An Improved He II State Equation

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The first analytical state equation for He II was developed from fundamental equations for quantum liquids by Landau in 1946. He derived a new Helmholtz potential term describing thermal excitation of rotons, additive to the known Debye equation for phonons. Landau's formulation was developed in a low temperature limit, and its applicability above 1 K has never been tested. Other notable forms of He II state equations have been published, but they are not directly related to the Helmholtz potential function.

A Helmholtz potential function that is thermodynamically consistent with lambda line mathematics was used in a previous state equation [NIST-12 computer program] down to 0.8 K. However, more recent zero-g measurements have corrected the assumed values of scaling law parameters at the lambda line. Also some residual inaccuracy has been noted (a) in the vicinity of the upper lambda point and (b) below 1.2 K.

In this work we have extended Landau's analysis to obtain good agreement with measured state properties up to about 1.5 K, and obtained a numerical connection between Landau's energy gap Δ and T_λ. Further we have obtained a revised Helmholtz function valid from T_λ down to 1.2 K. That revised function corrects and improves some of the accuracy problems (above), and numerically merges smoothly into the Landau function in the overlap range from 1.2 to 1.5 K. The combination provides a high accuracy state equation for He II over the complete range from 0 to T_λ K.