Debye Fluid State Equations for Helium

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Standard reference fluid state equations universally include factors of the form T^{-n}, where T is temperature and n is a positive number. The equations are generally valid for temperatures down to the triple point temperature, on the order of one-half of the critical temperature, T_c. For He^3 we desire a state equation that is continuously valid from nominal high T down to the superfluid regime, about 0.001 $T_{c.}$ A different mathematical form of the state equation is necessary.

We have taken the known Debye equation for the specific heat of a solid material and extended it to apply to thermal properties of monatomic fluids. The Debye characteristic temperature, θ, which is nominally a constant for solids, becomes a function of the fluid density. In further detail, assuming θ = constant $\rho^{2/3}$, Debye theory yields the ideal gas expressions PV=RT and $C_v/R=3/2$ in the high T and low density limit. In the low T limit, calculated thermal properties decrease smoothly to zero, in general agreement with observations. However, additional terms must be added to describe (a) compressibility of the dense subcooled fluid, and (b) properties in the near-critical range.

We have tested a fluid Debye equation against He^4 reference data, and created a He^3 Debye equation reasonably consistent with available experimental data from 0.005 K to 20 K. For He^4, the equation accuracy is not as high as the reference data, suggesting corresponding uncertainties in the He^3 equation. Additional questions arise because He^3 is a Fermi fluid. Details will be included in the paper.