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# An Examination of the 1955 Helium Vapor-Pressure Scales of Temperature

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In a previous communication, magnetic thermometer calibrations in the region 1.3° to 4.2° K were used to examine the internal consistency of two provisional helium vapor-pressure scales of temperature. Since that article went to press, these scales have been made available in their final form, and further measurements have also been made. The results of all the measurements, seven runs in all and with two different apparatuses, are used here to examine the latter scales. The results of six runs were self-consistent and could be reconciled with the empirical scale of Clement et al. ($T_{55E}$) to within 2 millidegrees, and with the calculated scale of Van Dijk and Durieux ($T_{55}$) to within 5 millidegrees. The remaining run showed better agreement with $T_{55}$. It appears, therefore, that the previous assessment of the $T_{55}$ scale may have been a little too favorable. The most critical interpretation of the findings is that the present technique of vapor-pressure measurement is not sufficiently precise to discriminate between the two scales.

## 1. Introduction

In a recent publication [1][1] the authors examined the internal consistency of two vapor pressure-absolute temperature ($p$-$T$) relations through the calibration of a magnetic thermometer in the range 1.3° to 4.2° K. One such relation was that of Clement, Logan, and Gaffney [2], based upon an empirical equation, and the other a thermodynamic calculation by Van Dijk and Durieux [3].

After reference [1] had been prepared for publication both the new $p$-$T$ relations were modified by their respective authors. Clement based his final temperature scale [4] (to be referred to by $T_{55E}$) on the experimental data of several authors, including Ambler and Hudson, obtained in one of two ways, viz, a measurement of the vapor pressure using (a) a separate vapor-pressure bulb, or (b) the pressure over the liquid helium bath plus an appropriate correction for the "hydrostatic head," when a heat source was employed to maintain a constant flow of bubbles up through the liquid. Van Dijk [5] has increased his temperature values slightly in the region 3.3° to 4.3° K so that his $p$-$T$ curve is tangent to a curve through the gas-thermometer data of Berman and Swenson [6] near the normal boiling point. Temperatures derived from this new scale will be denoted by $T_{55}$.

Concurrent with this work, the present authors carried out further measurements, employing the "second apparatus" of [1] to augment the meager amount of data obtained therewith. This was especially important as these same data were *not* in very close accord with those obtained with the "first apparatus."

The present paper deals with an examination for internal consistency of the $T_{55}$ and $T_{55E}$ tabulation, based upon all of the magnetic thermometer calibrations referred to above.

[1] Figures in brackets indicate the literature references at the end of this paper.

## 2. Experimental Procedure

The apparatus has been described in detail in [1] (see fig. 1, b, and text therein). The only modification in procedure was the employment of a manostat [2] to control the temperature of the bath. This proved very useful in that the system came to equilibrium twice as fast as previously and enabled one to obtain twice as many points per run. (It may be of interest to record that at the lowest temperature employed (1.3° K), where the magnetic thermometer is extremely sensitive, the bridge reading remained constant to within the equivalent of $10^{-6}$ deg for periods in excess of 5 min.)

## 3. Results

The data obtained in the new series of measurements are summarized in table 1. The pressures, $p$, have been corrected to 20° C and standard gravity, and the bridge readings, $n$, have been corrected for nonlinearity in the mutual-inductance decades.

The data of table 1 and those of table 1 in [1] will now be discussed in relation to $T_{55}$ and $T_{55E}$.

[2] The authors are indebted to L. D. Roberts of the Oak Ridge National Laboratory for a drawing of this device. The original design is due to H. S. Sommers, Los Alamos, Rev. Sci. Instr. 25, 793 (1954).

TABLE 1. *Corresponding values of pressure in millimeters of mercury, p (corrected to 20° C and standard gravity) and bridge dial-setting, n (corrected for nonlinearity in decade scale)*

| January 4, 1956 | | | | January 18, 1956 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $p$ | $n$ | $p$ | $n$ | $p$ | $n$ | $p$ | $n$ | $p$ | $n$ |
| 751.42 | 17.6077 | 124.33 | 20.6600 | 740.46 | 17.7584 | 40.395 | 22.8504 | 13.308 | 25.1069 |
| 717.24 | 17.6796 | 97.25 | 21.0249 | 670.52 | 17.8968 | 37.700 | 23.0118 | 9.016 | 25.9241 |
| 716.69 | 17.6797 | 57.994 | 22.0817 | 583.62 | 18.1089 | 32.392 | 23.3234 | 6.963 | 26.7213 |
| 628.73 | 17.8697 | 31.771 | 23.2392 | 489.09 | 18.3710 | 28.418 | 23.6206 | 4.017 | 27.6320 |
| 500.19 | 18.1953 | 24.546 | 23.7329 | 300.65 | 18.8495 | 24.012 | 23.9294 | 4.031 | 27.6271 |
| 307.73 | 18.7391 | 14.946 | 24.7613 | 197.36 | 19.3600 | 21.116 | 23.9169 | 2.964 | 28.3739 |
| 241.05 | 19.3912 | 8.123 | 26.0191 | 101.97 | 21.0572 | 18.124 | 24.4989 | 1.833 | 29.6000 |

### 3.1. Comparison With $T_{55}$ Temperature Scale

The data were analyzed according to the procedure outlined in [1]. When the constants $A$ and $B$ in the formula

$$n-B=A/T \quad (1)$$

have been determined, a value of temperature, "magnetic temperature," $T_m$, is at once calculable for a given value of $n$. The corresponding value of $p$ leads to $T_{55}$ from the $p$-$T$ table and $\Delta T=T_{55}-T_m$ may be plotted as a function of absolute temperature. This is done in figure 1. The values of $A$ and $B$ used for each run are summarized in table 2.

TABLE 2. *Values of constants A and B in equation 1 for $T_{55}$ evaluation*

| Date | $A$ | $B$ |
|---|---|---|
| June 7, 1955 | −34.0585 | 19.2841 |
| June 8, 1955 | −34.0035 | 19.2644 |
| June 16, 1955 | −34.0553 | 19.2996 |
| June 17, 1955 | −34.0404 | 19.2509 |
| August 17, 1955 | 23.5765 | 11.3537 |
| January 4, 1956 | 23.6073 | 11.9992 |
| January 18, 1956 | 23.6069 | 12.1151 |

It is evident that only the results of August 17, 1955—the first run with the second apparatus—can be brought into very close accord with the $T_{55}$ tabulation. The rest of the data can, however, be brought into very close harmony with each other by suitable choices for $A$ and $B$ in each case, and the entire group deviates considerably from the zero line with a maximum of +4.5 millidegrees at 3.6° K. There appears, furthermore, to be a discontinuity in the region of the lambda-point. (As described in detail in [1], the choice of $A$ and $B$ is made so as to give an optimum fit throughout the entire range of measurement. The implicit assumption is that the $T_{55}$ scale is nowhere in error by a large amount.)

### 3.2. Comparison With $T_{55E}$ Temperature Scale

Figure 2 was obtained by a procedure analogous to that leading to figure 1, now using $T_{55E}$ instead of $T_{55}$. Small changes in the values of $A$ and $B$ were necessary as may be seen by consulting table 3 and

TABLE 3. *Values of constants A and B in equation 1 for $T_{55E}$ evaluation*

| Date | $A$ | $B$ |
|---|---|---|
| June 7, 1955 | −34.1649 | 19.3136 |
| June 8, 1955 | −34.1461 | 19.3027 |
| June 16, 1955 | −34.1703 | 19.3187 |
| June 17, 1955 | −34.1555 | 19.3100 |
| August 17, 1955 | 23.8839 | 11.3273 |
| January 4, 1956 | 23.8985 | 11.9098 |
| January 18, 1956 | 23.8902 | 12.0017 |

comparing with table 2.[3] With this temperature scale it is possible to restrict the value of $\Delta T$ within the limits of ±2 millidegrees. The discontinuity at the lambda-point is still evident. (Although such a discontinuity is more likely due to faults in the measuring technique than genuinely anomalous behavior of the $p$-$T$ curve, it has been observed by other investigators. See, for example, Erickson and Roberts [7].)

## 4. Discussion

In [1] reasons were given for reposing more trust in the results obtained with the second apparatus (August 1955 data) than in those for the first apparatus (June 1955). These were based upon the attempted improvement in design and the fact that a (rather rough) measurement of the bath pressure plus the hydrostatic-head correction agreed with $p$ measured in the bulb system, within the limits of error of measurement. It can be seen, however, that the measurements of January 1956 reproduce the earlier results obtained with a different apparatus, and fail to agree with the first measurements, using the same apparatus. At the same time, the quality of the second apparatus, as determined by the above-mentioned criteria, had not changed. We have been unable to find a plausible explanation for the discrepancies, which must therefore be held to indicate the degree of trustworthiness for the entire series of experiments. Hence, while the present results viewed as a whole favor $T_{55E}$ to the disadvantage of $T_{55}$, it is probably correct to conclude that the presently used techniques of vapor-pressure measurement are

[3] It may be noticed, further, that in all cases the constant $A$ decreased slightly on the second day of a 2-day series. This effect, though very small, seems to be real.

not sufficiently precise to resolve the discrepancy between the two scales. This latter is illustrated in figure 3 where we have plotted $T_{55E}-T_{55}$ as a function of $T$.

In conclusion, it should perhaps be emphasized that although use was made of the results in [1] in the development of $T_{55E}$, no greater weight was accorded them than any other of four additional independent investigations over the same temperature range. This accounts for the systematic deviation in the regions 1.3° to 2.2°K and 3.6° to 4.2°K, visible in figure 2.

## 5. References and Notes


[1] E. Ambler and R. P. Hudson, J. Research NBS **56**, 99 (1956) RP2654.

[2] J. R. Clement, J. K. Logan, and J. Gaffney, Phys. Rev. **100**, 743 (1955).

[3] H. Van Dijk and M. Durieux, Proc. Conf. de Phys. des Basses Temperatures, Paris 1955; Commun. No. 145, p. 595.

[4] J. R. Clement (unpublished). This scale is the one referred to in the "note added in proof" to reference 2.

[5] H. Van Dijk (private communication). It is understood that copies of this scale are available on request to the Kamerlingh Onnes Laboratory.

[6] R. Berman and C. A. Swenson, Phys. Rev. **95**, 311 (1954).

[7] R. A. Erickson and L. D. Roberts, Phys. Rev. **93**, 957 (1954).


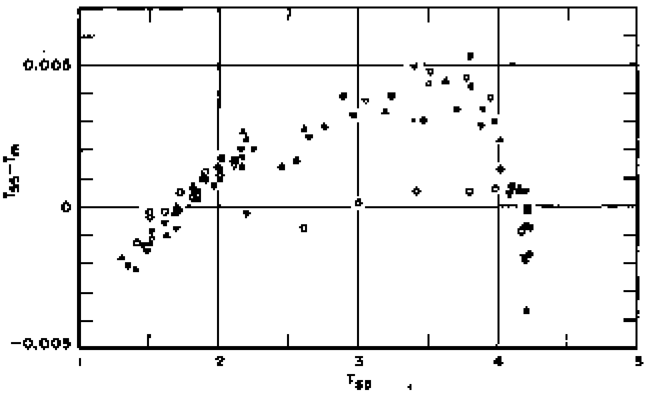


**Figure 1.** *Deviation of $T_{55}$ (from vapor pressure) from $T_m$ (from bridge reading) as a function of $T$.*

Apparatus I: ● June 7, 1955; ▲ June 8, 1955; ■ June 16, 1955; ▼ June 17, 1955.
Apparatus II: ○ August 17, 1955; △ January 4, 1956; ▽ January 18, 1956.

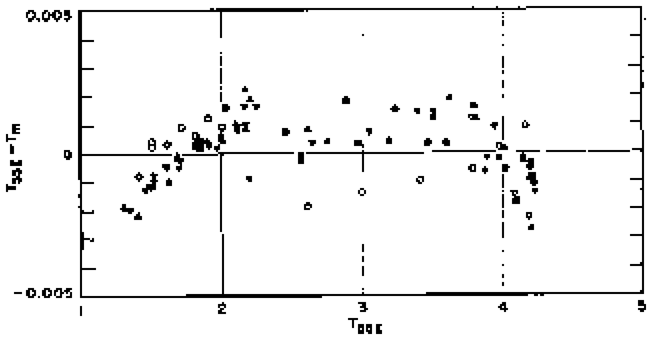


**Figure 2.** *Deviation of $T_{55E}$ from $T_m$ as a function of $T$.*

For symbol code, see caption to figure 1.

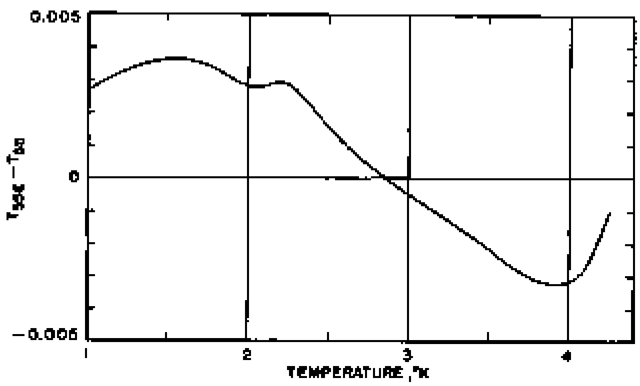


**Figure 3.** *Deviation of $T_{55E}$ from $T_{55}$ as a function of $T$.*

Washington, April 10, 1956.