Vibrating Wire thermometry in superfluid $^3$He

C. B. Winkelmann, E. Collin, Yu. M. Bunkov, and H. Godfrin

Centre de Recherches sur les Très Basses Températures, 25, av. des Martyrs, B.P. 166, 38042 Grenoble cedex 9, France

We report systematic measurements of the response of a Vibrating Wire Resonator (VWR) in normal and superfluid liquid $^3$He. Special attention has been paid to the hydrodynamic regime of the superfluid B-phase, where the response parameters of the VWR do not follow a simple law. We show that a simple interpolation between the region where first order slip-corrections can be applied and the ballistic regime is insufficient. Measuring an empirical effective viscosity, we propose a temperature calibration method which allows the use of VWRs as a secondary thermometer at intermediate and high pressures in the temperature range $0.2 \, T_c < T < 50 \, \text{mK}$.

1. INTRODUCTION

Thermometry is often the limiting factor to precision measurements in the millikelvin range and below. A method that has proved quite convenient in $^3$He consists in measuring the frequency response of a VWR as pointed out by the pioneering work in Lancaster.\(^1\) This method is relatively simple in comparison with Pt-NMR, has the advantage to access directly and rapidly the properties of the liquid itself and is sensitive down to temperatures of about 0.15 $T_c$. In the ballistic regime, at temperatures below 0.3 $T_c$, relative thermometry is extremely sensitive because of the $\exp(-\Delta/k_B T)$ decrease of the damping.\(^2\) These features can be conveniently used for achieving accurate bolometry with keV sensitivity\(^3,4\).

At higher temperatures, $0.4 \, T_c < T < T_{ab}$, where the superfluid is in the hydrodynamic regime, VWRs can also be used as thermometers. Their response however exhibits more complex behaviour in this range, which we shall focus on in the following. Finally in the A-phase, random textural effects dominate the damping, making the VWR rather inadapted for ther-
mometry in this region.

Guénault et al.\textsuperscript{1} measured the damping of a VWR versus Pt NMR thermometry over a very large temperature range, from 0.15 \(T_c\) up to \(T_c\) at 0 and 7.3 bar. These measurements showed good agreement with the suggestion of Carless et al.\textsuperscript{5} according to which the hydrodynamic approach including first order slip corrections\textsuperscript{6} should yield reasonable predictions in superfluid \(^3\text{He}\)-B down to the lowest temperatures where the mean free path of the quasiparticles exceeds by far the dimensions of the VWR. It seemed therefore possible to directly relate the dynamical response parameters of a VWR (its line width at half height, \(\Delta f_2\), and the resonance frequency shift from its vacuum value, \(\Delta f_1 = f_0^{\text{vac}} - f_0\)) to pressure and temperature and hence propose a simple thermometry calibration law from first principles - except for the phenomenological slip coefficient \(\alpha\) (see section 4).

Our measurements were motivated by our previous work on superfluid \(^3\text{He}\) confined in aerogel. The magnetization of the solid \(^3\text{He}\) layers adsorbed on the aerogel was found to display surprising deviations with respect to the Curie-Weiss law. We suggested that such a strange behaviour could be ascribed either to an interesting quantum melting phenomenon, or to a large (and less exciting) error in the temperature scale. In this experiment the thermometer used was a tantalum VWR of diameter \(\phi=125 \mu\text{m}\) (\(f_0^{\text{vac}} = 1808 \text{ Hz}\)) calibrated according the results of.\textsuperscript{1} We then removed the aerogel sample and added a Pt powder thermometer inside the cell in order to calibrate independently the VWRs. With this calibration, the susceptibility of adsorbed \(^3\text{He}\) in aerogel does not deviate from the Curie-Weiss law.\textsuperscript{7} In a previous work on heat capacity at ultra-low temperatures\textsuperscript{8} we already mentioned the observed difference of more than 5% between the temperature scales used in Lancaster and Grenoble deduced from VWRs in bolometer boxes.

We were thus led to reexamine the problem of the temperature dependence of the response of a VWR in superfluid \(^3\text{He}\)-B. In the following we present measurements of the frequency response of a VWR at pressures ranging from 7.8 to 29.3 bar and propose a general empirical procedure for thermometry with an arbitrary wire at these pressures.

2. EXPERIMENTAL

The nuclear demagnetization stage used was specially designed for NMR measurements. Thermometry was achieved by susceptibility measurements of platinum powder\textsuperscript{9} via pulsed NMR. The field used for both NMR and VWR measurements was of 122 mT and the Pt-NMR-thermometry was calibrated by referring to the superfluid transition temperature \(T_c\) at a given