The 1962 He³ Scale of Temperatures. II. Derivation

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ABSTRACT

An Experimental Thermodynamic Equation (ETE) temperature scale valid from 0.2 to 2.0ºK has been calculated for He³. The scale is based on new comparisons, \((P_3, P_4)\), of He³ and He⁴ vapor pressures above 0.9ºK; on the 1958 He⁴ temperature scale; and on the best available data for several thermodynamic properties of He³ from 0.2 to 2.0ºK.

The \(T_{58}\) Full-range Working Equation (FWE) scale,

\[
\ln P_3 = -2.49174/T + 4.80386 - 0.286001 T
+ 0.198608 T^2 - 0.0502237 T^3 + 0.00505486 T^4
+ 2.24846 \ln T
\]

fits the ETE scale and the \((P_3, T_{58})\) data and is therefore valid for use from 0.2 to the critical point, 3.324ºK. The maximum deviation from the ETE scale is 0.4 mdeg and the standard deviation from the input data is 0.25 mdeg. The fit to the seven recalculated isotherms of Keller in the range of the 1962 He³ scale can be determined by converting Keller's \(P_4\)'s to equivalent \(P_3\)'s, using direct \(P_4\) to \(P_3\) interpolation equations. The fit of the 1962 He³ scale is as good as the fit of the 1958 He⁴ scale to the same isotherms, the average displacements of the two scales both being 1.5 mdeg below the isotherms. The average standard deviation for \((T_{62} - T_{iso})\) and for \((T_{58} - T_{iso})\) is 1.2 and 1.0 mdeg, respectively, for these seven isotherms.

* Work performed under the auspices of the United States Atomic Energy Commission.
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Introduction

At the time He\textsuperscript{3} was first liquefied\textsuperscript{39} a comparison of its vapor pressures, P\textsubscript{3}, with those of He\textsuperscript{4}, P\textsubscript{4}, was given, along with a careful determination of its critical pressure, P\textsubscript{c}, which was found to be 875 mm Hg. Subsequently, Abraham, Osborne and Weinstock (AOW) presented\textsuperscript{5} more accurate (P\textsubscript{3},P\textsubscript{4}) comparisons, additional critical point data in agreement with Ref. 1, and an empirical temperature scale, T\textsubscript{K}, based on a modification\textsuperscript{5} of the 1948 He\textsuperscript{4} scale.\textsuperscript{41} They found it possible to fit all their data, ranging from 0.011 P\textsubscript{c} (1.02°K) up to P\textsubscript{c}, to an equation for $\log(P/T^{5/2})$ having only three fitted powers of T.

In 1953, Chen and London\textsuperscript{42} criticised the form of the T\textsubscript{K} equation and attempted to fit the same (P\textsubscript{3},P\textsubscript{4}) data of AOW to an equation having a proper theoretical form for extrapolation to 0°K. Although they fitted coefficients of 5 powers of T, and omitted data at pressures above 0.4 P\textsubscript{c}, the fit of their equation was not satisfactory above 0.1 P\textsubscript{c}.

In 1957 Sydoriak and Roberts\textsuperscript{9} extended the measured range of pressures down to 0.000074 P\textsubscript{c} (0.45°K), using two different paramagnetic salts calibrated against He\textsuperscript{3} above 1° for the temperature measurement. At that time two newer He\textsuperscript{4} temperature scales were in use, so two He\textsuperscript{3} scales were calculated: the T\textsubscript{E} He\textsuperscript{3} scale, based on the 1955E He\textsuperscript{4} scale,\textsuperscript{43} and the T\textsubscript{L} He\textsuperscript{3} scale, based on the 1955L He\textsuperscript{4} scale.\textsuperscript{25}

Only by abandoning attempts to retain an analytical expression of proper theoretical form for extrapolation to 0°K did Sydoriak and Roberts...
find it possible to get a good fit to their data in combination with those of AOW. To cover the four orders of magnitude range in $P_3$ only four fitted powers of $T$ were needed.

Following the adoption of the 1958 He$^4$ scale the present authors made a proposal to the VIIth. International Conference of Low Temperature Physics held at the University of Toronto in 1960 for a new He$^3$ vapor pressure scale to be based on the 1958 He$^4$ scale and on various thermodynamic properties of He$^3$. The proposed procedure was similar to that used for the existing $T_E$ and $T_L$ scales except that newly available specific heat data could now be included instead of using a calculated "spin entropy" term. In addition, a different magnetic temperature conversion was being studied for the paramagnetic salt data intended to be used to extend the scale below 1°K.

The proposal was favorably received by members of the conference, with some reservations as to the feasibility of including vapor pressure data obtained with an iron alum thermometer.

We have subsequently abandoned incorporation of any paramagnetic salt data into the scale derivation except for measurements of specific heat using a cerium magnesium nitrate thermometer.

An alternative procedure for establishment of the low temperature end of the new He$^3$ scale has been thoroughly discussed in a report to the Fourth Symposium on Temperature, Its Measurement and Control in
Science and Industry, Columbus, Ohio, March, 1961. In this method the thermodynamic consistency of the \((P,T)\) data can be examined point by point. The method showed \(^4^5\) that the AOW data could not be combined with the 1958 \(\text{He}^4\) scale to yield a thermodynamically consistent scale in the range from 1° to 2°K. A detailed discussion of the inconsistency, which is equivalent to several millidegrees, is given in a companion paper \(^7\) to this one, hereafter referred to as III. Because of this inconsistency new \((P_3,P_4)\) comparisons were undertaken \(^4^5\) in an improved apparatus designed to minimize errors due to \(\text{He}^4\) film reflux. The results are reported in detail in another companion paper \(^4^6\) to this one, hereafter referred to as I.

Since the measurements reported in I provide an explanation for the thermodynamic inconsistency, below \(T_\lambda\), of a scale based on the AOW data, we have used only \((P_3,P_4)\) data given in I in deriving the 1962 \(\text{He}^3\) scale, reserving the AOW data above \(T_\lambda\) and data \(^1^0\) of Roberts and Sydoriak near \(T_\lambda\) for the purpose of checking the final scale.

The second and third virial coefficients of \(\text{He}^3\) are needed to establish the low temperature end of the present scale. For this purpose Keller's isotherm data \(^1^2\) has been reanalyzed, using the method of multiple variable least squares \(^4^7,4^8\). For a further discussion of the method and results we refer to III, in which the scale derived below is examined for consistency with isotherm, paramagnetic salt, and latent heat data.
The High Temperature Working Equation Scale

The three steps required to arrive at a full range equation are those discussed in detail for a Method I derivation in Ref. 10.

The first step is to derive a working equation scale by which one can interpolate between the \( (P_3, P_4) \) data points of I converted to a \( (P_3, T_{ss}) \) table of data. The primary use of this scale is for making small corrections to experimental quantities of second order importance which enter into the thermodynamic treatment of the \( (P_3, T_{ss}) \) data. It will suffice to state that we used a working equation scale which fits the \( (P_3, T_{ss}) \) data with a variance of 0.25 millidegrees and a maximum deviation of 0.6 millidegrees. (In other He\(^3\) scale derivations a high temperature working scale was considerably more important, since it was also used in the determination of paramagnetic salt calibration equations\(^9\) and to assign temperatures to He\(^3\) latent heat data\(^10\).)

The Experimental Thermodynamic Scale

The second step is to derive an analytical expression for the thermodynamic vapor pressure equation (see equations (2) and (4) of reference 10) which can be written as follows, putting on the left those terms which can be evaluated from existing thermodynamic data:

\[
\bar{\delta} n P_3 + f(T) + f(C_{\text{sat}}, T) - \bar{\epsilon} + f(V_L, P_3, T) = -\frac{a}{RT} - \frac{b}{R}. \tag{1}
\]

The values of \( P_3 \) and \( T_{ss} \) used are given in Table I, which is a portion of the data of I, excluding the lowest three data points, at \( P_4 < 40 \) microns, because the calculated He\(^4\) film reflux pressure drop was excessive.
The second term is

\[ f(T) = -i - (5/2) \ln T \]  

(2)

where \( i \) is the chemical constant, \( i = 5.31733 \).

For the remaining terms on the left we write the thermodynamic function and its empirical equivalent as follows. The calculable part of the specific heat term is

\[ f(C_{\text{sat}}, T) = \frac{1}{RT} \int_{T_m}^{T'} T' \left( \frac{C_{\text{sat}}}{T''} \right) dT'' \]  

(3a)

where \( C_{\text{sat}} \) is the specific heat of saturated liquid He\( ^3 \). Smoothed values of the \( C_{\text{sat}} \) data of Brewer, Sreedhar, Kramers, and Daunt\(^3\) and data points of Weinstock, Abraham, and Osborne\(^4\) are shown in Table II, and are used to obtain an empirical equation for \( C_{\text{sat}} \):

\[ C_{\text{sat}}/R = 0.25154 + 0.47485 T - 0.54064 T^2 + 0.406356 T^3 - 0.082729 T^4 \]  

(3b)

for \( 0.2 < T < 2^0 \).

The lower limit of the fit, \( 0.2^0 K \), was arbitrarily selected within the range of measured values of \( C_{\text{sat}} \) \(^2\). By this choice the lower limit of reliability of the 1962 He\( ^3 \) scale is chosen to be \( 0.2^0 K \). By inserting equation (3b), the exact theoretical expression (3a) is converted to the experimental interpolation equation for \( T_m = 1.0^0 \) and \( 0.2 < T < 2^0 \):

\[ f_x(C_{\text{sat}}, T) = \frac{0.39332}{T} - 0.57013 + 0.237426 T - 0.090344 T^2 + 0.033863 T^3 - 0.0041364 T^4 + 0.25154 \ln T \]  

(3c)

For convenience we have taken \( T_m \) to be \( 1.0^0 K \), although any other temperature in the range of equation (3b) could as well have been selected. The effect of the specific heat term on the ETE scale below \( 1^0 K \) is easier to identify with this choice of \( T_m \).
The vapor volume term is
\[ \epsilon = \ln \left( \frac{P_3 V_G}{RT} \right) - \frac{2B}{V_G} - \frac{3C}{2V_G^2}. \]  
(4a)

For the vapor volume, \( V_G \), we used the inverse volume expansion form of the equation of state
\[ P V_G = RT \left( 1 + \frac{B}{V_G} + \frac{C}{V_G^2} \right). \]  
(4b)

For the second and third virial coefficients of \( \text{He}^3 \) we used the equations found in reference III in the multiple parameter least squares analysis of Keller's isotherm data,
\[ B = 4.942 - \frac{270.986}{T} \text{ cc/mole} \]  
(4c)
and
\[ C = 2866/\sqrt{T} \text{ cm}^3/\text{mole}^2. \]  
(4d)

Since a high speed calculator was available it was possible to use the implicit form (4a), with \( P_3 \) being taken from the \((P_3,T_{88})\) data of Table I. Table III shows values of the term and of its component parts.

The liquid volume term is
\[ f(V_L,P_3,T) = - \frac{1}{RT} \int_0^{P_3} V_L \, dP_3 \]  
(5a)
or
\[ f_x(V_L,P_3,T) = - 0.005554 \, T^3 - 0.000163 \, T^4, \]  
(5b)
for \( T < 2^\circ K \). The coefficients of (5b) were evaluated by fitting to the second last column of Table IV, which is calculated from the smoothed \( V_L \) data.
of Taylor and Kerr and of Sherman and Edeskuty and from the working equation (for $\Delta P_3$).

On the right side of equation (1) we have those terms of the thermodynamic equation which cannot be adequately calculated from existing data on He$^3$:

$$a = L_0 - \int_0^{T_m} C_{sat} dT$$  \hspace{1cm} (6)

and

$$b = S_L(T_m)$$  \hspace{1cm} (7)

where $L_0$ is the value of the latent heat of vaporization at absolute zero, and $S_L(T_m)$ is the liquid entropy at $T_m$.

Using the ordinary method of least squares analysis and weighting each data point equally in this step of the derivation of the 1962 He$^3$ scale, we find

$$a/R = 2.09842 \pm 0.00070 \text{ for } T_m = 1.0^\circ$$  \hspace{1cm} (8a)

and

$$b/R = 1.08360 \pm 0.00046 \text{ for } T_m = 1.0^\circ.$$  \hspace{1cm} (8b)

By combining all the above functions we obtain an experimental thermodynamic equation scale (ETE) which is valid from 0.2$^\circ$K to 2.0$^\circ$K.

Because of the complexity of the ETE equation, and the fact that it is implicit in the pressure, iterative solutions were obtained with the aid of an electronic digital computer. A table in steps of one millidegree was prepared for comparison with the working equation scale.
The 1962 He³ Full-range Working Equation Scale

To obtain an expression valid over the full range from 0.2°K to the critical point we now fit selected portions of equation (1) to a power series in $T^n$, using as input pressures all of the $(P_3, T_{s8})$ data of Table I. Using the method of multiple variable least squares analysis we fit

$$
\ln P_3 + f(T) + f_x(C_{sat}, T) + \frac{a}{RT} + \frac{b}{R} = \sum_{n=1}^{4} d_n T^n .
$$

(9a)

Note that in this fitting the vapor and liquid volume terms are expected to be fitted by the power series. To be acceptable it will therefore be necessary to demonstrate not only that the scale fits the input data but also that the scale of (9a) agrees with the ETE scale below the range of the input data.

The solution of the analysis, combining coefficients of identical powers of $T$, is the full range working equation scale, FWE,

$$
\ln P_3 = -2.49174/T + 4.80386 - 0.286001 T + 0.198608 T^2 - 0.0502237 T^3 + 0.00505486 T^4 + 2.24846 \ln T \quad 0.2 < T < 3.324.
$$

(9b)

The upper limit is the critical point temperature consistent with the redetermination of the critical pressure found in I to be at 873.0 mm Hg.

As shown in Fig. 1, a comparison of the two tables we generate from the ETE scale and the FWE scale shows excellent agreement: nowhere below 2°K do the scales differ by more than 0.4 millidegrees. Equation (9b) is therefore in effect an experimental thermodynamic scale from 0.2°K to 2.0°K and an empirical scale above 2°K.
A comparison of the fit of the 1962 He³ scale to the input \((P_3, T_{58})\)
data is given in Table I and Fig. 1. The standard deviation of the data
from the scale is 0.25 mdeg.

The He⁴ lambda point occurs at \(P_{4,\lambda} = 37.80\) mm Hg at 0°C and
standard gravity. On the 1958 He⁴ scale this corresponds to 2.1720°K. In
I a direct interpolation procedure is described by which the value of \(P_3\)
which corresponds to \(P_{4,\lambda}\) is 203.25 mm Hg. Hence \(T_{62,\lambda} = 2.1721°K\), for
\(P_3 = 203.25\) in good agreement with the value of this fixed point on the
1958 He⁴ scale of temperatures.

The most fundamental test which can be given to the 1962 He³ scale is
its fit to He³ and He⁴ isotherm data, of which those of Keller¹¹,¹² are
the most complete and accurate. Although Keller used a He⁴ thermometer
in most of his isotherms, his observed \(P_4\)'s can be related to \(P_3\)'s by the
direct interpolation equations described in I. In reference III Keller's
isotherms have been reanalyzed by the method of multiple variable least
squares. Results of the comparison with the 1962 He³ and with the 1958
He⁴ scales are shown in Fig. 2. We note that the weighted average of
\(T_{N,62}\) is 1.52 mdeg below \(T_{iso}\) whereas for the same isotherms \(T_{N,58}\) averages
1.50 mdeg below \(T_{iso}\). Since for these isotherms \(T_{N,62} - T_{iso}\) and \(T_{N,58} - T_{iso}\)
have average standard deviations of 1.2 mdeg and 1.0 mdeg respectively,
we conclude that not much would be gained by basing a He³ scale more directly
on the isotherm data. In other words, the 1958 He⁴ scale, which is itself
fundamentally based on these isotherm data,
has evidently been an adequate interpolation parameter for fitting the
He³ data to these isotherms.

Table V shows vapor pressures calculated from equation (9b) in
steps of 10 millidegrees. In Table VI we show dP/dT and T₆₂ - Tₓ in
0.1 degree steps, where T₆₂ corresponds to equation (9b) and Tₓ to the
ETE scale and to the various He³ scales in use in the past. We also
have included on the far right the two He⁴ scale difference (T₅₅ - T₅₈)
and (T₅₅E - T₅₈E), as given in the N.B.S. Monograph 10 "The 1958 He⁴
Scale of Temperatures" ². In a few recent publications an attempt has
been made to "correct" the Tₐ and Tₓ He³ scales by adding these He⁴
scale "correction" terms. To convert these temperatures to the 1962 He³
scale it is necessary to apply the sum of columns 3 and 6 (or 4 and 7)
to the "corrected Tₐ" or "corrected Tₓ" scales.

Detailed (P,T) and (T,P) tables have been published ⁸ by the
Los Alamos Scientific Laboratory and in paper IV of this series.

In order to make the advantages of He³ as a vapor pressure
thermometer more widely accessible, specially purified He³ is being
made available for purchase* for thermometry through the United States
Atomic Energy Commission isotopes program.

* Information may be obtained from Gaseous Isotopes Sales, Monsanto
Research Corporation, Mound Laboratory, Miamisburg, Ohio.
Acknowledgements

If it were possible the authors would like to acknowledge in detail the aid given by numerous cryogenists in the course of the development and evaluation of the 1962 He\textsuperscript{3} scale of temperatures and the discussions concerning the scale by the Advisory Committee on Thermometry of the International Committee on Weights and Measures. We are especially indebted to Drs. F. G. Brickwedde, B. M. Abraham, H. van Dijk, M. Durieux, R. I. Joseph, W. E. Keller, D. W. Osborne, and J. H. van Vleck. Since our correspondence ran to several dozen letters it would be impractical to specify all of the participants and to elaborate on their various contributions.
Table I

He³ vapor pressure data used in deriving the 1962 He³ scale. P₃ is the measured He³ vapor pressure in mm Hg at 0°C and standard gravity, δP₃ the estimated maximum error in P₃, and δT₆₂ the temperature error equivalent to δP₃. Temperature T₅₈ is obtained from the measured He⁴ vapor pressure, P₄, and the 1958 He⁴ temperature scale. δT₅₈ is the estimated maximum error in T₅₈ equivalent to the maximum estimated error in the measurement of P₄, excluding possible errors in the 1958 He⁴ scale itself. The last column showing the deviations of the 1962 He³ scale from the input data, exhibits a random scatter above 2 K. At lower temperatures there appears to be some small regularity in the misfit.

In fitting the coefficients of the equation for the 1962 He³ scale, the weight given to each data point was a function of both δP₃ and δT₅₈. As expected, for almost all of the data points (T₆₂ - T₅₈) < (δT₆₂ + δT₅₈), since the right side of the inequality is the estimated maximum error. On average, (δT₆₂ + δT₅₈) was 1.7 times (T₆₂ - T₅₈).

The last entry in the table is the measured value of the critical point. In addition to the pressure measurement error listed, there is an uncertainty of ± 1.5 mm Hg in the location of the critical point.
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<th>$\pm \delta T_{58}$</th>
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<td>0.22</td>
<td>2.40059</td>
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</tr>
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<td>333.14</td>
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<td>0.20</td>
<td>2.50137</td>
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</tr>
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<td>448.81</td>
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<td>0.22</td>
<td>2.60250</td>
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<td>453.39</td>
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<td>0.19</td>
<td>2.80389</td>
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<td>2.90538</td>
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<td>617.09</td>
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<tr>
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<td>721.41</td>
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<td>0.1</td>
</tr>
<tr>
<td>729.70</td>
<td>0.114</td>
<td>0.15</td>
<td>3.15203</td>
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<td>0.1</td>
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<tr>
<td>738.63</td>
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<td>3.16356</td>
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<td>804.98</td>
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<td>0.34</td>
<td>3.3240</td>
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<td>0.6</td>
</tr>
</tbody>
</table>

* Ref. (66) (Paper I of this series)

b Ref. (16) (Paper III of this series)
Table II

Values at selected temperatures, T, of the specific heat function $a$, $f(C_{sat}, T)$, appearing in the thermodynamic equation for $b^w P$. The function is evaluated by means of an explicit equation $b$, $C_{sat,x}$, fitted to smoothed $C_{sat}$ data of Brewer, Sreedhar, Kramers and Daunt $c$ below 1$^\circ$K and plotted data points of Weinstock, Abraham and Osborne $d$ above 1$^\circ$K. The misfit of the equation, $\Delta C = C_{sat,x} - C_{sat,obs}$, is seen to have a random scatter.

<table>
<thead>
<tr>
<th>T (deg)</th>
<th>$C_{sat,x}$ (cal mole$^{-1}$ deg$^{-1}$)</th>
<th>$\Delta C_{sat} \times 10^3$ (mcal mole$^{-1}$ deg$^{-1}$)</th>
<th>$f_x(C_{sat}, T)$ (dimensionless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.652$^b$</td>
<td>8$^c$</td>
<td>0.000</td>
</tr>
<tr>
<td>0.3</td>
<td>0.706</td>
<td>-8</td>
<td>0.0243</td>
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<tr>
<td>0.4</td>
<td>0.752</td>
<td>-5</td>
<td>0.0665</td>
</tr>
<tr>
<td>0.5</td>
<td>0.793</td>
<td>0</td>
<td>0.1109</td>
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<td>0.831</td>
<td>8</td>
<td>0.1539</td>
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<td>0.1946</td>
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<td>0.911</td>
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<td>0.957</td>
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<td>-4,$-9^d,e$</td>
<td>0.3362</td>
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<tr>
<td>1.2</td>
<td>1.136</td>
<td>+1,$-9,+4$</td>
<td>0.3675</td>
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<tr>
<td>1.3</td>
<td>1.211</td>
<td>+6,$+4$</td>
<td>0.3977</td>
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<td>1.294</td>
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<td>0.4269</td>
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<tr>
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<td>1.385</td>
<td>-6</td>
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<tr>
<td>1.6</td>
<td>1.482</td>
<td>-13,$+14$</td>
<td>0.4831</td>
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<td>1.7</td>
<td>1.585</td>
<td>+2</td>
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</tr>
<tr>
<td>1.8</td>
<td>1.692</td>
<td>+16,$-4$</td>
<td>0.5372</td>
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<tr>
<td>1.9</td>
<td>1.800</td>
<td>-20,$+2$</td>
<td>0.5637</td>
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<tr>
<td>2.0</td>
<td>1.908</td>
<td>+5</td>
<td>0.5839</td>
</tr>
</tbody>
</table>
a Eq. (3a)
b Eq. (3b)
c Ref. (11)
d Ref. (12). Both T and $C_{\text{sat}}$ were adjusted to the $T_{5a}$ scale; e.g., $C_{\text{sat}}$ was multiplied by the value of $dT_{5a}/dT_K$ at each data point.
e Where multiple entries appear they refer to data points nearest to the indicated temperatures.
Table III

The vapor volume term \( a, \epsilon \), in the equation for \( \ln P_3 \), as evaluated by an iterative procedure, using a high speed digital computer. For their general usefulness the table also shows solutions of the cubic equation for the vapor volume, \( V_G \), and values of the second \( c \) and third \( d \) virial coefficients, \( B \) and \( C \), based on reanalysis of the isotherms of Keller.

<table>
<thead>
<tr>
<th>( T ) (deg)</th>
<th>( V_G ) (cc/mole)</th>
<th>( B ) (cc/mole)</th>
<th>( C ) (cc/mole)</th>
<th>( \epsilon )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.03 \times 10^9</td>
<td>-1350</td>
<td>6409</td>
<td>0.0000</td>
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<td>5233</td>
<td>0.0001</td>
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<tr>
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<td>8.87 \times 10^6</td>
<td>-672.5</td>
<td>4532</td>
<td>0.0008</td>
</tr>
<tr>
<td>0.5</td>
<td>1.95 \times 10^6</td>
<td>-537.0</td>
<td>4053</td>
<td>0.0027</td>
</tr>
<tr>
<td>0.6</td>
<td>6.83 \times 10^4</td>
<td>-446.7</td>
<td>3700</td>
<td>0.0065</td>
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<tr>
<td>0.7</td>
<td>3.123 \times 10^4</td>
<td>-382.2</td>
<td>3426</td>
<td>0.0122</td>
</tr>
<tr>
<td>0.8</td>
<td>1.692 \times 10^4</td>
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<td>0.0195</td>
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<tr>
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<td>-296.2</td>
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</tr>
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<td>-241.4</td>
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<tr>
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<td>0.0613</td>
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<td>2340</td>
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<td>2266</td>
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<td>2.0</td>
<td>667.9</td>
<td>-130.6</td>
<td>2027</td>
<td>0.1723</td>
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</table>
The liquid volume term, \( f(V_L, P_3, T) \), in the equation for \( 2\pi P \) is calculated by numerical integration at selected temperatures, \( T \), using smoothed values \( a \), \( V_L \), of liquid volume data of Kerr and Taylor \( b \) and Sherman and Edeskuty \( c \). For \( P_3 \) the high temperature working equation is used. Column 3 shows values \( d \) calculated from a power series in \( T^n \) fitted to column 2. The last two columns show the mismatch and its equivalent in millidegrees.

<table>
<thead>
<tr>
<th>( T ) (deg)</th>
<th>( f(V_L, P_3, T) )</th>
<th>( f_x(V_L, P_3, T) )</th>
<th>( f_x - f )</th>
<th>( \Delta T ) (mdeg)</th>
</tr>
</thead>
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<td>0.0000</td>
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<td>0.0005</td>
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<td>0.0007</td>
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\( a \) Ref. (59)

\( b \) Ref. (50)

\( c \) Ref. (51)

\( d \) Eq. (5b)
Table V. He³ vapor pressures on the A scale, at 0°C and standard gravity, 980.66 cm/seg². The units of pressure are millimeters of mercury (millimeter Hg).

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<th>Pressure</th>
<th>50°C</th>
<th>20°C</th>
<th>15°C</th>
<th>10°C</th>
<th>5°C</th>
<th>0°C</th>
<th>5°C</th>
<th>10°C</th>
<th>15°C</th>
<th>20°C</th>
<th>50°C</th>
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<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
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</tr>
</tbody>
</table>
Table VI

The temperature derivative $dP_3/dT_{62}$ and deviations of various He$^3$ temperature scales from the present 1962 He$^3$ scale. Columns 3, 4, and 5 give differences of the $T_E$, $T_L$, and $T_K$ scales respectively from the 1962 He$^3$ scale in the form $(T_{62} - T_x)$ expressed in millidegrees. In Columns 6 and 7 are reproduced the deviations of the 1955 He$^4$ scales from the accepted 1958 He$^4$ scale as these deviations have been utilized by the investigators in an attempt to "update" $T_E$ and $T_L$. 
<table>
<thead>
<tr>
<th>( T ) (°K)</th>
<th>( \text{dP}<em>3/\text{dT}</em>{62} ) (mm Hg/°K)</th>
<th>( T_{v2}^{\text{a}} - T_L^{\text{a}} ) (m deg)</th>
<th>( T_{v2}^{\text{c}} - T_1^{\text{c}} ) (m deg)</th>
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**a** Reference 6  
**b** Reference 2, 3, 4  
**c** Reference 9
Fig. 1. The solid line is the deviation of the 1962 He³ scale (i.e., the Full-range Working Equation, eq. 9b) from the Experimental Thermodynamic Equation (ETE) scale in the range of validity of the ETE scale. Plotted points are deviations of the 1962 He³ scale from the (P₆, P₄) input data: T₆₂(P₆) - T₅₈(P₄).
Fig. 2. Deviations of temperature scales from Keller's (ref. 18,24) isotherm temperatures; \( T_{iso} \), as reanalyzed in III (ref. 16). 

\( (T_{62} - T_{iso}) \) for He\textsuperscript{4} isotherms; \( (T_{62} - T_{iso}) \) for He\textsuperscript{3} isotherms; 

\( O,\Box \) \( (T_{58} - T_{iso}) \) for He\textsuperscript{4} and He\textsuperscript{3} isotherms, respectively. To get \( T_{62} \), Keller's He\textsuperscript{4} vapor pressure thermometer readings are converted to equivalent \( P_{3} \)'s by means of direct \( P_{4} \)-to-\( P_{3} \) interpolation equations derived in I (ref. 17). Lengths of bars for the 1958 He\textsuperscript{4} scale deviations are equal to the standard deviation for \( T_{iso} \) as calculated in the analysis of the isotherm data. For 1952 He\textsuperscript{3} scale deviations we add on the standard deviation of the conversion from \( P_{4} \) to equivalent \( P_{3} \). The \( T_{62} \) and \( T_{58} \) bars terminate in solid and open triangles respectively.
References


34. W. Cawood and H. S. Patterson, Trans. Far. Soc. 29, 522 (1933).


Additional references will be added when papers III and IV are submitted.