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A STUDY OF NEUTRAL EXCITATION CURRENTS IN LIQUID HELIUM

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Résumé.- On montre que les excitations neutres, produites dans une décharge tout près d'une extrémité pointue en tungstène, se déplacent à la vitesse de l'écoulement du fluide. Les mesures de la durée de vie de ces excitations, qui atteignaient parfois trois secondes, ont été effectuées.

Abstract.- Neutral excitations generated in a discharge near a sharp tungsten tip are shown to move with the velocity of the flowing fluid. Neutral excitation lifetimes as large as three seconds are measured.

A current of neutral excitations created in the presence of a $^{210}_{90}$ alpha source submerged in liquid helium was first reported by Surko and Reif. \(/1/\). These excitations, which were shown not to be photons, travelled in straight lines for distances of the order of 1 cm at temperatures below 0.45 K, did not respond to electric fields of the order of $10^5$ V/cm, and produced $\text{He}_2^+$ ions and electrons at the free liquid surface. They detected these excitations by either collecting the charges created at the free surface or by the use of a surface ionization detector placed in the liquid. These authors suggested the possibility that the neutral excitations were long lived metastable atomic $^2S_1^+$ or diatomic $^3\Sigma_u^+$ states.

Rayfield \(/2/\) modulated the neutral excitation current with the application of an electric field in the source region and measured the lifetime of these excitations, presumably limited by neutral-neutral collisions on the liquid surface \(/3/\), to be $\sim 1.4$ ms. This is greater than the 15 μs lifetime \(/4/\) of the longest lived metastable atomic state, $^2S_1^+$, in the liquid.

In this note we report a study of neutral excitations created in a discharge at a field emission tip operated in liquid helium in the temperature range 1.1 K - 4.2 K. A cross section of our cylindrically symmetric pentode is shown in figure 1. It consists of a field emission tip, collector grid $G_1$ which serves to collect the tip current, a suppressor grid $G_2$ which blocks charges from passing beyond $G_1$, and two grids $G_3$ and $G_4$ which serve as the two electrodes of a metal detector for neutral excitations. The diameter of the channel is 0.95 cm and the electrode separations are: tip - $G_1$, 0.2 cm; $G_1$ - $G_2$, 0.1 cm; $G_2$ - $G_3$ - $G_4$, 1.3 cm; $G_3$ - $G_4$, 0.1 cm. All grids are 16 lines/cm and have a transparency of 0.58.

The experiment consists of applying a square wave voltage to the field emission tip. Charges moving from the tip to $G_1$ under the influence of an electric field exert a force on the fluid via momentum exchange collisions. This force sets the fluid in motion and excitations travel with the fluid to $G_3$ where electrons are ejected from the metallic grid when neutral excitations strike it. These electrons are collected on $G_4$. The time of flight of neutral excitations is determined by the delay in the detector response after a square wave voltage is applied to the tip.

A typical set of signals is shown in figure 2. The delay time for the onset of the detector signal $\tau$ is plotted versus $$(\mu I)^{1/2}$$ in figure 3 for a negative tip current $I$ at 4.2 K. With the mobility $\mu$ and $I$ given in c.g.s. units, the best fit to the data including the origin as a fixed point is...
Fig. 2 : Tip current and neutral excitation detector current response to a square wave voltage applied to the field emitter tip

\[ \eta = 2.05 \left( \mu \ell / I \right)^{1/2}. \]  

The longest transit time measured was 3 seconds in a cell with a longer drift space.

The above transit time for neutrals includes the time required to accelerate the fluid from rest. The steady state velocity of the fluid for a given tip current is determined by increasing or decreasing the tip current for a time short compared to the transit time, thus creating a density variation in the neutral current. A comparison of the time delays of the detector for an increase and a decrease in the tip current yields the steady state fluid velocity, \( u = L/\tau_u \), where \( L = 1.6 \text{ cm} \) is the tip - \( G_1 \) separation. The steady state transit time is related experimentally to \( \tau \) by \( \tau_u \approx 0.8 \tau \).

A theoretical expression for the steady state fluid velocity is obtained by equating the force \( F_I \) exerted on the fluid via the ions to the drag force \( F_d \) of the fluid on the grids. The force due to ions is

\[ F_I = \int n e \vec{d}_I^+ \cdot \hat{z} \, dz = \frac{I}{u}, \]

where \( b \) is the tip to \( G_1 \) separation. The drag force on a cylinder is given by \( F_d = \frac{1}{2} C_d \rho v^2 \ell d \), where \( C_d \) is empirically determined function of the Reynolds number, \( \rho \) is the fluid density, \( v \) is the undisturbed stream velocity, and \( \ell \) and \( d \) are respectively the length and diameter of the cylinder. For our experimental parameters, \( C_d = 1.3 \). For grids of high transparency \( \tau_u \) composed of circular wires, \( F_d \) can be written as

\[ F_d = \frac{1}{2} N C_d \rho \ell (1 - \tau_u)/\tau_u \]

where \( N \) is the number of grids of area \( A \), and \( u = v \tau_u \) is the velocity of the fluid far from the grid wires. The calculated steady state transit time is \( \tau_u = 1.92 \sqrt{u/I} \). The time \( \tau \) for the first neutral to arrive at the detector is calculated by taking into account the acceleration of the fluid and for our parameters is given by \( \tau = 1.3 \tau_u = 2.50 G/I \).

This 20 % agreement between theory and experiment is within the accuracy of the calculation and input parameters. The fluid velocity was checked by measuring the transit time for charges to drift to the detector with a field free drift space and found to agree with the neutral excitation transit times.

The agreement between the measured and predicted transit times shows that the neutral excitations observed here move with the flowing fluid and are not collective excitations propagating with a velocity relative to the liquid. The upper limit of 3 seconds on the lifetime of the excitation is strong evidence that the excitations observed in this experiment are \( \alpha_3^+ \) metastable helium molecules. The longest lived singlet state \( \alpha_3^+ \) is 300 us \( /6/ \). This identification is supported by the molecular transition \( \alpha_3^+ \rightarrow \alpha_3^+ \) observed by one of us (A.J.D.) in the discharge near a field emission tip. If the identification of the neutral excitation as an \( \alpha_3^+ \) molecule can be made, then the upper limit of the lifetime of this state is extended by a factor of 30. It cannot be proved that the excitations observed here are the same as those observed by Surko and Reif \(/1/\), and Rayfield \(/4/\) under different conditions.

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