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High-Temperature Properties of Potassium

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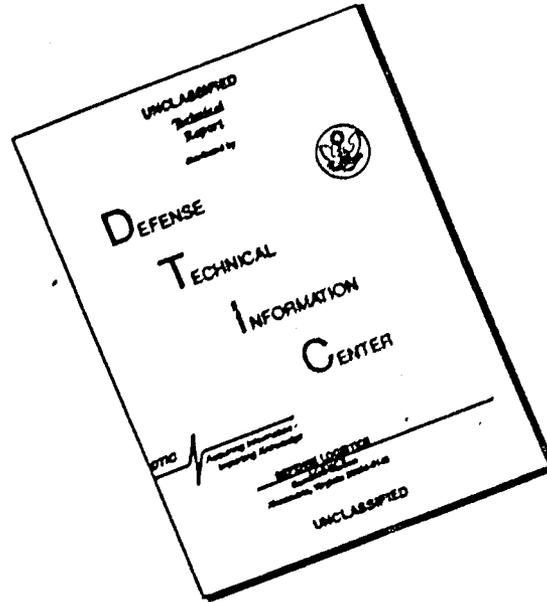
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ABSTRACT

An experimental program is in progress at this Laboratory to measure various thermophysical properties of sodium, potassium, and cesium. A final reporting of the experimental results for potassium (saturation and superheat properties of the vapor, density and specific heat of the liquid) is presented together with a thermodynamic treatment of the data. Two equations of state are advanced, one virial and one quasi-chemical; and additional saturation and superheat properties of the vapor are derived from these equations. Either of two paths can be used in deriving absolute thermodynamic properties, the monomeric gas path or the liquid path; but results obtained by the former procedure are believed to be more accurate. Enthalpy, entropy, specific volume, specific heat, and compositional information (weight fraction of dimer, weight fraction of tetramer, and average molecular weight) are tabulated for some 800 selected vapor states in the temperature range from 1400° to 2525° F and in the pressure range from 0.2 to 35 atm.

PROBLEM STATUS

This is a final report on the experimental work with potassium. All measurements have been completed as contracted except for the surface tension of the liquid.

AUTHORIZATION

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HIGH-TEMPERATURE PROPERTIES OF POTASSIUM

INTRODUCTION

In the development of compact turboelectric systems for space vehicles, the National Aeronautics and Space Administration is sponsoring a property measurement program for the evaluation of several liquid metals as possible working fluids. As an integral part of this program, the U.S. Naval Research Laboratory has measured several thermophysical properties of sodium to 2500°F, of potassium to 2300°F, and of cesium to 2300°F.

This report describes the properties of potassium which have been measured and thermodynamically computed. The saturated liquid properties which have been determined experimentally include density, vapor pressure, and specific heat. Saturated and superheated vapor properties including specific volume, specific heat, enthalpy, and entropy have been derived from experimental pressure-volume-temperature (PVT) studies.

EXPERIMENTAL MATERIALS AND METHODS COMMON TO ALL MEASUREMENTS

A number of materials and methods were common to all or to a majority of the experimental measurements. Furnaces and other special equipment were used repeatedly in the preparation of samples or in the performance of experiments. It is expedient to discuss these common factors under a single section rather than under the sections devoted to the individual property measurements.

Potassium Metal

Many of the physical properties, particularly vapor pressure, are sensitive to impurities in the alkali metal. Special techniques were developed to purify the reactive metal and to permit clean transfer operations. Potassium samples for the density and specific-heat determinations were distilled directly from a small nickel still (1) into each apparatus. However, for the PVT determinations this procedure was impractical, and it was necessary to distill and introduce the metal into small, closed-end tubes for subsequent transfer into the PVT apparatus. These transfer operations were performed in a vacuum inert-gas box.

The potassium introduced into the still pot was a high-purity grade obtained from the MSA Research Corporation with a quoted metal purity of 99.95% by weight. A typical spectrographic analysis of the metal fraction as distilled into a measurement apparatus is presented in Table 1. Even for the PVT experiments, the metal impurities were present in such moderate concentrations that the vapor pressures would not have been affected significantly. Potassium oxides, although probably present in low concentrations in the original charge, would be effectively gettered by the columbium and zirconium of the container alloy. For this reason, oxygen analyses were not made, but the oxygen content of potassium, purified by the same distillation technique in previous studies (2), was 10 ± 5 ppm as determined by the mercury-amalgamation method.

Table 1
Typical Spectrographic
Analysis of
Distilled Potassium

Metal	Analyses (Parts per Million by Weight (NRL))
Na	10 to 100
Rb	100 to 1000
Mg	<1
Si	<1
Cu	1 to 10
Li, Cs	Not detected

Container Material

Several materials, including columbium alloys, molybdenum alloys, tungsten alloys, and tantalum, were considered as possible containers for the alkali metals to 2500° F. The initial selection of columbium-1%zirconium was based on the weldabilities of the various materials and on the rather meager high-temperature information available on corrosion resistance and mechanical properties. The manufacturer's analysis of a typical batch of the electron-beam-melted alloy used in this program is presented in Table 2.

Table 2
Typical Impurity Analysis of
Columbium-1%Zirconium
(By Manufacturer)

Metal Impurity	Content (ppm)	Metal Impurity	Content (ppm)
Al	25	Mo	<20
B	<1	N	35
C	50	Ni	<20
Cd	<5	O	130
Cr	<20	Pb	<20
Cu	<40	Si	<100
Fe	<100	Sn	<20
H	3.7	Ta	<500
Hf	<80	Ti	<150
Mg	<20	V	<20
Mn	<20	W	<150
		Zn	<20

Preliminary high-temperature tests of the columbium alloy and of welded sections were made with a small cylindrical furnace in a vacuum bell-jar system. These were made to determine, first hand, the high-temperature performance of the material and to determine the degree of protection required to prevent contamination embrittlement. The tests showed that, in an attainable purity of argon and with stringent degassing techniques, the alloy and welded sections could be heated to 2500° F with no measurable decrease in ductility. The influence of the purity of the cover gas during welding was also investigated, and it was found that sections fired after being welded in tank argon were equivalent to those fired after being welded in more purified gas. Nevertheless, as a safety precaution, purified argon was used as a cover gas for welding all of the alkali metal containers. The effectiveness of thin sheet shrouds of gettering materials (zirconium and columbium-1%zirconium) in protecting the container was demonstrated, and this technique was used throughout the measurement program. In other tests, alkali metal samples were heated in small containers of columbium-1%zirconium for several hours at 2500° F with no visual evidence of attack.

The choice of the columbium alloy has proved to be a fortunate one. Helium-tight welds and containers have been made consistently. The mechanical properties of the alloy were particularly well suited to this work. Apparatuses have been consistently fired to temperatures in excess of 2500° F, remachined, rewelded, and used several times. The sensitivities of diaphragms used in the PVT studies have been unchanged by repeated firings. Dimensioning stability, which influences the accuracy of the volume measurement,

has exceeded expectations. Dimensions were always taken on an apparatus before and after a PVT measurement, and differences between corresponding dimensions have always been random and generally within the experimental error of the dimensioning techniques.

High-Pressure Furnace Systems

Two furnace systems, pressurizable to 500 psi, were designed and built for the PVT, vapor-pressure, and density measurements. External pressurization was a design requirement for the diaphragm technique, but the same furnaces were also very satisfactory for the density measurements. In fact, external pressurization increased dimensional stability and permitted the use of thinner walled pycnometers with simpler welds.

A diagram of one of the upright furnaces is presented as Fig. 1. The outer pressure shell was fabricated from 12-in., schedule 40, steel pipe with welding-neck flanges at each end. An alumina-core heater with three molybdenum windings was mounted at the center of the shell and insulated from it with zirconia bubble. In order to avoid a positive degassing of the huge surface area of the insulating particles, the furnace was divided into two chambers. The inner measurement chamber was separated from the furnace proper by a closed-end mullite tube or thimble, which was impervious to gases at temperatures to 2600°F. A helium-tight, water-cooled, silver chloride seal was provided between the mullite tube and the metal flange at the top of the furnace.

Auxiliary piping and control systems to each furnace permitted the inner and outer chambers to be independently evacuated and pressurized. For normal pressure operation the two chambers were interconnected by 50 ft of small-diameter tubing; and to minimize any movement of gas from the outer to the inner chamber, pressure was always added directly to the inner chamber and bled off from the outer. Purified argon was supplied by passing welding-grade gas through pressurized trains of molecular sieve and heated

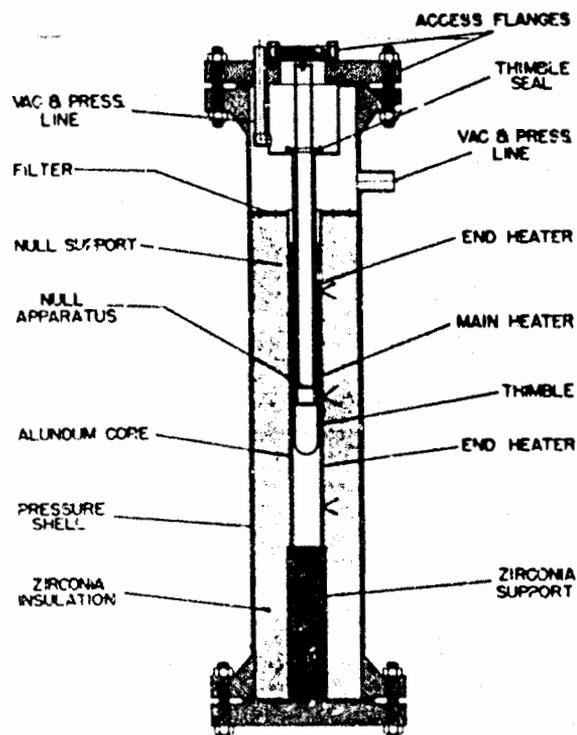


Fig. 1 - High-pressure furnace

titanium sponge (1500° to 1700° F). Oxygen analyses by a coulometric apparatus similar to that described by Keidel (3) showed the oxygen content of welding-grade argon to be 15 to 20 ppm or higher and that of the purified gas to be less than 1 ppm.

Stringent degassing procedures and absolute tightness integrity of the furnace system were required to prevent embrittlement of the columbium alloy apparatus by trace contaminants. Each apparatus was positioned at the center of the isothermal zone of the furnace by a jig suspended from the access flange at the top. The furnace with an apparatus assembled in the inner chamber was generally degassed at 600° F for approximately 3 hr at pressures below 10^{-5} torr. In order to insure tightness of all seals and closures, the entire furnace system prior to each measurement was carefully helium leak-checked with a mass spectrometer. To further protect the apparatus from contamination which could be introduced with the cover gas or released from metal and ceramic surfaces at higher temperatures, each apparatus was shrouded with thin sheets of a gettering material (columbium-1%zirconium or zirconium), and shields of like material were positioned at 1-in. intervals from the apparatus to the top of the furnace. These shields, in addition to their gettering action, reduced heat loss by radiation and convection.

Temperature Measurements

For the measurement of temperatures to 2500° F in argon, a thermocouple of Pt-6%Rh/Pt-30%Rh was selected. This combination, when used with low-iron-content sheathing, was shown by Walker et al. (4) to exhibit a stability considerably better than that of other noble metal combinations including Pt/Pt-10%Rh and Pt-1%Rh/Pt-30%Rh. All measurement thermocouples were calibrated at NRL by direct comparison with two types of NBS standardized thermocouples: (a) a Pt-6%Rh/Pt-30%Rh couple calibrated against primary melting points to the gold point, 1920° F, and against optical pyrometers from 1800° to 3000° F, and (b) a Pt/Pt-10%Rh couple, likewise calibrated against primary melting points to 1920° F. A calibration of this second couple to 2600° F was also furnished by NBS and was obtained by deriving coefficients for the standard quadratic relationship between emf and temperature.

The measurement thermocouples used in the PVT and liquid density studies were checked for instability (change in emf output with time) by the method outlined by Walker (4). Although the observed instabilities were very small, it appeared that they might become significant after three or four cycles to 2500° F. Therefore, thermocouples were used for a maximum of three cycles and then replaced.

The use of two types of reference thermocouples for calibration, together with the observations of instability on the working couples, increased the reliability of the temperature measurements. Errors in observed temperatures (relative to the thermodynamic scale) to the gold point, 1920° F, should not have exceeded 0.6° F. Above the gold point the error would be expected to increase with temperature but should not exceed ± 3.5 ° F at 2550° F.

EXPERIMENTAL MEASUREMENTS

Pressure-Volume-Temperature Measurements of Potassium

Apparatus and Method - For both the vapor-pressure and the PVT measurements, apparatuses with diaphragm null-detectors similar to those described by White and Hilsenrath (5) were used. Although it was necessary to completely redesign their apparatus to permit high-temperature operation, the three basic criteria which they suggested

for an apparatus of this type were met. The new apparatus had high sensitivity over the temperature and pressure range, a reproducible null-point after subjection to practical pressure differentials, and a negligible change in volume upon actuation of the diaphragm.

The null-point apparatus, as designed for the alkali metals (Fig. 2), was essentially a closed chamber of known volume equipped with a flexible (5-mil-thick) diaphragm. All parts of the apparatus, with the exception of the mullite insulation disk, were fabricated from columbium-1%zirconium. The vertical position of the diaphragm was determined by the difference between the internal and external pressures, and its position was monitored by a simple continuity circuit, one side of the circuit being attached to the insulated metal probe and the other directly to the diaphragm.

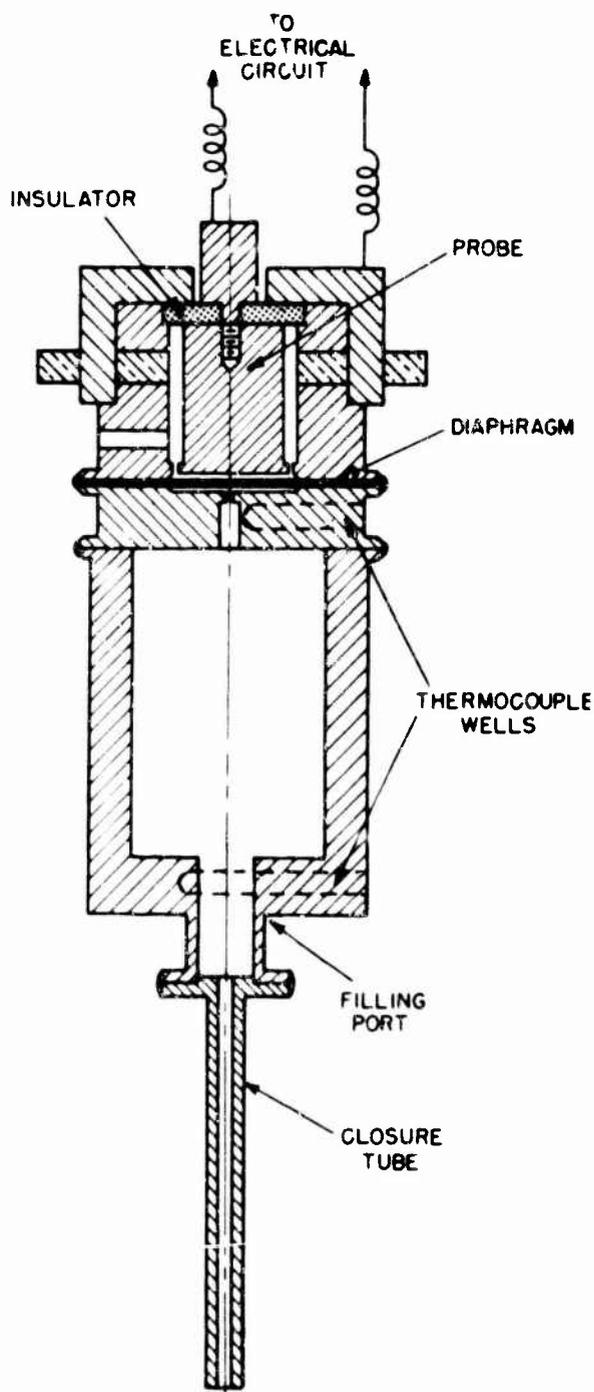


Fig. 2 - PVT apparatus

A method of introducing clean potassium into the chamber of an apparatus was developed. Distilled potassium was first introduced into small, closed-end tubes of the columbium alloy, and these sample capsules were, in turn, sealed in glass ampoules. The glass encapsulation permitted clean transfer of the alkali metal samples into the inert gas box for subsequent transfer into null-point chambers. However, prior to the introduction of a potassium capsule into a chamber, each apparatus was cleaned ultrasonically at room temperature and degassed at 500°F for three hours. The potassium capsule was then removed from its glass ampoule, weighed, and inserted; the chamber was evacuated and reheated to 280°F, evacuated while hot to a pressure below 10^{-5} torr, and closed under high vacuum by pinching and welding-off the closure tube. All welding and filling operations, including the two degassing steps and the weighing of the capsule, were performed in the vacuum inert-gas box.

The procedure for a typical PVT experiment was as follows. The loaded apparatus with thermocouples installed above and below the chamber was supported at the center of one of the pressure furnaces (Fig. 1), and equilibrium measurements of pressure and temperature were made from the normal boiling point to at least 2500°F. The furnace pressure was adjusted at each equilibrium temperature so that the diaphragm was just making or breaking its electrical contact with the probe. Under these conditions, the furnace pressure (except for a small deflection correction) was equal to the pressure of the metal vapor, and this pressure was observed externally at room temperature with Bourdon-tube gages.

An isothermal condition of the apparatus for each experimental determination was assured by an adjustment of the furnace heaters so that observed temperatures at the top and bottom of the apparatus were always matched within 2°F and generally within 1°F. The relatively short length (3 to 5 in.) and large bulk (1/4-in.-thick walls) of the chamber assured essentially isothermal conditions at intermediate points.

Diaphragm Operation - In order to insure reproducibility of the diaphragm motion, the parts of each apparatus were machined with fine tolerances so that the position of the probe relative to its diaphragm could be established and maintained without detectable movement. Each diaphragm was punched from a flat, annealed sheet of columbium-1%zirconium by a special technique to avoid the creation of unnecessary stresses which could have resulted in uneven movement under load.

Pressure sensitivities for diaphragms at room temperature were measured by observing with a traveling microscope the vertical movement of the diaphragm for various pressure loadings. The sensitivity of the typical diaphragm with a free diameter of 1.5 in. was between 10 and 20 mils of deflection per psi of pressure difference. Measurements were made at room temperature on several diaphragms before and after firing at 2500°F, and no significant change in sensitivity could be detected. Consequently, no special annealing of the columbium-1%zirconium sheet was required.

The position of the probe relative to the diaphragm was adjusted initially in each apparatus so that the probe was usually within 0.5 mil of the equilibrium position of the diaphragm. Depending upon this positioning, movement of the diaphragm from its equilibrium position to make electrical contact with the probe caused the pressure inside a given apparatus to be higher or lower than that observed externally. Although the pressure difference required for deflection of the diaphragm was usually below 0.1 psi, it was a significant correction which was applied to the observed pressure at each temperature.

The magnitude of the correction for each diaphragm and apparatus was determined experimentally at room temperature before and after each PVT experiment, by noting the pressure differential required to make (and break) electrical contact between the diaphragm and its probe. Although the corrections taken before and after a given experiment were

generally within ± 0.02 psi of the same value, the initial corrections were always used because the probe assembly received considerable handling after the experiment in removing the alkali metal from the chamber.

The deflection correction is a function of sensitivity and is, therefore, temperature dependent. In order to determine the influence of temperature on this correction, a series of experiments were made with a blank apparatus in which the probe was spaced to give a correction several times that normally observed. The pressure differentials to make (and break) electrical contact between this probe and its diaphragm were measured from room temperature to 2500°F . The observed coefficients required to correct the room temperature differential at higher temperatures were plotted (Fig. 3), and these coefficients were used to correct the room temperature value for each apparatus. Since the sensitivity of a particular diaphragm configuration is inversely proportional to the modulus of elasticity, the rapid increase in the observed sensitivity between 2200° and 2400°F implies a corresponding decrease in the modulus of elasticity of the columbium alloy.

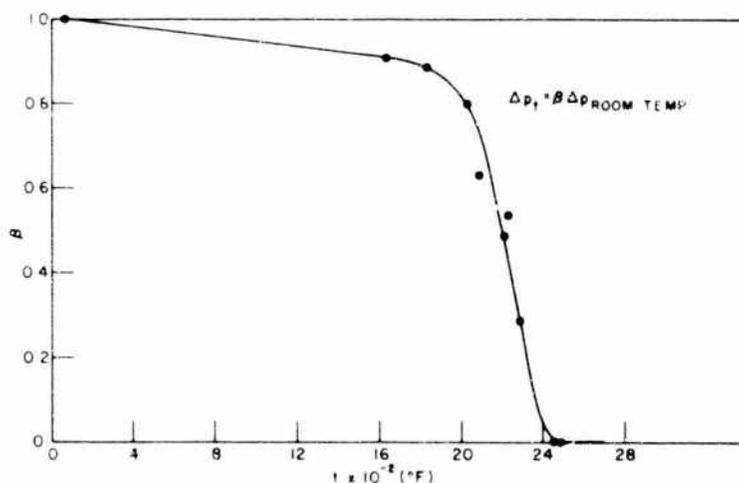


Fig. 3 - Coefficients to correct diaphragm deflection pressures for temperature change

Experimental Superheat Results - The PVT experiments for potassium covered a wide range in the superheat region with temperatures extending from 1600° to 2525°F and pressures from 2.3 to 27.4 atm. Final data in the superheat region for nine experiments are presented in Table 3. For each experimental point, pressure and temperature were directly observed, and the specific volume was calculated from the weight of potassium in the known volume. The nominal volume of the chambers for experiments 9 and 15 was 113 cc, and for all the other experiments it was 57 cc. The weights of the potassium samples varied from 0.1249 g in experiment 15 to 0.5892 g in experiment 22.

At each equilibrium point represented by the data in Table 3, multiple readings of temperature and pressure were made at 5 to 10 min intervals until successive readings showed a temperature drift of $0.07^\circ\text{F}/\text{min}$ or less and a temperature difference across the apparatus of less than 2°F (this difference was generally less than 1°F). For each PVT experiment, measurements were made over a minimum of one full cycle from the normal boiling point to 2525°F , and equilibrium pressures were reproduced in the superheat region to better than ± 0.1 psi before, during, and after cycling.

Specific Volumes of Saturated Vapor - Specific volumes* of several saturated vapor states (Table 4) were observed over the temperature range from 1570° to 2376°F. The measurements were made in the course of the PVT studies, and each point represents an intersection of the saturated and superheated vapor curves for one of the nine PVT experiments. The equation

$$\log \left[\frac{RT_g}{M_1 p_s} - v_g^3 \right] = \frac{4168}{T_g} - 1.8433 \quad (1)$$

was fitted to the observed specific volumes with an average deviation of $\pm 0.34\%$.

Table 4
Specific Volumes of Saturated Potassium Vapor

Experiment No.	Temperature (°F)	Specific Volume (cu ft/lb)
15	1570.2	14.8883
9	1776.4	7.1139
8	1886.9	5.1272
21	1939.1	4.4214
12	1999.7	3.7223
10	2122.2	2.7482
14	2191.3	2.3462
11	2289.0	1.8806
22	2376.1	1.5862

Observed pressures near the intersection of the saturated and superheated vapor curves were found to be abnormally low. To illustrate this phenomenon, a portion of the pressure-temperature curve for experiment 10 in the region of the intersection point is presented as Fig. 4. It will be noted that for a short temperature range observed pressures are below the true saturation and superheat curves. The saturated specific volume for each experiment, as illustrated for experiment 10, was obtained by a short extrapolation of the superheated vapor curve to the true saturation curve as defined by the vapor-pressure equation (to be presented as Eq. (3)).

Although the extrapolation procedure tended to minimize any error in the saturated specific volume resulting from the depression phenomenon, it is believed that specific volumes obtained from the virial equation (Eq. (25)) and the vapor-pressure equation (Eq. (3)) will be of higher reliability than those obtained from Eq. (1). However, specific volumes at the nine temperatures in Table 4 were also computed from the virial equation and showed an average deviation of only $\pm 0.33\%$ from the corresponding observed values.

It is believed that the principal factor contributing to the depression of the vapor-pressure curve in this region stems from the existence of dual states as the number of

*Preliminary values for the specific volume of saturated potassium vapor (30) were based on incorrect thermal expansion values for columbium-1%zirconium.

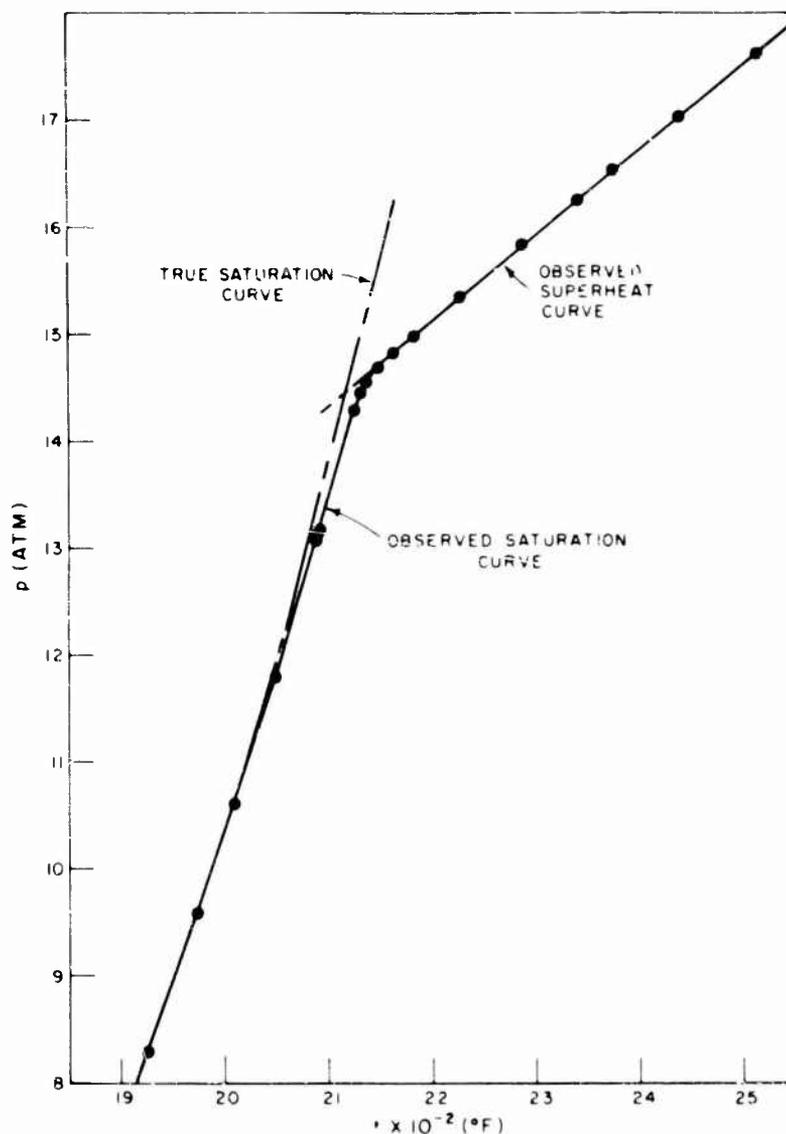


Fig. 4 - Phenomenon at intersection of saturation and superheat curves (illustrated with experiment 10)

atoms in the condensed phase are reduced to zero. Even with the temperatures at the top and bottom of the chamber perfectly matched, minute temperature differences would still exist along the axis of the apparatus, and all the remaining liquid could be condensed at one or more reduced temperature points. This could lead to the coexistence of a series of saturation and superheat states which would produce the apparent lowering of the vapor pressures as observed in Fig. 4. At least two additional factors could also contribute to the lowering phenomenon. One might be an elevation of the boiling point brought about by the concentration of any nonvolatile impurity such as columbium or zirconium in the condensed phase. Another might be a retention of potassium on the walls of the chamber by adsorption and capillarity effects and a gradual release of the potassium to the vapor phase as the temperature is increased.

Discussion of Superheat Results - It was recognized at the start of this program that high precision in all measurement parameters of the PVT study would be required if reliable thermodynamic quantities were to be derived. Therefore, the design of both apparatus and method was approached from the standpoint of obtaining maximum accuracy.

Pressures were observed with three precision Wallace and Tiernan gages with ranges of 0 to 50, 0 to 300, and 0 to 500 psia. The three gages were calibrated, in situ, with dead-weight piston gages by personnel of the Eastern Standards Laboratory at intervals of about six months. The 0 to 50 psia gage was also checked at atmospheric pressure against precision barometers and at lower pressures against a mercury manometer. The gages functioned exceptionally well, and calibrations were consistently reproduced over a three-year period. As a precaution against any shift in calibration by one gage, pressures were always read with at least two gages up to 300 psia. However, since no calibration problems developed, the reported pressures are based on the most accurate gage in each range. The absolute errors assigned to each pressure range, which take into account the random error in reading and calibration, are

14 to 50 psia, ± 0.02 to ± 0.05
 50 to 300 psia, ± 0.10 to ± 0.30
 300 to 500 psia, ± 0.30 to ± 0.50 .

The weight of potassium added to a given null chamber was determined by weighing a tared capsule filled with the alkali metal just prior to its introduction into the chamber. The precision Mettler balance was checked with calibrated weights prior to weighing each capsule, and it is believed that the observed weights of potassium were accurate within ± 0.1 mg. A check on this weight measurement was obtained indirectly by an analysis for total alkali at the conclusion of each experiment. Although the precision of this analytical determination was reduced in some cases by the large number of washings required for complete removal of the potassium, the weights by analysis were within 0.1 to 0.4 mg of the observed weights.

The volume of each null-point apparatus was obtained by precise dimensioning of the chamber before and after the experiment. Volumes computed from dimensions taken before and after firing differed randomly by about $\pm 0.1\%$, and the experimental volume in each case was taken as the arithmetical mean. Corrections for the expansion of the chamber with temperature were computed with new expansion data measured at this Laboratory. The maximum error to be expected in the final apparatus volumes at temperature should not exceed $\pm 0.25\%$, including error in dimensioning and in the linear expansion coefficient.

The majority of the PVT tests for potassium (and for sodium and cesium) were made with apparatuses fabricated from the initial batch of columbium-1%zirconium. Measurements of the thermal expansion of a sample of this material were reported previously (6). However, subsequent expansion tests on a sample from the second batch showed the previous measurements to be considerably in error. Therefore, the original sample from the first batch was carefully remeasured with both sapphire and quartz dilatometers, and the results are presented in Table 5. The new expansion coefficients by the two methods are in excellent agreement and are substantiated by existing measurements for both columbium-1%zirconium and columbium. Measurements on the second batch of columbium-1%zirconium have not been completed, but results are in good agreement with those reported in Table 5. The NRL results for the temperature range from 550° to 2500° F may be represented by the following equation,

$$L_t = L_0 \left[1.000265 + 3.1854 \times 10^{-6}(t - 75) + 4.615 \times 10^{-10}(t - 75)^2 \right] \quad (2)$$

where L_t is the length at temperature t ($^\circ$ F) and L_0 is the length at 75° F.

At the outset of the program, two problem areas were anticipated for a static diaphragm apparatus. One was the diffusion of gases through the thin diaphragm at higher temperatures; the other was the inclusion of inert gas in the chamber during the welding-off operation. The first problem of diffusion did not materialize as evidenced by the

Table 5
Thermal Expansion of Columbium-1%Zirconium

Sapphire Dilatometer				Quartz Dilatometer	
t (°C)	Percent Length Change $100(L_t - L_o)/L_o$	t (°C)	Percent Length Change $100(L_t - L_o)/L_o$	t (°C)	Percent Length Change $100(L_t - L_o)/L_o$
536.3	0.363	705.4	0.489	302.7	0.194
801.5	0.564	808.3	0.570	318.3	0.203
1003.8	0.749	901.6	0.648	415.7	0.274
1097.1	0.841	969.2	0.701	535.0	0.360
1191.6	0.900	1098.4	0.810	611.6	0.419
1260.0	0.961	1193.2	0.894	714.8	0.501
397.0	0.263	1300.2	1.002	803.7	0.573
500.7	0.335	1353.6	1.063	900.1	0.657
622.7	0.431			1001.8	0.747

reproducibility of pressure readings before and after multiple high-temperature firings. Initially the inclusion of gas in the chamber upon welding was a problem. This was solved by maintaining pressure with the pinch-off-tool jaws during the welding-off operation and by the degassing procedures which have been described. Each apparatus was checked for gas at the conclusion of an experiment by opening the chamber to an evacuated manometer. Gas pressures as low as 0.01 psi were detectable in this manner. No gas was detected in eight of the nine experiments reported for potassium. However, in experiment 12 the chamber at the conclusion of the measurements was found to contain 0.4 psia at room temperature. This represented an approximate error to the observed pressure at 2500° F of 0.3%. Although the observed pressures were roughly corrected for the effect of the small partial pressure of argon, they were still believed to contain uncertainties of $\pm 0.2\%$ from this factor.

The possibility that the quantity of surface adsorbed alkali metal might have been large enough to have significantly affected the observed pressures and specific volumes was recognized. Although no quantitative information on the degree of adsorption of alkali metals was available, a surface layer five atoms thick was believed to be a maximum for the temperature and pressure ranges encountered. A layer of this thickness for potassium would represent an insignificant fraction of even the lowest sample weight.

In order to increase weighing accuracy for the two experiments with the lowest sample weights (experiments 9 and 15), larger apparatuses with nominal volumes of 113 cc were used instead of the standard 57-cc apparatus. The surface-to-volume ratio of the larger apparatus was 1.66 cm^{-1} as compared to 2.15 cm^{-1} for the smaller. If adsorption had been significant, one would expect the low-weight experiments with their containers of lower surface-to-volume ratios to have observed pressures or specific volumes which would appear high on a comparative basis. This was not the case. It will be shown later in the reduction of the PVT data that the observed compressibilities (pV/RT) for experiments 9 and 15 are not high. This provides additional evidence that the influence of any surface adsorption was insignificant.

Another factor which can be important from the standpoint of interpretation of PVT data is thermal ionization. Again no experimental information was available, but a reliable estimation of the degree of ionization was obtained from the ionization potential (7). For potassium vapor at 2500°F and 1 atm, the degree of ionization was estimated to be less than 10^{-6} . This calculation led to the conclusion that the degree of thermal ionization is several orders of magnitude too low to produce a measurable increase in pressure.

The results of PVT measurements are generally reported in the form of compressibility factors ($p\tilde{V}/RT$), since these factors, in one form or another, are employed directly in the thermodynamic reduction of the data. Thus, it is desirable to express experimental error in terms of the compressibility factor. If we take into account all known sources of uncertainty, the percent probable error in this factor ranges from a minimum of 0.26% to a maximum of 0.35%. The maximum error occurred in experiment 15, where pressure and sample weight were low.

Experimental Saturation Pressures - Saturation pressures of potassium from 0.34 atm at 1206°F to 27.3 atm at 2393°F were measured with a separate null-point apparatus using a large excess of the alkali metal, and the results are presented in the "Vapor-Pressure Experiments" section of Table 6. Saturation pressures to 19 atm which were measured in the course of eight PVT experiments are presented in the second section of this table. Saturation pressures near the intersection of the saturation and superheat curves would be expected to be low, as explained earlier, and have not been included in the table.

The procedure described for performing a superheat experiment was similar to that used in the saturation region. After equilibrium was established, multiple readings of temperature and pressure were made at 5 to 10 min intervals until successive readings showed a temperature drift rate of 0.07°F/min or less and a temperature difference across the apparatus of 1°F or less.

Since a small temperature difference generally existed between the two ends of an apparatus during a saturation experiment, there was a question as to the true equilibrium temperature. Several experiments were made in which large temperature differences were generated between the two ends of an apparatus and pressures measured under these conditions were compared to corresponding values under isothermal conditions. It was found that the controlling equilibrium temperature was the low value if the bottom of the apparatus was cooler than the top but was the average temperature if the reverse was true. The temperatures for all reported saturation pressures were adjusted accordingly.

The vapor-pressure data in Table 6 are also presented graphically in Fig. 5. Gray (8) has shown that the graph of $\log p$ versus $1/T$ can be linear over rather wide temperature ranges for an associating gas if the apparent heat of vaporization is practically independent of temperature. However, the heat of vaporization is usually dependent upon temperature, so $\log p$ versus $1/T$ should usually exhibit curvature. It is evident from a larger scale plot of Fig. 5 that $\log p$ versus $1/T$ for potassium is not linear.

The vapor-pressure data were effectively fitted for the full temperature range (normal boiling point to 2400°F) with one three-term equation of the Kirchhoff type ($\log p = a + b/T + c \log T$). When the potassium data were precisely fitted with an equation of this type, deviations of observed pressures from those calculated with the equation were completely random with no temperature-dependent distribution. The few measurements of vapor pressure below 1 atm included in Table 6 were believed to be of lower precision and were given no weight in determining the coefficients of the vapor-pressure equation.

The least-squares method was used to derive the three coefficients of the vapor-pressure equation. A change in the dependent variable from p to $\log p$ would imply a change of weights in the least-squares method. The probable error $E_{\log p}$ of $\log p$ in

Table 6
Saturated Vapor Pressures of Potassium

Temp. (°F)	Pressure (Abs. Atm.)	Temp. (°F)	Pressure (Abs. Atm.)	Temp. (°F)	Pressure (Abs. Atm.)	Temp. (°F)	Pressure (Abs. Atm.)
Vapor-Pressure Experiments				Vapor Pressures from PVT Experiments			
1433.1	1.205	2152.2	15.648	1460.8	1.384	2151.3	15.625
1584.7	2.420	2115.1	14.229	1583.8	2.405	2061.7	12.348
1691.2	3.713	2078.8	12.921	1698.8	3.823	1974.4	9.651
1793.7	5.384	2046.0	11.796	1813.6	5.775	1938.4	8.652
				1781.4	5.178	1871.8	7.032
1901.5	7.687	1971.7	9.546	1652.4	3.225	1813.5	5.812
2009.8	10.648	1869.6	6.958	1499.5	1.696	1755.3	4.748
2111.2	14.083	1765.2	4.903	1595.9	2.562	1474.8	1.502
2215.6	18.323	1647.9	3.153	1430.1	1.199	1529.2	1.907
				1539.1	2.002	1644.4	3.097
2334.0	24.062	1507.3	1.7379	1638.5	3.040	1755.1	4.726
2376.3	26.332	1421.6	1.1566	1736.2	4.413	1859.4	6.746
2393.1	27.309	1392.8	0.9982	1812.2	5.776	1962.1	9.289
2362.3	25.597	1348.5	0.7886	1925.1	8.274	2067.1	12.518
2293.4	21.992	1319.2	0.6655	2009.3	10.603	2173.5	16.527
2292.3	21.943	1277.1	0.5205				
2253.0	20.042	1245.9	0.4321	1975.1	9.591	2228.9	18.832
2186.6	17.062	1205.6	0.3375	1864.2	6.823	2125.6	14.603
Vapor Pressures from PVT Experiments				1856.8	6.683	2006.4	10.589
1417.6	1.134	1441.0	1.282	1774.0	5.054	1919.8	8.164
1532.4	1.934	1557.9	2.188	1675.0	3.511	1821.2	5.949
1635.1	2.987	1675.6	3.532				
1736.2	4.403	1788.4	5.320	1573.0	2.323	1707.3	3.979
1836.9	6.276	1900.8	7.714	1479.0	1.526	1420.4	1.142
				1420.1	1.131	1552.9	2.110
1954.3	9.049	2004.1	10.523	1535.4	1.948	1656.9	3.261
2076.3	12.766	2108.3	13.981	1596.5	2.550	1756.3	4.732
2149.4	15.474	2187.1	17.062				
2005.3	10.536	2233.2	18.973	1716.7	4.101	1485.8	1.580
1888.3	7.409	2151.3	15.615	1607.0	2.672	1398.6	1.035

terms of the probable error E_p of p can be shown to be E_p/p and the weight factor to be $(p/E_p)^2$. Since E_p was roughly proportional to p for the PVT measurements, the weight factor was essentially constant, and no weighting of the data was employed in the least-squares treatment.

Two vapor-pressure equations

$$\log p = 6.12758 - \frac{8128.77}{T} - 0.53299 \log T \quad (3)$$

$$\log p = 6.34504 - \frac{8187.90}{T} - 0.59001 \log T \quad (4)$$

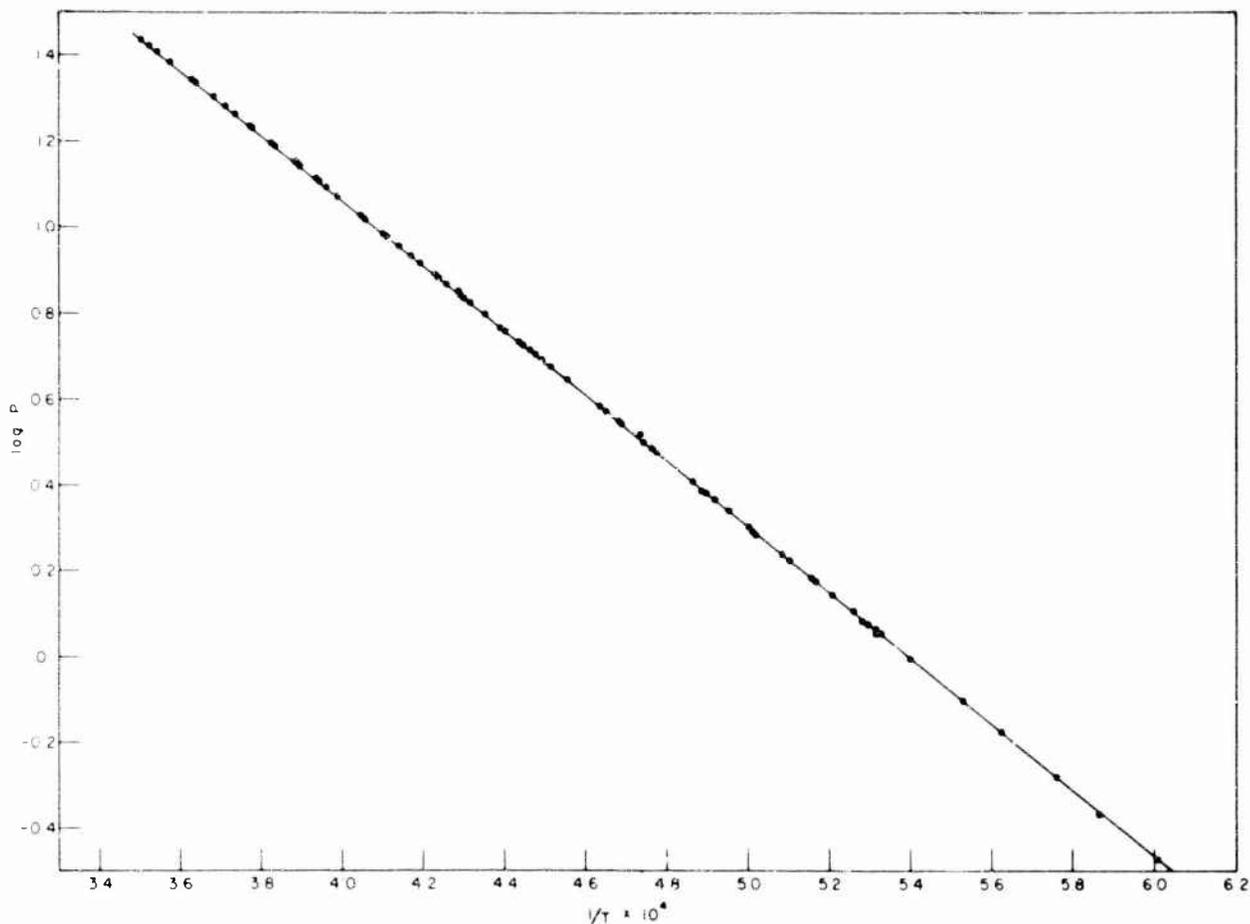


Fig. 5 - Vapor pressure of potassium as a function of the reciprocal absolute temperature

for potassium were obtained by a computer treatment of the data. Equation (3) was derived from twenty points selected at equal intervals of $1/T$ from a smoothed plot of $\log p$ versus $1/T$ for all the data. Equation (4), on the other hand, was derived using all the observed vapor pressures above the normal boiling point. The average deviation of the observed vapor-pressure data in Table 6 from corresponding values computed from Eq. (3) is $\pm 0.31\%$, and from Eq. (4) is $\pm 0.32\%$. The normal boiling point as obtained from Eq. (3) is 1393.7°F (756.5°C) and from Eq. (4) is 1394.1°F (756.7°C).

The current vapor-pressure results are compared to those of previous investigators in Fig. 6. Vapor pressures of potassium above the normal boiling point have been observed by Grachev and Kirilov (9) over the temperature range from 1022° to 2336°F , by Walling et al. (10) over the temperature range from 903° to 2115°F , and by Makansi et al. (11) over the temperature range from 1087° to 1846°F . In Fig. 6 the NRL results have been arbitrarily taken as standard, and the percent deviation of the vapor pressure of each investigator from that of NRL is plotted as a function of temperature. It will be noted that the NRL data are intermediate between those of Makansi and Walling and show reasonably good agreement with the data of either investigator. The data of Grachev and Kirilov deviate widely from all other results.

As an independent check on the internal consistency of the vapor-pressure measurements, the heat of vaporization to the monomer at absolute zero was computed for each

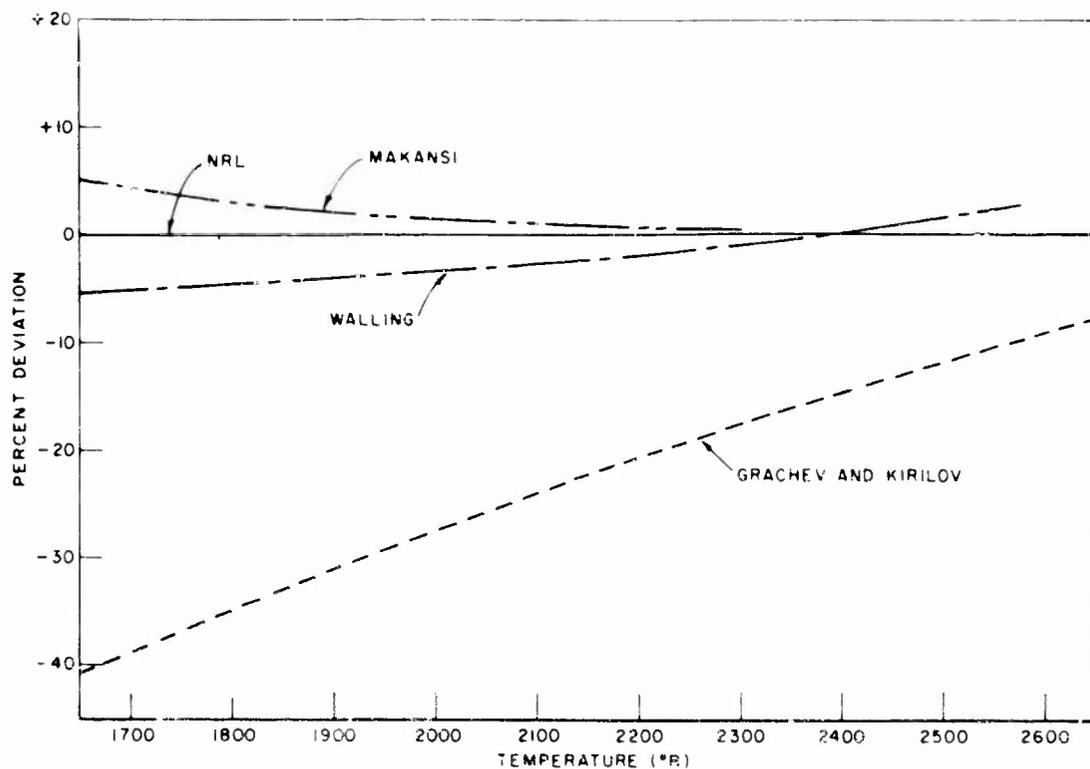


Fig. 6 - Comparison of vapor pressure data of potassium by several investigators using the NRL data as standard

observed saturation point using the basic third law equation

$$-(\Delta h_0^o)_v = \left[\left(\frac{f^o - h_0^o}{T} \right)^g - \left(\frac{f^o - h_0^o}{T} \right)^l \right] T - (\Delta f^o)_v \quad (5)$$

The free-energy function $(f^o - h_0^o/T)^g$ for the monomeric gas was evaluated with the data of Evans et al. (12) by substituting Eqs. (10) and (11) into

$$\left(\frac{f^o - h_0^o}{T} \right)^g = \left(\frac{h^o - h_0^o}{T} \right)^g - (s^o)^g \quad (5)$$

The corresponding free-energy function for the condensed liquid was evaluated with the heat-capacity data of Douglas et al. (13) by substituting Eqs. (13) and (14) into

$$\left(\frac{f^o - h_0^o}{T} \right)^l = \left(\frac{h^o - h_0^o}{T} \right)^l - (s^o)^l \quad (7)$$

The standard free energy of vaporization $(\Delta f^o)_v$ in Eq. (5) can be shown (14) to be equivalent to $(f^o - f)^g$, which can be evaluated from a knowledge of the virial coefficients. These coefficients are developed later in this report from observed vapor compressibilities, and $(f^o - f)^g$ was evaluated by substituting Eqs. (26) and (27) into the relation

$$-(f^o - f)^g = (h - h^o)^g - (s - s^o)^g T \quad (8)$$

The molal heats of vaporization at absolute zero $[(\Delta H_0^o)_v = M_1 (\Delta h_0^o)_v]$ for all of the vapor-pressure results are plotted versus temperature in Fig. 7. Theoretically, the same

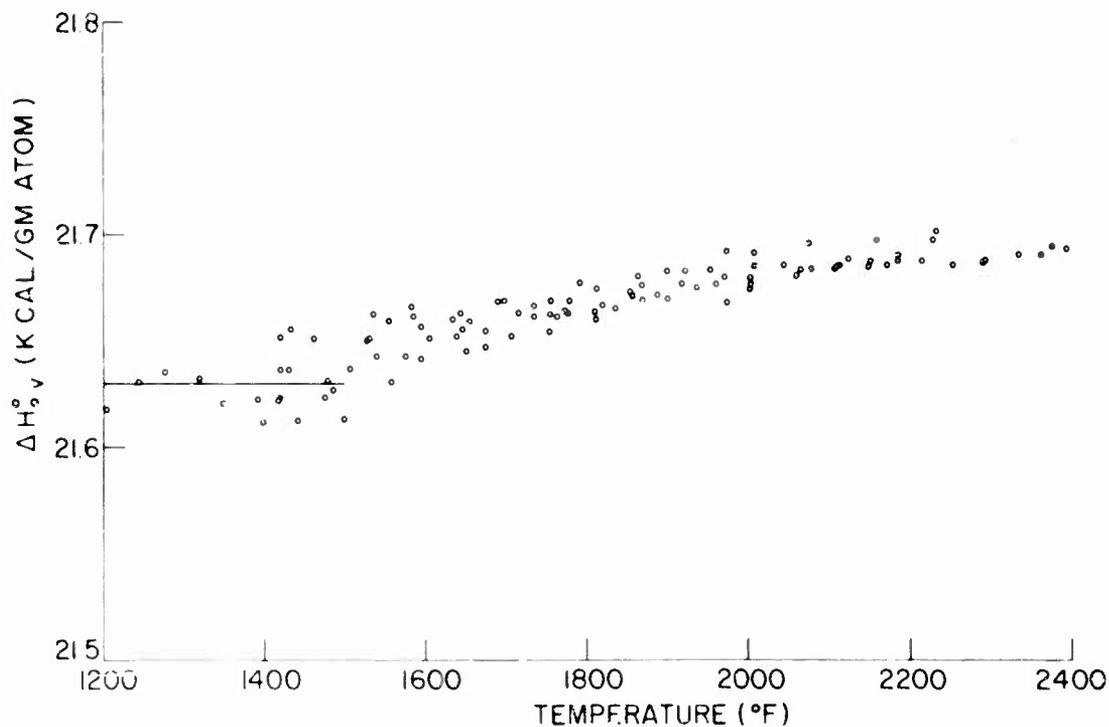


Fig. 7 - Heat of vaporization of monomeric potassium at absolute zero as computed from observed vapor pressure data

values of $(\Delta H_v^0)_v$ should be obtained for all the vapor pressures, and the heats of vaporization do cluster around a value of 21.63 kcal/mole at temperatures below 1500°F. Above this temperature the computed vaporization quantities exhibit a linear rise to an apparent value of 21.69 at 2400°F. This small temperature trend of $(\Delta H_v^0)_v$ is a function of the errors in the vapor pressure, the virial coefficients, or in any of the free-energy functions employed in the computations. The free-energy functions of the liquid are known precisely to only 1500°F, and above this temperature they were obtained by an extrapolation of the liquid specific-heat results of Ginnings (see "Specific Heat" section). Although this extrapolation was roughly justified to 2100°F by a few specific-heat measurements made at this Laboratory, it is believed that the true molal heat of vaporization is near 21.63 kcal/mole and that the apparent rise in this value above 1500°F results from error in extrapolating the specific heats of the liquid.

Discussion of Saturation Pressures - The uncertainties to be expected in the various parameters of the saturation measurements were covered under "Discussion of Superheat Results." If we take into account all known sources of error in the saturation measurement, the percent probable error in the pressure ranges from $\pm 0.70\%$ at 1 atm to $\pm 0.63\%$ at 27 atm.

The measurement of saturation pressures directly with a null-point apparatus of the diaphragm type is new to the high-temperature field, and some discussion of the relative merits of this method should be of interest. Since the boiling-point apparatus, in various modifications, is so often used with liquids for measurement of saturation pressures, it is appropriate to compare this method with the null-point technique.

The several sources which generally contribute to error in measuring the saturation pressures of liquids are (a) temperature measurement, (b) pressure measurement, (c) volatile and nonvolatile impurities, (d) method of selection of the equilibrium temperature for the observed pressure, (e) superheating of the liquid, and (f) Poynting effect. The

first three sources are common to all vapor-pressure methods, and errors may be controlled by the choice and calibration of measuring devices and by controlling the purity of the material being measured. In many measuring devices, particularly of the boiling-point type, a temperature difference exists along the length of the apparatus, and errors can readily be generated by superheating of the liquid, by undetected cold spots, or by a subjective selection of the equilibrium temperature. If the null-point apparatus is designed to be of short length and large bulk, the complete apparatus may be maintained at the same temperature during a pressure measurement, and no choice as to equilibrium temperature is required. In most apparatuses of the boiling-point type an inert gas is used in contact with the vapor, and error can be generated by diffusion of the inert gas to the surface of the liquid. Since no filling gas is in contact with the vapor in the null-point apparatus, there can be no Poynting effect.

There are, however, sources of error which are peculiar to the null-point apparatus. These include (a) the possible diffusion of gases through the diaphragm at higher temperatures, (b) the possible inclusion of inert gas in the chamber during the welding-off operation, and (c) sensitivity corrections for the diaphragm. These have been rather fully discussed in a preceding section of this report, and it has been demonstrated that with the columbium-1%zirconium apparatus these sources of error can be maintained at very low levels.

Density Measurements of Liquid Potassium

Apparatus and Method - The density of potassium was determined pointwise with columbium-1%zirconium pycnometers (Fig. 8) of 30 cc nominal volumes. The method was as follows. The alkali metal was distilled directly into the pycnometer, and an overflow vessel was welded to the top with an interconnecting capillary. The apparatus was pressurized internally (1 atm overpressure at all temperatures), heated to the desired equilibrium temperature, and the weight of metal remaining in the known volume determined, after cooling, by weight difference and by titration. Temperatures were measured with two Pt-6%Rh/Pt-30%Rh thermocouples attached at the top and bottom of the pycnometer chamber.

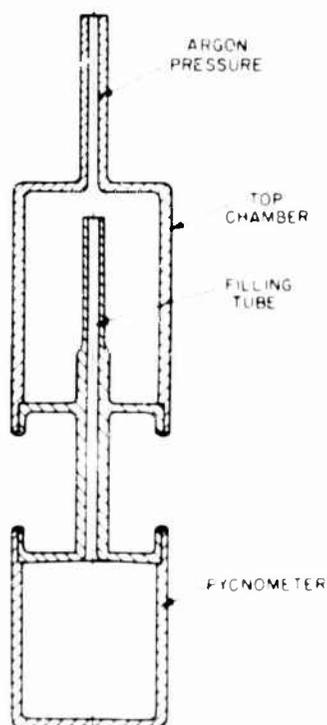


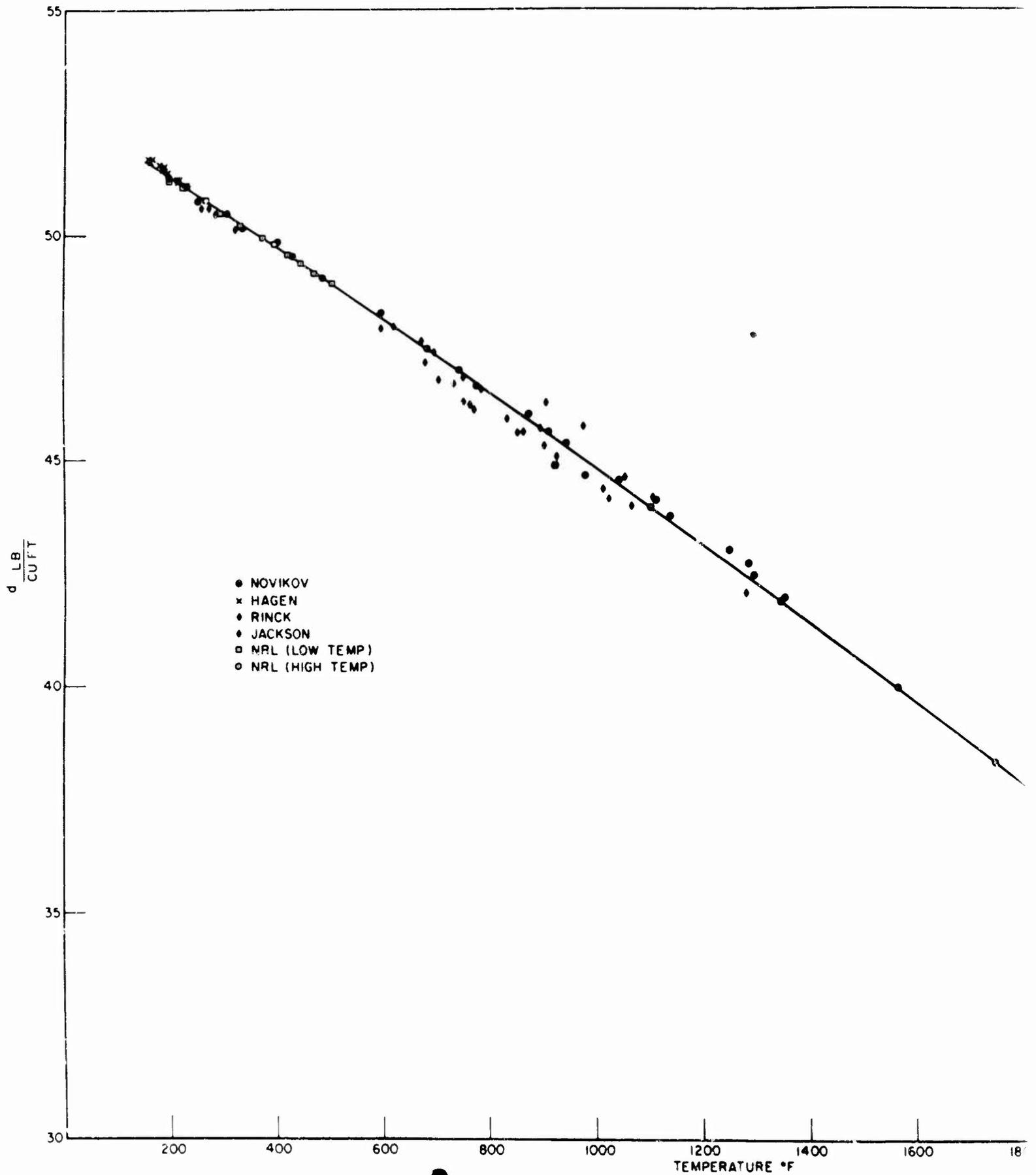
Fig. 8 - Density apparatus

Experimental Densities - The final density measurements of potassium are reported in Table 7, and they are presented graphically in Fig. 9 along with those of other investigators. The recommended density equation* for liquid potassium from the melting point to 2300°F is

$$d^l = 52.768 - 7.4975 \cdot 10^{-3}t - 0.5255 \cdot 10^{-6}t^2 + 0.0498 \cdot 10^{-9}t^3. \quad (9)$$

This equation was derived by fitting the best curve to the density determinations of Hagen (15) and NRL (16) at lower temperatures, to those of Novikov et al. (17), Jackson et al. (18), and Rinck (19) at moderate temperatures, and to those of NRL (Table 7) at higher temperatures. For each literature investigation, the average deviation of the observed densities

* Preliminary values and equations for the density of potassium (30,36) were based on either estimated or incorrect values for the thermal expansion of columbium-1%zirconium.



A

Fig. 9 - Density of liquid potassium

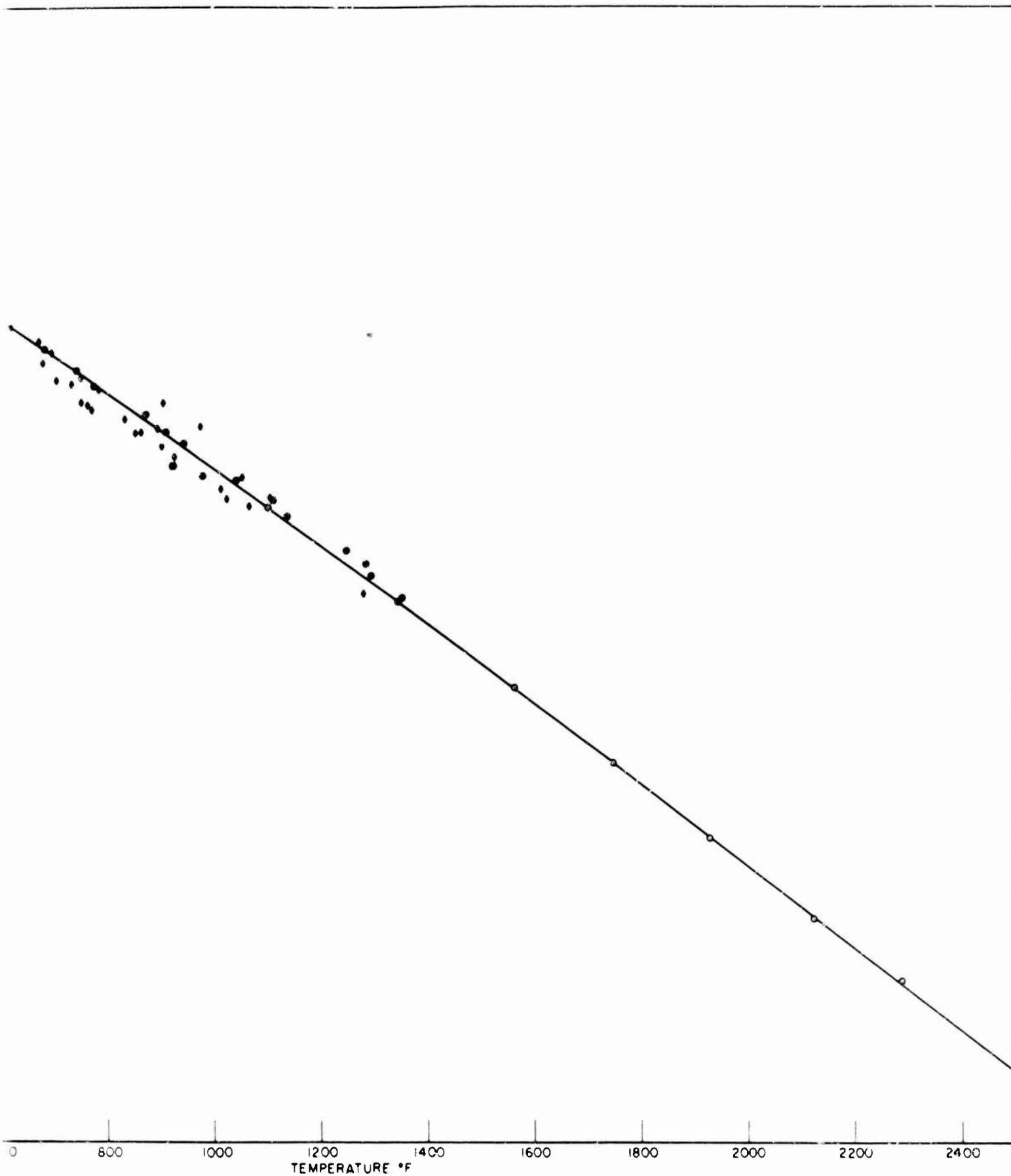


Fig. 9 - Density of liquid potassium

B

from those calculated using Eq. (9) is presented in Table 8. It will be noted that overlapping density determinations have been made from the melting point to 2300°F and that the bulk of these determinations are represented by Eq. (9) with deviations of less than $\pm 0.2\%$. This indicates a confidence limit for the equation of ± 0.2 to $\pm 0.4\%$.

Discussion of Liquid Densities - The pycnometer method, although time consuming, was chosen for the density measurements because of its high accuracy. The volume of each pycnometer was determined by a precise dimensioning of the chamber at room temperature and corrected to temperature using NRL linear expansion data for columbium-1% zirconium. The maximum error to be expected in the final volumes at temperature should not exceed $\pm 0.20\%$. The weight of metal remaining in the known volume was determined both by weight difference and by a chemical analysis for total alkali. Although the difference between the results of these two methods was never more than 0.1%, the reported values are those determined by weight difference, since they are believed to be more correct. The measured densities represent essentially saturation quantities. Compressibility factors for the liquid alkali metals are not known at these temperatures, but an overpressure of 1 atm would not be expected to make a measurable change in the density. If we include all known uncertainties, the percent probable error of the reported densities ranges from ± 0.25 to $\pm 0.30\%$.

Table 7
Density of Liquid Potassium at High Temperatures

Temperature (°F)	Density (lb/cu ft)
1099.0	43.954
1562.6	40.001
1747.0	38.337
1928.0	36.674
2121.7	34.911
2286.7	33.556

Table 8
Fit of General Density Equation for Potassium to Literature Data

Investigator	Temperature Range (°F)	% Average Deviation
		$\frac{\text{Obs.} - \text{Calc. (Eq. (9))}}{\text{Calc.}}$
Hagen (15)	(mp to 229.6)	+0.17
NRL (16)	(mp to 499.1)	+0.05
Novikov (17)	(196 to 1352)	+0.24
Jackson (18)	(257 to 1281)	-0.81
Rinck (19)	(617 to 1104)	+0.46*
NRL	(1099 to 2287)	+0.12

*Except for two results, the data of Rinck show an average deviation of $\pm 0.21\%$.

Specific-Heat Measurements of Liquid Potassium

Apparatus and Method - The copper-block calorimeter, the specially designed furnace for heating the samples, and the procedures used in these determinations are described in detail by Walker et al. (20). In brief, the method consists of equilibrating the sample contained in an Inconel bucket, at a known temperature, then dropping it into the calibrated calorimeter and measuring the temperature rise. This procedure is repeated at a series of furnace temperatures for both filled and empty buckets, and the heat capacities of the sample are derived by standard calorimetric procedures.

Experimental Specific Heats and Discussion - Three observations of the specific heat of potassium (Table 9) were made from heat-content measurements in the temperature

Table 9
Specific Heats of
Liquid Potassium

Temperature (°F)	Specific Heat (Btu/lb-°F)
1412.6	0.188
1677.5	0.189
1933.3	0.204

range from 1300° to 2100°F. The probable error of each observed result is $\pm 3\%$, which is considerably higher than that obtained in previous measurements with the same calorimetry system. The major portion of this error stems from a large random uncertainty observed in duplicate measurements. As a result of this problem, the method and measurement system were completely re-examined for possible sources of error, but no significant source was discovered. It is now believed that the reduced measurement precision resulted from the relatively low sample-to-container heat-content ratio, which tended to magnify nominal system errors. It was necessary to use the thick-walled container, with its accompanying unfavorable heat-content ratio, in order to withstand the pressure of potassium vapor at operating temperatures.

The three experimental points of NRL are compared to the existing data of Deem et al. (21) and Douglas et al. (13) in Fig. 10. The dashed curve above 1500°F represents a temperature extension of Douglas's data with his specific-heat equation. It will be noted that while the NRL points tend to verify this extension, the smoothed data of Deem diverge strongly at higher temperatures. The reason for this discrepancy is not known, and the true specific-heat curve for the liquid above 1500°F is in question.

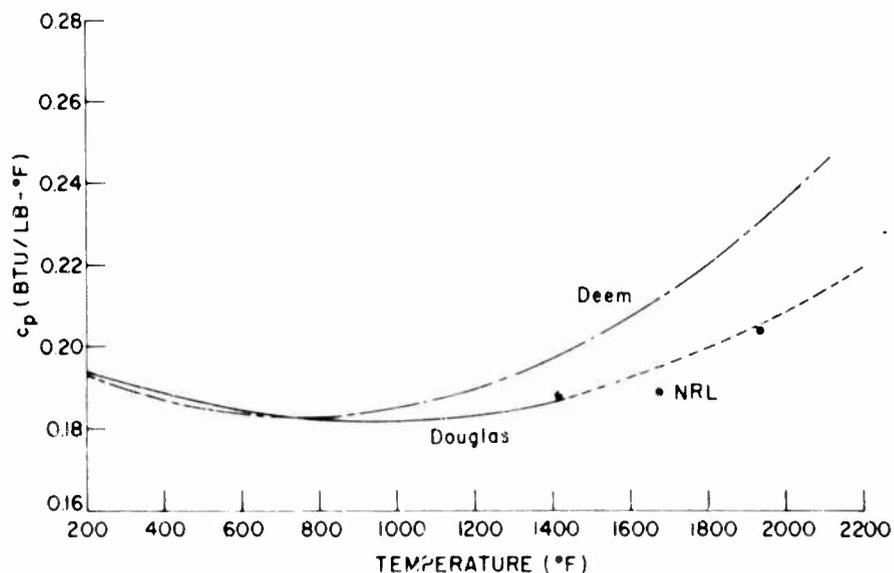


Fig. 10 - Specific heat of liquid potassium

SUMMARY OF FUNDAMENTAL PROPERTIES USED IN THE THERMODYNAMIC TREATMENTS

Density of Liquid Potassium

Densities of the condensed phase were obtained from Eq. (9), which was derived from the observed data of this Laboratory and of other investigators.

Enthalpy and Entropy of Monomeric Potassium Vapor

Equations for absolute enthalpy and entropy of monomeric vapor as functions of temperature were derived from the work of Evans et al. (12) and are based on their standard enthalpies and entropies for the monomeric gas over the temperature range from 0° to 3300° F and their enthalpy of vaporization at 0° R (21.70 mean kcal/mole). The equations for the monomeric gas at 1 atm (relative to the solid at 0° R) are

$$(h^g)^0 = 998.95 + 0.12700 T + 24,836 e^{-39,375/T} \quad (10)$$

and

$$(s^g)^0 = 0.18075 + 0.12700 \ln T + 0.7617 e^{-31,126/T}. \quad (11)$$

Specific Heat at Constant Pressure of Monomeric Potassium Vapor

The temperature equation for specific heat of monomeric potassium vapor at constant pressure was also derived from the work of Evans et al. (12) and is based on their computed specific heats over the temperature range from 0° to 3300° F. The relation for the monomeric gas at 1 atm is

$$(c_p^g)^0 = 0.12700 + 2.888 e^{-28,970/T}. \quad (12)$$

Enthalpy and Entropy of Liquid Potassium

The thermodynamic properties presented in this report are based on the properties of the monomeric gas at 1 atm, but comparison calculations were made in which the properties of the saturated liquid were used as a starting point. The absolute properties of the liquid (relative to the solid at 0° R) were computed with

$$h_s^l = 87.8783 + 0.2022t - 0.2177 \times 10^{-4} t^2 + 0.07741 \times 10^{-7} t^3 \quad (13)$$

and

$$s_s^l = 0.52298 \log T - 0.64848 \times 10^{-4} T + 0.11589 \times 10^{-7} T^2 - 0.9646. \quad (14)$$

These equations were derived directly from the work of Douglas et al. (13) and are based on their specific-heat equations for the solid and liquid over the temperature range from 32° to 1472° F. The absolute enthalpy and entropy of solid potassium at 32° F were taken from the work of Evans et al. (12). It was arbitrarily assumed in Eq. (14) that potassium liquid does not contain significant polyatomic species.

Saturation Pressure of Liquid Potassium

Two equivalent vapor-pressure equations were derived from least-squares correlations, but Eq. (3) was selected to compute other thermodynamic quantities in this report.

Enthalpy and Entropy of Vaporization of Potassium

Heats of vaporization were calculated with

$$\Delta h_v = J p_s \left[\frac{18,717}{T_s} - 0.53299 \right] \left[v_s^g - v_s^l \right] \quad (15)$$

which was derived by a differentiation of Eq. (3) and a substitution into the Clapeyron equation. Values of v_s^l at each temperature were obtained from Eq. (9) and values of v_s^g from the virial equation of state (Eq. (25)).

The entropy of vaporization at each saturation point was obtained by dividing the appropriate enthalpy change by the absolute temperature as shown in

$$\Delta s_v = \frac{\Delta h_v}{T} \quad (16)$$

Vaporization properties for potassium were first published in Ref. 30. The final properties are reported in Appendix A; and, except for corrections resulting from the new thermal expansion values for columbium-1%zirconium, they differ in only two respects from those published previously. First, the specific volume of the saturated vapor, which was required in the Clapeyron equation to compute the enthalpy of vaporization, was obtained more correctly from the virial equation than from Eq. (1). Secondly, the specific volume of the liquid, also required in the Clapeyron equation, was obtained from the final density equation (Eq. (9)) rather than from the preliminary equation used in Ref. 30.

THERMODYNAMIC TREATMENT OF PVT AND ASSOCIATED PROPERTIES

Imperfection in Potassium Vapor and Methods of Treatment

Spectroscopic studies (12) have shown that the vapors of the alkali metals contain molecular species of two or more atoms. In this investigation, the existence of dimers and higher-molecular-weight species in potassium vapor has been verified by a graphical analysis of PVT data. Potassium vapor is believed to contain both dimeric and tetrameric species, and the composition of the vapor may be considered to be regulated by the mobile equilibria

$$2K \rightleftharpoons K_2, \text{ where } k_2 = \frac{N_2}{(N_1)^2 p} \quad (17)$$

and

$$4K \rightleftharpoons K_4, \text{ where } k_4 = \frac{N_4}{(N_1)^4 p^3} \quad (18)$$

The polyatomic species are present in sufficient abundance to require a consideration of their presence in the determination of the thermodynamic properties of the vapor.

Where such mobile equilibria are present in the vapor state, the important properties (enthalpy, entropy, and specified heat) may be reduced from the PVT data by either of two methods. In the first, the gas is treated as a monatomic assembly with all apparent imperfections given by a virial equation of state, and the other thermodynamic quantities are obtained as corrections to those of the monatomic gas in terms of the virial coefficients. In the second method, equilibrium constants are derived for the mobile equilibria by treating the gas as a mixture of molecular species, and other thermodynamic quantities are derived from the enthalpy changes associated with changes in the molecular composition of the vapor.

In order to derive equilibrium constants by the second method, one must make an assumption regarding the treatment of gas imperfections. Theories dealing with association and gas imperfections may be reduced to two general forms. One is illustrated in the treatise by Vukalovich et al. (22). The fundamental assumption set forth by Vukalovich is that imperfect gases combine to form complexes, i.e., that simple two-body collisions

lead to van der Waals imperfections, while some of the complex collisions lead to stable particles. The second theory as illustrated by Hirschfelder et al. (23) has as a fundamental assumption that all imperfections may be regarded as association, i.e., that complex particles behave as perfect gases. In some modifications of this theory, a small excluded volume correction is considered, independent of association.

Simple collisions among the species undoubtedly do lead to imperfections of the type described by Vukalovich (22), and whether or not these van der Waals imperfections may be ideally incorporated into association equilibria is debatable. In any event, since the contribution from this source to total imperfection (including association) would be expected to be small and cannot, at present, be partitioned from the total, it was assumed in the equilibrium constant treatment that all species behave as perfect gases. This is, in effect, the same assumption made in the second general theory that all imperfections may be ideally treated as association.

In some treatments of PVT data, a small excluded volume correction is employed. This correction usually takes the form of $(\hat{V} - \tilde{b})$ in which \tilde{b} is the molal volume coefficient in the van der Waals equation of state. A volume correction of this type can be theoretically justified, and the significance of the correction for potassium vapor was studied. The molal volume coefficient \tilde{b}_a for an associating mixture of gases can be shown to be equal to \tilde{b} for the monomeric species (22). An estimation of the coefficient for the monomeric species was obtained empirically by correlating coefficients of more or less unassociated organic and inorganic gases. Volume coefficients from Ref. 24 for a large number of gases are shown in Fig. 11 to be a linear function of the liquid molal volume \hat{V}^l . This correlation, represented by the empirical equation

$$\tilde{b} = 1.288 \hat{V}^l - 0.072 \quad (19)$$

where

$$\begin{aligned} \tilde{b} &= \text{cc. mole} \\ \hat{V}^l &= \text{cc. mole,} \end{aligned}$$

permitted the volume coefficient of monomeric potassium vapor to be estimated from its condensed volume. This correction, in the moderate pressure range of the PVT experiments, represents a maximum change in the observed volume of only 2%. Since the excluded volume correction is small and would be balanced by any internal pressure correction of the van der Waals type, it has been neglected.

Both the virial method and the equilibrium constant method were used in preliminary analyses of the compressibility data, and the application of each method to the potassium data will be described in some detail later in this report.

Virial Coefficients of Potassium

The virial equation of state in the volume expansion form

$$\frac{p\hat{V}}{RT} = 1 + \frac{B}{\hat{V}} + \frac{C}{\hat{V}^2} + \frac{D}{\hat{V}^3} + \dots \quad (20)$$

was chosen for this analysis; and A , B , C , and D are commonly called the first, second, third, and fourth virial coefficients, respectively. The first virial coefficient in this form of the equation theoretically should be unity.

The major part of the imperfection present in the alkali metal vapor is due to the mobile equilibria; therefore, the shape of a compressibility isotherm is determined by the reactions present in the vapor and the magnitudes of their equilibrium constants.

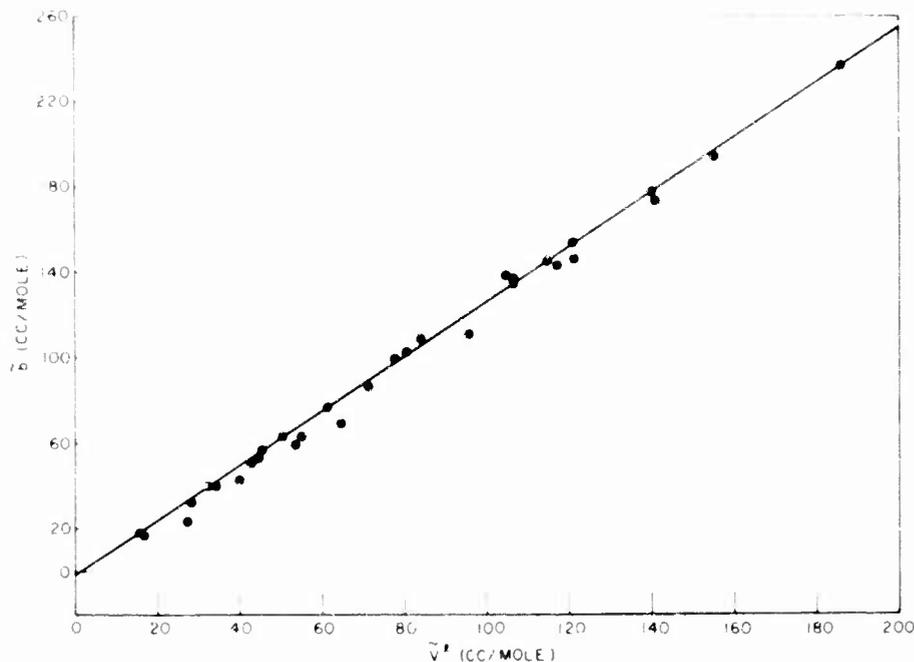


Fig. 11 - Correlation of van der Waals volume coefficients of organic and inorganic gases with molal liquid volume

The virial coefficients for the volume expansion form (Eq. (20)) have been related by Kahn and Uhlenbeck (25) and Woolley (26) to equilibrium constants of the association reactions by

$$B = -k_2 RT \quad (21)$$

$$C = (4k_2^2 - 2k_3)(RT)^2 \quad (22)$$

$$D = (-20k_2^3 + 18k_2k_3 - 3k_4)(RT)^3 \quad (23)$$

$$E = (112k_2^4 + 18k_3^2 - 144k_2k_3^2 + 32k_2k_4 - 4k_5)(RT)^4 \quad (24)$$

For a metal vapor where only dimeric and tetrameric reactions are present, all terms which include k_3 or k_5 may be taken to be zero, and it follows that the second and third virials are directly related to the equilibrium constant of the dimeric reaction, and the fourth virial to the equilibrium constants of the dimeric and tetrameric reactions. It may seem logical to reduce the data on the basis of equilibrium constants and then calculate the virial coefficients directly from Eqs. (21), (22), (23), and (24). This is entirely feasible; but since the coefficients and the equilibrium constants are related in a power series, coefficients through the fifth and sixth virials become significant, and the equations for all the thermodynamic properties become unnecessarily complicated. In the reduction of the potassium data by the graphical methods to be described, the influence of any virial above the fourth is incorporated into the third and fourth virials.

The virial coefficients are temperature dependent and are derived graphically by plotting functions along constant temperature lines. Compressibility data at selected temperatures were obtained from large-scale plots of the observed data for the nine experiments as reported in Table 3. Initially the quantity $(z - 1)/\hat{V}$ was computed from experimental PVT data and was plotted as a function of $1/\hat{V}$ for isotherms at 50-degree

intervals between 2525° and 1975° F. Preliminary second virial coefficients were obtained from these plots as the $\lim_{1/\hat{V} \rightarrow 0} (z - 1)\hat{V}$. As a second step, the quantity $[(z - 1)\hat{V} - B]\hat{V}$ was plotted as a function of $1/\hat{V}$ for isotherms at 50-degree intervals between 2525° and 2150° F. Preliminary third virial coefficients were obtained as the $\lim_{1/\hat{V} \rightarrow 0} [(z - 1)\hat{V} - B]\hat{V}$ as $1/\hat{V} \rightarrow 0$, and fourth virial coefficients from the slope of each isotherm. Although the average deviation of the observed compressibility factor from that computed using the best curve drawn through the data for each isotherm was below 0.25%, it was apparent that this accuracy was not sufficient at the lower pressures to define the intercepts nor, at lower temperatures, to define the temperature dependency of the virial coefficients.

Important information was obtained from these preliminary plots of the data. The deviations of the plotted quantities from the best linear curves were compared. It was noted that the sign and magnitude of the deviations for a particular null-point experiment were practically independent of temperature, and it was concluded that the composite error for each experiment must be largely systematic. This permitted the use of an alternative procedure. The maximum range of compressibility factors and the maximum definition of the three virial coefficients were obtained at either 2400° or 2450° F. At the latter temperature, the compressibility factor z was plotted as a function of $1/\hat{V}$ (Fig. 12), and the second virial coefficient B was obtained as the $\lim_{1/\hat{V} \rightarrow 0} dz/d(1/\hat{V})$ as $1/\hat{V} \rightarrow 0$. Also, $(z - 1)\hat{V}$ was plotted as a function of $1/\hat{V}$, and B was obtained as described above. The most consistent value of B obtained by both procedures was -18.447. Using this value of B , the quantity $[(z - 1)\hat{V} - B]\hat{V}$ was plotted against $1/\hat{V}$, and the best linear curve was drawn. From the deviation of each experimental point at 2450° F from the best curve (Fig. 13), the multiplying factor required to correct $p\hat{V}/RT$ to the linear curve was computed.

Assuming all errors to be systematic, the compressibility factors for each of the nine experiments were adjusted at all temperatures by the multiplying factor obtained at 2450° F. Using these adjusted compressibility factors, which are identified by z^* in all quantities, $(z^* - 1)\hat{V}$ was plotted as a function of $1/\hat{V}$ for isotherms at 50-degree intervals between 2525° and 2000° F. Second virial coefficients were obtained from these plots,

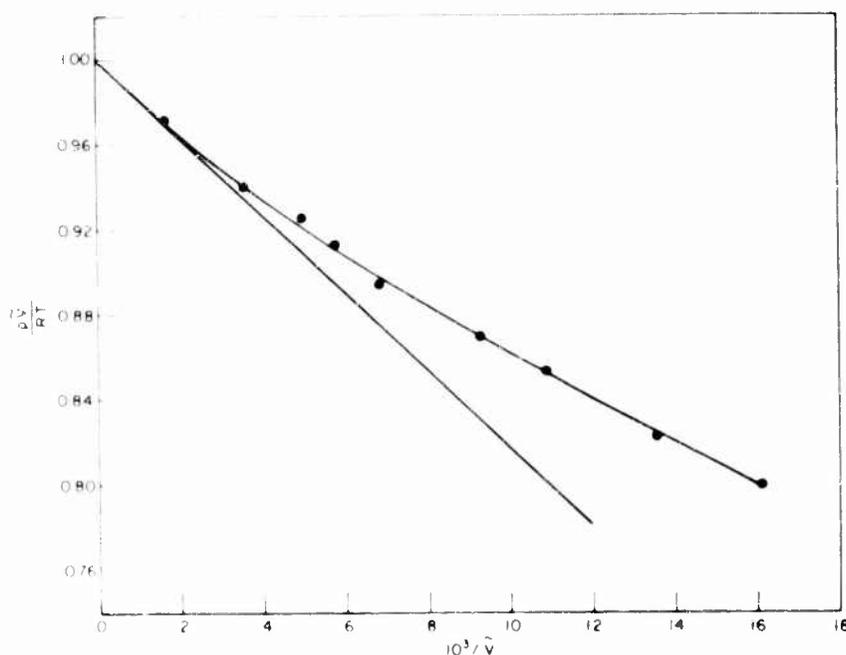


Fig. 12 - Plot of $p\hat{V}/RT$ versus $1/\hat{V}$ for potassium at 2450° F

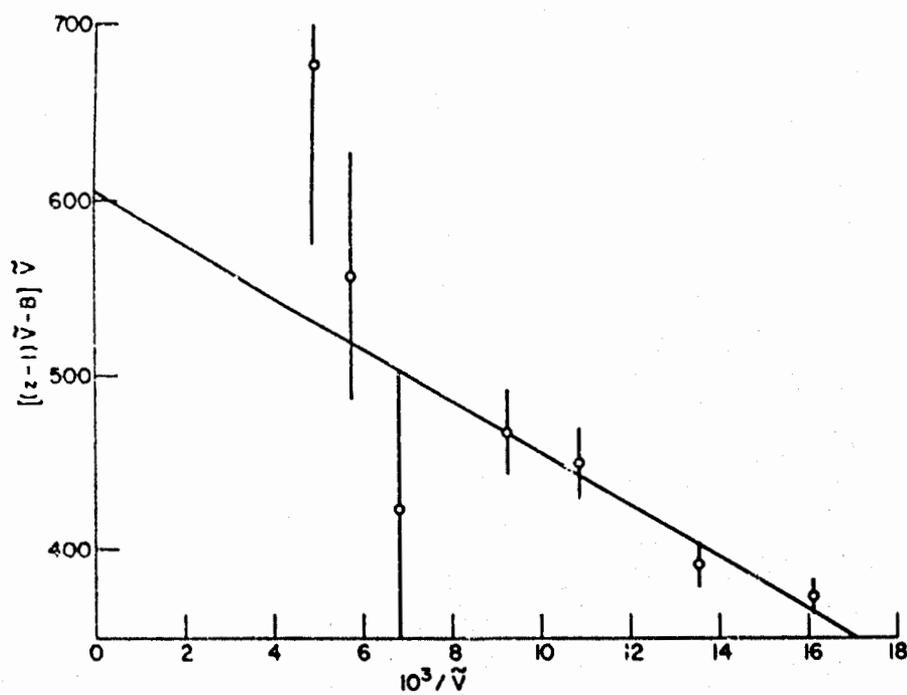


Fig. 13 - Plot of $[(z - 1)\tilde{V} - B]\tilde{V}$ versus $1/\tilde{V}$ for potassium at 2450°F

which are shown in Fig. 14. Third and fourth virial coefficients were obtained as already described by plotting the quantity $[(z^* - 1)\tilde{V} - B]\tilde{V}$ against $1/\tilde{V}$ (Fig. 15) for isotherms at 50-degree intervals between 2525° and 2150°F. Additional second virial coefficients in the lower temperature range from 1600° to 1950°F were obtained by computing the average value of $[(z - 1)\tilde{V} - C/\tilde{V} - D/\tilde{V}^2]$ for the lower pressure experiments on each isotherm. The values of C and D required for these calculations were obtained from preliminary temperature equations. The final virial coefficients, obtained as described, are shown graphically in Figs. 16, 17, and 18.

Since the virial coefficients are functions of equilibrium constants, it is not surprising that each coefficient can be represented for the full temperature range with a simple exponential equation in which $1/T$ is the principal variable (Eq. (25)). The $\log T$ term was added to the equation for the second virial coefficient, since the term can be derived directly from the relationship between k_2 and B (Eq. (21)).

Experimental PVT data were also obtained from 2000° to 1600°F, but the number of experimental points in this region were not sufficient for computing reliable third and fourth virial coefficients by the graphical method. Consequently, before the virial equation of state was acceptable for calculations below 2000°F, it was necessary to determine its fit to the observed lower temperature data. At temperatures and pressures corresponding to observed low-temperature points, compressibility factors were calculated and compared to the observed values. The fit of the virial equation of state to the lower temperature data was found to be equivalent to that obtained at higher temperatures.

It should be recognized that the procedure of adjusting the data (in no case did an adjustment factor exceed +0.4% of z) represents only one method of deriving the virial coefficients and that equally valid coefficients could have been obtained more laboriously from unadjusted data.

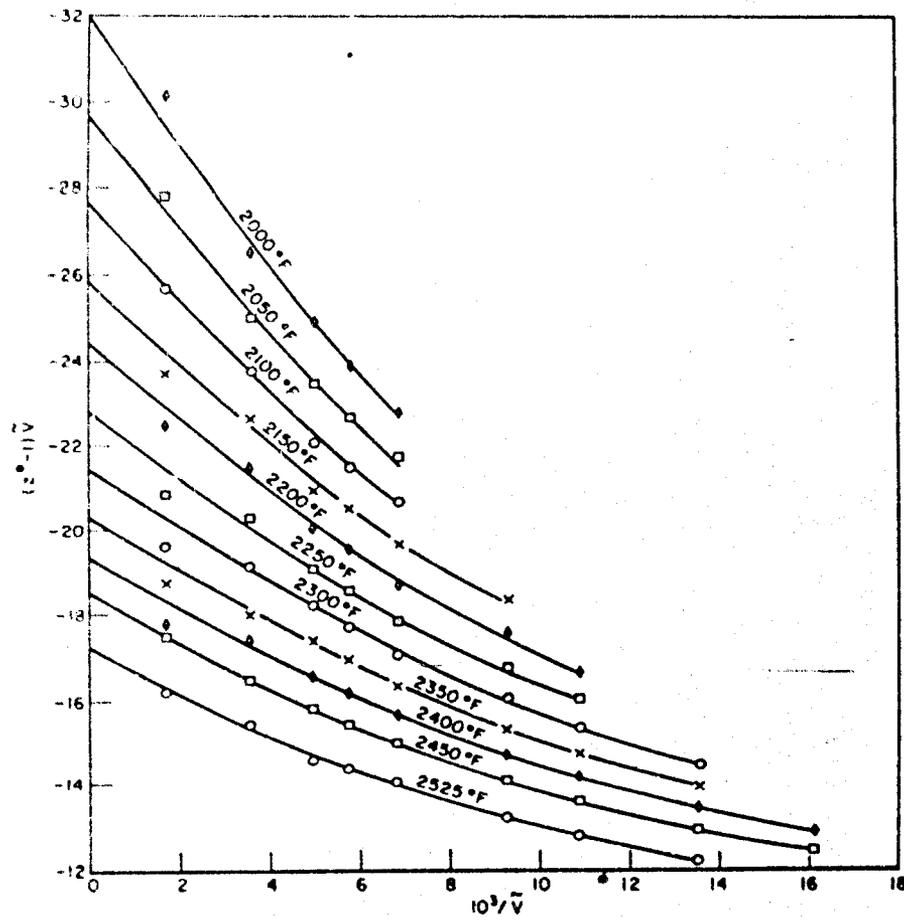


Fig. 14 - Plot of $(z^* - 1)\tilde{V}$ versus $1/\tilde{V}$ for potassium

The Virial Equation of State of Potassium

The virial equation of state* with coefficients through the fourth virial is

$$\frac{p\tilde{V}}{RT} = 1 + \frac{B}{\tilde{V}} + \frac{C}{\tilde{V}^2} + \frac{D}{\tilde{V}^3} \tag{25}$$

where

$$\log |B| = -3.8787 + \frac{4890.7}{T} + \log T$$

$$B < 0$$

$$\log C = 0.5873 + \frac{6385.7}{T}$$

$$C > 0$$

$$\log |D| = 1.4595 + \frac{7863.8}{T}$$

$$D < 0$$

* The preliminary virial equation for potassium(30) was based on incorrect values for the thermal expansion of columbium-1%zirconium.

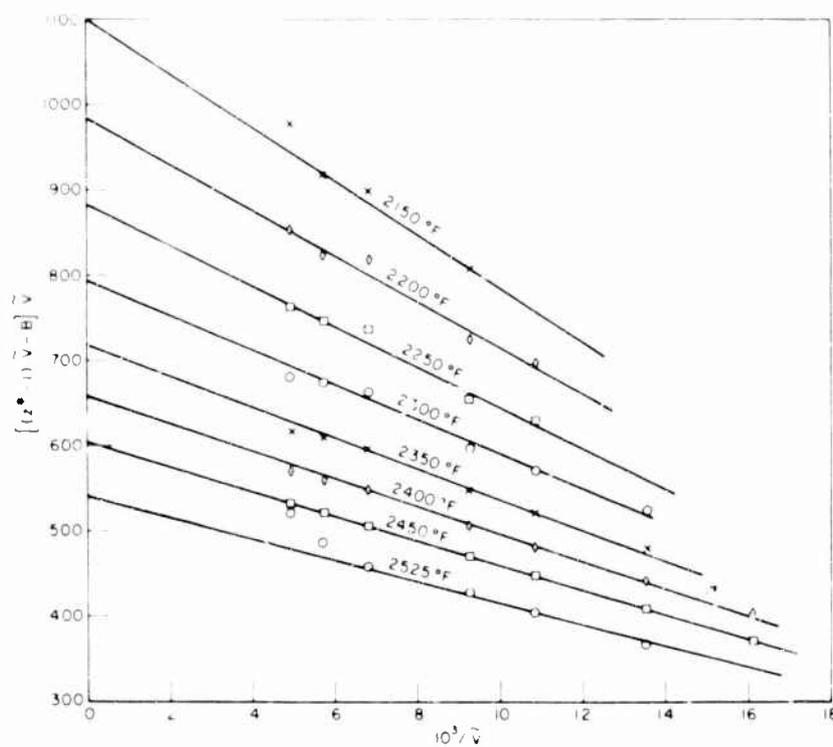


Fig. 15 - Plot of $[(z^* - 1)\tilde{V} - B]\tilde{V}$ versus $1/\tilde{V}$ for potassium

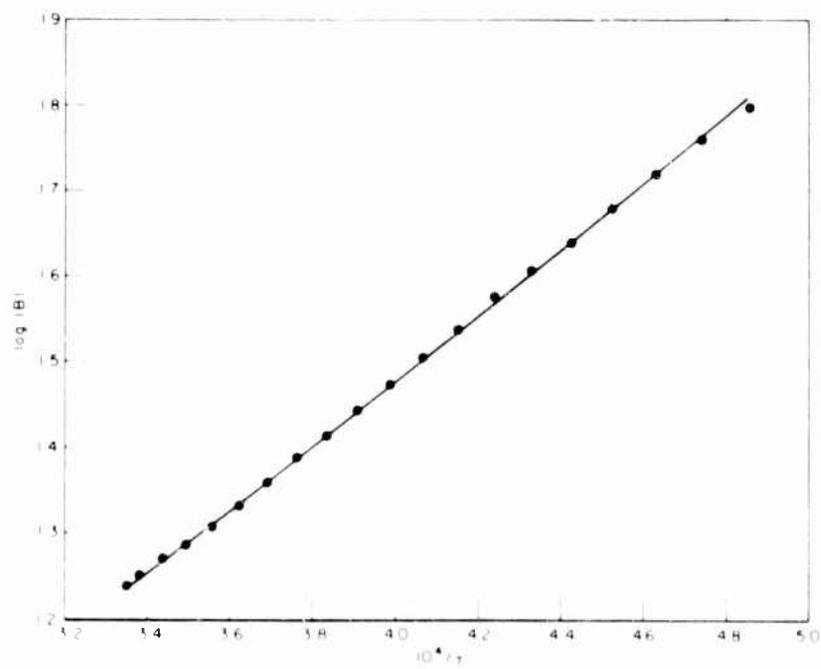


Fig. 16 - Second virial coefficients of potassium

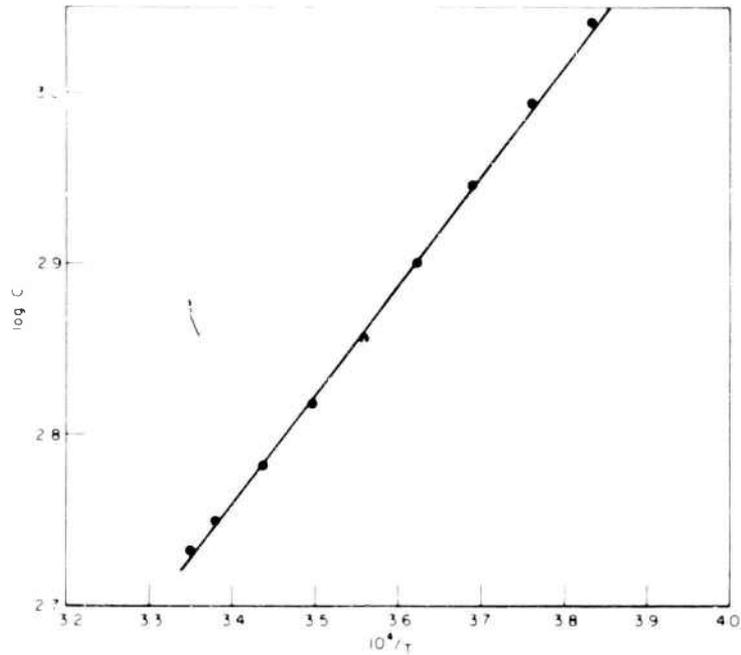


Fig. 17 - Third virial coefficients of potassium

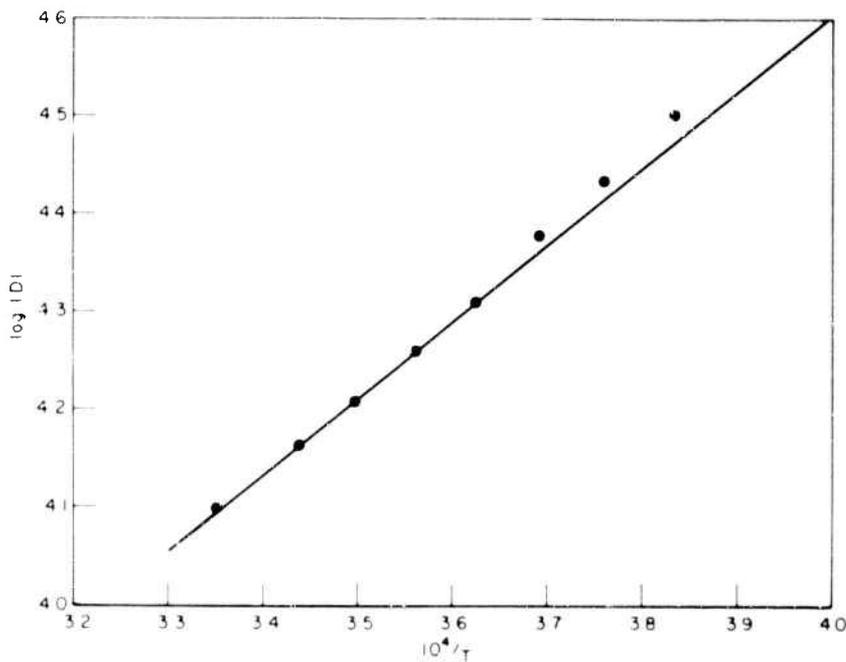


Fig. 18 - Fourth virial coefficients of potassium

The fit of the virial equation to measured data is shown graphically in Fig. 19, where compressibility isotherms generated from Eq. (25) are compared to experimental compressibilities at 100-degree intervals from 1600° to 2500° F. The observed specific volume data in Table 3, or compressibility factors computed from that data, may be calculated from the virial equation with an average deviation of $\pm 0.26\%$. This deviation is of the magnitude predicted by the combined random and systematic errors in the null-point measurements.

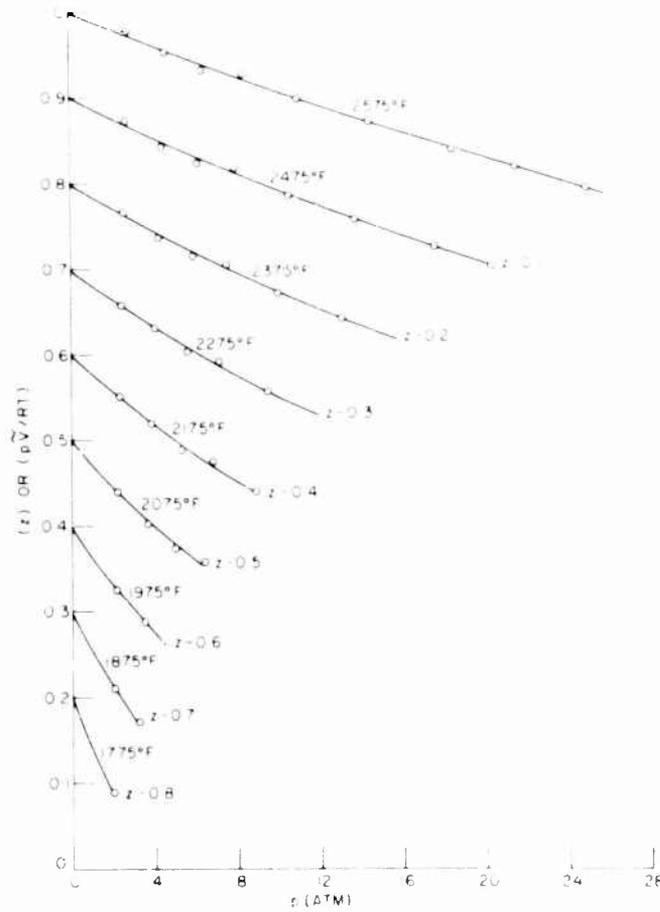


Fig. 19 - Compressibility of potassium vapor at several temperatures

Thermodynamic Properties of Potassium by the Virial Method (Monomeric Gas Path)

Expressions for the thermodynamic properties (monomeric gas path) in terms of the second and third virial coefficients were derived by Hirschfelder et al. (27). By the same method, another set of equations was derived and extended to include the fourth virial coefficient. These equations were used to compute the thermodynamic properties of potassium vapor (Appendixes A and B) and are presented in this section.

Enthalpy, Entropy, and Specific Heat of Saturated and Superheated Vapor - These properties at all vapor states were computed along isotherms using the following equations:

$$h_v^g = (h_v^g)^o + \frac{RT}{y_1} \left\{ \frac{1}{\tilde{V}} \left[B - T \left(\frac{dB}{dT} \right) \right] + \frac{1}{\tilde{V}^2} \left[C - \frac{T}{2} \left(\frac{dC}{dT} \right) \right] + \frac{1}{\tilde{V}^3} \left[D - \frac{T}{3} \left(\frac{dD}{dT} \right) \right] \right\} \quad (26)$$

$$s_v^g = (s_v^g)^o - \frac{R}{y_1} \left\{ \ln p - \ln \frac{p\tilde{V}}{RT} + \frac{B}{\tilde{V}} + \frac{T}{\tilde{V}} \left(\frac{dB}{dT} \right) + \frac{C}{2\tilde{V}^2} + \frac{T}{2\tilde{V}} \left(\frac{dC}{dT} \right) + \frac{D}{3\tilde{V}^3} + \frac{T}{3\tilde{V}} \left(\frac{dD}{dT} \right) \right\} \quad (27)$$

$$\begin{aligned}
 (c_p^g) - (c_p^l) = \frac{R}{M_1} \cdot \frac{R}{M_1} \left\{ \frac{\left[1 + \frac{1}{\tilde{V}} \left(B + T \frac{dB}{dT} \right) + \frac{1}{\tilde{V}^2} \left(C + T \frac{dC}{dT} \right) + \frac{1}{\tilde{V}^3} \left(D + T \frac{dD}{dT} \right) \right]^2}{\left[1 + \frac{2B}{\tilde{V}} + \frac{3C}{\tilde{V}^2} + \frac{4D}{\tilde{V}^3} \right]} \right\} \\
 - \frac{RT}{\tilde{V} M_1} \left\{ \left(T \frac{d^2B}{dT^2} + 2 \frac{dB}{dT} \right) + \frac{1}{2\tilde{V}} \left(T \frac{d^2C}{dT^2} + 2 \frac{dC}{dT} \right) + \frac{1}{3\tilde{V}^2} \left(T \frac{d^2D}{dT^2} + 2 \frac{dD}{dT} \right) \right\}. \quad (28)
 \end{aligned}$$

Specific Volume of Saturated and Superheated Vapor - This property at all vapor states (Appendixes A and B) was computed from the virial equation of state (Eq. (25)) by a trial and error solution.

Enthalpy and Entropy of the Condensed Phase - These properties of the saturated liquid (Appendix A) at each temperature were obtained by subtracting the enthalpy or entropy of vaporization from the corresponding properties of the saturated vapor.

Thermodynamic Properties of Potassium by the Virial Method (Liquid Path)

Expressions for the thermodynamic quantities with the properties of the condensed liquid as a base were derived directly from those in the preceding section. These new equations together with a procedural outline of the methods of calculation are presented below.

Enthalpy, Entropy, and Specific Heat of Saturated Vapor - The enthalpy and entropy of the saturated vapor at a given temperature were obtained by adding the enthalpy or entropy of vaporization to the corresponding properties of the saturated liquid.

The specific heat at saturation was obtained by numerically evaluating, at 50-degree intervals, the differential

$$(c_p^g)_s = \left[\left(\frac{h}{T} \right)_p^g \right]_s = \left[\left(\frac{Mh}{\Delta T} \right)_p^g \right]_s. \quad (29)$$

Enthalpy, Entropy, and Specific Heat of Superheated Vapor - These properties in the superheat region were computed along constant temperature lines with each saturated state as a starting point. The general equations in virial form are

$$h^g - h^l = \frac{RT}{M_1} \left\{ \frac{1}{\tilde{V}} \left[B - T \left(\frac{dB}{dT} \right) \right] + \frac{1}{\tilde{V}^2} \left[C - T \left(\frac{dC}{dT} \right) \right] + \frac{1}{\tilde{V}^3} \left[D - T \left(\frac{dD}{dT} \right) \right] \right\}_{T_1}^{T_2} \quad (30)$$

$$s^g - s^l = \frac{R}{M_1} \left\{ \ln p - \ln \frac{p}{RT} + \frac{B}{\tilde{V}} + \frac{T}{\tilde{V}} \left(\frac{dB}{dT} \right) + \frac{C}{2\tilde{V}^2} + \frac{T}{2\tilde{V}^2} \left(\frac{dC}{dT} \right) + \frac{D}{3\tilde{V}^3} + \frac{T}{3\tilde{V}^3} \left(\frac{dD}{dT} \right) \right\}_{T_1}^{T_2} \quad (31)$$

$$\begin{aligned}
(c_p^g)_1 - (c_p^g)_2 = \frac{R}{M_1} & \left\{ \frac{\left[1 + \frac{1}{\tilde{V}_1} \left(B + T \frac{dB}{dT} \right) + \frac{i}{\tilde{V}_2} \left(C + T \frac{dC}{dT} \right) + \frac{1}{\tilde{V}_3} \left(D + T \frac{dD}{dT} \right) \right]^2}{\left[1 + \frac{2B}{\tilde{V}_1} + \frac{3C}{\tilde{V}_2} + \frac{4D}{\tilde{V}_3} \right]} \right\}_{\tilde{V}_1}^{\tilde{V}_2} \\
& + \frac{R1}{\tilde{V}_1 M_1} \left\{ \left(T \frac{d^2 B}{dT^2} + 2 \frac{dB}{dT} \right) + \frac{1}{2\tilde{V}_1} \left(T \frac{d^2 C}{dT^2} + 2 \frac{dC}{dT} \right) + \frac{i}{\tilde{V}_1^2} \left(T \frac{d^2 D}{dT^2} + 2 \frac{dD}{dT} \right) \right\}_{\tilde{V}_1}^{\tilde{V}_2} \quad (32)
\end{aligned}$$

A Comparison of the Monomeric Gas Path and the Liquid Path for Thermodynamic Calculations

The thermodynamic properties of potassium were computed along constant temperature lines. The starting point for a particular property could have been the absolute value of that property for either the saturated liquid or for the monomeric gas at 1 atm. As an example of using the liquid property as a base, the enthalpy of the saturated vapor at a given temperature is obtained by adding the enthalpy of vaporization to the corresponding absolute enthalpy of the saturated liquid, and the enthalpy at any state in the superheat region is obtained by adding the enthalpy change in the superheat region to the enthalpy of the saturated vapor. For the monomeric gas base, the enthalpy of the vapor at saturation or at any other pressure is obtained by adding the enthalpy change to the corresponding absolute value of the ideal gas at 1 atm. The enthalpy of the saturated liquid is then obtained by subtracting the enthalpy of vaporization from that of the saturated vapor.

The three properties (enthalpy, entropy, and specific heat)* of the superheated vapor were computed by both paths, and values at selected states are compared in Table 10. In order for the comparison of the two computational paths to be more meaningful, several factors should be considered. The virial equation of state used for both paths was reduced from PVT data covering a pressure range from 2.35 to 27.4 atm. Therefore, an extrapolation of the virial equation is required to compute saturation properties of the vapor below 1575° or above 2375° F. Any error resulting from this extrapolation would be reflected strongly in the properties computed along the liquid path, since these properties are dependent upon vaporization quantities, which are, in turn, dependent upon saturation specific volumes as obtained from the virial equation of state. On the other hand, properties computed along the gas path are independent of vaporization quantities. It should also be recognized that the upper limit of the liquid specific-heat measurements was approximately 2200° F and that properties computed at higher temperatures along the liquid path require an extrapolation of the specific heat above its measured range.

A valid comparison of the two computational paths can be made only at temperatures below 2200° F, since this represents the measured limit of the liquid specific heats. In the temperature range from 1600° to 2200° F, absolute enthalpies (Table 10) in the superheat region, based on enthalpies of the saturated liquid, were 11 to 13 Btu/lb (approximately 0.8 to 1.1%) lower than corresponding values based on the monomeric gas enthalpies. Likewise, entropies by the liquid path were 0.004 to 0.005 Btu/lb-°F (approximately 0.3 to 0.5%) lower, and specific heats were 1 to 5% lower than those by the gas path.

* Preliminary properties as computed by the liquid path (30) and the monomeric gas path (37) were based on incorrect values for the thermal expansion of columbium-1%zirconium. They differ significantly in some cases from the final values in this report.

Table 10
Comparison of Monomeric Gas and Liquid Path Calculations
(Virial Method)

Temperature (°F)	Pressure (atm)	Monomeric Gas Path			Liquid Path		
		h^g	s^g	c_p^g	h^l	s^l	c_p^l
1600	2.0	1211.6	1.095	0.260	1198.7	1.090	0.255
	1.0	1236.0	1.140	0.193	1223.1	1.135	0.188
	0.2	1255.6	1.230	0.140	1242.7	1.224	0.135
1800	5.0	1213.3	1.054	0.287	1200.0	1.049	0.290
	1.0	1270.9	1.156	0.160	1257.6	1.151	0.163
	0.2	1282.9	1.242	0.134	1269.6	1.237	0.136
2000	10.0	1219.4	1.026	0.290	1207.2	1.022	0.298
	5.0	1262.8	1.075	0.217	1250.6	1.071	0.224
	1.0	1301.3	1.169	0.146	1289.1	1.165	0.153
	0.2	1309.3	1.253	0.131	1297.1	1.249	0.138
2200	17.0	1231.0	1.009	0.283	1219.9	1.005	0.285
	15.0	1241.9	1.018	0.268	1230.8	1.014	0.269
	10.0	1270.6	1.046	0.228	1259.5	1.042	0.230
	5.0	1302.2	1.091	0.181	1291.1	1.087	0.183
	1.0	1329.6	1.180	0.138	1318.5	1.176	0.140
	0.2	1335.3	1.264	0.129	1324.2	1.260	0.131
2400	27.0	1240.1	0.993	0.293	1227.1	0.989	0.268
	20.0	1269.4	1.016	0.245	1256.5	1.011	0.220
	15.0	1290.2	1.035	0.220	1277.2	1.031	0.195
	10.0	1312.4	1.062	0.193	1299.4	1.057	0.168
	5.0	1336.4	1.103	0.162	1323.4	1.099	0.137
	1.0	1356.9	1.190	0.134	1343.9	1.186	0.109
	0.2	1361.1	1.273	0.129	1348.1	1.269	0.103
	0.2	1361.1	1.273	0.129	1348.1	1.269	0.103
2500	30.0	1255.9	0.994	0.280	1238.9	0.989	0.221
	25.0	1274.8	1.008	0.247	1257.9	1.002	0.188
	20.0	1292.8	1.024	0.224	1275.9	1.018	0.166
	15.0	1311.4	1.043	0.204	1294.4	1.037	0.145
	10.0	1331.1	1.068	0.182	1314.1	1.062	0.123
	5.0	1352.3	1.109	0.156	1335.3	1.103	0.097
	1.0	1370.3	1.195	0.133	1353.3	1.189	0.075
	0.2	1373.9	1.277	0.128	1357.0	1.272	0.070

The relatively constant difference between the absolute property values as computed along the two paths over the temperature range from 1600° to 2200° F suggests that there is a small error in a base property along one or both of the two paths, but it has not been possible to determine the source or the path contributing this error. The most probable source of error along the gas path was believed to be the value selected for the heat of vaporization of solid potassium at 0°R. The value of this heat of vaporization is generally derived from vapor-pressure data. Evans et al. (12) analyzed the vapor-pressure measurements existing at that time and selected a value of 21.70 kcal/mole for $(\Delta H_0^0)_v$, which was

used in all the thermodynamic calculations in this report. Within the limits of experimental errors this value is verified by the value of 21.63 kcal/mole obtained in the analysis of the NRL vapor-pressure data in this report.

In Table 10 it will be noted that the enthalpy of the superheated vapor at a given pressure, if computed from the liquid base, exhibits an abnormal decrease in slope beginning at 2400°F and becoming pronounced at 2500°F. This is reflected in the specific-heat values which at 2500°F are 21 to 45% lower than those computed by the monomeric gas path. Part of this apparent error in enthalpy as computed along the liquid path may have resulted from the extrapolation of the liquid specific heats above their measured range or to errors in other quantities along the computational paths. It is believed that a large part must also be attributed to small errors in the enthalpies of vaporization caused by the required extrapolation of the virial equation above 2375°F.

Engineering design calculations put prime emphasis on the change in enthalpy or entropy when moving from one state to another rather than on their absolute values; therefore, the choice of path is of minor importance for both these properties. However, the specific heat of the vapor would be expected to be more accurate if computed from the monomeric gas path, since this path is independent of vaporization quantities and does not require an extrapolation of the specific heat of the liquid above its measured range. Therefore, the monomeric gas path has been chosen for computation of all the thermodynamic properties in this report.

Molecular Reactions in Potassium Vapor and Their Equilibrium Constants

For a preliminary analysis of the PVT data, the average molecular weights (from the ideal gas law) and the apparent dimerization equilibrium constants k'_2 of potassium vapor were computed for several isotherms covering the temperature range. When these apparent equilibrium constants were plotted against pressure, the values along each isotherm increased substantially and systematically with increase in pressure. If it is assumed that all species behave as perfect gases (see section entitled "Imperfections in Potassium Vapor and Methods of Treatment"), then the dependency of k'_2 on pressure must be explained by the existence of molecular weight species higher than the dimer.

If it is assumed that all molecular species behave as perfect gases, the association of potassium vapor can be represented by a series of independent equilibria of the type

$$n K_1 \rightleftharpoons K_n \quad (33)$$

The equilibrium constants are defined by

$$k_n = \frac{N_n}{(N_1)^n p^{n-1}} \quad (34)$$

where n may be 2, 3, or 4 for the dimeric, trimeric, and tetrameric reactions, respectively.

The existence of the dimeric species has been verified spectroscopically (31), but the higher-molecular-weight species have not been identified. Before equilibrium constants could be reduced from the raw PVT data, an identification of the species higher than the dimer was required. The method employed with potassium was one which has been applied frequently to the study of association in hydrogen-bonded organics (28,29). The apparent equilibrium constant of dimerization k'_2 , when all association is taken to be dimerization, can be expressed as a power series (28)

$$k'_2 = k_2 + 2k_3p + 3k_4p^2 + 2k_3^2p^3 - 2k_2k_4p^3 + \dots \quad (35)$$

in terms of the pressure and the true equilibrium constants of the association reactions. The apparent dimerization constants at a given temperature may be computed from the raw PVT data, and the relationship of the apparent constants to pressure may be used to identify the higher reactions present in the vapor and to compute their equilibrium constants.

Although the possibility of the coexistence of significant amounts of both trimer and tetramer was recognized, the existence of only one higher-molecular-weight species was believed to be more probable. If PVT data are of sufficiently high precision, a positive distinction between trimer and tetramer can be made with Eq. (35). If, in a vapor mixture, species of molecular weights higher than the trimer are not present, Eq. (35) (by setting $k_4 = 0$) reduces to

$$k_2' - 2k_3^2 p^3 = k_2 + 2k_3 p. \quad (36)$$

Likewise if the trimeric species is taken as insignificant, the same equation reduces to

$$k_2' + 2k_2 k_4 p^3 = k_2 + 3k_4 p^2. \quad (37)$$

When proper adjustments are made for the small p^3 term in each equation, a linear relationship between $(k_2' - 2k_3^2 p^3)$ and p implies the existence of trimer, while a linear relationship between $(k_2' + 2k_2 k_4 p^3)$ and p^2 implies the existence of tetramer. Accordingly, the fit of each relationship (Figs. 20 and 21) to the experimental PVT data for potassium at 2450°F was tested. The vertical line for each data point represents the probable error assigned to that equilibrium constant. It will be noted that the tetramer relationship (Eq. (37) and Fig. 21) appears to provide the best fit to the experimental data, but the distinction between trimer and tetramer is not conclusive.

Even though the above analysis was made prior to the first reduction of the potassium data (30), the properties at that time were computed and reported on the basis of the trimeric species. The evidence represented by Figs. 20 and 21 was not believed to be sufficient to justify the existence of the tetrameric species. However, since that time, experimental PVT measurements for sodium have been completed. The data for this metal, published in a companion report (38), have also been tested with Eqs. (36) and (37)

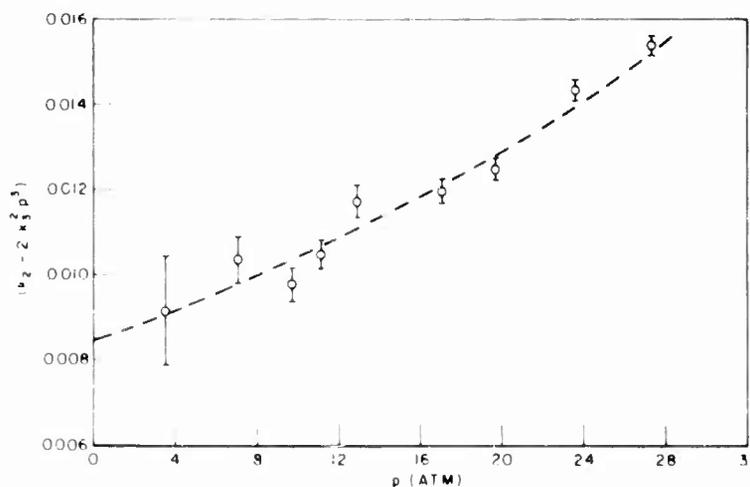


Fig. 20 - Plot of $(k_2' - 2k_3^2 p^3)$ versus p for potassium at 2450°F

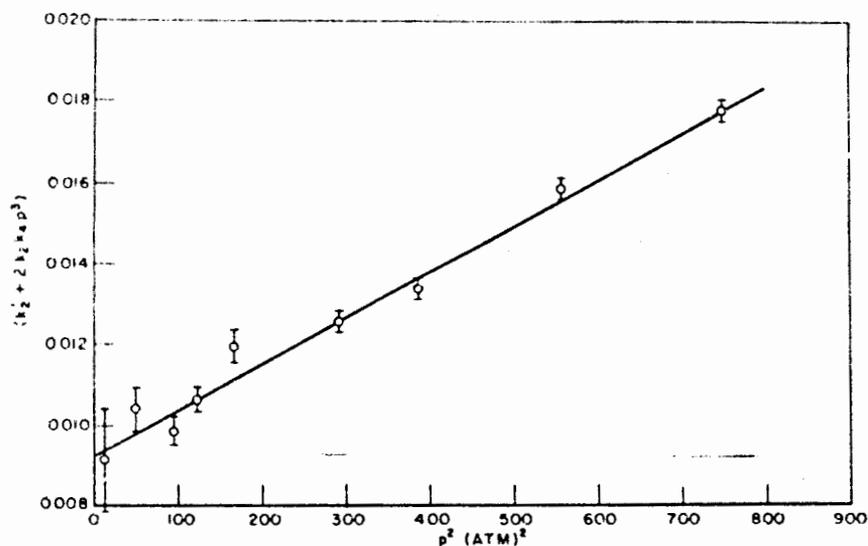


Fig. 21 - Plot of $(k'_2 + 2k_2k_4p^3)$ versus p^2 for potassium at 2450°F

and provide a more positive identification of the tetrameric species. Therefore, the assumption that potassium vapor consists of monomeric, dimeric, and tetrameric species is based on the combined evidence from the two alkali metal systems.

It is recognized that a fortuitous combination of a van der Waals imperfection with a trimer reaction in the vapor could be mistaken for a tetramer reaction. However, it seems unlikely that the relationship between the two types of imperfections would lead to apparent evidence for the tetramer in both metals.

Equilibrium constants for the dimeric and tetrameric association reactions were reduced from the PVT data with Eq. (37). When k'_2 along a constant temperature line is plotted versus $(3p^2 - 2k_2p^3)$, the thermodynamic constant k_2 is obtained by an extrapolation of k'_2 to zero pressure, and the thermodynamic constant k_4 is obtained as the slope of the linear curve. Plots of this type were made for potassium at 50-degree intervals between 2525° and 1950°F. It was again noted that errors in the PVT experiments were apparently systematic. This permitted the use of the same correlation technique which was applied with some advantage in deriving virial coefficients.

The temperature of 2450°F. was again chosen as a basis for the adjustment of the experimental data. The apparent equilibrium constants k'_2 at this temperature were plotted versus $(3p^2 - 2k_2p^3)$ on successive graphical plots until a final curve was obtained for which the intercept was not significantly different from the k_2 estimated from the previous plot. The factor required for each of the nine PVT experiments to correct the average molecular weight of the vapor for its apparent systematic error was computed from the deviation of k'_2 from the best linear curve. The plot of k'_2 versus $(3p^2 - 2k_2p^3)$ at 2450°F is not presented since the similar plot of $(k'_2 + 2k_2k_4p^3)$ versus p^2 was presented as Fig. 21. Deviations of experimental points and the probable errors assigned to the points are not altered by the slightly different method of plotting the data.

With the correction factors as derived above for the nine PVT experiments, all data were adjusted for their apparent systematic errors. The adjusted value of k'_2 , identified as $(k'_2)^*$, was plotted as a function of $(3p^2 - 2k_2p^3)$ for isotherms at 50-degree intervals between 2525° and 1950°F (Fig. 22). Thermodynamic constants for the dimeric and tetrameric reactions were obtained from a large-scale plot of this figure. The values

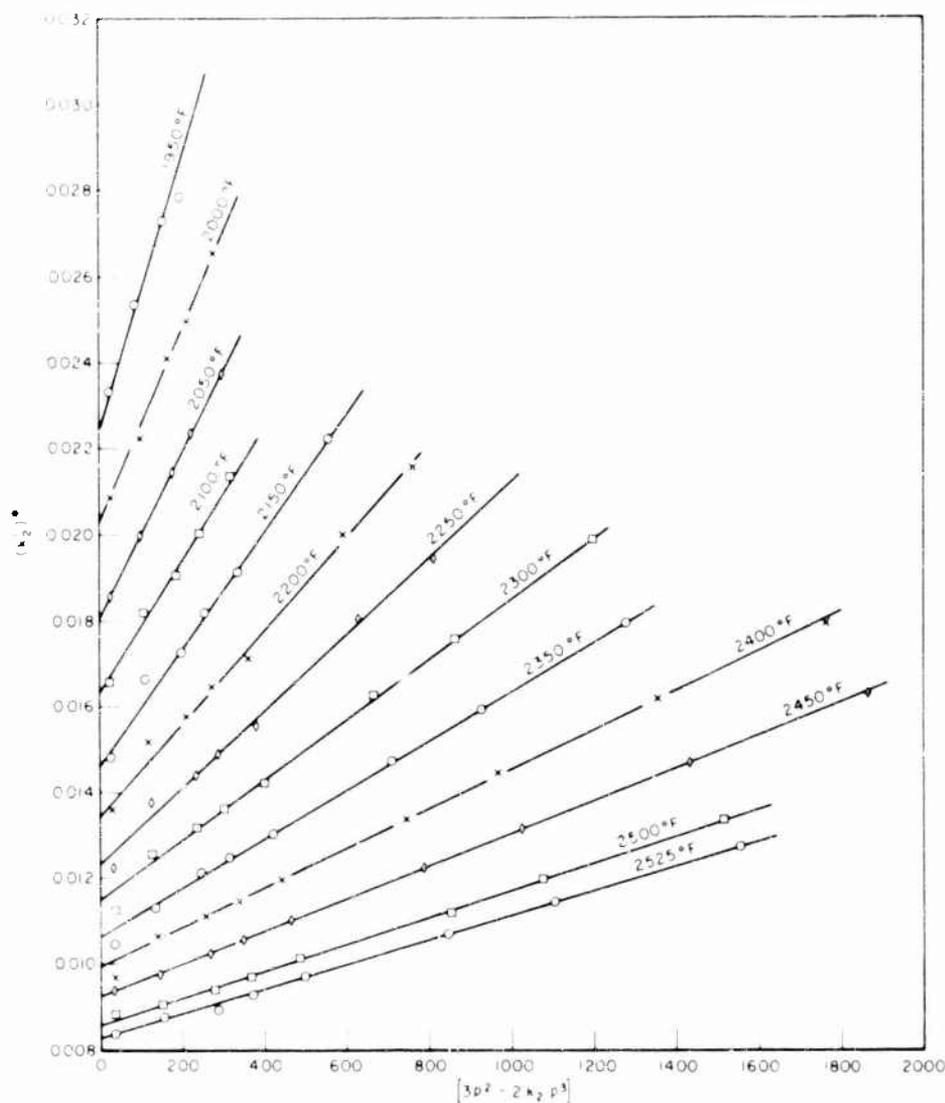


Fig. 22 - Plot of $(k_2')^0$ versus $(3p^2 - 2k_2p^3)$ for potassium

of $\log k_2$ and $\log k_4$ are plotted against $1/T$ in Figs. 23 and 24, respectively. It will be noted that within experimental error the points on each curve define a straight line (Eqs. (38) and (39)).

A few experimental PVT points were obtained between 1950° and 1600° F. Since dimerization is still significant at these temperatures, the reliability of Eq. (38) in this region had to be determined by testing the agreement of extrapolated and experimental points. Experimental values of k_2 for each observed k_2' below 1950° F were computed with Eq. (37) (values of k_4 were obtained from Eq. (39)), and these values were found to be in satisfactory agreement with those obtained by an extrapolation of Eq. (38).

It should again be recognized that the adjustment procedure was used only as a technique in the reduction of the data. The average adjustment factor was $\pm 0.19\%$ of M_a , and in no case did a factor exceed 0.6%.

Theoretically, the equilibrium constants derived for the dimerization reaction should be independent of the assumptions made regarding imperfections in the vapor, since k_2 for any type of imperfection is the $\lim k_2'$ as $p \rightarrow 0$. From a practical standpoint, this is

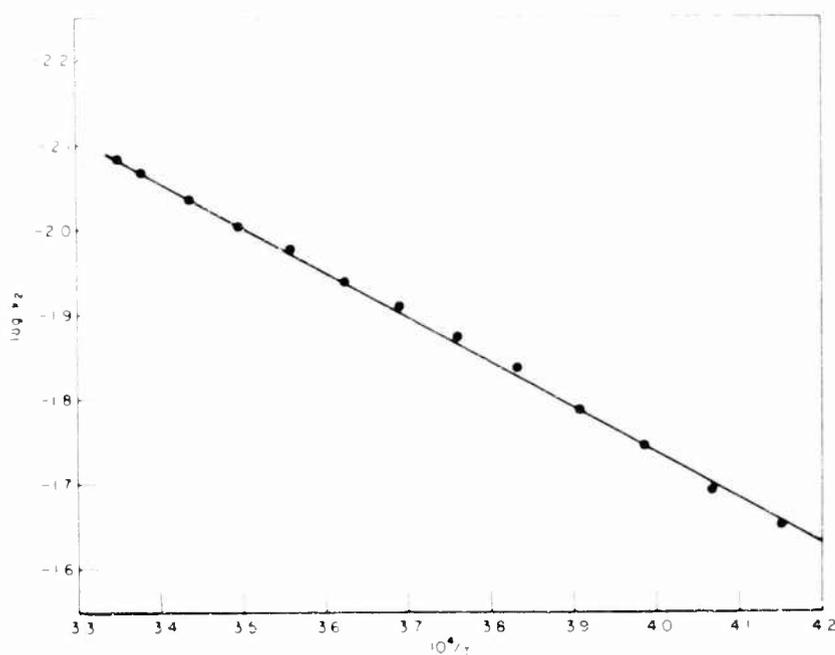


Fig. 23 - Equilibrium constants for the dimerization reaction in potassium vapor

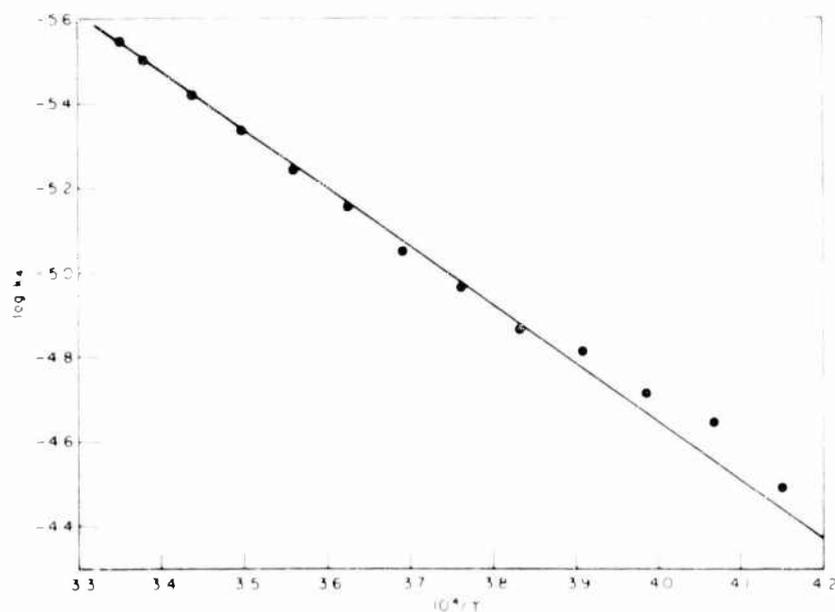


Fig. 24 - Equilibrium constants for the tetramerization reaction in potassium vapor

usually not the case. For example, with the potassium data (see Figs. 20 and 21) the intercept or k_2 for each isotherm had to be defined for the most part by the higher pressure data, since the data at pressures below 8 atm were too few and of too low precision. This meant that the choice of trimer or tetramer affected significantly (compare Fig. 20 and Fig. 21) the value obtained for k_2 . Values of k_2 (30) based on trimer (even when corrected for the new thermal-expansion coefficients of columbium-1%zirconium) are 16 to 18% lower (over the measured temperature range) from those based on tetramer in

this report. With the additional verification provided by the sodium data for the existence of the tetrameric species, as previously presented, it is now believed that the equilibrium constants of the dimeric reaction based on tetramer are more reliable than those based on trimer.

The Quasi-Chemical Equation of State of Potassium

A second equation of state of potassium vapor is constituted by the three equations,*

$$\log k_2 = -3.8611 + \frac{5312.5}{T} \quad (38)$$

$$\log k_4 = -10.1453 + \frac{13,745}{T} \quad (39)$$

$$pv = \frac{RT}{M_a} \quad (40)$$

The observed specific-volume data in Table 3, or the corresponding compressibility factors, may be calculated from these three equations with an average deviation of $\pm 0.23\%$. This equation of state, then, is equivalent to the virial form and may also be used to compute other thermodynamic properties.

Compositional Properties of Potassium by the Quasi-Chemical Method

Enthalpies of the Dimeric and Tetrameric Reactions in Potassium Vapor - Enthalpies of the two reactions were obtained with the van't Hoff equation

$$\frac{d \ln k}{dT} = \frac{\Delta H^\circ}{RT^2} \quad (41)$$

by substituting the known differentials from Eqs. (38) and (39). The standard enthalpies, so obtained, are

$$2k = k_2, \Delta H_2^\circ = -24,296 \text{ Btu lb-mole or } -13.50 \text{ kcal mole}$$

$$4k = k_4, \Delta H_4^\circ = -62,860 \text{ Btu lb-mole or } -34.92 \text{ kcal mole.}$$

The effect on the equilibrium constants of the dimeric reaction caused by treating the higher molecular association as trimeric or tetrameric has been discussed. Although equilibrium constants by the two treatments over the temperature range from 1950° to 2525° F differ in magnitude by 16 to 18%, the slopes of $\log k_2$ versus $1/T$, and therefore the enthalpies of the reaction, showed agreement within experimental errors. The probable error assigned to the reported value of ΔH_2° is ± 0.40 kcal/mole.

The enthalpy of the tetrameric reaction can be influenced by the treatment of imperfections, unless it is assumed that all simple collisions leading to intermolecular attractions may be treated ideally as molecular associations. In any event, no assignment of accuracy has been made to the enthalpy of this reaction.

The association enthalpy at absolute zero for the dimeric reaction was calculated by two methods. A value of -12.4 kcal/mole was obtained at an average temperature of

* Preliminary equilibrium constants of the dimerization reaction as reported in Ref. 30 were based on incorrect thermal expansion values for columbium-1%zirconium

2250°F from the equation

$$(\Delta H_0^0)_2 = \Delta H_2^0 - \Delta(H^0 - H_0^0)_{2K}^{K_2} \quad (42)$$

using the observed standard reaction enthalpy and the enthalpy functions of Evans et al. (12). Another value of -12.8 ± 0.2 kcal/mole (which is an average over the temperature range from 1950° to 2525°F) was obtained with the equation

$$\frac{(\Delta H_0^0)_2}{T} = -R \ln k_2 - \Delta \left(\frac{F^0 - H_0^0}{T} \right)_{2K}^{K_2} \quad (43)$$

using observed equilibrium constants and the free-energy functions of Evans. The difference between the values as computed by the two methods may be due to errors in either of the thermal functions or in either of the observed quantities. In any event, since the observed standard enthalpy is probably more reliable than the equilibrium constant and the computed enthalpy function is probably more reliable than the free-energy function, the value of -12.4 by the first method is believed to be the more reliable one. It may be compared with the spectroscopic value of -11.85 by Herzberg (31) and to the molecular-beam value of -12.67 by Lewis (32).

Equilibrium Composition of Saturated and Superheated Potassium Vapor - The relative amounts of dimer and tetramer in the equilibrium vapor and the average molecular weight of the vapor at each pressure and temperature state (Appendixes C and D) were computed by a modification of the method of Ritter and Simon (33). The application of this method required a knowledge of the average molecular weight of the vapor and the equilibrium constants of the two association reactions. The equilibrium constants at a given state were obtained from Eqs. (38) and (39), and the average molecular weight was computed from the three equations,

$$k_2' = k_2 + 3k_4 p^2 - 2k_2 k_4 p^3 \quad (44)$$

$$k_2' = \frac{(N_2')}{(N_1')^2 p} \quad (45)$$

$$M_a = N_1' M_1 + N_2' (2M_1) \quad (46)$$

The method of Ritter and Simon (33) has been used in the past primarily to derive equilibrium constants for the higher-molecular-weight reactions, but the same formulas may be used in reverse to compute the relative proportions of dimer and tetramer in potassium vapor. The equation

$$\alpha_1 = \frac{3 M_1}{4 M_a k_2 p} \left\{ \left[1 + \frac{8 k_2 p}{9} \left(4 - \frac{M_a}{M_1} \right) \right]^{1/2} - 1 \right\} \quad (47)$$

may be used to compute α_1 , which in turn may be used to compute the mole fractions of the higher-molecular-weight species by substitution into

$$N_2 = (\alpha_1)^2 p \left(\frac{M_a}{M_1} \right)^2 k_2 \quad (48)$$

$$N_4 = (\alpha_1)^4 p^3 \left(\frac{M_a}{M_1} \right)^4 k_4 \quad (49)$$

These equations were satisfactory for computing the contents of the higher-molecular-weight species, but over one portion of the temperature range there was an inconsistency

as high as 0.87 between the w_1 computed from Eq. (46) and the final value computed from the mole fractions of the two species. Actually, one would not expect the ratio of the two equilibrium constants to be exact enough to avoid inconsistencies of this magnitude, and an alternative procedure was employed.

The degree of dissociation α_1 at each state was computed with the equation

$$\left[3 \left(\frac{p M_a}{M_1} \right)^2 k_3 \right] (\alpha_1)^3 + \left[\left(\frac{p M_a}{M_1} \right) k_2 \right] (\alpha_1)^2 = \left(1 - \frac{M_1}{M_a} \right) \quad (50)$$

and the mole fractions of dimer and tetramer in the vapor were computed with Eqs. (48) and (49).

Enthalpy of Vaporization of Monomeric Potassium Vapor - This quantity from 1400° to 2525° F is presented in Appendix C and was computed with

$$\Delta h_{v,1} = \Delta h_1 - (\Delta h_2)(x_2)_s - (\Delta h_4)(x_4)_s \quad (51)$$

Thermodynamic Properties of Potassium by the Quasi-Chemical Method (Monomeric Gas Path)

Enthalpies of Saturated and Superheated Vapor - As with the virial method, the enthalpies of the vapor were computed along isotherms with the enthalpy of the monomeric gas at each temperature as a starting point. The general relationship for the absolute enthalpy is

$$h^g = (h^g)^0 + \Delta h_2 x_2 + \Delta h_4 x_4 \quad (52)$$

Since $(h^g - p) = 0$ for a perfect gas, any change in enthalpy must result from the association reactions. The enthalpy changes contributed by each species in moving from zero to some finite concentration were evaluated analytically by the functions in Eq. (52). The reaction enthalpies are those for the association reactions, and it was assumed that $\Delta h_2 = \Delta H_2^0 - 2M_1$ and $\Delta h_4 = \Delta H_4^0 - 4M_1$ for the full temperature range.

Entropies of Saturated and Superheated Vapor - The general entropy equation along a constant temperature line is

$$s_1^g = (s^g)^0 + \frac{\Delta h_2 x_2}{T} + \frac{\Delta h_4 x_4}{T} - \frac{R \ln p}{M_a} + \frac{x_2 R \ln k_2}{2 M_1} + \frac{x_4 R \ln k_4}{4 M_1} - \left\{ \frac{R (N_1 \ln N_1 + N_2 \ln N_2 + N_4 \ln N_4)}{M_1} \right\} \quad (53)$$

This equation differs slightly from that previously published (30) and is an exact form.

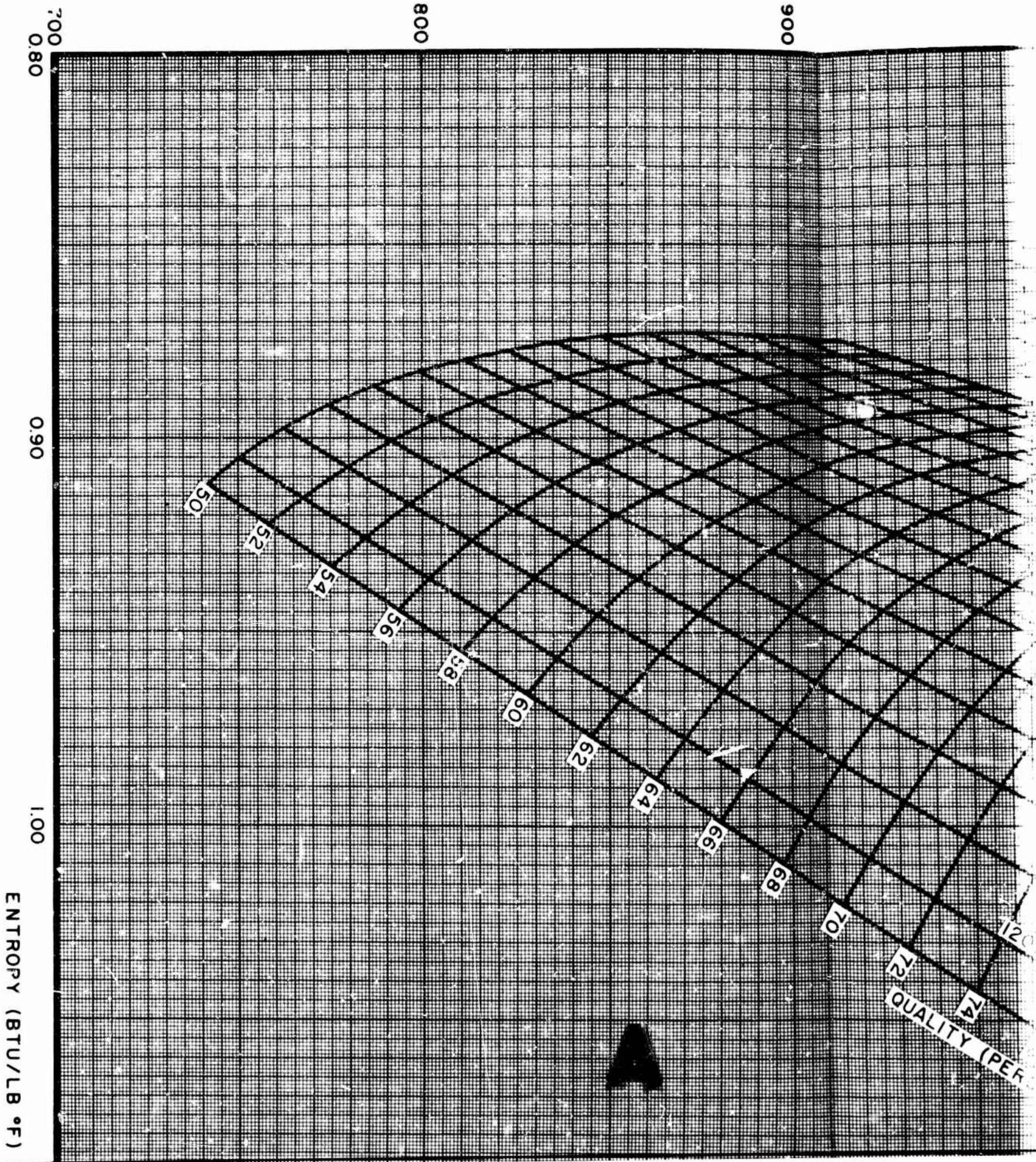
A Comparison of the Thermodynamic Properties by the Virial and the Quasi-Chemical Methods (Monomeric Gas Path)

Enthalpies and entropies of potassium were computed by the quasi-chemical method principally as a check on those computed by the virial method. The properties as obtained by the two methods are compared at selected vapor states in Table 11 and are shown to be in excellent agreement.

Table 11
Comparison of Thermodynamic Properties
by the Virial and the Quasi-Chemical Methods
(Monomer Gas Path)

Temperature (°F)	Pressure (atm)	Virial Method		Quasi-Chemical Method	
		h^g	s^g	h^g	s^g
1400	1.0	1190.3	1.117	1185.9	1.115
	0.2	1226.3	1.215	1223.5	1.213
1600	2.0	1211.6	1.095	1208.5	1.094
	1.0	1236.0	1.140	1232.0	1.138
	0.2	1255.6	1.230	1254.2	1.229
1800	5.0	1213.3	1.054	1212.6	1.054
	1.0	1270.9	1.156	1268.2	1.155
	0.2	1282.9	1.242	1282.2	1.242
2000	10.0	1219.4	1.026	1218.8	1.026
	5.0	1262.8	1.075	1260.4	1.074
	1.0	1301.3	1.169	1299.6	1.169
	0.2	1309.3	1.253	1308.9	1.253
2200	17.0	1231.0	1.009	1229.1	1.008
	15.0	1241.9	1.018	1239.7	1.017
	10.0	1270.6	1.046	1268.5	1.046
	5.0	1302.2	1.091	1300.0	1.090
	1.0	1329.6	1.180	1328.6	1.180
	0.2	1335.3	1.264	1335.1	1.264
2400	27.0	1240.1	0.993	1238.9	0.993
	20.0	1269.4	1.016	1266.0	1.014
	15.0	1290.2	1.035	1287.5	1.035
	10.0	1312.4	1.062	1310.4	1.061
	5.0	1336.4	1.103	1334.6	1.102
	1.0	1356.9	1.190	1356.2	1.190
	0.2	1361.1	1.273	1360.9	1.273
2500	30.0	1255.9	0.994	1254.1	0.994
	25.0	1274.8	1.008	1270.9	1.007
	20.0	1292.8	1.024	1289.4	1.022
	15.0	1311.4	1.043	1308.9	1.042
	10.0	1331.1	1.068	1329.3	1.067
	5.0	1352.3	1.109	1350.7	1.108
	1.0	1370.3	1.195	1369.7	1.194
	0.2	1373.9	1.277	1373.8	1.277

Although the two equations of state are effectively equivalent, the thermodynamic properties as computed by the virial method have been selected over those by the other method for several reasons: (a) a higher confidence in the thermodynamic relationships of the virial method, (b) the appreciable error that may be generated in quantities computed from equilibrium constants and enthalpies of the reactions by the assumption of linear relationships for the variation of $\log k_p$ with $1/T$, and (c) the relative simplicity of the calculation of the specific heat of the vapor by the virial method. All the final thermodynamic properties of potassium in Appendixes A and B and in the Mollier diagram (Fig. 25) were computed by the virial method.

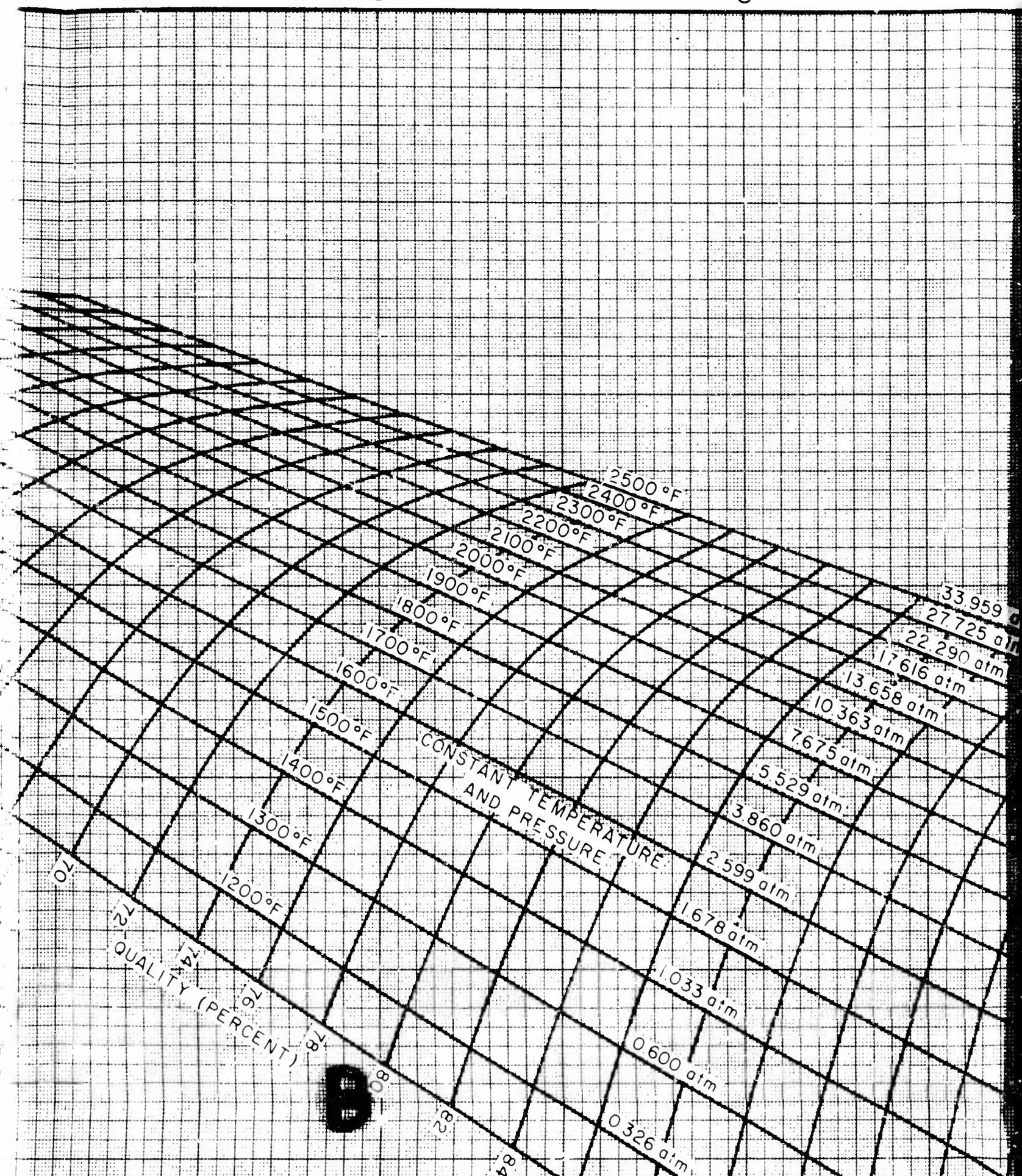


ENTHALPY (BTU/LB)

906

1000

1100



1400
0.80

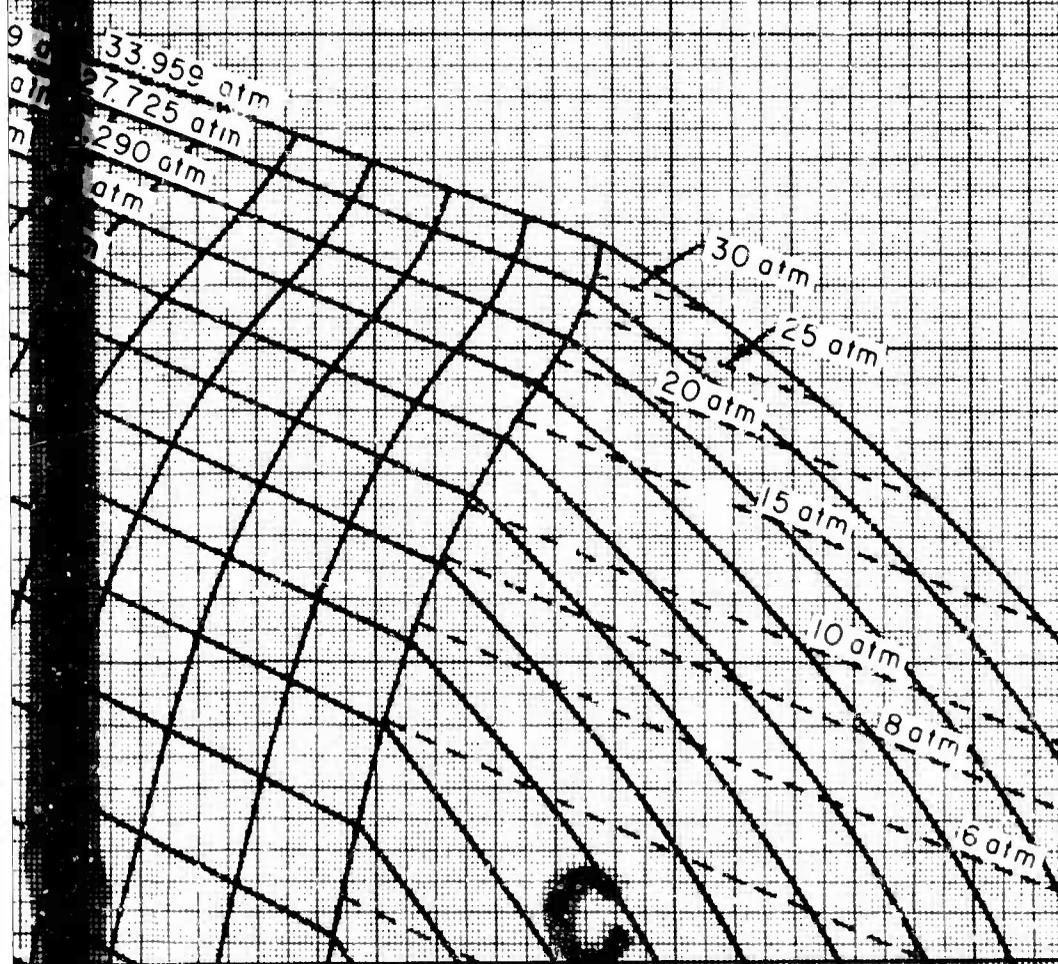
1300

1200

0.50

1.00

ENTROPY (BTU/LB·F)



ENTROPY (BTU/LB °F)

1.00

1.10

1.20

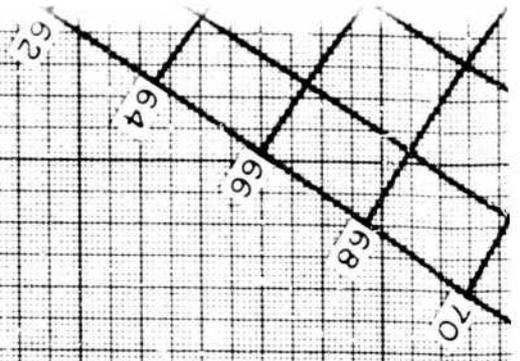
1.30

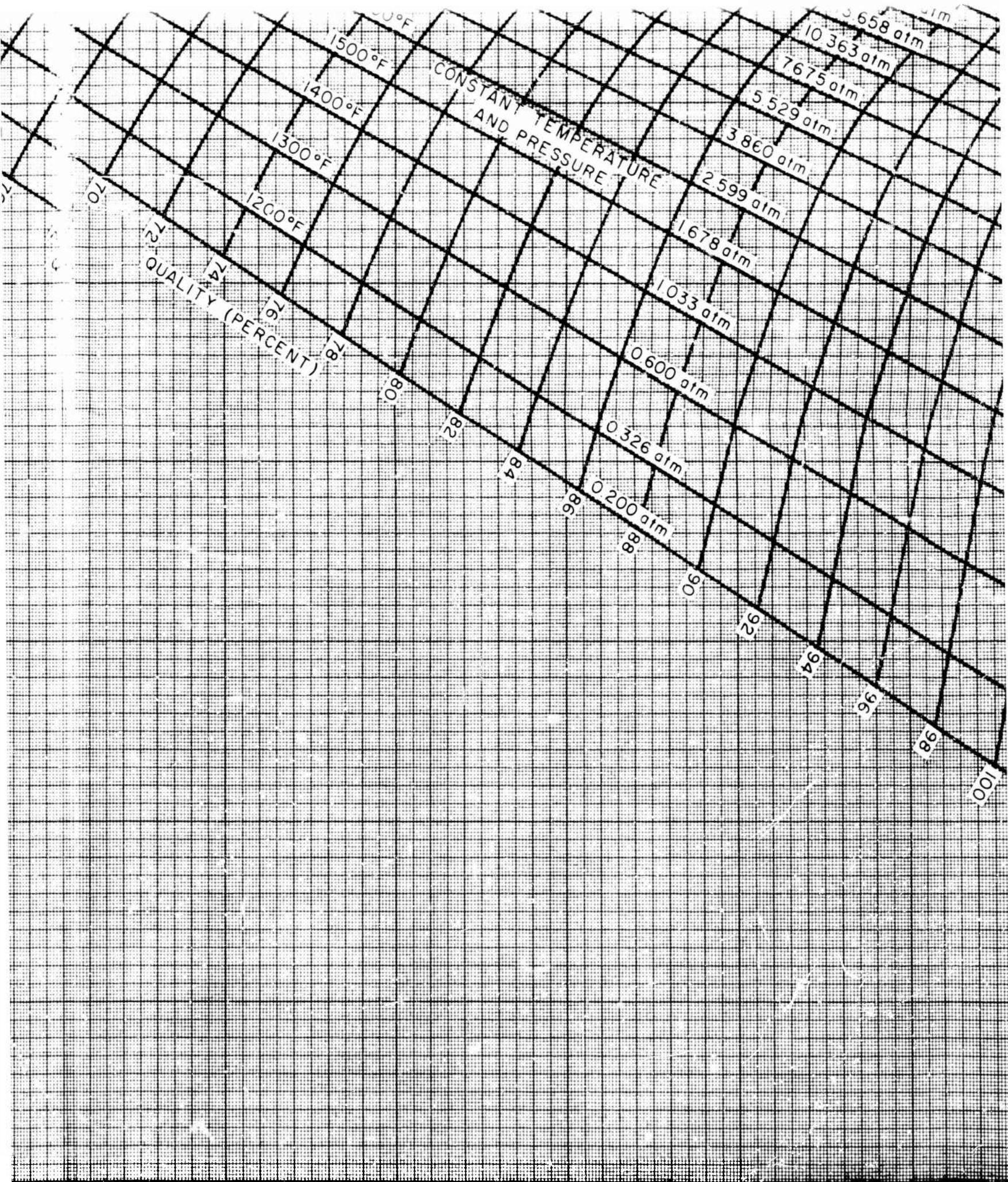
700

800

900

D





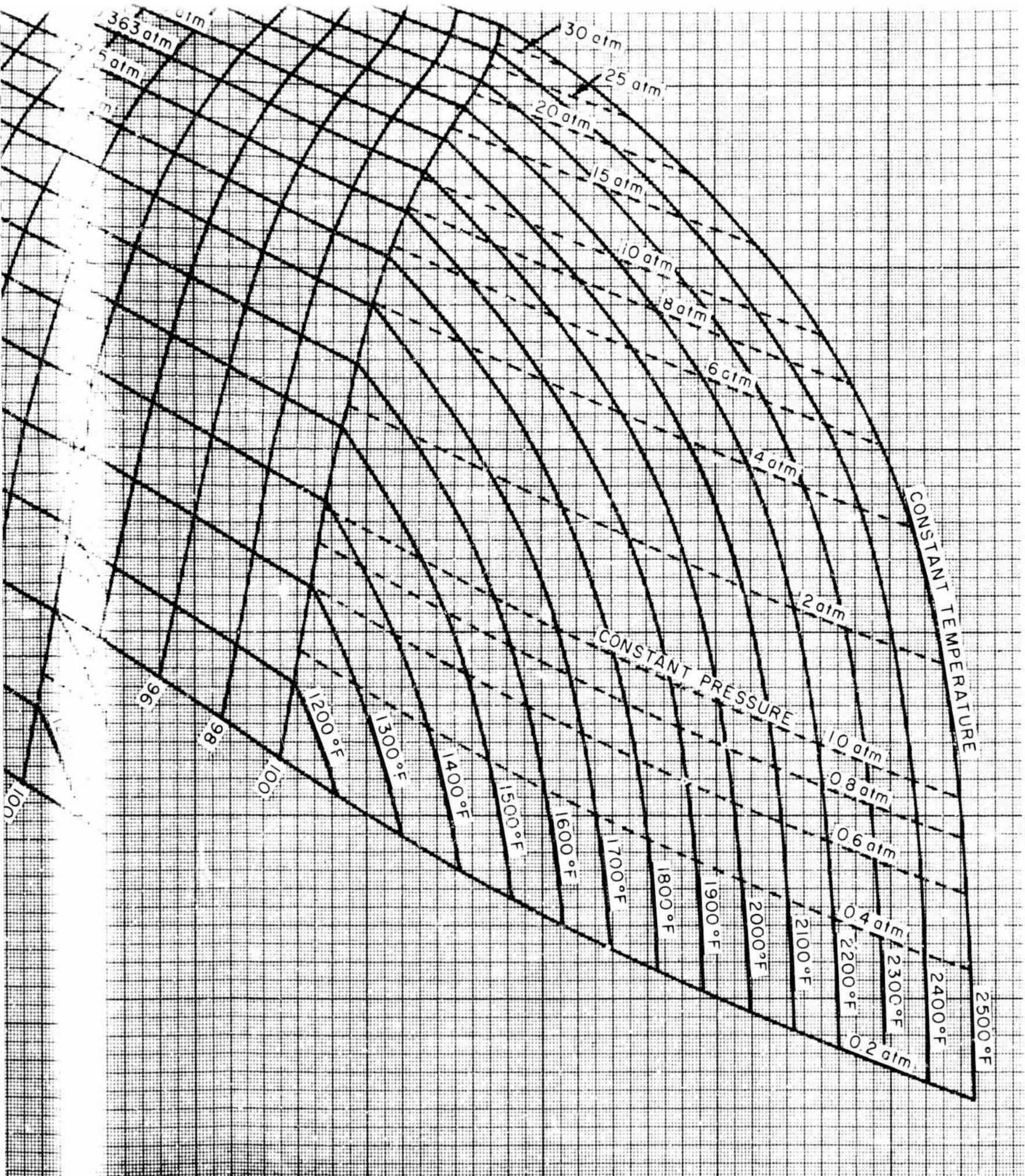
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ENTHALPY (BTU/LB)

1100

Fig. 25 - Mollier diagram of potassium vapor



1200

1300

F

DISCUSSION OF THERMODYNAMIC AND ENGINEERING PROPERTIES

The engineering and thermodynamic properties of potassium,* which are presented in Appendixes A and B and in the Mollier diagram, Fig. 25, are based directly on the virial equation of state as derived from PVT measurements. The properties are completely independent of any assumptions made regarding gas imperfections. They have been examined and evaluated by several tests for internal consistency and by duplicate calculations with two independent equations of state. It is believed that they represent the best values and that they will be satisfactory for any type of calculation required in the design of nuclear-powered turboelectric systems using potassium as working fluid.

Several remarks are in order regarding the data in Appendixes A and B. The virial equation of state used to derive the properties was reduced from PVT data covering a pressure range from 2.35 to 27.4 atm. Therefore, all saturation properties below 1575°F or above 2375°F and all superheat properties for states outside the measured pressure range required for their computation an extension of the virial equation outside its measured range. It should be recognized that all these properties, and especially those computed at pressure states higher than 27 atm, may be of reduced accuracy.

It is of interest to compare the engineering properties of potassium resulting from this study with those obtained in two recent publications by Walling et al. (34) and Weatherford et al. (35). The results generated in these studies were not based directly on measured PVT data in the superheat region; the properties reported by Walling were based on second and third virial coefficients which were deduced principally from saturation pressures, and the properties reported by Weatherford were computed from published thermodynamic functions of the monomeric and dimeric vapors. If we arbitrarily take the NRL data as a reference and compare at each temperature the enthalpy and entropy changes from p_s to 0.2 atm, the enthalpy changes reported by Walling are 17 to 95% higher and the entropy changes are 2 to 14% higher. By a similar comparison, the enthalpy changes reported by Weatherford are 28 to 40% lower and entropy changes are 5 to 8% lower than those of NRL. Specific heats and specific volumes of potassium vapor were tabulated by Walling, and these values also are in considerable disagreement with those of NRL.

The compositional properties of the vapor in Appendixes C and D are based directly on the quasi-chemical equation of state which was also derived from the PVT measurements. Two principal assumptions were made in deriving these properties. The higher-molecular-weight species were taken to be dimeric and tetrameric, and all species were treated as ideal gases. Experimental evidence to justify the choice of dimers and tetramers has been discussed, but greater confidence could be placed in the compositional data if the tetrameric species were identified by an alternative technique. The average molecular weights of the vapor states of potassium by the quasi-chemical method (Appendix D) are not entirely consistent with those in Appendix B (where $\bar{M} = M_1/M_0$) by the virial method. However, the average difference between the molecular weights by the two methods is $\pm 0.3\%$, which is within the probable error of the PVT measurements.

Saturation pressures of potassium were measured between 1206° and 2393°F with the null-point apparatus. This method, which is new to the measurement of vapor pressure at high temperatures, has been shown to be capable of high accuracy. The accuracy and the internal consistency of the saturation measurements are evidenced by the small variation in $(\Delta H_v)_s$ as computed for all the vapor-pressure data and by the small deviation ($\pm 0.31\%$) of all measured data from a simple three-term equation. The present work has

* Preliminary tables of thermodynamic properties (30,37) were based on incorrect thermal expansion values for columbium-1%zirconium.

also demonstrated clearly that $\log p$ versus $1/T$ is not linear but that a three-term equation of the Kirchhoff type is required to represent the vapor-pressure data over an extended temperature range.

Densities of the condensed phase were measured in the temperature range from 1099° to 2287° F with pycnometers. An independent measurement was required at each temperature point, but results of unquestionable accuracy were obtained. With these measurements and those generated by several other investigators at lower temperatures, overlapping determinations have been made from the melting point to 2287° F, and the density of liquid potassium is well defined for this full temperature range.

The specific heat of the condensed phase was measured at only three points between 1413° and 1933° F. These values are of low precision, but they tend to substantiate the specific-heat data by Douglas et al. (13). Additional data by Deem et al. (21), on the other hand, diverge strongly at higher temperatures. The specific-heat picture for the liquid is rather unsettled. This is a significant point, since the reliability of this quantity affects several important thermodynamic calculations. The liquid provides one path by which the absolute thermodynamic properties of the vapor may be derived, and the specific heat of the liquid is used to compute enthalpy and entropy along this path. The property is also used in the evaluation of saturation pressures by the computation of the enthalpy of vaporization at absolute zero. New techniques and methods are needed to provide a more accurate knowledge of this property.

The liquid metal program at this Laboratory is only a small part of the total national effort in this area. The internal consistency and the confidence limits of the engineering properties of potassium (and of the properties of sodium and cesium (38,39)) can be more fully evaluated as additional properties are measured for the three metals. Particularly important in this respect would be reliable determinations of the heat of vaporization, the specific heat of liquid and vapor, and the electrical conductivity of the vapor. A direct determination of the heat of vaporization would help to evaluate the thermodynamic computation of this quantity from the Clapeyron equation. Similarly, a direct determination of the specific heat of the vapor would test the values computed from the virial equation of state, and a determination of the electrical conductivity would provide additional information on the degree of ionization of the vapor.

ACKNOWLEDGMENTS

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NOMENCLATURE AND UNITS

a_1	fraction of 1 mole of monomer remaining unassociated
A	first virial coefficient
B	second virial coefficient, cu ft/mole
C	third virial coefficient, (cu ft) ² /(mole) ²
D	fourth virial coefficient, (cu ft) ³ /(mole) ³
c_p	specific heat at constant pressure, Btu/lb-°F
d	density, lb/cu ft
f	free energy, Btu/lb
F	free energy, Btu/lb-mole
Δf_v	free-energy change upon vaporization of a unit mass at equilibrium, Btu/lb
ΔF_v	free-energy change upon vaporization of a mole at equilibrium, Btu/lb-mole
h	enthalpy per unit mass, Btu/lb
Δh	enthalpy change per unit mass, Btu/lb
Δh_2	enthalpy change for the formation of a unit mass of dimer from monomer, Btu/lb
Δh_4	enthalpy change for the formation of a unit mass of tetramer from monomer, Btu/lb
Δh_v	enthalpy change upon vaporization of a unit mass at equilibrium, Btu/lb
$\Delta h_{v,1}$	enthalpy change upon vaporization of a unit mass of monomer, Btu/lb
H	enthalpy per mole, Btu/lb-mole
ΔH	enthalpy change per mole, Btu/lb-mole
ΔH_2	enthalpy change for the formation of one mole of dimer from monomer, Btu/lb-mole
ΔH_4	enthalpy change for the formation of one mole of tetramer from monomer, Btu/lb-mole
ΔH_v	enthalpy change upon vaporization of a mole of equilibrium vapor, Btu/lb-mole
J	any unit conversion
k	equilibrium constant
k'_2	apparent equilibrium constant assuming only diatomic and monatomic species
M	molecular weight

N	mole fraction
p	absolute pressure, atm
R	gas constant
s	entropy per unit mass, Btu/lb-°F
Δs_v	entropy change upon vaporization of a unit mass of equilibrium vapor, Btu/lb-°F
T	absolute temperature, °R
t	temperature, °F
\bar{V}	molal volume (normally per formula weight of monomer), cu ft/lb-mole
v	specific volume, cu ft/lb
z	compressibility factor, $p\bar{V}/RT$

Subscripts

a	quantity for equilibrium molecular mixture
i	quantity for the vapor in a state
0	quantity at 0°R
p	constant pressure change
s	quantity at saturation
t	constant temperature change
1	quantity for monatomic species
2	quantity for diatomic species
3	quantity for triatomic species
4	quantity for tetratomic species
5	quantity for pentatomic species

Superscripts

g	quantity in gas state
l	quantity in liquid state
o	standard state, 1 atm for gas
$'$	apparent quantity, when assuming only diatomic and monatomic species
\cdot	adjusted value

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APPENDIX A

SATURATION PROPERTIES OF POTASSIUM
(Monomer Gas Base)

t	p	v^l	v^g	v^s	v^l	v^g	v^s	v^l	v^g	v^s	v^l	v^g	v^s
1400.	1.0327	.02417	30.9486	360.73	828.08	1188.81	.6691	.4453	1.1143				
1425.	1.1719	.02429	27.5353	365.68	824.22	1189.89	.6717	.4373	1.1090				
1450.	1.3252	.02442	24.5767	370.63	820.33	1190.96	.6743	.4296	1.1039				
1475.	1.4938	.02455	22.0034	375.58	816.43	1192.01	.6769	.4220	1.0989				
1500.	1.6785	.02469	19.7578	380.54	812.52	1193.06	.6794	.4146	1.0940				
1525.	1.8803	.02482	17.7920	385.49	808.61	1194.10	.6819	.4074	1.0893				
1550.	2.1003	.02496	16.0657	390.44	804.70	1195.14	.6844	.4004	1.0848				
1575.	2.3394	.02509	14.5453	395.39	800.79	1196.18	.6868	.3936	1.0804				
1600.	2.5988	.02523	13.2023	400.33	796.89	1197.23	.6892	.3869	1.0761				
1625.	2.8795	.02537	12.0129	405.27	793.01	1198.28	.6916	.3804	1.0720				
1650.	3.1824	.02552	10.9566	410.21	789.14	1199.34	.6940	.3741	1.0680				
1675.	3.5088	.02566	10.0162	415.14	785.29	1200.42	.6963	.3679	1.0641				
1700.	3.8596	.02581	9.1768	420.06	781.46	1201.52	.6986	.3618	1.0604				
1725.	4.2359	.02596	8.4257	424.98	777.65	1202.63	.7008	.3560	1.0568				
1750.	4.6388	.02611	7.7522	429.90	773.87	1203.77	.7030	.3502	1.0532				
1775.	5.0694	.02626	7.1468	434.82	770.11	1204.93	.7052	.3446	1.0498				
1800.	5.5287	.02641	6.6014	439.74	766.37	1206.11	.7074	.3391	1.0465				
1825.	6.0179	.02657	6.1090	444.65	762.66	1207.32	.7096	.3338	1.0434				
1850.	6.5378	.02673	5.6636	449.58	758.97	1208.55	.7117	.3286	1.0403				
1875.	7.0897	.02689	5.2598	454.50	755.30	1209.80	.7138	.3235	1.0373				
1900.	7.6745	.02705	4.8931	459.44	751.65	1211.09	.7159	.3185	1.0344				
1925.	8.2932	.02722	4.5593	464.39	748.00	1212.39	.7179	.3137	1.0316				
1950.	8.9469	.02738	4.2550	469.36	744.37	1213.72	.7200	.3089	1.0289				
1975.	9.6366	.02755	3.9770	474.34	740.74	1215.08	.7220	.3042	1.0263				
2000.	10.3632	.02772	3.7226	479.35	737.10	1216.45	.7241	.2997	1.0237				
2025.	11.1276	.02790	3.4893	484.39	733.45	1217.83	.7261	.2952	1.0213				
2050.	11.9309	.02807	3.2751	489.46	729.78	1219.23	.7281	.2908	1.0189				
2075.	12.7740	.02825	3.0780	494.57	726.08	1220.64	.7301	.2865	1.0165				
2100.	13.6577	.02844	2.8963	499.72	722.34	1222.06	.7321	.2822	1.0143				
2125.	14.5829	.02862	2.7287	504.92	718.55	1223.47	.7341	.2780	1.0121				
2150.	15.5504	.02881	2.5736	510.18	714.70	1224.88	.7361	.2739	1.0099				
2175.	16.5612	.02900	2.4299	515.51	710.77	1226.28	.7381	.2698	1.0078				
2200.	17.6159	.02919	2.2967	520.90	706.75	1227.65	.7401	.2657	1.0058				
2225.	18.7154	.02938	2.1728	526.37	702.63	1229.00	.7421	.2617	1.0038				
2250.	19.8605	.02958	2.0575	531.93	698.38	1230.31	.7441	.2577	1.0019				
2275.	21.0517	.02978	1.9499	537.59	693.99	1231.58	.7462	.2538	.9999				
2300.	22.2899	.02998	1.8494	543.36	689.43	1232.79	.7482	.2498	.9980				
2325.	23.5757	.03019	1.7553	549.24	684.68	1233.93	.7503	.2459	.9962				
2350.	24.9097	.03040	1.6671	555.26	679.72	1234.98	.7524	.2419	.9943				
2375.	26.2926	.03061	1.5843	561.43	674.50	1235.93	.7546	.2379	.9925				
2400.	27.7249	.03083	1.5062	567.77	668.99	1236.76	.7568	.2339	.9907				
2425.	29.2072	.03105	1.4325	574.29	663.15	1237.43	.7590	.2299	.9889				
2450.	30.7400	.03127	1.3628	581.03	656.92	1237.94	.7613	.2258	.9870				
2475.	32.3234	.03150	1.2967	588.01	650.23	1238.24	.7636	.2216	.9852				
2500.	33.9590	.03173	1.2337	595.28	642.99	1238.27	.7660	.2172	.9833				
2525.	35.6462	.03196	1.1734	602.90	635.09	1237.99	.7685	.2128	.9813				

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR
(Monomer Gas Base)

t	p	v^g	z	h^g	s^g	c_p^g
1400.	1.0327	50.9486	.92025	1188.81	1.11434	.2842
1400.	1.0000	32.0491	.92276	1190.30	1.11664	.2789
1400.	.8000	40.7307	.93818	1199.36	1.13207	.2473
1400.	.6000	55.2017	.95363	1208.38	1.15075	.2163
1400.	.4000	84.1450	.96909	1217.35	1.17538	.1859
1400.	.2000	170.9752	.98455	1226.27	1.21460	.1561
1425.	1.1719	27.5353	.91573	1189.89	1.10902	.2869
1425.	1.0000	32.6950	.92887	1197.06	1.12026	.2625
1425.	.8000	41.4924	.94305	1205.38	1.13528	.2344
1425.	.6000	56.1570	.95726	1213.66	1.15357	.2068
1425.	.4000	85.4884	.97150	1221.92	1.17782	.1797
1425.	.2000	173.4846	.98575	1230.13	1.21667	.1531
1450.	1.3252	24.5767	.91320	1190.96	1.10386	.2894
1450.	1.0000	33.3235	.93434	1203.44	1.12362	.2482
1450.	.8000	42.2572	.94741	1211.07	1.13829	.2232
1450.	.6000	57.0956	.96052	1218.73	1.15624	.1986
1450.	.4000	86.2153	.97366	1226.34	1.18015	.1744
1450.	.2000	175.9780	.98683	1233.93	1.21867	.1505
1475.	1.4938	22.0034	.90965	1192.01	1.09887	.2917
1475.	1.0000	33.9369	.93924	1209.48	1.12676	.2358
1475.	.8000	42.9669	.95132	1216.55	1.14113	.2135
1475.	.6000	58.0195	.96345	1223.60	1.15877	.1914
1475.	.4000	88.1277	.97561	1230.64	1.18239	.1697
1475.	.2000	178.4570	.98780	1237.66	1.22061	.1482
1500.	1.6785	19.7578	.90610	1193.06	1.09403	.2938
1500.	1.0000	34.5370	.94365	1215.24	1.12972	.2249
1500.	.8000	43.6836	.95485	1221.78	1.14382	.2049
1500.	.6000	58.9304	.96609	1228.31	1.16119	.1851
1500.	.4000	89.4273	.97737	1234.83	1.18454	.1655
1500.	.2000	180.9234	.98867	1241.34	1.22250	.1461
1525.	1.8803	17.7920	.90255	1194.10	1.08934	.2957
1525.	1.0000	35.1253	.94764	1220.74	1.13251	.2154
1525.	.8000	44.3885	.95804	1226.80	1.14637	.1974
1525.	.6000	59.8297	.96848	1232.86	1.16350	.1796
1525.	.4000	90.7154	.97896	1238.92	1.18662	.1619
1525.	.2000	183.3785	.98947	1244.97	1.22434	.1443
1550.	2.1003	16.0657	.89900	1195.14	1.08480	.2974
1550.	2.0000	16.9589	.90368	1197.94	1.08843	.2891
1550.	1.0000	35.7032	.95125	1226.02	1.13515	.2070
1550.	.8000	45.0830	.96092	1231.65	1.14880	.1908
1550.	.6000	60.7186	.97064	1237.29	1.16572	.1747
1550.	.4000	91.9934	.98040	1242.93	1.18862	.1586
1550.	.2000	185.8235	.99019	1248.56	1.22614	.1428
1575.	2.3394	14.5453	.89547	1196.18	1.08040	.2988
1575.	2.0000	17.2931	.91016	1204.97	1.09191	.2737
1575.	1.0000	36.2717	.95452	1231.10	1.13767	.1996
1575.	.8000	45.7683	.96354	1236.35	1.15112	.1849
1575.	.6000	61.5984	.97261	1241.60	1.16785	.1703
1575.	.4000	93.2621	.98171	1246.86	1.19056	.1558
1575.	.2000	188.2594	.99084	1252.11	1.22789	.1413
1600.	2.5988	13.2023	.89195	1197.23	1.07614	.3001
1600.	2.0000	17.6188	.91605	1211.64	1.09517	.2602
1600.	1.0000	36.8319	.95750	1236.01	1.14006	.1931
1600.	.8000	46.4452	.96593	1240.91	1.15334	.1797

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	u^2	z	h^u	s^u	$\frac{g}{c_p}$
1600.	.3000	62.4699	.97440	1245.81	1.16991	.1664
1600.	.4000	94.5227	.98290	1250.72	1.19245	.1532
1600.	.2000	190.6872	.99144	1255.62	1.22961	.1401
1625.	2.8795	12.0129	.88845	1198.28	1.07201	.3011
1625.	2.0000	17.9371	.92142	1217.99	1.09823	.2482
1625.	1.0000	37.3846	.96021	1240.76	1.14236	.1873
1625.	.8000	47.1147	.96810	1245.34	1.15548	.1751
1625.	.6000	63.3341	.97603	1249.93	1.17189	.1630
1625.	.4000	95.7760	.98399	1254.52	1.19429	.1509
1625.	.2000	193.1077	.99198	1259.11	1.23129	.1389
1650.	3.1824	10.9566	.88498	1199.34	1.06801	.3019
1650.	3.0000	11.7048	.89121	1203.11	1.07246	.2921
1650.	2.0000	18.2487	.92631	1224.06	1.10113	.2375
1650.	1.0000	37.9306	.96269	1245.37	1.14456	.1821
1650.	.8000	47.7776	.97009	1249.67	1.15755	.1710
1650.	.6000	64.1915	.97752	1253.96	1.17382	.1599
1650.	.4000	97.0226	.98498	1258.27	1.19607	.1489
1650.	.2000	195.5215	.99248	1262.57	1.23294	.1379
1675.	3.5088	10.0162	.88153	1200.42	1.06414	.3025
1675.	3.0000	11.9309	.89779	1210.23	1.07581	.2778
1675.	2.0000	18.5542	.93079	1229.88	1.10387	.2280
1675.	1.0000	38.4706	.96496	1249.87	1.14667	.1774
1675.	.8000	48.4344	.97191	1253.89	1.15954	.1673
1675.	.6000	65.0430	.97889	1257.93	1.17568	.1572
1675.	.4000	98.2632	.98590	1261.97	1.19782	.1471
1675.	.2000	197.9294	.99293	1266.01	1.23456	.1370
1700.	3.8596	9.1768	.87812	1201.52	1.06039	.3029
1700.	3.0000	12.1516	.90382	1217.02	1.07897	.2651
1700.	2.0000	18.8544	.93490	1235.47	1.10647	.2196
1700.	1.0000	39.0051	.96704	1254.25	1.14871	.1733
1700.	.8000	49.0857	.97357	1258.03	1.16147	.1640
1700.	.6000	65.8890	.98014	1261.82	1.17750	.1547
1700.	.4000	99.4983	.98673	1265.62	1.19952	.1455
1700.	.2000	200.3319	.99335	1269.42	1.23615	.1362
1725.	4.2359	8.4257	.87474	1202.63	1.05676	.3030
1725.	4.0000	8.9885	.88120	1206.56	1.06111	.2939
1725.	3.0000	12.3677	.90936	1223.50	1.08196	.2537
1725.	2.0000	19.1496	.93867	1240.85	1.10896	.2120
1725.	1.0000	39.5346	.96895	1258.53	1.15069	.1695
1725.	.8000	49.7322	.97511	1262.09	1.16334	.1610
1725.	.6000	66.7300	.98129	1265.66	1.17927	.1525
1725.	.4000	100.7286	.98750	1269.24	1.20118	.1440
1725.	.2000	202.7295	.99374	1272.82	1.23772	.1355
1750.	4.6388	7.7522	.87140	1203.77	1.05325	.3030
1750.	4.0000	9.1596	.88781	1213.73	1.06438	.2804
1750.	3.0000	12.5793	.91446	1229.71	1.08478	.2435
1750.	2.0000	19.4403	.94214	1246.07	1.11133	.2052
1750.	1.0000	40.0597	.97071	1262.73	1.15260	.1662
1750.	.8000	50.3741	.97652	1266.09	1.16515	.1583
1750.	.6000	67.5666	.98235	1269.45	1.18099	.1505
1750.	.4000	101.9543	.98821	1272.82	1.20281	.1426
1750.	.2000	205.1226	.99409	1276.20	1.23925	.1348
1775.	5.0694	7.1468	.86809	1204.93	1.04985	.3028
1775.	5.0000	7.2596	.86973	1205.93	1.05090	.3006
1775.	4.0000	9.3269	.89392	1220.59	1.08746	.2683
1775.	3.0000	12.7871	.91916	1235.68	1.11360	.2343
1775.	2.0000	19.7270	.94534	1251.12	1.14445	.1990
1775.	1.0000	40.5807	.97234	1266.84	1.18692	.1631
1775.	.8000	51.0119	.97782	1270.01	1.19990	.1559
1775.	.6000	68.3991	.98333	1273.19	1.21487	.1487

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^g	z	h^g	s^g	c_p^g
1775.	.4000	103.1/60	.98886	1276.37	1.20441	.1414
1775.	.2000	207.5116	.99442	1279.56	1.24077	.1342
1800.	5.5287	6.6014	.86482	1206.11	1.04655	.3024
1800.	5.0000	7.3986	.87657	1213.27	1.05417	.2873
1800.	4.0000	9.4908	.89956	1227.16	1.07039	.2574
1800.	3.0000	12.9912	.92350	1241.45	1.09003	.2260
1800.	2.0000	20.0101	.94830	1256.03	1.11578	.1935
1800.	1.0000	41.0980	.97384	1270.89	1.15625	.1604
1800.	.8000	51.6461	.97902	1273.88	1.16864	.1537
1800.	.6000	69.2279	.98423	1276.89	1.18432	.1470
1800.	.4000	104.3940	.98947	1279.90	1.20598	.1404
1800.	.2000	209.8969	.99472	1282.91	1.24226	.1337
1825.	6.0179	6.1090	.86159	1207.32	1.04337	.3019
1825.	6.0000	6.1298	.86196	1207.54	1.04360	.3014
1825.	5.0000	7.5346	.88292	1220.30	1.05727	.2753
1825.	4.0000	9.6516	.90479	1233.47	1.07316	.2476
1825.	3.0000	15.1922	.92752	1246.99	1.09248	.2185
1825.	2.0000	20.2893	.95103	1260.80	1.11789	.1885
1825.	1.0000	41.6119	.97523	1274.86	1.15800	.1579
1825.	.8000	52.2768	.98014	1277.70	1.17032	.1517
1825.	.6000	70.0533	.98507	1280.54	1.18593	.1455
1825.	.4000	105.6086	.99003	1283.39	1.20752	.1394
1825.	.2000	212.2789	.99500	1286.25	1.24373	.1332
1850.	6.5378	5.6636	.85839	1208.55	1.04028	.3012
1850.	6.0000	6.2461	.86881	1214.91	1.04681	.2887
1850.	5.0000	7.6680	.88881	1227.05	1.06020	.2644
1850.	4.0000	9.8096	.90964	1239.54	1.07581	.2387
1850.	3.0000	15.3901	.93125	1252.36	1.09482	.2117
1850.	2.0000	20.5665	.95357	1265.46	1.11991	.1840
1850.	1.0000	42.1227	.97651	1278.78	1.15970	.1556
1850.	.8000	52.9045	.98117	1281.47	1.17196	.1499
1850.	.6000	70.8756	.98585	1284.16	1.18750	.1442
1850.	.4000	106.8201	.99055	1286.86	1.20903	.1385
1850.	.2000	214.6577	.99526	1289.57	1.24517	.1327
1875.	7.0897	5.2598	.85523	1209.80	1.03730	.3004
1875.	7.0000	5.3572	.85684	1210.79	1.03828	.2985
1875.	6.0000	6.3601	.87519	1221.99	1.04985	.2772
1875.	5.0000	7.7988	.89430	1233.53	1.06299	.2545
1875.	4.0000	9.9649	.91415	1245.41	1.07833	.2306
1875.	3.0000	15.5853	.93471	1257.58	1.09706	.2056
1875.	2.0000	20.8403	.95592	1270.01	1.12187	.1798
1875.	1.0000	42.6306	.97770	1282.65	1.16137	.1536
1875.	.8000	53.5293	.98213	1285.20	1.17357	.1483
1875.	.6000	71.6950	.98657	1287.75	1.18905	.1430
1875.	.4000	108.0287	.99103	1290.32	1.21052	.1377
1875.	.2000	217.0336	.99550	1292.88	1.24660	.1323
1900.	7.6745	4.8931	.85210	1211.09	1.03441	.2994
1900.	7.0000	5.4367	.86357	1218.10	1.04139	.2867
1900.	6.0000	6.4719	.88114	1228.78	1.05275	.2667
1900.	5.0000	7.9273	.89940	1239.78	1.06566	.2455
1900.	4.0000	10.1178	.91834	1251.08	1.08075	.2232
1900.	3.0000	15.7780	.93792	1262.65	1.09922	.2000
1900.	2.0000	21.1116	.95810	1274.45	1.12376	.1761
1900.	1.0000	43.1360	.97881	1286.46	1.16299	.1517
1900.	.8000	54.1514	.98302	1288.88	1.17514	.1468
1900.	.6000	72.5119	.98724	1291.31	1.19057	.1419
1900.	.4000	109.2347	.99147	1293.75	1.21198	.1369
1900.	.2000	219.4070	.99573	1296.19	1.24801	.1320
1925.	8.2932	4.5593	.84899	1212.39	1.03161	.2984
1925.	8.0000	4.7523	.85364	1215.24	1.03436	.2934

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^g	z	h^g	s^g	c_p^g
1925.	7.0000	5.5344	.86986	1225.13	1.04435	.2758
1925.	6.0000	6.5818	.88670	1235.33	1.05551	.2571
1925.	5.0000	8.0537	.90416	1245.81	1.06820	.2373
1925.	4.0000	10.2684	.92225	1256.57	1.08307	.2165
1925.	3.0000	13.9684	.94092	1267.58	1.10130	.1949
1925.	2.0000	21.3805	.96013	1278.81	1.12560	.1727
1925.	1.0000	43.6389	.97985	1290.23	1.16458	.1500
1925.	.8000	54.7712	.98384	1292.54	1.17663	.1454
1925.	.6000	73.3263	.98786	1294.85	1.19206	.1408
1925.	.4000	110.4383	.99189	1297.16	1.21342	.1362
1925.	.2000	221.7779	.99594	1299.48	1.24940	.1316
1950.	8.9469	4.2550	.84591	1213.72	1.02890	.2973
1950.	8.0000	4.8388	.86017	1222.44	1.03736	.2825
1950.	7.0000	5.6303	.87575	1231.90	1.04718	.2659
1950.	6.0000	6.6897	.89189	1241.64	1.05814	.2483
1950.	5.0000	8.1781	.90861	1251.65	1.07063	.2298
1950.	4.0000	10.4171	.92589	1261.91	1.08529	.2104
1950.	3.0000	14.1567	.94371	1272.40	1.10331	.1903
1950.	2.0000	21.6473	.96203	1283.09	1.12739	.1696
1950.	1.0000	44.1397	.98081	1293.96	1.16614	.1484
1950.	.8000	55.3888	.98461	1296.16	1.17819	.1442
1950.	.6000	74.1385	.98844	1298.35	1.19352	.1399
1950.	.4000	111.6397	.99228	1300.56	1.21484	.1356
1950.	.2000	224.1466	.99613	1302.77	1.25077	.1313
1975.	9.6366	3.9770	.84284	1215.08	1.02627	.2962
1975.	9.0000	4.3036	.85182	1220.56	1.03146	.2872
1975.	8.0000	4.9239	.86630	1229.37	1.04022	.2724
1975.	7.0000	5.7245	.88127	1238.43	1.04987	.2567
1975.	6.0000	6.7959	.89675	1247.75	1.06066	.2402
1975.	5.0000	8.3007	.91276	1257.31	1.07297	.2229
1975.	4.0000	10.5638	.92929	1267.10	1.08743	.2048
1975.	3.0000	14.3430	.94631	1277.10	1.10525	.1860
1975.	2.0000	21.9120	.96379	1287.29	1.12912	.1667
1975.	1.0000	44.6384	.98170	1297.65	1.16766	.1470
1975.	.8000	56.0043	.98533	1299.74	1.17967	.1430
1975.	.6000	74.9487	.98898	1301.84	1.19496	.1390
1975.	.4000	112.8390	.99264	1303.94	1.21623	.1350
1975.	.2000	226.5133	.99631	1306.05	1.25212	.1310
2000.	10.3632	3.7228	.83979	1216.45	1.02373	.2950
2000.	10.0000	3.8799	.84460	1219.38	1.02644	.2903
2000.	9.0000	4.3800	.85812	1227.61	1.03435	.2770
2000.	8.0000	5.0075	.87205	1236.06	1.04296	.2631
2000.	7.0000	5.8172	.88644	1244.74	1.05245	.2484
2000.	6.0000	6.9006	.90131	1253.66	1.06308	.2329
2000.	5.0000	8.4217	.91665	1262.80	1.07521	.2166
2000.	4.0000	10.7088	.93247	1272.15	1.08950	.1997
2000.	3.0000	14.5276	.94874	1281.70	1.10713	.1821
2000.	2.0000	22.1749	.96544	1291.43	1.13081	.1641
2000.	1.0000	45.1353	.98254	1301.31	1.16916	.1457
2000.	.8000	56.6180	.98601	1303.31	1.18113	.1420
2000.	.6000	75.7569	.98948	1305.31	1.19638	.1383
2000.	.4000	114.0364	.99298	1307.31	1.21761	.1345
2000.	.2000	228.8781	.99648	1309.32	1.25346	.1306
2025.	11.1276	3.4893	.83673	1217.83	1.02126	.2939
2025.	11.0000	3.5365	.83833	1218.81	1.02214	.2924
2025.	10.0000	3.9490	.85101	1226.51	1.02933	.2803
2025.	9.0000	4.4550	.86404	1234.42	1.03710	.2677
2025.	8.0000	5.0897	.87746	1242.53	1.04557	.2545
2025.	7.0000	5.9086	.89130	1250.85	1.05493	.2407
2025.	6.0000	7.0037	.90557	1259.39	1.06540	.2261

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

	t	p	v^g	z	h^g	s^g	c_p^g
58	2025.	5.0000	8.5411	.92029	1268.14	1.07738	.2108
71	2025.	4.0000	10.8522	.93545	1277.08	1.09150	.1950
73	2025.	3.0000	14.7104	.95102	1286.21	1.10896	.1786
65	2025.	2.0000	22.4361	.96699	1295.50	1.13246	.1617
49	2025.	1.0000	45.6304	.98333	1304.94	1.17063	.1445
27	2025.	.8000	57.2299	.98663	1306.84	1.18256	.1410
00	2025.	.6000	76.5635	.98996	1308.75	1.19777	.1375
54	2025.	.4000	115.2321	.99329	1310.67	1.21897	.1340
08	2025.	.2000	231.2411	.99664	1312.59	1.25478	.1305
62	2050.	11.9309	3.2751	.83366	1219.23	1.01886	.2928
16	2050.	11.0000	3.5998	.84481	1225.99	1.02501	.2824
73	2050.	10.0000	4.0171	.85705	1233.40	1.03209	.2710
25	2050.	9.0000	4.5289	.86961	1241.00	1.03974	.2591
59	2050.	8.0000	5.1707	.88254	1248.79	1.04808	.2467
83	2050.	7.0000	5.9986	.89586	1256.78	1.05730	.2336
98	2050.	6.0000	7.1055	.90958	1264.97	1.06763	.2199
04	2050.	5.0000	8.6591	.92371	1273.34	1.07946	.2055
03	2050.	4.0000	10.9941	.93824	1281.90	1.09343	.1907
96	2050.	3.0000	14.8918	.95315	1290.63	1.11073	.1753
84	2050.	2.0000	22.6958	.96843	1299.51	1.13407	.1595
42	2050.	1.0000	46.1239	.98406	1308.54	1.17207	.1434
99	2050.	.8000	57.8402	.98722	1310.36	1.18397	.1401
56	2050.	.6000	77.3684	.99040	1312.18	1.19914	.1369
13	2050.	.4000	116.4262	.99359	1314.01	1.22031	.1336
62	2050.	.2000	233.6025	.99679	1315.85	1.25609	.1303
72	2075.	12.7740	3.0780	.83058	1220.64	1.01653	.2917
24	2075.	12.0000	3.3112	.83938	1225.95	1.02128	.2837
67	2075.	11.0000	3.6619	.85093	1232.93	1.02777	.2732
02	2075.	10.0000	4.0841	.86275	1240.07	1.03473	.2624
29	2075.	9.0000	4.6016	.87487	1247.38	1.04227	.2512
48	2075.	8.0000	5.2505	.88733	1254.87	1.05049	.2394
60	2075.	7.0000	6.0873	.90015	1262.54	1.05958	.2270
67	2075.	6.0000	7.2060	.91335	1270.39	1.06978	.2141
70	2075.	5.0000	8.7757	.92692	1278.42	1.08147	.2007
30	2075.	4.0000	11.1346	.94086	1286.62	1.09530	.1867
90	2075.	3.0000	15.0717	.95515	1294.97	1.11245	.1723
50	2075.	2.0000	22.9539	.96979	1303.48	1.13564	.1575
10	2075.	1.0000	46.6159	.98475	1312.11	1.17348	.1424
50	2075.	.8000	58.4490	.98777	1313.85	1.18535	.1393
03	2075.	.6000	78.1718	.99081	1315.60	1.20050	.1363
70	2075.	.4000	117.6188	.99386	1317.35	1.22163	.1332
31	2075.	.2000	235.9624	.99693	1319.10	1.25738	.1301
84	2100.	13.6577	2.8963	.82747	1222.06	1.01427	.2907
29	2100.	13.0000	3.0691	.83460	1226.33	1.01802	.2843
66	2100.	12.0000	3.3685	.84555	1232.93	1.02402	.2746
97	2100.	11.0000	3.7232	.85671	1239.65	1.03041	.2647
21	2100.	10.0000	4.1500	.86812	1246.53	1.03727	.2545
41	2100.	9.0000	4.6733	.87982	1253.56	1.04469	.2438
57	2100.	8.0000	5.3293	.89184	1260.76	1.05281	.2327
20	2100.	7.0000	6.1750	.90419	1268.14	1.06178	.2210
83	2100.	6.0000	7.3053	.91689	1275.68	1.07186	.2088
45	2100.	5.0000	8.8911	.92993	1283.38	1.08342	.1962
08	2100.	4.0000	11.2738	.94332	1291.24	1.09711	.1830
39	2100.	3.0000	15.2503	.95703	1299.25	1.11413	.1675
24	2100.	2.0000	23.2108	.97106	1307.39	1.13717	.15
03	2100.	1.0000	47.1065	.98539	1315.66	1.17488	.1215
77	2100.	.8000	59.0565	.98829	1317.32	1.18671	.1386
45	2100.	.6000	78.9739	.99120	1319.00	1.20183	.1357
07	2100.	.4000	118.8100	.99412	1320.67	1.22294	.1328
61	2100.	.2000	238.3209	.99706	1322.35	1.25865	.1299

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^g	z	h^g	s^g	c_p^g
2125.	14.5829	2.7287	.82432	1223.47	1.01207	.2898
2125.	14.0000	2.8631	.83037	1227.08	1.01518	.2845
2125.	13.0000	3.1221	.84081	1233.33	1.02074	.2754
2125.	12.0000	3.4248	.85139	1239.69	1.02664	.2662
2125.	11.0000	3.7835	.86217	1246.17	1.03294	.2568
2125.	10.0000	4.2151	.87320	1252.80	1.03971	.2471
2125.	9.0000	4.7440	.88450	1259.57	1.04703	.2370
2125.	8.0000	5.4070	.89609	1266.50	1.05504	.2265
2125.	7.0000	6.2615	.90800	1273.59	1.06390	.2154
2125.	6.0000	7.4035	.92022	1280.83	1.07386	.2040
2125.	5.0000	9.0053	.93277	1288.23	1.08531	.1920
2125.	4.0000	11.4118	.94563	1295.77	1.09887	.1797
2125.	3.0000	15.4276	.95880	1303.45	1.11576	.1670
2125.	2.0000	23.4663	.97226	1311.26	1.13868	.1539
2125.	1.0000	47.5959	.98600	1319.18	1.17625	.1408
2125.	.8000	59.6626	.98878	1320.78	1.18806	.1379
2125.	.6000	79.7746	.99157	1322.38	1.20315	.1352
2125.	.4000	119.9999	.99437	1323.99	1.22422	.1325
2125.	.2000	240.6781	.99718	1325.60	1.25991	.1298
2150.	15.5504	2.5736	.82112	1224.88	1.00993	.2891
2150.	15.0000	2.6858	.82660	1228.13	1.01268	.2843
2150.	14.0000	2.9125	.83679	1234.08	1.01787	.2756
2150.	13.0000	3.1743	.84663	1240.11	1.02335	.2671
2150.	12.0000	3.4804	.85691	1246.24	1.02917	.2584
2150.	11.0000	3.8430	.86734	1252.50	1.03538	.2495
2150.	10.0000	4.2792	.87800	1258.89	1.04205	.2403
2150.	9.0000	4.8138	.88891	1265.42	1.04928	.2307
2150.	8.0000	5.4837	.90011	1272.09	1.05719	.2207
2150.	7.0000	6.3471	.91159	1278.91	1.06595	.2103
2150.	6.0000	7.5006	.92337	1285.88	1.07580	.1994
2150.	5.0000	9.1184	.93544	1292.98	1.08714	.1882
2150.	4.0000	11.5487	.94781	1300.22	1.10059	.1766
2150.	3.0000	15.6038	.96046	1307.59	1.11736	.1646
2150.	2.0000	23.7207	.97338	1315.08	1.14015	.1523
2150.	1.0000	48.0840	.98657	1322.69	1.17760	.1398
2150.	.8000	60.2675	.98924	1324.22	1.18938	.1373
2150.	.6000	80.5741	.99191	1325.76	1.20445	.1347
2150.	.4000	121.1885	.99460	1327.30	1.22550	.1322
2150.	.2000	243.0340	.99729	1328.84	1.26116	.1296
2175.	16.5612	2.4299	.81785	1226.28	1.00784	.2886
2175.	16.0000	2.5318	.82324	1229.45	1.01048	.2838
2175.	15.0000	2.7320	.83284	1235.12	1.01535	.2756
2175.	14.0000	2.9611	.84249	1240.86	1.02046	.2675
2175.	13.0000	3.2258	.85224	1246.69	1.02586	.2594
2175.	12.0000	3.5352	.86214	1252.61	1.03160	.2511
2175.	11.0000	3.9017	.87223	1258.65	1.03772	.2427
2175.	10.0000	4.3426	.88254	1264.81	1.04431	.2339
2175.	9.0000	4.8828	.89309	1271.11	1.05145	.2248
2175.	8.0000	5.5596	.90390	1277.54	1.05927	.2154
2175.	7.0000	6.4317	.91498	1284.11	1.06793	.2055
2175.	6.0000	7.5968	.92633	1290.81	1.07768	.1953
2175.	5.0000	9.2305	.93796	1297.64	1.08891	.1846
2175.	4.0000	11.6846	.94986	1304.60	1.10226	.1737
2175.	3.0000	15.7789	.96202	1311.68	1.11892	.1624
2175.	2.0000	23.9740	.97444	1318.87	1.14160	.1508
2175.	1.0000	48.5711	.98711	1326.17	1.17893	.1391
2175.	.8000	60.8714	.98967	1327.64	1.19069	.1367
2175.	.6000	81.3726	.99224	1329.12	1.20573	.1343
2175.	.4000	122.3761	.99482	1330.60	1.22676	.1319
2175.	.2000	245.3889	.99740	1332.08	1.26240	.1295

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

T	P	ρ^*	Z	h^*	s^*	c_p^*
2200.	17.6159	2.2967	.81449	1227.65	1.00580	.2883
2200.	17.0000	2.3966	.82022	1230.99	1.00853	.2832
2200.	16.0000	2.5752	.82948	1236.43	1.01312	.2752
2200.	15.0000	2.7775	.83875	1241.91	1.01791	.2675
2200.	14.0000	3.0090	.84807	1247.45	1.02295	.2599
2200.	13.0000	3.2765	.85751	1253.08	1.02828	.2522
2200.	12.0000	3.5792	.86709	1258.80	1.03394	.2444
2200.	11.0000	3.9196	.87686	1264.64	1.03998	.2364
2200.	10.0000	4.3051	.88683	1270.59	1.04649	.2280
2200.	9.0000	4.7309	.89704	1276.66	1.05355	.2194
2200.	8.0000	5.2046	.90748	1282.86	1.06128	.2104
2200.	7.0000	5.7354	.91818	1289.19	1.06985	.2011
2200.	6.0000	6.3220	.92913	1295.64	1.07951	.1914
2200.	5.0000	6.9647	.94033	1302.22	1.09064	.1814
2200.	4.0000	7.6634	.95179	1308.91	1.10388	.1710
2200.	3.0000	8.4281	.96350	1315.71	1.12044	.1604
2200.	2.0000	9.2588	.97544	1322.63	1.14302	.1495
2200.	1.0000	10.1555	.98761	1329.64	1.18024	.1384
2200.	.8000	11.1182	.99007	1331.05	1.19198	.1361
2200.	.6000	12.1469	.99254	1332.47	1.20700	.1339
2200.	.4000	13.2406	.99502	1333.89	1.22800	.1316
2200.	.2000	14.3993	.99751	1335.31	1.26362	.1293
2225.	18.7154	2.1728	.61103	1229.00	1.00380	.2883
2225.	18.0000	2.2772	.61750	1232.74	1.00681	.2824
2225.	17.0000	2.4076	.62647	1237.96	1.01114	.2746
2225.	16.0000	2.5619	.63539	1243.21	1.01566	.2672
2225.	15.0000	2.7423	.64434	1248.50	1.02038	.2600
2225.	14.0000	2.9462	.65337	1253.86	1.02535	.2528
2225.	13.0000	3.1726	.66250	1259.30	1.03061	.2455
2225.	12.0000	3.4206	.67179	1264.83	1.03619	.2381
2225.	11.0000	3.6906	.68125	1270.47	1.04217	.2305
2225.	10.0000	4.0829	.69091	1276.22	1.04860	.2225
2225.	9.0000	4.5083	.70078	1282.08	1.05558	.2143
2225.	8.0000	4.9668	.71087	1288.06	1.06323	.2058
2225.	7.0000	5.4584	.72120	1294.16	1.07171	.1970
2225.	6.0000	5.9834	.73177	1300.38	1.08128	.1878
2225.	5.0000	6.5420	.74258	1306.71	1.09232	.1783
2225.	4.0000	7.1353	.75362	1313.15	1.10547	.1685
2225.	3.0000	7.7643	.76489	1319.70	1.12193	.1585
2225.	2.0000	8.4288	.77638	1326.35	1.14441	.1482
2225.	1.0000	9.1291	.78809	1333.09	1.18153	.1377
2225.	.8000	9.8652	.79045	1334.45	1.19325	.1356
2225.	.6000	10.6363	.79283	1335.81	1.20825	.1335
2225.	.4000	11.4422	.79521	1337.18	1.22923	.1314
2225.	.2000	12.2835	.79760	1338.55	1.26483	.1292
2250.	19.8605	2.0575	.80745	1230.31	1.00185	.2886
2250.	19.0000	2.1709	.81504	1234.66	1.00528	.2815
2250.	18.0000	2.3159	.82374	1239.69	1.00939	.2739
2250.	17.0000	2.4778	.83237	1244.73	1.01365	.2668
2250.	16.0000	2.6600	.84100	1249.80	1.01810	.2598
2250.	15.0000	2.8665	.84965	1254.91	1.02276	.2530
2250.	14.0000	3.0929	.85839	1260.10	1.02766	.2462
2250.	13.0000	3.3400	.86725	1265.36	1.03285	.2393
2250.	12.0000	3.6093	.87625	1270.71	1.03837	.2322
2250.	11.0000	3.9014	.88541	1276.16	1.04428	.2250
2250.	10.0000	4.2161	.89477	1281.72	1.05064	.2174
2250.	9.0000	4.5549	.90432	1287.38	1.05754	.2096
2250.	8.0000	4.9183	.91409	1293.15	1.06511	.2015
2250.	7.0000	5.3065	.92407	1299.04	1.07352	.1931
2250.	6.0000	5.7200	.93427	1305.03	1.08301	.1844

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	ρ^g	z	ρ^l	ρ^s	$\frac{c_p^g}{P}$
2250.	5.0000	9.5615	.94470	1311.13	1.09396	.1755
2250.	4.0000	12.0866	.95534	1317.34	1.10702	.1662
2250.	3.0000	16.2986	.96620	1323.64	1.12339	.1568
2250.	2.0000	24.7280	.97727	1330.04	1.14578	.1471
2250.	1.0000	50.0262	.98854	1336.52	1.18280	.1372
2250.	.8000	62.6768	.99082	1337.83	1.19450	.1352
2250.	.6000	83.7618	.99310	1339.14	1.20948	.1331
2250.	.4000	125.9328	.99539	1340.46	1.23045	.1311
2250.	.2000	252.4475	.99769	1341.77	1.26603	.1291
2275.	21.0517	1.9499	.80372	1231.58	.99993	.2893
2275.	21.0000	1.9558	.80417	1231.84	1.00013	.2888
2275.	20.0000	2.0756	.81281	1236.73	1.00392	.2806
2275.	19.0000	2.2077	.82128	1241.59	1.00783	.2731
2275.	18.0000	2.3540	.82965	1246.44	1.01187	.2661
2275.	17.0000	2.5175	.83798	1251.30	1.01607	.2595
2275.	16.0000	2.7015	.84631	1256.20	1.02045	.2529
2275.	15.0000	2.9101	.85470	1261.15	1.02505	.2465
2275.	14.0000	3.1489	.86317	1266.17	1.02990	.2400
2275.	13.0000	3.4249	.87176	1271.27	1.03502	.2335
2275.	12.0000	3.7474	.88048	1276.45	1.04048	.2268
2275.	11.0000	4.1293	.88937	1281.72	1.04632	.2198
2275.	10.0000	4.5886	.89843	1287.09	1.05261	.2127
2275.	9.0000	5.1509	.90768	1292.56	1.05945	.2052
2275.	8.0000	5.8551	.91713	1298.14	1.06695	.1975
2275.	7.0000	6.7619	.92678	1303.82	1.07528	.1896
2275.	6.0000	7.9728	.93664	1309.60	1.08469	.1813
2275.	5.0000	9.6702	.94670	1315.48	1.09556	.1728
2275.	4.0000	12.2189	.95697	1321.46	1.10854	.1641
2275.	3.0000	16.4701	.96744	1327.54	1.12483	.1551
2275.	2.0000	24.9776	.97811	1333.70	1.14717	.1460
2275.	1.0000	50.5095	.98896	1339.95	1.18406	.1366
2275.	.8000	63.2769	.99116	1341.20	1.19574	.1347
2275.	.6000	84.5565	.99336	1342.47	1.21070	.1328
2275.	.4000	127.1165	.99556	1343.73	1.23165	.1309
2275.	.2000	254.7985	.99778	1345.00	1.26721	.1290
2300.	22.2899	1.8494	.79982	1232.79	.99804	.2904
2300.	22.0000	1.8796	.80232	1234.18	.99908	.2878
2300.	21.0000	1.9899	.81078	1238.94	1.00271	.2796
2300.	20.0000	2.1107	.81905	1243.64	1.00644	.2722
2300.	19.0000	2.2438	.82718	1248.32	1.01028	.2654
2300.	18.0000	2.3916	.83525	1253.00	1.01426	.2589
2300.	17.0000	2.5567	.84330	1257.70	1.01840	.2527
2300.	16.0000	2.7425	.85137	1262.45	1.02272	.2465
2300.	15.0000	2.9532	.85950	1267.24	1.02727	.2404
2300.	14.0000	3.1944	.86771	1272.10	1.03205	.2343
2300.	13.0000	3.4732	.87604	1277.03	1.03712	.2280
2300.	12.0000	3.7990	.88451	1282.05	1.04252	.2216
2300.	11.0000	4.1847	.89312	1287.15	1.04830	.2150
2300.	10.0000	4.6484	.90191	1292.35	1.05453	.2082
2300.	9.0000	5.2162	.91087	1297.64	1.06130	.2011
2300.	8.0000	5.9272	.92001	1303.03	1.06873	.1938
2300.	7.0000	6.8427	.92935	1308.52	1.07699	.1863
2300.	6.0000	8.0650	.93888	1314.10	1.08633	.1784
2300.	5.0000	9.7782	.94860	1319.77	1.09712	.1704
2300.	4.0000	12.3505	.95852	1325.54	1.11002	.1621
2300.	3.0000	16.6409	.96862	1331.40	1.12623	.1536
2300.	2.0000	25.2264	.97890	1337.33	1.14845	.1450
2300.	1.0000	50.9920	.98937	1343.35	1.18530	.1361
2300.	.8000	63.8762	.99148	1344.57	1.19697	.1343
2300.	.6000	85.3503	.99360	1345.78	1.21191	.1325

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^g	z	A^g	s^g	c_p^g
2300.	.4000	128.2995	.99573	1347.00	1.23284	.1307
2300.	.2000	257.1488	.99785	1348.22	1.26639	.1289
2325.	23.5757	1.7553	.79573	1233.93	.99618	.2921
2325.	23.0000	1.8104	.80064	1236.63	.99816	.2868
2325.	22.0000	1.9123	.80893	1241.26	1.00164	.2787
2325.	21.0000	2.0233	.81701	1245.82	1.00520	.2713
2325.	20.0000	2.1451	.82494	1250.35	1.00886	.2646
2325.	19.0000	2.2795	.83277	1254.86	1.01264	.2582
2325.	18.0000	2.4286	.84056	1259.39	1.01656	.2522
2325.	17.0000	2.5953	.84835	1263.94	1.02065	.2464
2325.	16.0000	2.7829	.85617	1268.53	1.02492	.2406
2325.	15.0000	2.9958	.86406	1273.18	1.02941	.2348
2325.	14.0000	3.2394	.87203	1277.89	1.03414	.2289
2325.	13.0000	3.5209	.88012	1282.67	1.03916	.2230
2325.	12.0000	3.8500	.88833	1287.53	1.04450	.2169
2325.	11.0000	4.2395	.89669	1292.47	1.05022	.2105
2325.	10.0000	4.7077	.90521	1297.50	1.05639	.2040
2325.	9.0000	5.2810	.91390	1302.62	1.06309	.1973
2325.	8.0000	5.9987	.92275	1307.83	1.07046	.1904
2325.	7.0000	6.9228	.93179	1313.13	1.07865	.1832
2325.	6.0000	8.1565	.94101	1318.52	1.08792	.1758
2325.	5.0000	9.8855	.95040	1324.00	1.09865	.1681
2325.	4.0000	12.4814	.95998	1329.57	1.11148	.1603
2325.	3.0000	16.8109	.96973	1335.22	1.12761	.1522
2325.	2.0000	25.4745	.97966	1340.95	1.14975	.1440
2325.	1.0000	51.4738	.98975	1346.75	1.18652	.1356
2325.	.8000	64.4747	.99179	1347.92	1.19818	.1339
2325.	.6000	86.1434	.99383	1349.09	1.21311	.1322
2325.	.4000	129.4817	.99588	1350.27	1.23402	.1305
2325.	.2000	259.4983	.99794	1351.44	1.26955	.1288
2350.	24.9097	1.6671	.79140	1234.98	.99434	.2943
2350.	24.0000	1.7471	.79909	1239.18	.99734	.2858
2350.	23.0000	1.8417	.80724	1243.69	1.00068	.2776
2350.	22.0000	1.9443	.81515	1248.12	1.00409	.2703
2350.	21.0000	2.0562	.82289	1252.51	1.00759	.2637
2350.	20.0000	2.1790	.83052	1256.87	1.01119	.2575
2350.	19.0000	2.3146	.83808	1261.24	1.01492	.2516
2350.	18.0000	2.4652	.84562	1265.62	1.01879	.2460
2350.	17.0000	2.6335	.85316	1270.02	1.02282	.2405
2350.	16.0000	2.8229	.86075	1274.48	1.02704	.2350
2350.	15.0000	3.0379	.86840	1278.98	1.03148	.2295
2350.	14.0000	3.2839	.87615	1283.55	1.03617	.2239
2350.	13.0000	3.5682	.88400	1288.18	1.04113	.2182
2350.	12.0000	3.9004	.89197	1292.89	1.04642	.2124
2350.	11.0000	4.2937	.90009	1297.68	1.05208	.2064
2350.	10.0000	4.7665	.90835	1302.55	1.05819	.2002
2350.	9.0000	5.3452	.91677	1307.51	1.06484	.1937
2350.	8.0000	6.0696	.92535	1312.55	1.07215	.1871
2350.	7.0000	7.0023	.93410	1317.67	1.08028	.1803
2350.	6.0000	8.2473	.94302	1322.89	1.08948	.1732
2350.	5.0000	9.9922	.95211	1328.18	1.10014	.1660
2350.	4.0000	12.6116	.96137	1333.55	1.11290	.1586
2350.	3.0000	16.9803	.97079	1339.01	1.12896	.1509
2350.	2.0000	25.7219	.98037	1344.53	1.15103	.1431
2350.	1.0000	51.9548	.99011	1350.13	1.18773	.1352
2350.	.8000	65.0725	.99207	1351.26	1.19937	.1336
2350.	.6000	86.9358	.99405	1352.39	1.21429	.1320
2350.	.4000	130.6632	.99603	1353.53	1.23519	.1304
2350.	.2000	251.8471	.99801	1354.66	1.27070	.1288
2375.	26.2926	1.5843	.78681	1235.93	.99251	.2973

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	u^g	z	h^g	s^g	c_p^g
2375.	26.0000	1.6072	.78933	1237.28	.99344	.2943
2375.	25.0000	1.6892	.79768	1241.80	.99661	.2848
2375.	24.0000	1.7773	.80570	1246.21	.99983	.2766
2375.	23.0000	1.8724	.81346	1250.52	1.00310	.2693
2375.	22.0000	1.9757	.82103	1254.78	1.00645	.2628
2375.	21.0000	2.0886	.82847	1259.01	1.00989	.2567
2375.	20.0000	2.2124	.83582	1263.23	1.01344	.2510
2375.	19.0000	2.3493	.84313	1267.45	1.01712	.2455
2375.	18.0000	2.5012	.85043	1271.69	1.02094	.2402
2375.	17.0000	2.6712	.85774	1275.97	1.02493	.2350
2375.	16.0000	2.8625	.86511	1280.28	1.02910	.2298
2375.	15.0000	3.0795	.87254	1284.65	1.03349	.2245
2375.	14.0000	3.3280	.88007	1289.08	1.03813	.2192
2375.	13.0000	3.6150	.88769	1293.58	1.04304	.2138
2375.	12.0000	3.9504	.89544	1298.15	1.04828	.2082
2375.	11.0000	4.3475	.90332	1302.79	1.05389	.2024
2375.	10.0000	4.8247	.91134	1307.51	1.05995	.1965
2375.	9.0000	5.4088	.91951	1312.31	1.06654	.1904
2375.	8.0000	6.1400	.92783	1317.19	1.07379	.1841
2375.	7.0000	7.0812	.93630	1322.15	1.08186	.1776
2375.	6.0000	8.3376	.94494	1327.19	1.09101	.1709
2375.	5.0000	10.0982	.95373	1332.30	1.10160	.1640
2375.	4.0000	12.7413	.96268	1337.50	1.11430	.1569
2375.	3.0000	17.1490	.97179	1342.76	1.13030	.1497
2375.	2.0000	25.9686	.98104	1348.10	1.15230	.1423
2375.	1.0000	52.4352	.99045	1353.51	1.18893	.1348
2375.	.8000	65.6696	.99235	1354.60	1.20055	.1333
2375.	.6000	87.7275	.99425	1355.69	1.21545	.1318
2375.	.4000	131.8441	.99616	1356.78	1.23634	.1302
2375.	.2000	264.1952	.99808	1357.88	1.27184	.1287
2400.	27.7249	1.5062	.78190	1236.76	.99069	.3012
2400.	27.0000	1.5590	.78815	1240.07	.99291	.2933
2400.	26.0000	1.6359	.79639	1244.50	.99597	.2838
2400.	25.0000	1.7182	.80429	1248.81	.99907	.2756
2400.	24.0000	1.8068	.81191	1253.02	1.00222	.2683
2400.	23.0000	1.9025	.81932	1257.16	1.00543	.2618
2400.	22.0000	2.0066	.82659	1261.26	1.00873	.2558
2400.	21.0000	2.1204	.83376	1265.34	1.01211	.2502
2400.	20.0000	2.2454	.84086	1269.42	1.01562	.2449
2400.	19.0000	2.3835	.84793	1273.51	1.01925	.2398
2400.	18.0000	2.5369	.85501	1277.63	1.02302	.2348
2400.	17.0000	2.7084	.86211	1281.77	1.02697	.2298
2400.	16.0000	2.9016	.86927	1285.97	1.03110	.2249
2400.	15.0000	3.1208	.87649	1290.21	1.03544	.2199
2400.	14.0000	3.3716	.88380	1294.51	1.04003	.2148
2400.	13.0000	3.6614	.89122	1298.87	1.04490	.2096
2400.	12.0000	4.0000	.89874	1303.30	1.05009	.2042
2400.	11.0000	4.4008	.90640	1307.80	1.05565	.1988
2400.	10.0000	4.8824	.91418	1312.38	1.06166	.1931
2400.	9.0000	5.4720	.92211	1317.03	1.06820	.1873
2400.	8.0000	6.2098	.93018	1321.75	1.07539	.1813
2400.	7.0000	7.1596	.93839	1326.55	1.08341	.1751
2400.	6.0000	8.4273	.94676	1331.43	1.09250	.1687
2400.	5.0000	10.2037	.95527	1336.38	1.10304	.1622
2400.	4.0000	12.8703	.96393	1341.40	1.11567	.1554
2400.	3.0000	17.3172	.97274	1346.49	1.13161	.1486
2400.	2.0000	26.2148	.98169	1351.65	1.15354	.1416
2400.	1.0000	52.9150	.99078	1356.87	1.19011	.1344
2400.	.8000	66.2662	.99261	1357.93	1.20172	.1330
2400.	.6000	88.5186	.99445	1358.98	1.21661	.1315

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^0	z	h^0	s^0	c_p^0
2400.	.4000	133.0243	.99629	1360.04	1.23748	.1301
2400.	.2000	266.5427	.99814	1361.10	1.27297	.1286
2425.	29.2072	1.4325	.77663	1237.44	.98886	.3062
2425.	29.0000	1.4462	.77848	1238.40	.98948	.3036
2425.	28.0000	1.5144	.78708	1242.93	.99244	.2923
2425.	27.0000	1.5867	.79522	1247.27	.99541	.2828
2425.	26.0000	1.6639	.80299	1251.48	.99840	.2746
2425.	25.0000	1.7466	.81049	1255.59	1.00143	.2673
2425.	24.0000	1.8357	.81776	1259.63	1.00452	.2608
2425.	23.0000	1.9322	.82487	1263.62	1.00768	.2549
2425.	22.0000	2.0371	.83187	1267.57	1.01092	.2494
2425.	21.0000	2.1519	.83878	1271.52	1.01427	.2442
2425.	20.0000	2.2780	.84565	1275.47	1.01772	.2392
2425.	19.0000	2.4173	.85251	1279.44	1.02131	.2344
2425.	18.0000	2.5721	.85938	1283.43	1.02504	.2297
2425.	17.0000	2.7453	.86628	1287.46	1.02895	.2250
2425.	16.0000	2.9403	.87323	1291.53	1.03304	.2203
2425.	15.0000	3.1616	.88026	1295.65	1.03734	.2155
2425.	14.0000	3.4147	.88737	1299.82	1.04188	.2106
2425.	13.0000	3.7073	.89458	1304.06	1.04671	.2057
2425.	12.0000	4.0491	.90189	1308.36	1.05185	.2006
2425.	11.0000	4.4536	.90933	1312.73	1.05737	.1953
2425.	10.0000	4.9397	.91689	1317.17	1.06333	.1899
2425.	9.0000	5.5346	.92459	1321.67	1.06982	.1843
2425.	8.0000	6.2792	.93241	1326.25	1.07696	.1788
2425.	7.0000	7.2375	.94038	1330.90	1.08492	.1727
2425.	6.0000	8.5165	.94849	1335.62	1.09396	.1667
2425.	5.0000	10.3087	.95673	1340.41	1.10444	.1604
2425.	4.0000	12.9988	.96512	1345.27	1.11702	.1540
2425.	3.0000	17.4848	.97364	1350.19	1.13289	.1475
2425.	2.0000	26.4603	.98230	1355.18	1.15477	.1409
2425.	1.0000	53.3942	.99108	1360.23	1.19128	.1341
2425.	.8000	66.8621	.99286	1361.25	1.20288	.1327
2425.	.6000	89.3092	.99463	1362.26	1.21775	.1313
2425.	.4000	134.2039	.99642	1363.29	1.23861	.1299
2425.	.2000	268.8896	.99821	1364.31	1.27409	.1286
2450.	30.7400	1.3628	.77093	1237.94	.98703	.3125
2450.	30.0000	1.4085	.77760	1241.39	.98917	.3027
2450.	29.0000	1.4730	.78611	1245.84	.99205	.2913
2450.	28.0000	1.5413	.79415	1250.10	.99492	.2818
2450.	27.0000	1.6138	.80181	1254.22	.99781	.2735
2450.	26.0000	1.6912	.80919	1258.24	1.00074	.2663
2450.	25.0000	1.7744	.81633	1262.18	1.00371	.2598
2450.	24.0000	1.8641	.82330	1266.06	1.00674	.2539
2450.	23.0000	1.9613	.83013	1269.91	1.00985	.2485
2450.	22.0000	2.0671	.83688	1273.73	1.01305	.2434
2450.	21.0000	2.1829	.84357	1277.56	1.01635	.2386
2450.	20.0000	2.3101	.85022	1281.39	1.01976	.2340
2450.	19.0000	2.4507	.85687	1285.23	1.02331	.2294
2450.	18.0000	2.6070	.86355	1289.11	1.02701	.2249
2450.	17.0000	2.7818	.87025	1293.02	1.03087	.2204
2450.	16.0000	2.9786	.87702	1296.98	1.03492	.2159
2450.	15.0000	3.2020	.88385	1300.98	1.03918	.2114
2450.	14.0000	3.4576	.89077	1305.04	1.04368	.2067
2450.	13.0000	3.7528	.89778	1309.15	1.04847	.2020
2450.	12.0000	4.0978	.90490	1313.33	1.05357	.1971
2450.	11.0000	4.5060	.91213	1317.57	1.05904	.1921
2450.	10.0000	4.9966	.91948	1321.87	1.06495	.1869
2450.	9.0000	5.5968	.92695	1326.25	1.07140	.1816
2450.	8.0000	6.3481	.93455	1330.68	1.07849	.1761

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^g	z	h^g	s^g	c_p^g
2450.	7.0000	7.3149	.94227	1335.19	1.08640	.1705
2450.	6.0000	8.6053	.95013	1339.76	1.09539	.1647
2450.	5.0000	10.4132	.95812	1344.40	1.10582	.1588
2450.	4.0000	13.1268	.96625	1349.10	1.11834	.1527
2450.	3.0000	17.6518	.97450	1353.87	1.13416	.1465
2450.	2.0000	26.7054	.98287	1358.69	1.15598	.1402
2450.	1.0000	53.8728	.99138	1363.57	1.19244	.1337
2450.	.8000	67.4575	.99309	1364.56	1.20402	.1324
2450.	.6000	90.0991	.99481	1365.54	1.21889	.1311
2450.	.4000	135.3830	.99654	1366.53	1.23974	.1298
2450.	.2000	271.2360	.99827	1367.52	1.27520	.1285
2475.	32.3238	1.2967	.76473	1238.24	.98517	.3206
2475.	32.0000	1.3151	.76780	1239.80	.98609	.3155
2475.	31.0000	1.3734	.77682	1244.42	.98891	.3017
2475.	30.0000	1.4346	.78523	1248.79	.99171	.2903
2475.	29.0000	1.4990	.79317	1252.98	.99449	.2807
2475.	28.0000	1.5674	.80073	1257.02	.99729	.2725
2475.	27.0000	1.6402	.80799	1260.95	1.00011	.2652
2475.	26.0000	1.7181	.81502	1264.80	1.00298	.2588
2475.	25.0000	1.8018	.82185	1268.58	1.00590	.2530
2475.	24.0000	1.8921	.82854	1272.33	1.00889	.2476
2475.	23.0000	1.9901	.83513	1276.04	1.01195	.2426
2475.	22.0000	2.0968	.84165	1279.75	1.01511	.2379
2475.	21.0000	2.2135	.84812	1283.45	1.01837	.2334
2475.	20.0000	2.3419	.85458	1287.17	1.02174	.2290
2475.	19.0000	2.4838	.86104	1290.91	1.02525	.2247
2475.	18.0000	2.6415	.86753	1294.68	1.02891	.2205
2475.	17.0000	2.8180	.87405	1298.48	1.03274	.2162
2475.	16.0000	3.0166	.88064	1302.32	1.03675	.2119
2475.	15.0000	3.2420	.88729	1306.22	1.04097	.2075
2475.	14.0000	3.5000	.89402	1310.16	1.04544	.2031
2475.	13.0000	3.7980	.90084	1314.16	1.05018	.1985
2475.	12.0000	4.1461	.90777	1318.22	1.05524	.1938
2475.	11.0000	4.5580	.91480	1322.33	1.06067	.1890
2475.	10.0000	5.0530	.92194	1326.51	1.06654	.1841
2475.	9.0000	5.6586	.92920	1330.75	1.07294	.1790
2475.	8.0000	6.4165	.93658	1335.06	1.07999	.1738
2475.	7.0000	7.3919	.94408	1339.43	1.08785	.1684
2475.	6.0000	8.6935	.95170	1343.86	1.09679	.1629
2475.	5.0000	10.5172	.95945	1348.35	1.10717	.1573
2475.	4.0000	13.2543	.96732	1352.90	1.11964	.1515
2475.	3.0000	17.8184	.97531	1357.52	1.13541	.1456
2475.	2.0000	26.9499	.98342	1362.19	1.15718	.1396
2475.	1.0000	54.3510	.99165	1366.91	1.19358	.1334
2475.	.8000	68.0524	.99331	1367.87	1.20515	.1322
2475.	.6000	90.8886	.99498	1368.82	1.22001	.1310
2475.	.4000	136.5616	.99665	1369.78	1.24085	.1297
2475.	.2000	273.5818	.99832	1370.73	1.27630	.1285
2500.	33.9590	1.2337	.75791	1238.27	.98327	.3309
2500.	33.0000	1.2850	.76719	1242.94	.98596	.3145
2500.	32.0000	1.3406	.77612	1247.49	.98870	.3006
2500.	31.0000	1.3987	.78444	1251.80	.99142	.2893
2500.	30.0000	1.4598	.79229	1255.92	.99412	.2797
2500.	29.0000	1.5244	.79975	1259.88	.99683	.2714
2500.	28.0000	1.5929	.80690	1263.73	.99957	.2642
2500.	27.0000	1.6661	.81361	1267.49	1.00233	.2578
2500.	26.0000	1.7444	.82052	1271.18	1.00515	.2520
2500.	25.0000	1.8287	.82708	1274.83	1.00802	.2467
2500.	24.0000	1.9197	.83353	1278.44	1.01096	.2418
2500.	23.0000	2.0185	.83989	1282.04	1.01399	.2372

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^0	z	h^0	s^0	c_p^0
2500.	22.0000	2.1261	.84620	1285.63	1.01710	.2328
2500.	21.0000	2.2438	.85247	1289.23	1.02033	.2285
2500.	20.0000	2.3734	.85874	1292.84	1.02367	.2244
2500.	19.0000	2.5165	.86502	1296.47	1.02714	.2203
2500.	18.0000	2.6757	.87133	1300.13	1.03076	.2163
2500.	17.0000	2.8538	.87768	1303.83	1.03455	.2122
2500.	16.0000	3.0543	.88409	1307.57	1.03853	.2081
2500.	15.0000	3.2818	.89057	1311.36	1.04272	.2039
2500.	14.0000	3.5421	.89713	1315.19	1.04714	.1996
2500.	13.0000	3.8428	.90377	1319.04	1.05185	.1953
2500.	12.0000	4.1940	.91051	1323.02	1.05687	.1908
2500.	11.0000	4.6097	.91734	1327.02	1.06226	.1862
2500.	10.0000	5.1090	.92429	1331.08	1.06809	.1815
2500.	9.0000	5.7200	.93134	1335.20	1.07445	.1766
2500.	8.0000	6.4846	.93851	1339.37	1.08145	.1716
2500.	7.0000	7.4684	.94580	1343.61	1.08927	.1665
2500.	6.0000	8.7813	.95319	1347.91	1.09816	.1613
2500.	5.0000	10.6207	.96071	1352.26	1.10850	.1559
2500.	4.0000	13.3813	.96834	1356.68	1.12092	.1504
2500.	3.0000	17.9845	.97609	1361.14	1.13664	.1447
2500.	2.0000	27.1940	.98395	1365.67	1.15836	.1390
2500.	1.0000	54.8286	.99192	1370.25	1.19471	.1332
2500.	.8000	68.6468	.99353	1371.17	1.20627	.1320
2500.	.6000	91.6776	.99514	1372.09	1.22112	.1308
2500.	.4000	137.7397	.99676	1373.02	1.24194	.1296
2500.	.2000	275.9272	.99838	1373.94	1.27739	.1284
2525.	35.6462	1.1734	.75035	1237.99	.98132	.3442
2525.	35.0000	1.2057	.75707	1241.31	.98313	.3306
2525.	34.0000	1.2569	.76667	1246.12	.98587	.3134
2525.	33.0000	1.3099	.77550	1250.61	.98854	.2996
2525.	32.0000	1.3652	.78374	1254.85	.99118	.2882
2525.	31.0000	1.4232	.79149	1258.89	.99381	.2786
2525.	30.0000	1.4843	.79885	1262.79	.99643	.2703
2525.	29.0000	1.5491	.80591	1266.56	.99908	.2631
2525.	28.0000	1.6179	.81270	1270.24	1.00176	.2567
2525.	27.0000	1.6915	.81930	1273.85	1.00447	.2510
2525.	26.0000	1.7703	.82574	1277.40	1.00724	.2458
2525.	25.0000	1.8552	.83205	1280.92	1.01007	.2409
2525.	24.0000	1.9470	.83827	1284.42	1.01297	.2364
2525.	23.0000	2.0465	.84442	1287.90	1.01596	.2321
2525.	22.0000	2.1550	.85054	1291.39	1.01904	.2280
2525.	21.0000	2.2738	.85663	1294.88	1.02223	.2240
2525.	20.0000	2.4045	.86272	1298.39	1.02554	.2201
2525.	19.0000	2.5490	.86883	1301.93	1.02898	.2162
2525.	18.0000	2.7096	.87497	1305.49	1.03257	.2123
2525.	17.0000	2.8893	.88116	1309.09	1.03632	.2084
2525.	16.0000	3.0916	.88740	1312.73	1.04026	.2045
2525.	15.0000	3.3212	.89371	1316.41	1.04442	.2005
2525.	14.0000	3.5838	.90010	1320.14	1.04881	.1964
2525.	13.0000	3.8872	.90656	1323.92	1.05348	.1922
2525.	12.0000	4.2416	.91312	1327.76	1.05846	.1879
2525.	11.0000	4.6609	.91978	1331.64	1.06381	.1835
2525.	10.0000	5.1647	.92653	1335.58	1.06961	.1790
2525.	9.0000	5.7810	.93339	1339.58	1.07592	.1743
2525.	8.0000	6.5522	.94036	1343.64	1.08289	.1696
2525.	7.0000	7.5446	.94743	1347.75	1.09067	.1647
2525.	6.0000	8.8687	.95462	1351.92	1.09951	.1597
2525.	5.0000	10.7238	.96191	1356.14	1.10980	.1545
2525.	4.0000	13.5079	.96932	1360.42	1.12218	.1493
2525.	3.0000	18.1502	.97683	1364.75	1.13786	.1439

APPENDIX B

THERMODYNAMIC PROPERTIES OF POTASSIUM VAPOR (cont'd)
(Monomer Gas Base)

t	p	v^g	z	h^g	s^g	c_p^g
2525.	2.0000	27.4376	.98445	1369.14	1.15953	.1385
2525.	1.0000	55.3058	.99217	1373.57	1.19583	.1329
2525.	.8000	69.2408	.99373	1374.46	1.20738	.1318
2525.	.6000	92.4661	.99529	1375.36	1.22222	.1306
2525.	.4000	138.9173	.99686	1376.25	1.24303	.1295
2525.	.2000	278.2721	.99843	1377.15	1.27647	.1284

APPENDIX C

THE MOLECULAR COMPOSITION OF SATURATED POTASSIUM
VAPOR AND ENTHALPIES OF VAPORIZATION

t	P_s	$(x_2)_s$	$(x_4)_s$	$(M_a)_s$	Δh_v	Δh_{v1}
1400.	1.0327	.156495	.004951	42.5908	828.08	878.70
1425.	1.1719	.161145	.005677	42.7243	824.22	876.56
1450.	1.3252	.165730	.006481	42.8599	820.33	874.43
1475.	1.4938	.170246	.007366	42.9976	816.43	872.29
1500.	1.6785	.174687	.008339	43.1376	812.52	870.15
1525.	1.8803	.179048	.009402	43.2798	808.61	868.02
1550.	2.1003	.183324	.010559	43.4243	804.70	865.90
1575.	2.3394	.187510	.011816	43.5711	800.79	863.80
1600.	2.5988	.191601	.013175	43.7205	796.89	861.72
1625.	2.8795	.195593	.014640	43.8723	793.01	859.66
1650.	3.1824	.199482	.016214	44.0266	789.14	857.53
1675.	3.5088	.203265	.017899	44.1836	785.29	855.63
1700.	3.8596	.206937	.019697	44.3432	781.46	853.67
1725.	4.2359	.210495	.021611	44.5055	777.65	851.73
1750.	4.6388	.213938	.023642	44.6704	773.87	849.84
1775.	5.0694	.217261	.025790	44.8381	770.11	847.97
1800.	5.5287	.220463	.028056	45.0084	766.37	846.15
1825.	6.0179	.223542	.030440	45.1815	762.66	844.35
1850.	6.5378	.226497	.032942	45.3573	758.97	842.58
1875.	7.0897	.229325	.035560	45.5357	755.30	840.84
1900.	7.6745	.232026	.038293	45.7167	751.65	839.13
1925.	8.2932	.234599	.041139	45.9003	748.00	837.43
1950.	8.9469	.237045	.044096	46.0864	744.37	835.74
1975.	9.6366	.239362	.047160	46.2750	740.74	834.06
2000.	10.3632	.241553	.050330	46.4659	737.10	832.37
2025.	11.1276	.243617	.053600	46.6592	733.45	830.68
2050.	11.9309	.245555	.056967	46.8546	729.78	828.97
2075.	12.7740	.247369	.060428	47.0520	726.08	827.22
2100.	13.6577	.249061	.063976	47.2515	722.34	825.43
2125.	14.5829	.250632	.067609	47.4528	718.55	823.59
2150.	15.5504	.252084	.071320	47.6557	714.70	821.68
2175.	16.5612	.253421	.075105	47.8603	710.77	819.69
2200.	17.6159	.254643	.078959	48.0663	706.75	817.60
2225.	18.7154	.255755	.082875	48.2736	702.63	815.40
2250.	19.8605	.256759	.086849	48.4821	698.38	813.06
2275.	21.0517	.257659	.090875	48.6915	693.99	810.57
2300.	22.2899	.258456	.094949	48.9019	689.43	807.89
2325.	23.5757	.259156	.099063	49.1129	684.68	805.02
2350.	24.9097	.259760	.103214	49.3245	679.72	801.91
2375.	26.2926	.260273	.107395	49.5365	674.50	798.53
2400.	27.7249	.260698	.111602	49.7488	668.99	794.84
2425.	29.2072	.261038	.115830	49.9611	663.15	790.81
2450.	30.7400	.261298	.120074	50.1735	656.92	786.36
2475.	32.3238	.261479	.124328	50.3857	650.23	781.44
2500.	33.9590	.261588	.128589	50.5976	642.99	775.95
2525.	35.6462	.261625	.132852	50.8090	635.09	769.77

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR

t	p	x_2	x_4	M_a
1400.	1.0327	.156495	.004951	42.5908
1400.	1.0000	.152700	.004554	42.4892
1400.	.8000	.128114	.002526	41.8608
1400.	.6000	.100936	.001158	41.2159
1400.	.4000	.070835	.000374	40.5475
1400.	.2000	.037383	.000051	39.8463
1425.	1.1719	.161145	.005677	42.7243
1425.	1.0000	.142702	.003755	42.2323
1425.	.8000	.119322	.002072	41.6496
1425.	.6000	.093676	.000944	41.0518
1425.	.4000	.065491	.000303	40.4332
1425.	.2000	.034419	.000041	39.7859
1450.	1.3252	.165730	.006481	42.8599
1450.	1.0000	.133420	.003106	41.9996
1450.	.8000	.111219	.001704	41.4585
1450.	.6000	.087032	.000772	40.9036
1450.	.4000	.060636	.000246	40.3302
1450.	.2000	.031748	.000033	39.7317
1475.	1.4938	.170246	.007366	42.9976
1475.	1.0000	.124813	.002576	41.7886
1475.	.8000	.103752	.001407	41.2853
1475.	.6000	.080949	.000634	40.7695
1475.	.4000	.056221	.000201	40.2372
1475.	.2000	.029336	.000027	39.6829
1500.	1.6785	.174687	.008339	43.1376
1500.	1.0000	.116839	.002143	41.5969
1500.	.8000	.096873	.001165	41.1280
1500.	.6000	.075378	.000523	40.6479
1500.	.4000	.052202	.000165	40.1530
1500.	.2000	.027155	.000022	39.6388
1525.	1.8803	.179048	.009402	43.2798
1525.	1.0000	.109453	.001788	41.4225
1525.	.8000	.090536	.000969	40.9851
1525.	.6000	.070273	.000433	40.5375
1525.	.4000	.048539	.000136	40.0767
1525.	.2000	.025178	.000018	39.5991
1550.	2.1003	.183324	.010559	43.4243
1550.	2.0000	.177079	.009340	43.2304
1550.	1.0000	.102616	.001497	41.2635
1550.	.8000	.084694	.000808	40.8549
1550.	.6000	.065591	.000360	40.4371
1550.	.4000	.045197	.000113	40.0075
1550.	.2000	.023385	.000015	39.5630
1575.	2.3394	.187510	.011816	43.5711
1575.	2.0000	.167689	.007965	42.9585
1575.	1.0000	.096285	.001257	41.1183
1575.	.8000	.079313	.000676	40.7361
1575.	.6000	.061295	.000300	40.3456
1575.	.4000	.042144	.000094	39.9445
1575.	.2000	.021754	.000012	39.5303
1600.	2.5988	.191601	.013175	43.7205
1600.	2.0000	.158819	.006606	42.7095

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	x_2	x_4	M_a
1400.	1.0000	.090424	.001059	40.9856
1600.	.8000	.074349	.000568	40.6276
1600.	.6000	.057349	.000251	40.2621
1600.	.4000	.039352	.000078	39.8871
1600.	.2000	.020270	.000010	39.5006
1625.	2.8795	.195593	.014640	43.8723
1625.	2.0000	.150454	.005826	42.4814
1625.	1.0000	.084996	.000894	40.8641
1625.	.8000	.069768	.000478	40.5283
1625.	.6000	.053721	.000211	40.1858
1625.	.4000	.036794	.000065	39.8348
1625.	.2000	.018916	.000009	39.4736
1650.	3.1824	.199482	.016214	44.0266
1650.	3.0000	.191762	.014038	43.7560
1650.	2.0000	.142574	.004998	42.2719
1650.	1.0000	.079968	.000758	40.7526
1650.	.8000	.065539	.000404	40.4374
1650.	.6000	.050383	.000178	40.1159
1650.	.4000	.034450	.000055	39.7870
1650.	.2000	.017679	.000007	39.4489
1675.	3.5088	.203265	.017899	44.1836
1675.	3.0000	.182931	.012196	43.4740
1675.	2.0000	.135160	.004296	42.0793
1675.	1.0000	.075307	.000644	40.6503
1675.	.8000	.061630	.000343	40.3539
1675.	.6000	.047308	.000150	40.0519
1675.	.4000	.032297	.000046	39.7432
1675.	.2000	.016547	.000006	39.4264
1700.	3.8596	.206937	.019697	44.3432
1700.	3.0000	.174501	.010610	43.2144
1700.	2.0000	.128189	.003701	41.9020
1700.	1.0000	.070985	.000549	40.5561
1700.	.8000	.058016	.000291	40.2772
1700.	.6000	.044472	.000128	39.9931
1700.	.4000	.030317	.000039	39.7030
1700.	.2000	.015509	.000005	39.4057
1725.	4.2359	.210495	.021611	44.5055
1725.	4.0000	.202976	.018851	44.2121
1725.	3.0000	.166471	.009244	42.9750
1725.	2.0000	.121637	.003195	41.7385
1725.	1.0000	.066974	.000470	40.4695
1725.	.8000	.054671	.000249	40.2066
1725.	.6000	.041855	.000109	39.9391
1725.	.4000	.028496	.000033	39.6661
1725.	.2000	.014557	.000004	39.3868
1750.	4.6388	.213938	.023642	44.6704
1750.	4.0000	.194609	.016585	43.9199
1750.	3.0000	.158833	.008066	42.7540
1750.	2.0000	.115482	.002765	41.5876
1750.	1.0000	.063250	.000403	40.3895
1750.	.8000	.051573	.000213	40.1415
1750.	.6000	.039437	.000093	39.8893
1750.	.4000	.026816	.000028	39.6322
1750.	.2000	.013682	.000004	39.3694
1775.	5.0694	.217261	.025790	44.8381
1775.	5.0000	.215463	.024974	44.7605
1775.	4.0000	.186560	.014607	43.6499
1775.	3.0000	.151578	.007050	42.5498
1775.	2.0000	.109702	.002398	41.4480
1775.	1.0000	.059790	.000346	40.3157

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	P	x_2	x_3	M_a
1775.	.8000	.048700	.000183	40.0815
1775.	.6000	.037200	.000080	39.8435
1775.	.4000	.025267	.000024	39.6010
1775.	.2000	.012876	.000003	39.3535
1800.	5.5287	.220463	.029056	45.0084
1800.	5.0000	.207405	.022177	44.4488
1800.	4.0000	.178835	.012879	43.3999
1800.	3.0000	.144694	.006172	42.3608
1800.	2.0000	.104273	.002084	41.3188
1800.	1.0000	.056573	.000299	40.2475
1800.	.8000	.046034	.000157	40.0260
1800.	.6000	.035128	.000068	39.8011
1800.	.4000	.023835	.000021	39.5722
1800.	.2000	.012133	.000003	39.3387
1825.	6.0179	.223542	.030440	45.1815
1825.	6.0000	.223160	.030234	45.1635
1825.	5.0000	.199596	.019707	44.1597
1825.	4.0000	.171434	.011370	43.1684
1825.	3.0000	.138167	.005413	42.1856
1825.	2.0000	.099174	.001816	41.1990
1825.	1.0000	.053578	.000258	40.1843
1825.	.8000	.043558	.000136	39.9747
1825.	.6000	.033207	.000059	39.7620
1825.	.4000	.022510	.000018	39.5456
1825.	.2000	.011447	.000002	39.3252
1850.	6.5378	.226497	.032942	45.3573
1850.	6.0000	.215496	.027056	44.8415
1850.	5.0000	.192046	.017527	43.8916
1850.	4.0000	.164355	.010050	42.9536
1850.	3.0000	.131983	.004755	42.0230
1850.	2.0000	.094385	.001585	41.0879
1850.	1.0000	.050790	.000224	40.1257
1850.	.8000	.041256	.000118	39.9272
1850.	.6000	.031425	.000051	39.7257
1850.	.4000	.021283	.000016	39.5210
1850.	.2000	.010813	.000002	39.3126
1875.	7.0897	.229325	.035560	45.5357
1875.	7.0000	.227721	.034558	45.4534
1875.	6.0000	.208025	.024223	44.5422
1875.	5.0000	.184763	.015602	43.6425
1875.	4.0000	.157592	.008896	42.7541
1875.	3.0000	.126126	.004185	41.8720
1875.	2.0000	.089886	.001387	40.9846
1875.	1.0000	.048190	.000195	40.0714
1875.	.8000	.039114	.000102	39.8831
1875.	.6000	.029770	.000044	39.6921
1875.	.4000	.020144	.000013	39.4982
1875.	.2000	.010226	.000002	39.3010
1900.	7.6745	.232026	.038293	45.7167
1900.	7.0000	.220462	.031127	45.1280
1900.	6.0000	.200761	.021701	44.2636
1900.	5.0000	.177752	.013903	43.4109
1900.	4.0000	.151138	.007885	42.5686
1900.	3.0000	.120581	.003690	41.7315
1900.	2.0000	.085657	.001216	40.8885
1900.	1.0000	.045766	.000170	40.0209
1900.	.8000	.037119	.000089	39.8421
1900.	.6000	.028230	.000038	39.6610
1900.	.4000	.019088	.000012	39.4771
1900.	.2000	.009682	.000001	39.2902

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	r_2	r_4	M_0
1925.	8.2932	.234599	.041139	45.9003
1925.	8.0000	.230168	.037996	45.6552
1925.	7.0000	.213354	.028047	44.8246
1925.	6.0000	.193717	.019456	44.0043
1925.	5.0000	.171014	.012403	43.1953
1925.	4.0000	.144984	.007000	42.3959
1925.	3.0000	.115333	.003260	41.6007
1925.	2.0000	.081682	.001069	40.7990
1925.	1.0000	.043502	.000149	39.9739
1925.	.8000	.035259	.000078	39.8040
1925.	.6000	.026796	.000034	39.6320
1925.	.4000	.018105	.000010	39.4575
1925.	.2000	.009177	.000001	39.2803
1950.	8.9469	.237045	.044096	46.0864
1950.	8.0000	.223295	.034414	45.3311
1950.	7.0000	.206414	.025283	44.5416
1950.	6.0000	.186902	.017457	43.7626
1950.	5.0000	.164546	.011078	42.9945
1950.	4.0000	.139121	.006223	42.2350
1950.	3.0000	.110366	.002885	41.4787
1950.	2.0000	.077944	.000942	40.7155
1950.	1.0000	.041386	.000130	39.9302
1950.	.8000	.033523	.000068	39.7666
1950.	.6000	.025460	.000029	39.6050
1950.	.4000	.017191	.000009	39.4393
1950.	.2000	.008707	.000001	39.2710
1975.	9.6366	.239362	.047160	46.2750
1975.	9.0000	.231159	.040645	45.7879
1975.	8.0000	.216544	.031179	45.0283
1975.	7.0000	.199658	.022806	44.2775
1975.	6.0000	.180319	.015678	43.5372
1975.	5.0000	.158345	.009906	42.8072
1975.	4.0000	.133537	.005541	42.0848
1975.	3.0000	.105665	.002557	41.3647
1975.	2.0000	.074427	.000831	40.6376
1975.	1.0000	.039407	.000114	39.8894
1975.	.8000	.031901	.000060	39.7356
1975.	.6000	.024214	.000026	39.5800
1975.	.4000	.016339	.000008	39.4223
1975.	.2000	.008271	.000001	39.2624
2000.	10.3632	.241553	.050330	46.4659
2000.	10.0000	.237383	.046634	46.1993
2000.	9.0000	.224643	.036992	45.4686
2000.	8.0000	.209933	.028260	44.7451
2000.	7.0000	.193094	.020586	44.0308
2000.	6.0000	.173971	.014094	43.3268
2000.	5.0000	.152405	.008869	42.6323
2000.	4.0000	.128222	.004941	41.9446
2000.	3.0000	.101216	.002271	41.2583
2000.	2.0000	.071116	.000735	40.5648
2000.	1.0000	.037555	.000101	39.8513
2000.	.8000	.030385	.000053	39.7048
2000.	.6000	.023050	.000023	39.5566
2000.	.4000	.015545	.000007	39.4065
2000.	.2000	.007864	.000001	39.2544
2025.	11.1276	.243617	.053600	46.6592
2025.	11.0000	.242306	.052315	46.5692
2025.	10.0000	.231126	.042619	45.8666
2025.	9.0000	.218228	.033676	45.1695
2025.	8.0000	.203474	.025626	44.4802

NAVAL RESEARCH LABORATORY

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	x_2	x_4	M_d
2025.	7.0000	.186729	.018595	43.8003
2025.	6.0000	.167858	.012683	43.1301
2025.	5.0000	.146721	.007951	42.4688
2025.	4.0000	.123165	.004413	41.8134
2025.	3.0000	.097004	.002021	41.1587
2025.	2.0000	.067999	.000651	40.4966
2025.	1.0000	.035820	.000089	39.8158
2025.	.8000	.028966	.000045	39.6750
2025.	.6000	.021962	.000020	39.5347
2025.	.4000	.014803	.000006	39.3917
2025.	.2000	.007484	.000001	39.2469
2050.	11.9309	.245555	.056967	46.8546
2050.	11.0000	.236316	.047991	46.2258
2050.	10.0000	.224937	.038954	45.5543
2050.	9.0000	.211931	.030667	44.8892
2050.	8.0000	.197181	.023252	44.2322
2050.	7.0000	.180569	.016812	43.5846
2050.	6.0000	.161977	.011426	42.9462
2050.	5.0000	.141284	.007138	42.3158
2050.	4.0000	.118352	.003948	41.6905
2050.	3.0000	.093017	.001801	41.0654
2050.	2.0000	.065061	.000579	40.4329
2050.	1.0000	.034193	.000079	39.7825
2050.	.8000	.027637	.000041	39.6491
2050.	.6000	.020943	.000018	39.5143
2050.	.4000	.014109	.000005	39.3780
2050.	.2000	.007130	.000001	39.2399
2075.	12.7740	.247369	.060428	47.0520
2075.	12.0000	.240465	.053069	46.5495
2075.	11.0000	.230364	.044025	45.9028
2075.	10.0000	.218833	.035611	45.2612
2075.	9.0000	.205766	.027940	44.6264
2075.	8.0000	.191060	.021112	44.0000
2075.	7.0000	.174614	.015213	43.3826
2075.	6.0000	.156325	.010304	42.7739
2075.	5.0000	.136086	.006416	42.1725
2075.	4.0000	.113774	.003537	41.5754
2075.	3.0000	.089241	.001609	40.9779
2075.	2.0000	.062292	.000515	40.3731
2075.	1.0000	.032667	.000070	39.7513
2075.	.8000	.026390	.000036	39.6239
2075.	.6000	.019990	.000016	39.4952
2075.	.4000	.013460	.000005	39.3651
2075.	.2000	.006799	.000001	39.2334
2100.	13.6577	.249061	.063976	47.2515
2100.	13.0000	.243772	.057830	46.8408
2100.	12.0000	.234753	.048846	46.2181
2100.	11.0000	.224471	.040391	45.5992
2100.	10.0000	.212832	.032566	44.9860
2100.	9.0000	.199744	.025468	44.3800
2100.	8.0000	.185118	.019182	43.7823
2100.	7.0000	.168866	.013779	43.1933
2100.	6.0000	.150898	.009304	42.6124
2100.	5.0000	.131119	.005775	42.0381
2100.	4.0000	.109419	.003174	41.4674
2100.	3.0000	.085664	.001439	40.8958
2100.	2.0000	.059680	.000459	40.3169
2100.	1.0000	.031233	.000062	39.7222
2100.	.8000	.025121	.000032	39.6003
2100.	.6000	.019096	.000014	39.4773

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	r_2	r_4	H_d
2100.	.4000	.012853	.000004	39.3530
2100.	.2000	.006489	.000001	39.2273
2125.	14.5829	.250632	.067609	47.4528
2125.	14.0000	.246395	.062266	47.1027
2125.	13.0000	.238296	.053393	46.5029
2125.	12.0000	.229077	.044961	45.9060
2125.	11.0000	.218654	.037065	45.3137
2125.	10.0000	.206946	.029793	44.7275
2125.	9.0000	.193873	.023228	44.1487
2125.	8.0000	.179357	.017443	43.5781
2125.	7.0000	.163322	.012492	43.0157
2125.	6.0000	.145690	.008411	42.4609
2125.	5.0000	.126374	.005205	41.9119
2125.	4.0000	.105277	.002852	41.3659
2125.	3.0000	.082276	.001289	40.8187
2125.	2.0000	.057215	.000410	40.2642
2125.	1.0000	.029885	.000055	39.6948
2125.	.8000	.024123	.000029	39.5782
2125.	.6000	.018256	.000012	39.4606
2125.	.4000	.012283	.000004	39.3417
2125.	.2000	.006198	.000000	39.2216
2150.	15.5504	.252084	.071320	47.6557
2150.	15.0000	.248458	.066384	47.3376
2150.	14.0000	.241145	.057653	46.7598
2150.	13.0000	.232835	.049294	46.1841
2150.	12.0000	.223454	.041390	45.6120
2150.	11.0000	.212927	.034022	45.0451
2150.	10.0000	.201185	.027269	44.4846
2150.	9.0000	.188159	.021200	43.9316
2150.	8.0000	.173780	.015875	43.3864
2150.	7.0000	.157982	.011337	42.8490
2150.	6.0000	.140695	.007612	42.3186
2150.	5.0000	.121842	.004698	41.7934
2150.	4.0000	.101335	.002567	41.2705
2150.	3.0000	.079064	.001157	40.7461
2150.	2.0000	.054887	.000367	40.2147
2150.	1.0000	.028617	.000049	39.6691
2150.	.8000	.023090	.000026	39.5575
2150.	.6000	.017468	.000011	39.4448
2150.	.4000	.011748	.000003	39.3311
2150.	.2000	.005926	.000000	39.2162
2175.	16.5612	.253421	.075105	47.8603
2175.	16.0000	.250062	.070189	47.5480
2175.	15.0000	.243425	.061625	46.9913
2175.	14.0000	.235895	.053375	46.4359
2175.	13.0000	.227409	.045513	45.8833
2175.	12.0000	.217900	.038111	45.3351
2175.	11.0000	.207304	.031241	44.7923
2175.	10.0000	.195560	.024972	44.2562
2175.	9.0000	.182607	.019362	43.7275
2175.	8.0000	.168387	.014460	43.2063
2175.	7.0000	.152840	.010300	42.6924
2175.	6.0000	.135906	.006898	42.1848
2175.	5.0000	.117514	.004246	41.6818
2175.	4.0000	.097585	.002314	41.1808
2175.	3.0000	.076018	.001040	40.6779
2175.	2.0000	.052687	.000329	40.1681
2175.	1.0000	.027423	.000044	39.6449
2175.	.8000	.022119	.000023	39.5379
2175.	.6000	.016727	.000010	39.4301

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

	P	F_2	F_1	M_0
2175.	.4000	.011245	.000003	39.3212
2175.	.2000	.005670	.000000	39.2112
2200.	17.6159	.254643	.078259	48.0663
2200.	17.0000	.251287	.073693	47.7361
2200.	16.0000	.245232	.065317	47.1995
2200.	15.0000	.238377	.057199	46.6636
2200.	14.0000	.230664	.049415	46.1299
2200.	13.0000	.222033	.042027	45.5996
2200.	12.0000	.212428	.035101	45.0741
2200.	11.0000	.201793	.028700	44.5544
2200.	10.0000	.190074	.022882	44.0414
2200.	9.0000	.177219	.017697	43.5355
2200.	8.0000	.163176	.013186	43.0368
2200.	7.0000	.147894	.009368	42.5450
2200.	6.0000	.131316	.006258	42.0589
2200.	5.0000	.113381	.003843	41.5768
2200.	4.0000	.094015	.002090	41.0962
2200.	3.0000	.073130	.000937	40.6136
2200.	2.0000	.050607	.000296	40.1242
2200.	1.0000	.026297	.000039	39.6222
2200.	.8000	.021204	.000020	39.5196
2200.	.6000	.016030	.000009	39.4162
2200.	.4000	.010773	.000003	39.3118
2200.	.2000	.005430	.000000	39.2065
2225.	18.7154	.255755	.082875	48.2736
2225.	16.0000	.252198	.076912	47.9039
2225.	17.0000	.246649	.068726	47.3864
2225.	16.0000	.240378	.060766	46.8692
2225.	15.0000	.233334	.053088	46.3536
2225.	14.0000	.225466	.045752	45.8407
2225.	13.0000	.216721	.038816	45.3319
2225.	12.0000	.207050	.032340	44.8281
2225.	11.0000	.196403	.026379	44.3303
2225.	10.0000	.184734	.020981	43.8391
2225.	9.0000	.171997	.016188	43.3548
2225.	8.0000	.158147	.012031	42.8774
2225.	7.0000	.143137	.008529	42.4062
2225.	6.0000	.126918	.005685	41.9403
2225.	5.0000	.109434	.003483	41.4779
2225.	4.0000	.090618	.001889	41.0165
2225.	3.0000	.070388	.000845	40.5529
2225.	2.0000	.048640	.000266	40.0828
2225.	1.0000	.025237	.000035	39.6067
2225.	.8000	.020342	.000018	39.5023
2225.	.6000	.015374	.000008	39.4031
2225.	.4000	.010328	.000002	39.3030
2225.	.2000	.005204	.000000	39.2020
2250.	19.8405	.256759	.086849	48.4821
2250.	19.0000	.252849	.079862	48.0533
2250.	18.0000	.247739	.071877	47.5540
2250.	17.0000	.241977	.064083	47.0546
2250.	16.0000	.235517	.056531	46.5563
2250.	15.0000	.228312	.049274	46.0602
2250.	14.0000	.220317	.042366	45.5675
2250.	13.0000	.211485	.035861	45.0792
2250.	12.0000	.201774	.029809	44.5962
2250.	11.0000	.191140	.024259	44.1192
2250.	10.0000	.179542	.019251	43.6486
2250.	9.0000	.166941	.014820	43.1846
2250.	8.0000	.153295	.010990	42.7271

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

T	p	x_2	x_4	y_a
2250.	7.0000	.138565	.007774	42.2754
2250.	6.0000	.122705	.005170	41.8285
2250.	5.0000	.105665	.003161	41.3846
2250.	4.0000	.087383	.001711	40.9413
2250.	3.0000	.067786	.000764	40.4957
2250.	2.0000	.046777	.000240	40.0438
2250.	1.0000	.024235	.000032	39.5806
2250.	.8000	.019529	.000016	39.4861
2250.	.6000	.014755	.000007	39.3908
2250.	.4000	.009909	.000002	39.2948
2250.	.2000	.004992	.000000	39.1978
2275.	21.0517	.257659	.090875	48.6915
2275.	21.0000	.257457	.090464	48.6667
2275.	20.0000	.253281	.082561	48.1860
2275.	19.0000	.248555	.074777	47.7039
2275.	18.0000	.243239	.067157	47.2215
2275.	17.0000	.237289	.059746	46.7398
2275.	16.0000	.230665	.052590	46.2599
2275.	15.0000	.223325	.045739	45.7828
2275.	14.0000	.215229	.039240	45.3094
2275.	13.0000	.206336	.033142	44.8407
2275.	12.0000	.196608	.027489	44.3774
2275.	11.0000	.186008	.022322	43.9200
2275.	10.0000	.174500	.017676	43.4689
2275.	9.0000	.162049	.013579	43.0242
2275.	8.0000	.148618	.010049	42.5854
2275.	7.0000	.134172	.007093	42.1521
2275.	6.0000	.118670	.004708	41.7229
2275.	5.0000	.102065	.002872	41.2964
2275.	4.0000	.084303	.001552	40.8703
2275.	3.0000	.065314	.000691	40.4417
2275.	2.0000	.045013	.000217	40.0069
2275.	1.0000	.023289	.000029	39.5615
2275.	.8000	.018762	.000015	39.4707
2275.	.6000	.014171	.000006	39.3792
2275.	.4000	.009514	.000002	39.2870
2275.	.2000	.004791	.000000	39.1939
2300.	22.2899	.258456	.094949	48.9019
2300.	22.0000	.257418	.092707	48.7677
2300.	21.0000	.253531	.085024	48.3034
2300.	20.0000	.249143	.077442	47.8377
2300.	19.0000	.244217	.070001	47.3715
2300.	18.0000	.238715	.062739	46.9057
2300.	17.0000	.232601	.055700	46.4412
2300.	16.0000	.225637	.048927	45.9791
2300.	15.0000	.218386	.042465	45.5202
2300.	14.0000	.210212	.036355	45.0654
2300.	13.0000	.201281	.030642	44.6154
2300.	12.0000	.191558	.025363	44.1709
2300.	11.0000	.181011	.020553	43.7321
2300.	10.0000	.169609	.016243	43.2995
2300.	9.0000	.157319	.012453	42.8728
2300.	8.0000	.144111	.009197	42.4517
2300.	7.0000	.129952	.006480	42.0356
2300.	6.0000	.114805	.004292	41.6233
2300.	5.0000	.098627	.002614	41.2132
2300.	4.0000	.081368	.001409	40.8032
2300.	3.0000	.062966	.000626	40.3906
2300.	2.0000	.043341	.000196	39.9721
2300.	1.0000	.022395	.000026	39.5436

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

T	p	x_2	x_1	M_d
2300.	.8000	.018037	.000013	39.4562
2300.	.6000	.013620	.000006	39.3683
2300.	.4000	.009142	.000002	39.2796
2300.	.2000	.004602	.000000	39.1902
2325.	23.5757	.259156	.099063	49.1129
2325.	23.0000	.257260	.094737	48.8556
2325.	22.0000	.253628	.087268	48.4070
2325.	21.0000	.249537	.079886	47.9568
2325.	20.0000	.244955	.072524	47.5060
2325.	19.0000	.239848	.065519	47.0553
2325.	18.0000	.234184	.058608	46.6057
2325.	17.0000	.227927	.051930	46.1581
2325.	16.0000	.221045	.045525	45.7132
2325.	15.0000	.213506	.039434	45.2718
2325.	14.0000	.205277	.033694	44.8348
2325.	13.0000	.196327	.028343	44.4026
2325.	12.0000	.186628	.023414	43.9758
2325.	11.0000	.176151	.018938	43.5547
2325.	10.0000	.164867	.014937	43.1394
2325.	9.0000	.152750	.011431	42.7298
2325.	8.0000	.139771	.008427	42.3254
2325.	7.0000	.125899	.005926	41.9255
2325.	6.0000	.111103	.003918	41.5290
2325.	5.0000	.095342	.002382	41.1344
2325.	4.0000	.078571	.001282	40.7396
2325.	3.0000	.060733	.000569	40.3423
2325.	2.0000	.041756	.000177	39.9392
2325.	1.0000	.021550	.000023	39.5266
2325.	.8000	.017352	.000012	39.4426
2325.	.6000	.013099	.000005	39.3579
2325.	.4000	.008790	.000002	39.2726
2325.	.2000	.004424	.000000	39.1867
2350.	24.9097	.259760	.103214	49.3245
2350.	24.0000	.257002	.096569	48.9318
2350.	23.0000	.253596	.089309	48.4979
2350.	22.0000	.249768	.082123	48.0625
2350.	21.0000	.245491	.075041	47.6264
2350.	20.0000	.240733	.068095	47.1902
2350.	19.0000	.235466	.061319	46.7548
2350.	18.0000	.229658	.054749	46.3210
2350.	17.0000	.223279	.048420	45.8896
2350.	16.0000	.216301	.042368	45.4612
2350.	15.0000	.208693	.036630	45.0367
2350.	14.0000	.200429	.031240	44.6166
2350.	13.0000	.191480	.026229	44.2014
2350.	12.0000	.181822	.021628	43.7915
2350.	11.0000	.171428	.017461	43.3871
2350.	10.0000	.160275	.013748	42.9882
2350.	9.0000	.148339	.010502	42.5947
2350.	8.0000	.135591	.007728	42.2060
2350.	7.0000	.122007	.005425	41.8214
2350.	6.0000	.107557	.003581	41.4399
2350.	5.0000	.092203	.002173	41.0598
2350.	4.0000	.075905	.001167	40.6795
2350.	3.0000	.058610	.000517	40.2965
2350.	2.0000	.040252	.000161	39.9080
2350.	1.0000	.020749	.000021	39.5105
2350.	.8000	.016703	.000011	39.4296
2350.	.6000	.012606	.000005	39.3481
2350.	.4000	.008457	.000001	39.2661

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	x_2	x_4	M_2
2350.	.2000	.004256	.000000	39.1834
2375.	26.2926	.260273	.107395	49.5365
2375.	26.0000	.259505	.105315	49.4148
2375.	25.0000	.256660	.098219	48.9972
2375.	24.0000	.253454	.091162	48.5774
2375.	23.0000	.249861	.084167	48.1560
2375.	22.0000	.245854	.077263	47.7338
2375.	21.0000	.241406	.070478	47.3114
2375.	20.0000	.236491	.063842	46.8896
2375.	19.0000	.231082	.057388	46.4692
2375.	18.0000	.225150	.051147	46.0507
2375.	17.0000	.218669	.045153	45.6349
2375.	16.0000	.211614	.039439	45.2225
2375.	15.0000	.203957	.034037	44.8141
2375.	14.0000	.195675	.028977	44.4101
2375.	13.0000	.186744	.024287	44.0111
2375.	12.0000	.177141	.019991	43.6172
2375.	11.0000	.166843	.016112	43.2286
2375.	10.0000	.155830	.012664	42.8452
2375.	9.0000	.144079	.009657	42.4669
2375.	8.0000	.131568	.007095	42.0930
2375.	7.0000	.118270	.004973	41.7229
2375.	6.0000	.104160	.003277	41.3554
2375.	5.0000	.089204	.001985	40.9892
2375.	4.0000	.073363	.001063	40.6225
2375.	3.0000	.056589	.000471	40.2532
2375.	2.0000	.038823	.000146	39.8785
2375.	1.0000	.019991	.000019	39.4953
2375.	.8000	.016089	.000010	39.4174
2375.	.6000	.012140	.000004	39.3389
2375.	.4000	.008142	.000001	39.2599
2375.	.2000	.004096	.000000	39.1802
2400.	27.7249	.260698	.111602	49.7488
2400.	27.0000	.258941	.106597	49.4572
2400.	26.0000	.256248	.099702	49.0529
2400.	25.0000	.253220	.092840	48.6464
2400.	24.0000	.249835	.086032	48.2393
2400.	23.0000	.246069	.079302	47.8294
2400.	22.0000	.241898	.072677	47.4202
2400.	21.0000	.237298	.066185	47.0114
2400.	20.0000	.232243	.059852	46.6037
2400.	19.0000	.226709	.053710	46.1977
2400.	18.0000	.220671	.047788	45.7940
2400.	17.0000	.214107	.042116	45.3934
2400.	16.0000	.206992	.036724	44.9963
2400.	15.0000	.199304	.031640	44.6032
2400.	14.0000	.191020	.026891	44.2147
2400.	13.0000	.182121	.022500	43.8309
2400.	12.0000	.172586	.018491	43.4522
2400.	11.0000	.162396	.014878	43.0786
2400.	10.0000	.151530	.011675	42.7099
2400.	9.0000	.139970	.008889	42.3459
2400.	8.0000	.127695	.006521	41.9860
2400.	7.0000	.114682	.004563	41.6296
2400.	6.0000	.100906	.003002	41.2754
2400.	5.0000	.086336	.001816	40.9223
2400.	4.0000	.070938	.000972	40.5685
2400.	3.0000	.054666	.000429	40.2121
2400.	2.0000	.037466	.000133	39.8505
2400.	1.0000	.019272	.000017	39.4810

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	x_2	x_4	M_u
2400.	.8000	.015507	.000009	39.4058
2400.	.6000	.011698	.000004	39.3302
2400.	.4000	.007845	.000001	39.2540
2400.	.2000	.003945	.000000	39.1773
2425.	29.2072	.261038	.115830	49.9611
2425.	29.0000	.260602	.114441	49.8808
2425.	28.0000	.258334	.107732	49.4915
2425.	27.0000	.255776	.101031	49.0997
2425.	26.0000	.252908	.094356	48.7058
2425.	25.0000	.249710	.087729	48.3105
2425.	24.0000	.246160	.081171	47.9142
2425.	23.0000	.242236	.074705	47.5176
2425.	22.0000	.237916	.068356	47.1212
2425.	21.0000	.233178	.062150	46.7257
2425.	20.0000	.227999	.056113	46.3317
2425.	19.0000	.222358	.050273	45.9397
2425.	18.0000	.216232	.044658	45.5504
2425.	17.0000	.209501	.039293	45.1642
2425.	16.0000	.202443	.034207	44.7818
2425.	15.0000	.194738	.029424	44.4034
2425.	14.0000	.186468	.024967	44.0295
2425.	13.0000	.177614	.020858	43.6604
2425.	12.0000	.168159	.017114	43.2960
2425.	11.0000	.158084	.013749	42.9366
2425.	10.0000	.147373	.010773	42.5818
2425.	9.0000	.136007	.008190	42.2313
2425.	8.0000	.123969	.005999	41.8846
2425.	7.0000	.111237	.004191	41.5410
2425.	6.0000	.097788	.002754	41.1995
2425.	5.0000	.083595	.001663	40.8587
2425.	4.0000	.068623	.000889	40.5172
2425.	3.0000	.052834	.000392	40.1731
2425.	2.0000	.036176	.000121	39.8240
2425.	1.0000	.018590	.000016	39.4673
2425.	.8000	.014955	.000008	39.3948
2425.	.6000	.011280	.000003	39.3219
2425.	.4000	.007562	.000001	39.2484
2425.	.2000	.003803	.000000	39.1745
2450.	30.7400	.261298	.120074	50.1735
2450.	30.0000	.259857	.115253	49.8959
2450.	29.0000	.257690	.108732	49.5184
2450.	28.0000	.255254	.102217	49.1385
2450.	27.0000	.252529	.095724	48.7566
2450.	26.0000	.249499	.089272	48.3733
2450.	25.0000	.246142	.082881	47.9891
2450.	24.0000	.242440	.076571	47.6044
2450.	23.0000	.238372	.070366	47.2199
2450.	22.0000	.233918	.064288	46.8361
2450.	21.0000	.229058	.058362	46.4536
2450.	20.0000	.223771	.052612	46.0729
2450.	19.0000	.218039	.047063	45.6945
2450.	18.0000	.211840	.041742	45.3190
2450.	17.0000	.205157	.036671	44.9468
2450.	16.0000	.197972	.031875	44.5783
2450.	15.0000	.190265	.027376	44.2140
2450.	14.0000	.182022	.023194	43.8541
2450.	13.0000	.173224	.019348	43.4987
2450.	12.0000	.163858	.015852	43.1480
2450.	11.0000	.153906	.012716	42.8020
2450.	10.0000	.143354	.009949	42.4603

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	x_2	x_4	M_d
2450.	9.0000	.132186	.007553	42.1226
2450.	8.0000	.120384	.005524	41.7885
2450.	7.0000	.107929	.003855	41.4571
2450.	6.0000	.094801	.002529	41.1275
2450.	5.0000	.080972	.001525	40.7984
2450.	4.0000	.066414	.000814	40.4685
2450.	3.0000	.051088	.000358	40.1360
2450.	2.0000	.034950	.000111	39.7988
2450.	1.0000	.017943	.000014	39.4544
2450.	.8000	.014432	.000007	39.3844
2450.	.6000	.010883	.000003	39.3140
2450.	.4000	.007295	.000001	39.2432
2450.	.2000	.003667	.000000	39.1718
2475.	32.3238	.261479	.124328	50.3857
2475.	32.0000	.260932	.122282	50.2685
2475.	31.0000	.259092	.115951	49.9049
2475.	30.0000	.257016	.109610	49.5385
2475.	29.0000	.254689	.103272	49.1699
2475.	28.0000	.252094	.096953	48.7995
2475.	27.0000	.249214	.090671	48.4277
2475.	26.0000	.246032	.084442	48.0549
2475.	25.0000	.242529	.078286	47.6817
2475.	24.0000	.238688	.072223	47.3086
2475.	23.0000	.234489	.066274	46.9360
2475.	22.0000	.229915	.060461	46.5644
2475.	21.0000	.224948	.054807	46.1945
2475.	20.0000	.219568	.049335	45.8267
2475.	19.0000	.213760	.044067	45.4614
2475.	18.0000	.207504	.039026	45.0992
2475.	17.0000	.200784	.034235	44.7403
2475.	16.0000	.193584	.029714	44.3853
2475.	15.0000	.185889	.025483	44.0343
2475.	14.0000	.177683	.021560	43.6877
2475.	13.0000	.168952	.017959	43.3455
2475.	12.0000	.159682	.014693	43.0077
2475.	11.0000	.149860	.011770	42.6743
2475.	10.0000	.139471	.009197	42.3450
2475.	9.0000	.128501	.006972	42.0195
2475.	8.0000	.116934	.005093	41.6972
2475.	7.0000	.104752	.003549	41.3773
2475.	6.0000	.091937	.002325	41.0590
2475.	5.0000	.078463	.001400	40.7411
2475.	4.0000	.064303	.000746	40.4223
2475.	3.0000	.049424	.000328	40.1008
2475.	2.0000	.033782	.000101	39.7749
2475.	1.0000	.017328	.000013	39.4421
2475.	.8000	.013935	.000007	39.3745
2475.	.6000	.010506	.000003	39.3066
2475.	.4000	.007041	.000001	39.2382
2475.	.2000	.003539	.000000	39.1693
2500.	33.9590	.261588	.128589	50.5976
2500.	33.0000	.260082	.122703	50.2615
2500.	32.0000	.258310	.116544	49.9083
2500.	31.0000	.256317	.110374	49.5526
2500.	30.0000	.254089	.104207	49.1947
2500.	29.0000	.251611	.098056	48.8352
2500.	28.0000	.248868	.091937	48.4743
2500.	27.0000	.245842	.085866	48.1124
2500.	26.0000	.242520	.079859	47.7501
2500.	25.0000	.238863	.073937	47.3878

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

t	p	x_2	x_4	x_a
2500.	24.0000	.234915	.068117	47.0260
2500.	23.0000	.230599	.062419	46.6651
2500.	22.0000	.225919	.056865	46.3055
2500.	21.0000	.220858	.051475	45.9478
2500.	20.0000	.215400	.046270	45.5925
2500.	19.0000	.209528	.041271	45.2398
2500.	18.0000	.203228	.036499	44.8903
2500.	17.0000	.196485	.031973	44.5443
2500.	16.0000	.189283	.027712	44.2021
2500.	15.0000	.181610	.023734	43.8639
2500.	14.0000	.173453	.020052	43.5298
2500.	13.0000	.164797	.016681	43.2001
2500.	12.0000	.155631	.013629	42.8746
2500.	11.0000	.145943	.010904	42.5532
2500.	10.0000	.135720	.008508	42.2356
2500.	9.0000	.124949	.006442	41.9216
2500.	8.0000	.113615	.004699	41.6104
2500.	7.0000	.101702	.003270	41.3015
2500.	6.0000	.089191	.002140	40.9939
2500.	5.0000	.076062	.001287	40.6866
2500.	4.0000	.062287	.000685	40.3783
2500.	3.0000	.047836	.000301	40.0674
2500.	2.0000	.032670	.000093	39.7521
2500.	1.0000	.016744	.000012	39.4305
2500.	.8000	.013462	.000006	39.3652
2500.	.6000	.010148	.000003	39.2995
2500.	.4000	.006800	.000001	39.2334
2500.	.2000	.003417	.000000	39.1669
2525.	35.6462	.261625	.132852	50.8090
2525.	35.0000	.260743	.129008	50.5905
2525.	34.0000	.259226	.123034	50.2499
2525.	33.0000	.257515	.117039	49.9066
2525.	32.0000	.255597	.111034	49.5611
2525.	31.0000	.253459	.105031	49.2135
2525.	30.0000	.251087	.099041	48.8643
2525.	29.0000	.248467	.093080	48.5138
2525.	28.0000	.245585	.087161	48.1624
2525.	27.0000	.242425	.081301	47.8105
2525.	26.0000	.238973	.075516	47.4586
2525.	25.0000	.235213	.069824	47.1070
2525.	24.0000	.231131	.064242	46.7562
2525.	23.0000	.226711	.058790	46.4066
2525.	22.0000	.221937	.053487	46.0587
2525.	21.0000	.216796	.048352	45.7129
2525.	20.0000	.211272	.043404	45.3696
2525.	19.0000	.205351	.038663	45.0291
2525.	18.0000	.199020	.034147	44.6918
2525.	17.0000	.192265	.029873	44.3581
2525.	16.0000	.185073	.025858	44.0280
2525.	15.0000	.177432	.022116	43.7020
2525.	14.0000	.169331	.018661	43.3799
2525.	13.0000	.160759	.015504	43.0620
2525.	12.0000	.151703	.012651	42.7481
2525.	11.0000	.142153	.010109	42.4381
2525.	10.0000	.132098	.007879	42.1317
2525.	9.0000	.121525	.005958	41.8285
2525.	8.0000	.110421	.004341	41.5280
2525.	7.0000	.098771	.003017	41.2294
2525.	6.0000	.086559	.001972	40.9321
2525.	5.0000	.073763	.001185	40.6348

APPENDIX D

MOLECULAR COMPOSITION OF POTASSIUM VAPOR (cont'd)

	P	x_2	x_4	M_u
2525.	4.0000	.060360	.000630	40.3364
2525.	3.0000	.046321	.000276	40.0355
2525.	2.0000	.031611	.000085	39.7305
2525.	1.0000	.016158	.000011	39.4194
2525.	.8000	.013013	.000006	39.3562
2525.	.6000	.009808	.000002	39.2928
2525.	.4000	.006571	.000001	39.2289
2525.	.2000	.003302	.000000	39.1647

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<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1 ORIGINATING ACTIVITY (Corporate author) U.S. Naval Research Laboratory Washington, D.C. 20390		2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b GROUP
3 REPORT TITLE HIGH-TEMPERATURE PROPERTIES OF POTASSIUM		
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) A final report on one phase of the problem.		
5 AUTHOR(S) (Last name, first name, initial) Ewing, C.T., Stone, J.P., Spann, J.R., Steinkuller, E.W., Williams, D.D., and Miller, R.R.		
6 REPORT DATE September 24, 1965	7a TOTAL NO OF PAGES 89	7b NO OF REFS 39
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c		
d		
10 AVAILABILITY/LIMITATION NOTICES Unlimited availability - Available at CFSTI - \$3.00		
11 SUPPLEMENTARY NOTES		12 SPONSORING MILITARY ACTIVITY NASA
13 ABSTRACT <p>An experimental program is in progress at this Laboratory to measure various thermophysical properties of sodium, potassium, and cesium. A final reporting of the experimental results for potassium (saturation and superheat properties of the vapor, density and specific heat of the liquid) is presented together with a thermodynamic treatment of the data. Two equations of state are advanced, one virial and one quasi-chemical; and additional saturation and superheat properties of the vapor are derived from these equations. Either of two paths can be used in deriving absolute thermodynamic properties, the monomeric gas path or the liquid path; but results obtained by the former procedure are believed to be more accurate. Enthalpy, entropy, specific volume, specific heat, and compositional information (weight fraction of dimer, weight fraction of tetramer, and average molecular weight) are tabulated for some 800 selected vapor states in the temperature range from 1400° to 2525° F and in the pressure range from 0.2 to 35 atm.</p>		

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Potassium Columbium-1%zirconium Superheated vapor Saturated vapor Virial equation of state Quasi-chemical equation of state Monomeric gas path Liquid path Association Compressibility data High-temperature properties Thermodynamic properties Thermophysical properties Liquid metals						

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