Royal Holloway

UNIVERSITY OF LONDON

MSci EXAMINATION

LOW TEMPERATURE PHYSICS CP4500A

SUMMER 1998

Time Allowed: TWO HOURS

Answer **TWO** questions only. No credit will be given for attempting a further question.

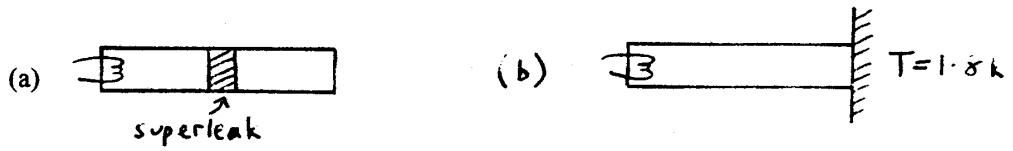
Each question carries 20 marks. The mark *provisionally allocated* to each section is indicated in the margin.

TURN OVER WHEN INSTRUCTED

CP4500A
PART MARKS

1. (i) Discuss in detail the assumptions of the two fluid model of superfluidity in liquid ^{4}He. [5]

(ii) In terms of this model discuss, qualitatively and quantitatively, and using the data provided, the effect of turning on the heater inside the cylindrical tubes containing superfluid ^{4}He shown in (a) (with a superleak) and (b) (without). In both cases the radius of the tube is 0.01m and the length 0.1m. [5]



Note that: In (a) the system is thermally isolated and the heater is turned on until there is a temperature difference of 10mK between the left hand side and right hand side of the superleak, the initial temperature being 1.8K.

In (b) a steady heater power Q *is supplied, such that there is a temperature gradient corresponding to a temperature difference of 10mK along the length of the tube with the temperature of the right hand wall held at 1.8K*

(iii) For case (b) calculate the heater power Q required to produce the temperature gradient given. Show that the effective thermal conductivity of the column of superfluid ^{4}He is of order that of high purity annealed copper at the same temperature (1000 $WK^{-1}m^{-1}$). Briefly state the difference in the processes of heat conduction in copper and superfluid ^{4}He. [4]

(iv) Discuss qualitatively any differences in the observations when the experiments are repeated at 1.2K. [3]

(v) The macroscopic wavefunction describing the ground state of ^{4}He is of the form

$$\Psi(r) = \Psi_0 \exp[\, i\, \varphi\, (r)]$$

State the physical interpretation of Ψ_0 and $\varphi\,(r)$ in terms of parameters of the two fluid model. Show how this order parameter leads to vortex excitations, for which the circulation is quantized.

[3]

Some properties of superfluid ^{4}He

Temperature (K)	Entropy ($J\,K^{-1}\,kg^{-1}$)	Density ($kg\,m^{-3}$)	Normal viscosity ($kg\,m^{-1}s^{-1}$)
1.8	550	150	130
1.2	51	150	182

3. Liquid ^{3}He is a strongly interacting Fermi system with the following properties at very low temperatures

- The low temperature heat capacity is proportional to temperature, $C = \gamma T$, but the coefficient γ is greater than that for an ideal Fermi gas of the same density and atomic mass. The enhancement of γ increases with increasing pressure.
- The nuclear magnetic susceptibility χ is independent of temperature, significantly larger than that of an ideal Fermi gas, and χ / γ is pressure dependent.
- The viscosity varies as T^{-2}.
- The thermal conductivity is proportional to T^{-1} and greater than that of copper at 3mK.

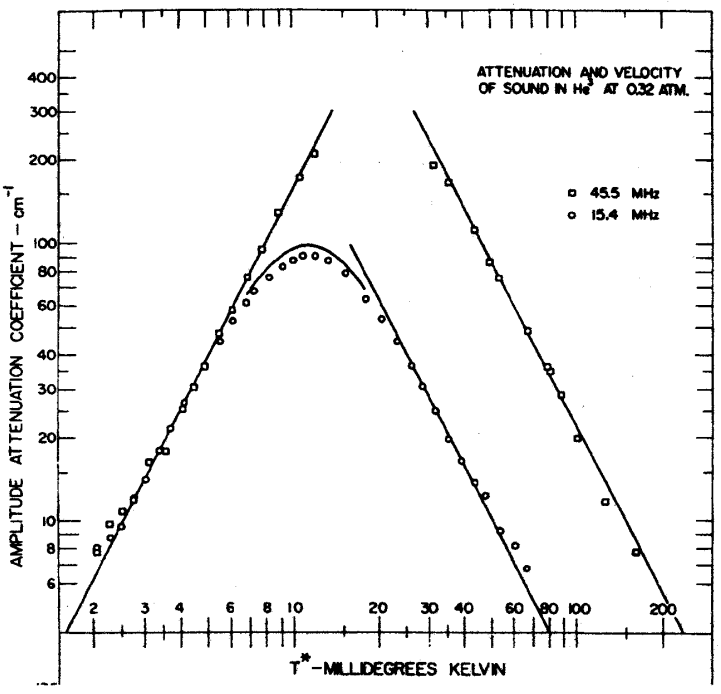
(i) Account for these observations, in as much detail as possible, within the framework of Landau Fermi liquid theory. **[14]**

The graph below shows the attenuation of sound at two frequencies by liquid ^{3}He.

(ii) Show the data can be well described by the expression for the attenuation α,

$\alpha = A\omega^2\tau / (1 + \omega^2\tau^2)$, where ω is the angular frequency of the sound, τ is the quasiparticle relaxation time, and A is a constant. **[3]**

(iii) Discuss briefly the interpretation of these results in terms of Landau theory. **[3]**



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