Influence of Impurities on the Laser Induced Breakdown in Liquid He^4

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Dedicated to Professor Dr. H. Maier-Leibnitz on his 60th birthday

The threshold power for laser induced breakdown in liquid He^4 has been investigated above and below the λ-transition. The results seem to indicate that the threshold power is mainly determined by the impurity content of the liquid.

Recent experiments [1–4] on laser induced breakdown in compressed helium gas and in liquid helium suggest that optical breakdown is caused by an electronic avalanche mechanism [5]. According to this mechanism the threshold power for optical breakdown should increase with decreasing electronic scattering rate, or with atomic density since electrons are mainly scattered by atoms. This close relationship between the threshold power and the atomic density has indeed been observed both in helium gas [1–3] and in liquid helium from 4.2 °K to 2.2 °K [3, 4].

At lower temperatures, however, WINTERLING, HEINICKE and DRANSFELD [4] observed a strong temperature variation of the threshold power, which increased by one order of magnitude on cooling from T_λ to 1.5 °K, although the atomic density remains almost constant in this temperature interval.

In this communication we present evidence that this anomalous temperature dependence is not caused by a temperature dependent electronic scattering rate as suggested previously [4, 6] but by the impurity content of the liquid.

The Role of Initial Electrons

ABRIKOSOVA and BOCHKOVA [3] as well as WINTERLING and HEINICKE [7] have observed an interesting time dependence of the threshold power: The initial optical breakdown required the highest available laser power, while subsequent breakdowns a few minutes later could be produced by a power which was about one order of magnitude smaller. This reduction only disappeared if the time interval between pulses was larger than 30 minutes.

Theoretically, optical breakdown in pure helium can only occur at moderate threshold powers *if there is at least one free electron* in the focal volume [5] of the liquid when the laser pulse is arriving. Therefore the question arises whether the relatively high threshold power observed for the first breakdown is simply caused by the lack of an initial electron, and whether the electrons — left over from the first breakdown — are responsible for igniting the subsequent breakdown at a much lower threshold power.

In order to check this assumption we injected electrons from a hot cathode [8] into the liquid sweeping them into the focal volume by an electric field (50 V/cm). From the measured current density ($2 \cdot 10^{-11}$ A/cm^2) and the known electronic mobility [9] the number of electrons in the focal volume was estimated to be at least 10^3. This high density of electrons (6 orders of magnitude higher than the natural background [10]) produced no observable influence on the threshold power neither for the first nor for subsequent pulses. — WINTERLING, HEINICKE and DRANSFELD [4] reached essentially the same conclusion from their experiments: By a dc electric field they swept away all charge carriers out of the focal volume. This removal of electrons prior to inducing breakdown had again no influence on the observed threshold power.

The Role of Impurities

From the above observations one can safely conclude that a considerably higher density of free electrons must be necessary for the production of breakdown. Presumably impurities alone, having a much lower ionisation energy than helium atoms, produce the first copious supply of electrons when the laser pulse arrives.

If no special precautions are taken to purify liquid helium, it may have an impurity content of one part per million or more, not only of He^3 but also of microcrystallites of air and other materials which can be easily ionized in the initial phases of each laser pulse. If the number of free carriers generated this way inside the focal volume exceeds about 10^6 the threshold power for optical breakdown is expected to decrease noticeably [5].

Since these foreign materials have mostly a density higher than that of the liquid, they are able to sediment out, only rather slowly in He I, but relatively fast in superfluid He II [11].

[1] R. G. MEYERAND and A. F. HAUGHT, Phys. Rev. Letters **11**, 401 [1963].
[2] D. H. GILL and A. A. DOUGAL, Phys. Rev. Letters **15**, 845 [1965].
[3] I. I. ABRIKOSOVA and O. M. BOCHKOVA, Zh ETF Pis. Red. **9**, 285 [1969]. (English transl.: Sov. Phys. JETP Letters **9**, 167 [1969].)
[4] G. WINTERLING, W. HEINICKE, and K. DRANSFELD, Phys. Rev. **185**, 285 [1969].
[5] YA B. ZEL'DOVICH and YU P. RAIZER, J. Exptl. Theoret. Phys. (USSR) **47**, 1150 [1964]. *(English transl.: Sov.* Phys. JETP **20**, 772 [1965].
[6] M. SILVER, J. P. HERNANDEZ, and D. G. ONN, Phys. Rev. **A1**, 1268 [1970].
[7] G. WINTERLING and W. HEINICKE, private communication.
[8] G. E. SPANGLER and F. L. HEREFORD, Phys. Rev. Letters **20**, 1229 [1968].
[9] K. W. SCHWARZ and R. W. STARK, Phys. Rev. Letters **22**, 1278 [1969].
[10] C. BLANK and M. H. EDWARDS, Phys. Rev. **119**, 50 [1960].
[11] P. SAVICH and A. I. SHAL'NIKOV, J. Physics **10**, 299 [1946].

If the breakdown is indeed promoted by sedimenting impurities one would except the threshold power to increase in time if the liquid is kept in the superfluid state:

1) When the liquid was maintained at 1.9 °K for 30 minutes we observed an increase of the threshold power by one order of magnitude.
2) At the same temperature the threshold power decreased again by similar amount if the sedimentation of the impurities was prevented, for example, by simply stirring the liquid mechanically.

All these observations lead to the conclusion that the presence of impurities in liquid helium plays a very important role in the observed process of optical breakdown.

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Curie-Weiß Temperature Dependence of Paraelasticity *

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Anelastic strains exceeding elastic strains up to a factor of 30 have been observed close to the critical point of H in Nb. The temperature dependence of the relaxation strength follows a Curie-Weiß law for temperatures

$$(T-T_c)/T_c \geqq 6\cdot 10^{-3}\,.$$

I. Introduction

The Curie-Weiß type temperature dependence of magnetic or dielectric susceptibilities as well as of the compressibility of real gases have been known for long time. Only recently the analogous temperature dependence has been discovered for the elastic response of a solid, namely niobium loaded with hydrogen [1]. Actually this system shows elastic properties which are a mixture of those of a solid and a real gas. This peculiar behaviour results from the fact that hydrogen in metals like Nb behaves like a gas in the space of the metallic host lattice [2]. The phase diagram for H in Nb [3] shows a miscibility gap separating the lattice-gas- and lattice-liquid-phases and ending in a critical point.

The properties of the lattice gas can be studied experimentally by means of the elastic diffusional relaxation process (Gorsky effect) [4]. The relaxation strength Δ_E of the Gorsky effect is given by [5]

$$\Delta_E = \frac{\varepsilon_a}{\varepsilon_e} \sim \left(\frac{\partial \mu}{\partial \varrho}\right)^{-1}_{iso} \sim \varkappa_{iso}\,,$$

ε_e = elastic strain, ε_a = total anelastic strain, μ = chemical potential, ϱ = density of the lattice gas, $\varkappa_{iso}$ = isothermal compressibility of the lattice gas.

For the critical density ϱ_c the compressibility approaches infinity for $T \to T_c$. Therefore the relaxation strength should diverge as it approaches the critical point.

II. Experiments

Static Gorsky-effect measurements have been performed in a torsion pendulum apparatus. The sample consisted of a Nb-spring, loaded with the critical concentration of 34 at.-% H. Both the relaxation strength and the relaxation time have been measured as a function of temperature. More experimental details have been published in Ref. [6].

1) Relaxation Strength

Usually, elastic after-effect phenomena are at maximum in the percent region of the elastic strain. Fig. 1 shows as a counter-example an elastic after-effect curve as measured for a $NbH_{0.34}$ — sample at 181 °C. The anelastic strain ε_a exceeds the elastic strain by a factor of 20, and still remains fully reversible. Fig. 2, in which

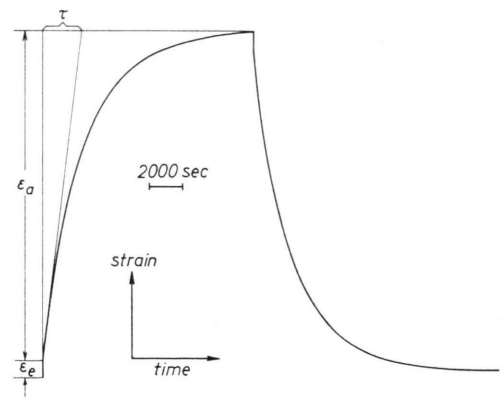

Fig. 1. Recorder chart of a measured elastic after-effect curve for Nb+34 at.-% H at 181 °C.

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* Troubles caused by elastic after-effects of gold foils in a gold-leaf electrometer were the starting point for a research program, initiated by Prof. H. MAIER-LEIBNITZ, finally leading to the discovery of ferro-elasticity.

[1] G. ALEFELD, G. SCHAUMANN, J. TRETKOWSKI, and J. VÖLKL, Phys. Rev. Letters **22**, 697 [1969].

[2] G. ALEFELD, Phys. Stat. Sol. **32**, 67 [1969].

[3] R. J. WALTER and W. T. CHANDLER, Trans. AIME **233**, 762 [1965].

[4] G. SCHAUMANN, J. VÖLKL, and G. ALEFELD, Phys. Rev. Letters **21**, 891 [1968].

[5] G. ALEFELD, J. VÖLKL, and G. SCHAUMANN, Phys. Stat. Sol. **37**, 337 [1970].