. A. Khramov, Generation of Vortices by Gravity Waves on a Water Surface, JETP Letters, Vol. **104**, No. 10, pp. 702–708 (2016), doi: 10.1134/S0021364016220082

Reports at conferences and seminars

The key results of the dissertation have been reported at the following conferences:

1. 1. XXIV-th Scientific Session of the Council of Nonlinear Dynamics of the Russian Academy of Sciences (Russia, Moscow, 2015)
2. 2. Scientific School "Nonlinear Waves – 2016" (Russia, Nizhny Novgorod, 2016)
3. VIII-th International Conference "SOLITONS, COLLAPSES AND TURBULENCE: Achievements, Developments and Perspectives"(SCT-17) in honor of Evgeny Kuznetsov's 70th birthday (Черноголовка, Россия, 2017)
4. The 11th International Conference on Cryocrystals and Quantum Crystals (Finland, Turku, 2016)
5. 5. Scientific School "Nonlinear Waves – 2018" (Russia, Nizhny Novgorod, 2018)
6. 12th International Conference on Cryocrystals and Quantum Crystals(Poland, Wroclaw, 2018)

CONTENTS AND STRUCTURE OF THE DISSERTATION

The dissertation consists of an introduction, five chapters, and conclusion. The total volume of the dissertation is 82 pages including 44 figures. The list of references includes 49 items.

The **general description of the dissertation** provides the proofs of the relevance of the dissertation topic, states the goals of the dissertation and ideas to be defended, and describes the structure of the dissertation.

The **Introduction** provides a review of scientific literature on the problem under study.

Chapter 1 is devoted to the experimental study of the peculiarities of energy distribution over the dissipative region of a stationary turbulent spectrum in the system of capillary waves on the liquid hydrogen surface. It describes the experimental setup and discusses the experimental results.

Chapter 2 provides the results of the experimental study of the peculiarities of energy distribution over the dissipative region of a stationary turbulent spectrum in the system of capillary waves on the water surface, as well as the position of the high-frequency boundary of the inertial interval depending on the amplitude and type of pumping.

Chapter 3 is devoted to the study of the generation of vortex motion as a result of the interaction between nonlinear capillary waves propagating at an angle to each other on the water surface.

Chapter 4 is devoted to the experimental study of the generation of vortex motion as a result of the interaction between nonlinear gravity waves propagating at an angle to each other on the water surface.

Chapter 5 is devoted to the experimental study of the penetration of a vortex lattice, generated by the interaction between nonlinear waves, to the liquid bulk.

The **Conclusion** contains the enumeration of the key results of the dissertation.