Photo-electron emission directly in superfluid helium

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Photo-electron emission directly in superfluid helium

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Abstract. Despite the fact that electron transport in condensed helium has been studied for over half a century [1], observations of new intriguing effects still appear [2]. Alas, the traditional methods of injecting electrons into condensed helium (radioactive-sources, electrical discharge or field emission) lead to generation of helium ions, recombination of which is accompanied by emergence of a large number of excitations. As a result, interpretation of such experiments is not simple and sometimes may be questionable. In this respect, photoelectron emitters, which operate with energies substantially smaller than the ionization energy of helium, are preferable. However, immersion of the photocathode into condensed helium suppresses electron emission. Nevertheless, we managed to achieve electron currents (>20 fA) with the In photocathode immersed directly in liquid superfluid helium. The UV light (λ=254 nm) was guided to the photocathode through a two-meter long Al-covered quartz optical fiber.

1. Introduction

For many low-temperature experiments a source of electrons in liquid helium is required. Such a source should emit a controlled amount of electrons, whose energy should be sufficiently low not to create high energy excitations. In addition, the process of electron emission has to draw the minimum possible power into the low-temperature system.

There are several traditional methods to produce electrons with, namely a hot tungsten filament, a glow discharge, a radioactive source, or a field emission tip. Being placed in superfluid helium, a hot filament produces a significant flow of excitations. As to the other methods, they create high-energy electrons, causing ionization of helium. Resonant photons, arising in the ionization-recombination process, easily pass through retarding grids and carry sufficient energy to contribute to the creation of a large number of excimers and other metastable helium states [3, 4] in the entire volume of the experimental cell. Some of them are long lived excitations in liquid helium both above and below the λ-point [5, 6]. As a result, the interpretation of experiments is not simple and sometimes may be questionable. In this respect, the method of photoelectron emission, which operates with energies substantially smaller than the ionization energy of helium, seems preferable.

Unfortunately, when immersing the photocathode into liquid helium, the value of photo-injected electron current ($I_{\rm liq}$), in relation to the one measured under the same conditions in vacuum ($I_{\rm vac}$), becomes substantially smaller. This behavior can be characterized by the attenuation coefficient $J = I_{\rm liq}/I_{\rm vac}$.

In the simple and ingenious experiment[7], intended to measure the energy required to inject an electron into liquid helium, the cesium-antimony photocathode was immersed in liquid helium,

cooled to a temperature of 1.1 K. In this case, the attenuation coefficient J turned out to be equal to 10^{-6}.

In the experimental work [8] the steady-state photoelectron current arising from an Au cathode, which was immersed in liquid He at 4.2 K and irradiated by a deuterium lamp, was studied. The attenuation J was measured as a function of applied field strength, E. At E=10^3 V/cm the value of J comprised $4 \cdot 10^{-6}$, and at E=10^5 V/cm the value of J increased to 10^{-3}. In this experiment, the UV radiation power falling on the photocathode was not explicitly specified, however, given the magnitude of the photocurrent in vacuum ($I_{\text{vac}} = 3 \div 5$ nA) is already quite informative.

In [9] the cesium photocathode at T=1.33 K was used. Photoelectron currents through gaseous ^{3}He or ^{4}He and through thin liquid ^{3}He films, were investigated. It was found that the growth of a ^{3}He film on Cs can be studied up to a film thickness of 1.5 nm. Beyond that, the tunnel current is so low (<100 fA) that it is comparable with the noise in the electrometer used. As for ^{4}He, the photocurrent vs film thickness dependency was not studied, because ^{4}He does not wet Cs at T<2 K, even if the Cs is formed by quench condensation, which creates a relatively rough surface.

In the above-mentioned works the photocurrents in the bulk He were obtained at the very special conditions, namely, by using the UV radiation near the vacuum-ultraviolet edge [8] that makes it problematic to use optical fibers for delivery radiation to the photocathode, or using alkali metals that degrade easily and need to be *in situ* prepared [7, 9], which imposes strong limitations in their practical implementation.

The few practical realizations of cryogenic photoemissive electron sources has been described in [10, 11] but they were not used to work in the bulk He and so far have been mainly used above the helium surface to create a surface layer of electrons.

2. Experimental setup

A high-pressure mercury lamp was used as a source of 253 nm UV radiation. At a distance of $\sim$ 60 mm from the lamp the Avantes$^{\text{TM}}$COL collimating lens of 6 mm diameter and 8.7 mm confocal length was placed with an electromechanical shutter just before the lens. The UV-radiation was transmitted by the lens onto the end of Al-shielded 2 m long quartz fiber, whose diameter of core was 600 mkm and the numerical aperture was 0.22. According to the manufacturer information, absorption of the optical fiber at the working wavelength did not exceed 300 dB/km, which was quite acceptable. The optical fiber was passed into the cryostat through a silicone seal.

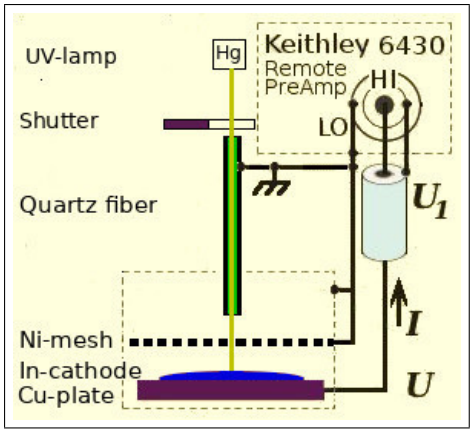

Figure 1. The measuring scheme. Radiation from the UV mercury lamp passes through the electromechanical TTL-driven shutter, enters the experimental cell through the quartz optical fiber, and generates photoelectrons at the cathode. The measuring scheme of a diode type with a grounded grid (mesh) was used. Sourcing U potential and measuring I current was provided by the Keithley$^{\text{TM}}$6430 Sub-Femtoamp SourceMeter. The triaxial cable with a cable guard, supported at almost the same potential U_1 as the potential U, was used to minimize the problem of capacitance and leakage currents in measuring wiring. Shutter control was also performed by the SourceMeter with its digital I/O ports.

The lamp's radiation power passing into the experimental cell through the fiber was not exceed 20 uW. To measure this value, we used the platinum resistance thermometer which was installed in place of the photocathode and calibrated for power by measuring its current-voltage characteristics.

To study photoemission a diode scheme was used (see Figure 1). The UV light passed through the optical fiber, then through a nickel 130-mkm mesh (transparency of 70 percent) that served as a collector, and reached the photocathode. The distance between the mesh and the photocathode was 0.3 mm. The photocathode used was an indium drop, soldered on a copper substrate and mechanically cleaned before each low-temperature experiment session. Using the optical constants of In obtained in [12] it is possible to estimate that its reflectivity for 253 nm UV-light does not exceed 40%.

For measuring ultra-low photoemission currents the Keithley^{TM}Model 6430 Sub-Femtoamp SourceMeter with the remote preamplifier was used. It combines the voltage sourcing (-200 to $+200$ V) and high sensitivity measurement functions (0.4 fA noise).

To minimize the problem of capacitance and current leakage in measurement circuit, a shielded triaxial cable was used. The center conductor (HI) is surrounded by the inner shield, which acts as the cable guard. The source-meter keeps the shield at potential U_1 which practically the same as the potential U at HI terminal ($U_1 - U < 1$ mV).

3. Experimental results

At first, the preliminary experiments measuring photoelectron current at T=300 K in vacuum were carried out. The necessary evacuation was produced with a standard backing pump. It turned out that, under continuous illumination of the cathode, the photocurrent decreased with time exponentially and went to saturation after 10–30 min (in relation with the pumping extent), thus relaxed from 0.6 to 0.16 nA, respectively. This effect could be explained by redistribution of charges on dielectric parts of the experimental cell. In order to bring the system to its initial state, it was sufficient to switch off the UV-lamp and to fill the cell with gaseous helium.

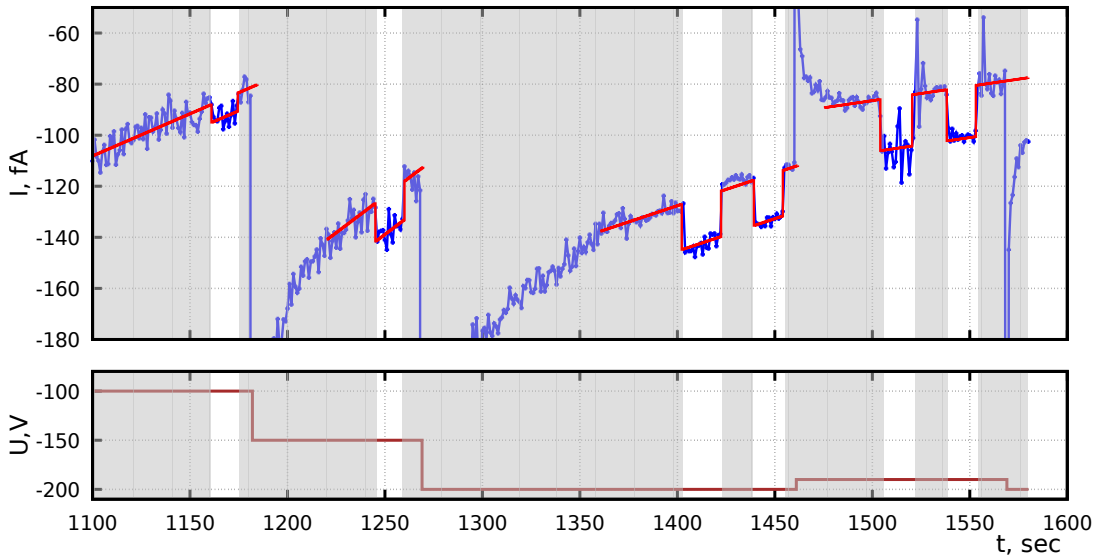

Figure 2. The time-chart fragment of the measured current, I (blue) and its linear-piecewise approximation (red) clearly show the photocurrent steps. Dark and light areas correspond to the modulation of the UV beam with the electromechanical shutter. The cathode potential, U is shown in the lower part of the diagram (brown).

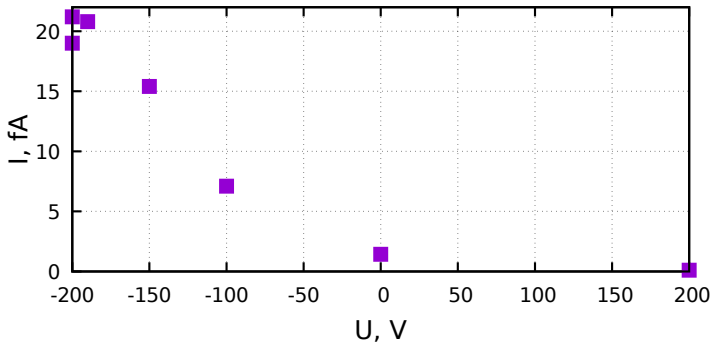

Figure 3. Photoelectron current vs. cathode potential. (The information obtained after the analysis of the measured charts.) The cathode was immersed in liquid helium at T=1.5 K .

Measurements in liquid helium at temperatures above the λ-point were not possible due to acoustic noise of boiling process, which led to electrical interference in the measuring circuit. That is why all the low temperature measurements were carried out at T=1.5 K.

Figure 2 shows a portion of a chart recording during the time interval, in which the potential of the cathode was changed four times. The graph demonstrates both the current relaxation processes caused by changes in the cathode potential, and the effect of UV-radiation modulation. This graph also shows the result of linear-piecewise approximation of the experimental data, which allowed us to reveal the contribution of photoelectrons with a sensitivity of ≈ 1 fA, that was close to a value corresponding to the highest sensitivity of the Keithley$^{\text{TM}}$6430 electrometer.

Figure 3 presents the dependence of photoelectron current vs. cathode potential. The maximum value of 20 fA was observed at the cathode potential of -200 V, which corresponds to field strength of $E \approx 7000$ V/cm. Based on this data and considering that the measured value of the corresponding photoelectric current in vacuum was 0.16 nA, we can estimate the attenuation coefficient value, $J = 1.2 \cdot 10^{-4}$, which constitutes the coordinates of a point that surprising exactly falls on the LHe curve shown in Fig.2 in [8]. Note that the power of illumination of the photocathode is substantially less than in [8]. This can be judged by comparing the magnitudes of the corresponding photocurrents in vacuum. In [8] ($I_{\text{vac}} = 3 \div 5$ nA) and in our case ($I_{\text{vac}} = 0.6 \div 0.16$ nA).

We have previously mentioned the phenomenon of photoelectron current relaxation, which apparently can arise due to photoelectrons precipitating on dielectric parts of the experimental cell. It is hoped, that by optimizing the cell design, this parasitic effect can be reduced and, thus, we can count on a tenfold increase of the photoelectron currents with the same optical setup.

4. References

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