4. A. B. Migdal. Sov. Phys. JETP 16 (1964) 1366.
5. G. M. Eliashberg. Sov. Phys. JETP 14 (1963) 886.

6. J. Gavoret and P. Nozières, Ann. of Phys. 28, 349.
7. H. Winter, Z. Phys., to be published.

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# EVIDENCE FOR A SUPERFLUID-INDUCED SURFACE BARRIER FOR ELECTRONS IN LIQUID HELIUM

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The free surface of liquid helium acts as an energy barrier on electron currents across the surface into the vapor, if the liquid is superfluid. In zero electric field, the barrier vanishes at $T_\lambda$. The measurements were performed in pure $^4$He and in a solution of $^3$He in $^4$He.

Bruschi et al. [1] have reported that for temperatures less than 1.7°K electrons encountered increasing difficulty to pass through the free surface of liquid $^4$He into the vapor phase, if the temperature is lowered. Below 1.5°K the electron current decreased rapidly according to $\exp(-\phi/k_B T)$, with $\phi/k_B = 25 \pm 1$°K. This behavior was mainly attributed to the image-force potential which acts on a charge near the interface of two media having different dielectric constants. The effect of the image-force potential outside the liquid was recently discussed in detail by Cole and Cohen [2]. Using the assumption of the image-force, however, it can be readily shown, that the work function $\phi$ must depend on the extracting field $E$, in contradiction to the results of ref. [1]. In addition, the saturation of the currents at 1.7°K remained unexplained since this temperature is much smaller than the barrier. Therefore, we made a special effort to determine $\phi$ with a higher accuracy. Besides pure $^4$He we also investigated a solution of $^3$He in $^4$He. Our results demonstrate that the barrier depends not only on the applied field but also on the temperature, giving clear evidence that the barrier is present only in the superfluid state.

The measuring cell was similar to that shown in ref. [1], consisting of three electrodes as indicated in fig. 1. We measured the currents when the liquid level was *above* the collector and compared them with the corresponding currents when the liquid surface was *below* the collector. The currents with the collector being immersed were nearly temperature independent, in agreement with ref. [1]. On the other hand, when the liquid level was lowered below the collector the current showed a striking dependence on the temperature as plotted in fig. 1 for different extracting fields. For example for a field of 154 V/cm the current remains temperature independent from 4.2°K down to 1.7°K. Only below 1.7°K the current decreases rapidly with temperature as $\exp(-\phi/k_B T)$, indicating an effective energy barrier $\phi/k_B = 30.4$°K, which the emitted electrons have to overcome. It is evident that this positive energy barrier only exists well below 1.7°K and apparently disappears when this temperature is exceeded. It is essential to point out that for lower extracting fields the energy barrier disappears at higher temperatures, which approach the $\lambda$-point for zero extracting fields. The same behavior is observed in a solution of 32% $^3$He in $^4$He below the shifted $\lambda$-point of 1.66°K. Thus a finite energy barrier for the emission of electrons from liquid helium seems to be closely related to the superfluid state.

Besides this temperature dependence of the barrier it is important to emphasize that $\phi$ also
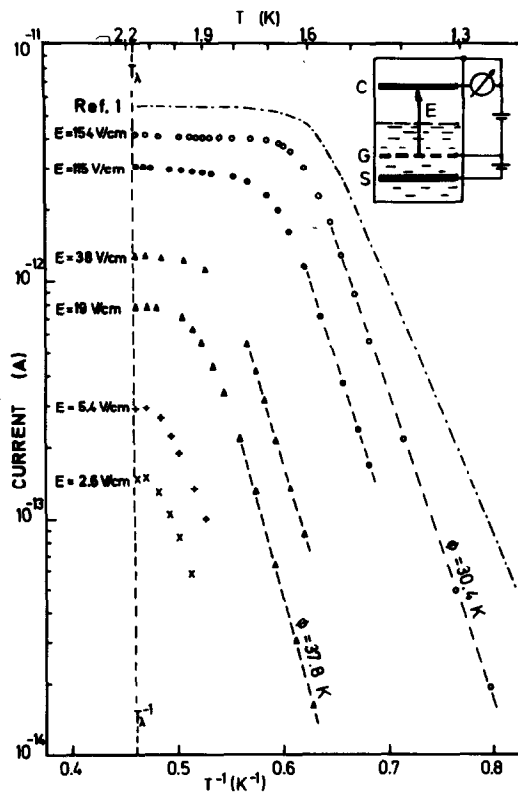
Fig. 1. Measured collector current through the surface
of liquid $^4$He as a function of the temperature at dif-
ferent extracting fields $E$, indicated in the insert to-
gether with the electrode structure of the gold plated
measuring cell (collector C, grid G, and radioactive
source S). The slopes of the dashed curves yield the
effective energy barrier $\phi(E)$. The relative current
values of ref. [1] are indicated by the dash-dotted curve.

depends on the extracting field. This conclusion
can be reached not only from the behavior at
higher temperatures described above but also
from the fact, that at the lower temperatures the
slope of the curves in fig. 1 (dashed lines) de-
pends clearly on the extracting field.

A full account of the experimental results in-
cluding a detailed description of the temperature
and field dependence of the surface barrier will
be presented elsewhere together with a tentative
explanation.

Finally, it should be mentioned that the ob-
served absence of a surface barrier in rotating
helium for electrons trapped in vortex lines [3]
could now be considered as a possible conse-
quence of the normal fluid vortex core proposed
recently by Glaberson, Strayer and Donelly [4].

*References*

1. L. Bruschi, B. Maraviglia and F. E. Moss, Phys.
   Rev. Letters 17 (1966) 682.
2. M. W. Cole and M. H. Cohen, Phys. Rev. Letters 23
   (1969) 1238.
3. W. Schoepe and K. Dransfeld, Phys. Letters 29A
   (1969) 165.
4. W. I. Glaberson, D. M. Strayer and R. J. Donnelly,
   Phys. Rev. Letters 21 (1968) 1780.

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