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Publication Date
1963-08-01
University of California

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Berkeley, California
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VAPORIZATION OF IRON OXIDES

Charles A. Washburn

Master's Thesis

August 1963
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VAPORIZATION OF IRON OXIDES

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ABSTRACT

The vapor species in equilibrium with iron oxide samples of compositions between FeO_{1.1} and FeO_{1.33} were studied with a mass spectrometer in the temperature range 1500 to 1594°C. The molecules O, O_2, Fe, and FeO, and only these molecules, were observed over the entire composition and temperature range. The existence of (FeO)_3(g) or Fe_{3.04}(g), which was recently claimed from the interpretation of vapor density experiments, appears to have been disproved. At 1594°C the pressure of FeO(g) in equilibrium with the congruently vaporizing composition is approximately one-third the pressure of Fe(g).
I. INTRODUCTION

The first attempt to obtain information concerning the vaporization behavior of the system iron-oxygen was made by Darken and Gurry. They determined that the congruently vaporizing composition in the system iron-oxygen occurs at the atom ratio \( \frac{O}{Fe} = 1.116 \). This composition was established by heating samples of various \( \frac{O}{Fe} \) ratios in platinum crucibles under vacuum and analyzing the residues. Darken and Gurry also measured the total "equilibrium" pressure over the congruently vaporizing sample by reading a vacuum gauge in the system while pumping on the sample. From this data, together with activity of iron and the pressure of oxygen at the congruently vaporizing composition and the vapor pressure of pure iron at 1600°C, they showed that the contribution of \( \text{FeO}(g) \) to the total vapor pressure was negligible if \( O, O_2, \text{Fe}, \) and \( \text{FeO} \) were considered to be the only possible vapor species.

Brewer and Mastick heated samples of nearly stoichiometric \( \text{Fe}_3\text{O}_4 \) in a platinum Knudsen cell and measured the weight losses during given times at temperature. Their effusion runs were performed at 1503°C on a univariant sample composed of \( \text{Fe}_3\text{O}_4 \) plus liquid oxide. In interpreting their data, Brewer and Mastick assumed first that the only vapor species present were \( O, O_2, \) and \( \text{FeO} \), and second that the only vapor species present were \( O, O_2, \) and \( \text{Fe} \). The average value of the \( \text{Fe}(g) \) pressure obtained by their second assumption agrees well with that calculated using Darken and Gurry's iron activity data together with the vapor pressure of pure iron; this suggested that \( \text{Fe}(g) \) might be more important than \( \text{FeO}(g) \) during the vaporization of \( \text{Fe}_3\text{O}_4 \). Using Darken and Gurry's oxygen pressure and iron activity data together with their own experimental data, Brewer and Mastick concluded
that the dissociation energy for $\text{FeO}(g)$ is equal to, or less than, 98 kcal/mole.

Recently Glemser and Weizenkorn$^{3,4}$ published the results of very high temperature vapor density measurements using $\text{Fe}_3\text{O}_4$ and $\text{Mn}_3\text{O}_4$ as the starting materials. Samples of $\text{Fe}_3\text{O}_4$ were introduced into an iridium bulb held at temperatures from 1875°C to 2150°C. Argon at various pressures from 60 torr to one atmosphere filled the system. From the movement of a mercury bead in a calibrated capillary which communicated with the iridium bulb, Glemser and Weizenkorn calculated that about one mole of gas was formed per mole of $\text{Fe}_3\text{O}_4$ vaporized. They therefore concluded that the principal vapor species resulting from the vaporization of $\text{Fe}_3\text{O}_4$ at high temperatures is $\text{Fe}_3\text{O}_4(g)$ or $(\text{FeO})_3(g)$.

Rengstorff$^5$ recently reported results of transpiration experiments in which $\text{Fe}_3\text{O}_4$ was heated in dry oxygen, wet oxygen (dew point 77°F), and dry oxygen containing 3.2% CO$_2$. The total pressure was one atmosphere in all cases. The experiments were performed using molten magnetite at 1600°C. From the rate or weight loss, Rengstorff concluded that an important gaseous molecule which contains a higher ratio of oxygen to iron than FeO must exist under the conditions of the experiment. His experiments indicated no effect due to the addition of water vapor or CO$_2$ to the oxygen.

The results of Glemser and Weizenkorn$^{3,4}$ together with those of Rengstorff$^5$ indicate that the vaporization behavior of the system iron-oxygen might be more complex than previous experience$^{1,2}$ indicated. In an attempt to identify the molecular species that effuse from a Knudsen cell containing iron oxides, a high temperature mass spectrometer investigation was undertaken.
II. EXPERIMENTAL

A. Knudsen Cell Arrangement

With the exception of the Glemser and Weizenkorn work, all of the investigations discussed above used platinum to contain the iron oxides. For the present study Knudsen cells were prepared by welding 0.010 inch platinum sheet using a hydrogen-oxygen torch. Right circular cylinder cans approximately 7 mm diameter by 15 mm high were prepared, all seams being carefully fused to insure against leaks. A twist drill was used to form the orifice in the top of the cell. Orifice diameters used in these experiments ranged from 1.0 to 1.5 mm. The iron oxide samples, in the form of powder, were loaded into the cells through the effusion orifices.

The platinum Knudsen cell was either placed directly in a tantalum cup or was first placed in a Morganite "Triangle RR" grade recrystallized alumina crucible which was then placed in the tantalum cup. The sample was heated in the mass spectrometer by electron bombardment of the tantalum outer cup. The temperature was measured by a Leeds and Northrup (Serial No. 1053323) disappearing filament optical pyrometer, previously calibrated by the National Bureau of Standards, which was sighted on a black body hole drilled in the side of the tantalum cup. Radiation shields of six concentric layers of 0.002 inch tantalum sheet surrounded the Knudsen cell. The Pyrex window through which readings were taken was calibrated before and after each series of measurements.

The mass spectrometer was similar to that described by Chupka and Inghram. It was manufactured by Nuclide Analysis Associates, State College, Pennsylvania from the basic design of Professor Mark Inghram of the University of Chicago. In this experiment an electron multiplier was used to detect the ion beam.
B. Experimental Method

The objectives of the mass spectrometer experiments were to identify the molecular species present, and to measure their relative concentrations. From the relative intensities and the relative ionization cross sections published by Otvos and Stevenson, the relative pressures can be calculated. The relative pressure data can be used to calculate absolute pressures by use of the iron activity and oxygen pressure data of Darken and Gurry, and the vapor pressure of pure iron. In order to use Darken and Gurry's data in this manner -- essentially as an internal calibration -- it is necessary to use a composition of iron oxide which has iron and oxygen activities that will not vary with time while at constant temperature. Two locations in the iron-oxygen system satisfy this condition and have high enough iron activities to be useful in this study. The liquid oxide-magnetite field, being a two-phase field in a two component system, is invariant if the temperature is fixed. However, because this field rapidly narrows as the temperature is increased (of course, the oxygen pressure also increases rapidly with temperature), it is not suitable for use in a quantitative mass spectrometer study because too large an initial Fe$_3$O$_4$ sample would be necessary to prevent the sample composition from going into the one-phase liquid-oxide field during the course of the experiments. The only composition satisfying the above requirements that will remain invariant as long as the temperature is fixed and material remains in the Knudsen cell is the congruently vaporizing composition. The determination of the congruently vaporizing composition at 1600°C by Darken and Gurry is the only direct measurement of this property that has been made in the system iron-oxygen.
C. Material

The sample of wustite used in the vaporization experiment was the same as that used by Coughlin, King, and Bonnickson. The sample analyzed 76.60% iron (near the high iron limit of the "FeO" field) and the principal impurity was 0.017% SiO₂.

The Fe₃O₄ was prepared by heating Baker Reagent Grade Fe₂O₃ at approximately 1300°C under vacuum in a platinum crucible. X-ray diffraction patterns showed that the product was Fe₃O₄.
III. RESULTS

Three experiments were performed using samples of Fe$_3$O$_4$. The purpose of these experiments was to search for vapor species in the system at high oxygen pressures. Samples were heated to as high as 1600°C, and the mass spectrum was examined to above mass 300. The only vapor species effusing from the Knudsen cell were identified as mass 16 (O), mass 32 (O$_2$), mass 56 (Fe), and mass 72 (FeO).

Ionization-voltage vs. ion-intensity curves were plotted for FeO(g) and Fe(g) to show that these species were not the result of fragmentation of more complex molecules (Fig. 1). Fragmentation occasionally occurs during ionization by impact with low energy electrons. The curves show that the ionization cross sections are near their maximum for electron energies of 60 ev, but no indication of important fragmentation appeared.

Samples of wustite were heated to above 1500°C; once again the only vapor species effusing from the Knudsen cell were O, O$_2$, Fe, and FeO. Intensities of mass 56 (Fe) and mass 72 (FeO) were recorded at eleven temperatures between 1783°K (1510°C) and 1867°K (1594°C). These data are presented in Table I. Sufficient time was allowed between each temperature change to allow the intensities as measured by the recorder to come to constant values; constancy of intensity was interpreted as evidence that the congruently vaporizing composition has been reached. Although mass 16 (O) and mass 32 (O$_2$) intensities could easily be recorded in equilibrium with Fe$_3$O$_4$, background contaminants in the mass spectrometer prevented the establishment of the intensities of these species in equilibrium with the congruently vaporizing composition.

Figure 2 shows that on changing the composition from Fe$_3$O$_4$ to the
congruently vaporizing composition \((O/Fe = 1.116)\) at 1600°C, the \(O(g)\) pressure was decreased by more than two orders of magnitude while the \(O_2(g)\) pressure was decreased by over four orders of magnitude. The ratio \(\frac{P_{FeO}}{P_{Fe}}\) varied from 0.298 to 0.147 and averaged 0.231 for the series of measurements made in equilibrium with the congruently vaporizing composition. The ratio tended to decrease with increasing temperatures. Approximately 0.25 grams of wustite was charged into the Knudsen cell at the start of this experiment, and approximately 0.050 grams of residue remained at the completion.

Tables II and III and Fig. 2 present results of calculations of the equilibrium pressures of \(O, O_2, Fe\) and \(FeO\) for the system iron-oxygen at 1600°C. Two values of the pressure of \(FeO(g)\) are given: one is based on a dissociation energy for \(FeO\) of 99 kcal/mole, the other is based on a dissociation energy of 92 kcal/mole. The data used in this calculation are Darken and Gurry's oxygen pressure and iron activity data, the vapor pressure data for pure iron selected by Hultgren, et al., the estimated free energy functions for \(FeO(g)\) published by Brewer and Chandrasekharaiash and the free energy functions for \(O(g), O_2(g)\), and \(Fe(g)\) given in Lewis, et al.

The value for the dissociation energy of \(FeO\) is not well known, although many emission spectogographic studies have been made to determine the properties of this molecule. Brewer estimated the dissociation energy of \(FeO\) to be \(99 \pm 11\) kcal/mole. Cottrell reports other values of 4 ev (92 kcal/mole) and 4.8 ev (110 kcal/mole).
IV. DISCUSSION

These experiments show that the equilibrium vapor species in the system iron-oxygen in the composition range from \(0/Fe = 1.11\) to \(0/Fe = 1.33\) at temperatures from 1500°C to 1600°C are \(O, O_2, Fe,\) and \(FeO.\) The pressure of \(FeO(g)\) in equilibrium with the congruently vaporizing composition \((0/Fe = 1.116)\) at 1600°C is about 0.3 times the pressure of \(Fe(g)\).

Glemser and Weizenkorn\(^3,4\) concluded that the vapor species resulting from the vaporization of \(Fe_3O_4\) at temperatures above 1875°C was \(Fe_3O_4(g)\) and/or \((FeO)_3(g).\) In the present work, no evidence was found for \(Fe_3O_4(g)\) or \((FeO)_3(g)\) above compositions near \(Fe/O = 3/4\) at 1600°C. Assuming that both of these pieces of evidence are correct, the values of \(\Delta H^\circ_{vap}\) and \(\Delta S^\circ_{vap}\) required to reconcile the divergent results can be calculated. The calculated values of \(\Delta H^\circ_{vap}\) and \(\Delta S^\circ_{vap}\) can be compared with previous experience to learn if the indicated sudden change in vaporization behavior is credible.

Glemser and Weizenkorn's\(^4\) lowest temperature experiment with \(Fe_3O_4\) was Number 25 in which 0.442 mg of \(Fe_3O_4\) were used at 1875°C (2148°K). If it is assumed that this sample vaporized to form saturated vapor of \(Fe_3O_4(g)\) in the hot iridium bulb (which had a volume of 4 cm\(^3\)) with an infinitesimal amount of condensed phase present, the minimum vapor pressure required to assure complete vaporization is obtained. This minimum vapor pressure of \(Fe_3O_4(g)\) can be used to calculate the maximum \(\Delta F^\circ_{vap}\) at 2148°K. Performing these calculations for the reaction:

\[
Fe_3O_4(s) = Fe_3O_4(g)
\]

at 2148°K,

\[
P_{Fe_3O_4} \geq \frac{nR(2148)}{V_{\text{bulb}}}
\]
\[ 
\begin{align*}
\Delta F^\circ_{\text{vap}} & \leq -4.576 \cdot \log (0.0845) \\
& \leq +10,600 \text{ cal/mole at } 2148^\circ \text{K}
\end{align*}
\]

Similarly, a minimum value of \( \Delta F^\circ_{\text{vap}} \) can be calculated at 1500°C (1773 K) because it was shown in this work that the pressure of \( \text{Fe}_3\text{O}_4(g) \) at 1773 K was less than \( 10^{-8} \) atm., which is approximately the limit of detection of the mass spectrometer.

\[ 
\Delta F^\circ_{\text{vap}} \geq -4.576 \cdot \log 10^{-8} \\
\geq +65,000 \text{ cal/mole at } 1773^\circ \text{K}.
\]

Using these two limiting values of \( \Delta F^\circ_{\text{vap}} \) and assuming that \( \Delta C_p = 0 \) from 1773 K to 2148 K, \( \Delta H^\circ_{\text{vap}} \) and \( \Delta S^\circ_{\text{vap}} \) can be calculated. When this is done, it is found that \( \Delta H^\circ_{\text{vap}} = 322.6 \text{ kcal/mole} \) and \( \Delta S^\circ_{\text{vap}} = 145.0 \text{ eu} \). Since the low temperature value of \( \Delta F^\circ_{\text{vap}} \) is a minimum value while the high temperature value is a maximum, 145.0 eu is the minimum \( \Delta S^\circ_{\text{vap}} \) required to reconcile the mass spectrometer results of no \( \text{Fe}_3\text{O}_4(g) \) at 1773 K with Gleiser and Weizenkorn's claim of vaporization to \( \text{Fe}_3\text{O}_4(g) \) or \( (\text{FeO})_3(g) \) at 2148 K. This value of \( \Delta S^\circ_{\text{vap}} \) is much larger than would be expected for a vaporization reaction in which one mole of gas is formed per mole of condensed phase vaporized. Using the estimated high temperature thermodynamic values in Elliott and Gleiser, the entropy of \( \text{Fe}_3\text{O}_4(g) \) at 2148 K is calculated to be \( S^\circ_{2148} \geq 300 \text{ eu} \). Kubaszewski and Evans give an empirical relationship between entropy and molecular weight for polyatomic gaseous molecules. Using \( M = 231.6 \) (the molecular weight of \( \text{Fe}_3\text{O}_4 \)), a value of \( S^\circ_{298} = 84.5 \text{ eu} \) is estimated.
Consideration of the high values of the lower limits of $\Delta S^\circ_{\text{vap}}$ for $\text{Fe}_3\text{O}_4$ and $S^\circ_{\text{Fe}_3\text{O}_4}$ leads to the conclusion that if the mass spectrometer results (failure to detect $\text{Fe}_3\text{O}_4(g)$ or $\text{(FeO)}_3(g)$ at temperatures to 1600°C) are accepted, Glemsen and Weizenko's results must be considered wrong.

Rengstorff concluded from the results of transpiration measurements of volatile molecules containing iron and oxygen in addition to FeO were formed when one atmosphere of oxygen was passed over iron oxide samples at 1600°C. Close examination of his results do not support this conclusion, which was made after comparing the results of the experiment with calculations based on a dissociation energy for FeO of 92 kcal/mole. Using Rengstorff's data and assuming that Fe and FeO are the only volatile molecules containing iron, a dissociation energy for FeO of 104 kcal/mole is calculated. This is well within the range of 99±11 estimated by Brewer. 10

Rengstorff did not detect any additional effect when wet oxygen was passed over the sample of iron oxide. A recent publication by Belton and Richardson establishes the existence of a volatile hydroxide of iron, probably Fe(OH)$_2$. Rengstorff's experiments with wet oxygen used oxygen with a dew point of 77°F, the total pressure being one atmosphere. At 1600°C the reactive gas would be composed of 0.969 atmospheres of oxygen, 3.14 x 10$^{-2}$ atmospheres of water vapor, and 3.27 x 10$^{-6}$ atmospheres of hydrogen. Belton and Richardson state that:

$$\Delta F^\circ = 38,900 - 5.80 T$$

for the reaction:

$$\text{FeO}\_2(g) + 2\text{H}_2\text{O}_2(g) \rightarrow \text{FeOH}_2(g) + \text{H}_2(g)$$

From this one can calculate that:

$$K_{1600} = 5.5 \times 10^{-4} = \frac{P_{\text{H}_2} P_{\text{Fe(OH)}_2}}{P_{\text{H}_2\text{O}_2} P_{\text{Fe}}^2}$$
Figure 73 of Ref. (1) gives the activity of iron in iron oxides at 1600°C in equilibrium with one atmosphere of oxygen as approximately $10^{-5}$. Solving for the pressure of $\text{Fe(OH)}_2$:

$$P_{\text{Fe(OH)}_2} = \frac{5.5 \times 10^{-4} a_{\text{Fe}} P_{\text{H}_2}\text{O}^2}{P_{\text{H}_2}}$$

$$= 5.5 \times 10^{-4} (10^{-5})(3.14 \times 10^{-2})^2$$

$$= 1.65 \times 10^{-6} \text{ atm. or 1.25 microns.}$$

The combined pressure of Fe and FeO in Rengstorff's experiments was about one micron, so the addition of the water vapor should have approximately doubled the rate of iron transfer in his experiments. The scatter in his data is about a factor of two, making it difficult to detect the effect of this low partial pressure of water vapor.
V. SUMMARY AND CONCLUSIONS

The vapor species in equilibrium with the system iron-oxygen were found to be only O, O₂, Fe and FeO. The pressure of FeO, although easily detected by a mass spectrometer, is considerably less than the pressure of Fe in the range 1500°-1600°C over the congruently vaporizing composition.

These results agree with the early work of Darken and Curry¹ and Brewer and Mastick.² The results do not agree with the more recent work of Glenser and Weizenkorn³,⁴ or Rengstorff.⁵

It is suggested that the pressures of Fe, O, O₂, and FeO be measured using a "clean" mass spectrometer and working with the constant boiling composition in an iridium Knudsen cell. The measured pressures of O, O₂, Fe, and FeO can then be used to calculate the dissociation energy for FeO. Use of an iridium cell should help reduce any contamination of the sample by the Knudsen cell. The much higher melting point of iridium (2454°C) compared to platinum (1769°C) may allow one to extend the measurements to at least 1700°C.
ACKNOWLEDGMENTS

The author would like to thank Professor Alan W. Searcy and Dr. David J. Meschi for their help and encouragement during this work. Professor John Chipman is thanked for his advice and encouragement. Dr. K. K. Kelley furnished the sample of vustite.

This work was done under the auspices of the United States Atomic Energy Commission.
TABLE I: Experimental Pressures of Fe\(_{(g)}\) and FeO\(_{(g)}\) in Equilibrium with the Congruently Vaporizing Composition in the System Iron-Oxygen.

<table>
<thead>
<tr>
<th>Temp., °C</th>
<th>Temp., °K</th>
<th>(\frac{P_{\text{FeO}}}{P_{\text{Fe}}}) (1)</th>
<th>Log (P_{\text{Fe}}) (2)</th>
<th>(P_{\text{FeO}}) (atmos.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1522</td>
<td>1795</td>
<td>0.384</td>
<td>-5.96</td>
<td>4.22 x 10(^{-7})</td>
</tr>
<tr>
<td>1549</td>
<td>1822</td>
<td>0.294</td>
<td>-5.72</td>
<td>5.60 x 10(^{-7})</td>
</tr>
<tr>
<td>1510</td>
<td>1783</td>
<td>0.281</td>
<td>-6.01</td>
<td>2.75 x 10(^{-7})</td>
</tr>
<tr>
<td>1522</td>
<td>1795</td>
<td>0.277</td>
<td>-5.92</td>
<td>3.32 x 10(^{-7})</td>
</tr>
<tr>
<td>1536</td>
<td>1809</td>
<td>0.298</td>
<td>-5.80</td>
<td>4.70 x 10(^{-7})</td>
</tr>
<tr>
<td>1557</td>
<td>1830</td>
<td>0.263</td>
<td>-5.65</td>
<td>5.90 x 10(^{-7})</td>
</tr>
<tr>
<td>1569</td>
<td>1842</td>
<td>0.181</td>
<td>-5.58</td>
<td>4.77 x 10(^{-7})</td>
</tr>
<tr>
<td>1569</td>
<td>1842</td>
<td>0.207</td>
<td>-5.58</td>
<td>5.45 x 10(^{-7})</td>
</tr>
<tr>
<td>1579</td>
<td>1852</td>
<td>0.206</td>
<td>-5.50</td>
<td>6.52 x 10(^{-7})</td>
</tr>
<tr>
<td>1594</td>
<td>1867</td>
<td>0.198</td>
<td>-5.38</td>
<td>8.25 x 10(^{-7})</td>
</tr>
<tr>
<td>1578</td>
<td>1851</td>
<td>0.147</td>
<td>-5.50</td>
<td>4.65 x 10(^{-7})</td>
</tr>
<tr>
<td>1566</td>
<td>1866</td>
<td>0.159</td>
<td>-5.59</td>
<td>4.07 x 10(^{-7})</td>
</tr>
</tbody>
</table>

(1) \(\frac{P_{\text{FeO}}}{P_{\text{Fe}}} = \frac{I_{\text{FeO}}}{I_{\text{Fe}}} \frac{a_{\text{Fe}}}{a_{\text{FeO}}} = \frac{I_{\text{FeO}}}{I_{\text{Fe}}} (0.895)\)

(2) See text - Calculated from Darken and Gurry's\(^1\) iron activity data and Hultgren, et.al.\(^12\) iron vapor pressure values.
TABLE II Pressures in Atmospheres of $O_2$, $O_2$, and Fe in Equilibrium with the System Iron-Oxygen at 1600°C

<table>
<thead>
<tr>
<th>$O/Fe$</th>
<th>$P_{O_2}$</th>
<th>$P_o$</th>
<th>log $a_{Fe}$</th>
<th>$P_{Fe}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.012</td>
<td>6.30x10^{-9}</td>
<td>1.84x10^{-8}</td>
<td>0.00</td>
<td>8.30x10^{-5}</td>
</tr>
<tr>
<td>1.04</td>
<td>3.46x10^{-8}</td>
<td>4.31x10^{-8}</td>
<td>-0.367</td>
<td>3.60x10^{-5}</td>
</tr>
<tr>
<td>1.07</td>
<td>1.74x10^{-7}</td>
<td>9.69x10^{-8}</td>
<td>-0.736</td>
<td>1.53x10^{-5}</td>
</tr>
<tr>
<td>1.10</td>
<td>7.59x10^{-7}</td>
<td>2.02x10^{-7}</td>
<td>-1.079</td>
<td>6.93x10^{-6}</td>
</tr>
<tr>
<td>1.15</td>
<td>8.12x10^{-6}</td>
<td>6.61x10^{-7}</td>
<td>-1.660</td>
<td>1.82x10^{-6}</td>
</tr>
<tr>
<td>1.20</td>
<td>7.75x10^{-5}</td>
<td>2.04x10^{-6}</td>
<td>-2.24</td>
<td>4.80x10^{-7}</td>
</tr>
<tr>
<td>1.25</td>
<td>7.75x10^{-4}</td>
<td>6.45x10^{-6}</td>
<td>-2.83</td>
<td>1.23x10^{-7}</td>
</tr>
<tr>
<td>1.30</td>
<td>9.76x10^{-3}</td>
<td>2.29x10^{-5}</td>
<td>-3.55</td>
<td>2.40x10^{-8}</td>
</tr>
<tr>
<td>1.333</td>
<td>5.89x10^{-2}</td>
<td>5.34x10^{-5}</td>
<td>-4.07</td>
<td>7.09x10^{-9}</td>
</tr>
<tr>
<td>1.34</td>
<td>8.70x10^{-2}</td>
<td>6.85x10^{-5}</td>
<td>-4.18</td>
<td>5.50x10^{-9}</td>
</tr>
<tr>
<td>1.37</td>
<td>5.36x10^{-1}</td>
<td>1.70x10^{-4}</td>
<td>-4.72</td>
<td>1.58x10^{-9}</td>
</tr>
</tbody>
</table>
### TABLE III
Pressures in Atmospheres of FeO\(_{(g)}\) in Equilibrium with the System Iron-Oxygen at 1600°C Calculated by Assuming the Values of 92 Kcal/mole and 99 Kcal/mole for the Dissociation Energy of FeO

<table>
<thead>
<tr>
<th>0/Fe</th>
<th>Assuming (\Delta H^\circ_{\text{FeO}}) = 99 Kcal/mole</th>
<th>Assuming (\Delta H^\circ_{\text{FeO}}) = 92 Kcal/mole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(P_{\text{FeO}} \times 10^6)</td>
<td>(P_{\text{FeO}}/P_{\text{Fe}})</td>
</tr>
<tr>
<td>1.012</td>
<td>1.97</td>
<td>2.37\times10^{-2}</td>
</tr>
<tr>
<td>1.04</td>
<td>1.95</td>
<td>5.56\times10^{-2}</td>
</tr>
<tr>
<td>1.07</td>
<td>1.91</td>
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<td>1.37</td>
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<td>228.</td>
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</table>
Fig. 1

(Electron Energy vs. Ion Intensity for FeO and Fe.)
Figure 2

Pressure in Atmospheres of $O$, $O_2$, Fe, and FeO in Equilibrium with the System Iron-Oxygen at 1600°C
REFERENCES


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