SOLUBILITY STUDIES
OF
Cr, Co, Mn, Mo, Ni, Nb, Ti, V, AND Zr
IN
LIQUID SODIUM

AEC Research and Development Report
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SOLUBILITY STUDIES
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IN
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By
R. L. EICHELBERGER
R. L. McKISSON

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<th>Page</th>
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<td>2. Nickel Concentration in Sodium</td>
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<td>3. Niobium Concentration in Sodium</td>
<td>22</td>
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<tr>
<td>5. Zirconium Concentration in Sodium</td>
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</table>
ABSTRACT

Solubility experiments with solid refractory metals and iron group metals in liquid sodium were conducted in the temperature range of 600 to 1000°C. All materials used were the highest purity available, and procedures stressed the prevention of contamination from the environment.

Equations were derived for four solutes as follows:

\[
\begin{align*}
\text{Cr:} & \quad \log_{10} S(\text{wppm Cr in Na}) = 5.876 - \frac{5362}{T(°K)} \quad S_{700°C} = 2.3 \text{ wppm} \\
\text{Ni:} & \quad \log_{10} S(\text{wppm Ni in Na}) = 1.594 - \frac{1087}{T(°K)} \quad S_{700°C} = 3 \text{ wppm} \\
\text{Nb:} & \quad \log_{10} S(\text{wppm Nb in Na}) = 2.20 - \frac{654}{T(°K)} \quad S_{700°C} = 34 \text{ wppm} \\
\text{Zr:} & \quad \log_{10} S(\text{wppm Zr in Na}) = 5.429 - \frac{3464}{T(°K)} \quad S_{700°C} = 74 \text{ wppm}
\end{align*}
\]

Limitations in analytical methods, and experimental scatter precluded the derivation of similar equations for the other five solutes investigated. In the temperature range studied, the results for these metals are summarized as follows:

<table>
<thead>
<tr>
<th>Solute</th>
<th>Concentration in Sodium (wppm)</th>
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<tbody>
<tr>
<td>Co</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Mn</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Mo</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Ti</td>
<td>10 ± 5</td>
</tr>
<tr>
<td>V</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

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I. INTRODUCTION

Because sodium is the most promising coolant for the present generation of fast breeder reactors, a knowledge of the solubility of construction metals in sodium has seemed to be of practical importance as well as of theoretical interest. Of the nine solutes discussed in this report, no solubility-in-sodium data have previously been reported for manganese, molybdenum, titanium, vanadium, and zirconium. The previously reported work on the other solutes is discussed in relation to the present results later in this report. A comprehensive compilation of solubility data may be found in the latest edition of the Sodium-NaK Supplement to the Liquid Metal Handbook (Gordon and Breach Science Publishers, in press 1970).

The approach to measuring solubilities which is described here stresses the purity of the solvent and solute materials. The presence of impurities, especially those originating from the nonmetallic elements oxygen, carbon, nitrogen, and hydrogen has appeared to be detrimental to the measurement of solubilities in liquid alkali metal systems. Therefore, the care taken to procure the solutes in "pure" form, and to purify the sodium solvent, was as extensive as was practical within the limits of the work.

This report does not attempt to present a generalized discussion of the solubility of metals in liquid sodium, but is mainly a description of experimental results. However, generalizations are invoked in the discussion where appropriate.
### TABLE 1
MANUFACTURERS' TYPICAL ANALYSES OF SOLUTE MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Chromium</th>
<th>Titanium</th>
<th>Molybdenum</th>
<th>Nickel</th>
<th>Niobium</th>
<th>Cobalt</th>
<th>Manganese</th>
<th>Vanadium</th>
<th>Zirconium</th>
</tr>
</thead>
<tbody>
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<td>Impurity Element</td>
<td>Content (ppm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>78</td>
<td>10</td>
<td>37</td>
<td>8</td>
<td>40</td>
<td>40</td>
<td>57</td>
<td>20</td>
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<td>4</td>
<td>0.9</td>
<td>0.2</td>
<td>0.4</td>
<td>1.6</td>
<td>7.5</td>
<td>3</td>
<td>3</td>
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<tr>
<td>O</td>
<td>1.3</td>
<td>63</td>
<td>4.3</td>
<td>18</td>
<td>23.4</td>
<td>50</td>
<td>-</td>
<td>250</td>
<td>200</td>
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<td>0.7</td>
<td>0.002</td>
<td>0.04</td>
<td>0.04</td>
<td>&lt;10</td>
<td>1.1</td>
<td>-</td>
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<td>&lt;10</td>
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<td>0.04</td>
<td>0.01</td>
<td>0.008</td>
<td>-</td>
<td>&lt;0.05</td>
<td>&lt;0.01</td>
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<td>Au</td>
<td>&lt;1</td>
<td>0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.15</td>
<td>0.03</td>
<td>&lt;0.3</td>
<td>-</td>
<td>0.6</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Bi</td>
<td>&lt;0.1</td>
<td>0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>-</td>
<td>&lt;0.02</td>
<td>&lt;0.007</td>
</tr>
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<td>0.04</td>
<td>0.1</td>
<td>0.02</td>
<td>0.7</td>
<td>&lt;10</td>
<td>0.1</td>
<td>0.04</td>
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<td>0.1</td>
<td>0.01</td>
<td>-</td>
<td>&lt;10</td>
<td>0.15</td>
<td>&lt;0.007</td>
</tr>
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<td>0.4</td>
<td>0.1</td>
<td>0.03</td>
<td>8</td>
<td>-</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Co</td>
<td>&lt;0.3</td>
<td>0.4</td>
<td>0.06</td>
<td>0.1</td>
<td>0.01</td>
<td>-</td>
<td>&lt;10</td>
<td>&lt;0.15</td>
<td>&lt;0.007</td>
</tr>
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<td>-</td>
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<td>1.5</td>
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<td>0.2</td>
<td>&lt;10</td>
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<td>8</td>
<td>0.02</td>
<td>&lt;0.04</td>
<td>0.01</td>
<td>0.5</td>
<td>&lt;10</td>
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<td>0.01</td>
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<td>10</td>
<td>200</td>
<td>30</td>
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<tr>
<td>Ga</td>
<td>&lt;0.6</td>
<td>0.1</td>
<td>0.02</td>
<td>0.4</td>
<td>0.01</td>
<td>0.3</td>
<td>-</td>
<td>&lt;20</td>
<td>&lt;0.02</td>
</tr>
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<td>Ge</td>
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<td>&lt;0.15</td>
<td>0.02</td>
<td>&lt;0.7</td>
<td>0.01</td>
<td>0.12</td>
<td>-</td>
<td>&lt;0.6</td>
<td>&lt;0.03</td>
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<td>Hf</td>
<td>&lt;0.1</td>
<td>12</td>
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<td>0.02</td>
<td>0.03</td>
<td>-</td>
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<td>In</td>
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<td>&lt;0.05</td>
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<td>0.1</td>
<td>-</td>
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<td>0.05</td>
<td>-</td>
<td>&lt;0.06</td>
<td>&lt;0.03</td>
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<td>K</td>
<td>&lt;0.2</td>
<td>0.08</td>
<td>1</td>
<td>0.2</td>
<td>&lt;0.04</td>
<td>0.8</td>
<td>-</td>
<td>0.4</td>
<td>0.004</td>
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<tr>
<td>Li</td>
<td>&lt;0.1</td>
<td>&lt;0.001</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>0.01</td>
<td>0.001</td>
<td>-</td>
<td>&lt;0.02</td>
<td>&lt;0.001</td>
</tr>
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<td>0.25</td>
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<td>&lt;0.05</td>
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<td>&lt;0.02</td>
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<td>-</td>
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<td>-</td>
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<td>&lt;0.02</td>
<td>-</td>
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<td>0.04</td>
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<tr>
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<td>&lt;4</td>
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<td>-</td>
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<td>&lt;0.2</td>
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<td>&lt;1</td>
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<td>&lt;0.02</td>
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<td>&lt;0.1</td>
<td>&lt;10</td>
<td>&lt;0.12</td>
<td>-</td>
</tr>
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<td>Rare Earths</td>
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<td>&lt;2</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>-</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

*Not analyzed

*Mass spectrometer analysis, except for Mn, for which the method is not stated.

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8
II. METHODS AND MATERIALS

The experimental method for determining solubility has been previously described in some detail.\(^{(1)}\) It consists of contacting the solute under study with sodium at the desired temperature for 6 hours (this time period has been previously shown to be adequate to attain equilibrium) and then removing the sodium from the solute material. The entire sample of sodium is analyzed for the solute after it has solidified. The sodium is purified before use by a process combining hot gettering and fractional distillation,\(^{(2)}\) and is dispensed by extruding it into an ion-pumped high vacuum system. The crucible-collector assemblies are loaded and sealed by welding, and the outer pressure capsules are welded, in the vacuum system, without exposing any components or materials to any environment except high vacuum \(10^{-7}\) to \(10^{-8}\) torr) after purification or final outgassing. After the capsules are loaded, they are removed from the vacuum system and equilibrated at temperature in a furnace installed in a purified argon atmosphere glove box, as previously described.\(^{(1)}\) Separation of the solvent from the solute is accomplished by inverting the equilibration furnace at the test temperature, causing the sodium to flow by gravity away from the solute end of the assembly into the collector.

Table 1 shows the analyses of the solute materials used in these studies. Specific information relating to these solutes is summarized in Table 2. Three different configurations of solute specimens were used for the several solutes. Where the physical properties and availability of the solute permitted, crucibles of the material were machined and electron-beam welded to the collectors. In some cases, rods were machined from the solute materials, threaded on one end, and screwed into mating threads in the bottom of a crucible made of the collector material. In the case of manganese, the only form available was an electrolytic deposit about 2 mm thick. Samples of manganese were formed in small plates and mounted with niobium wire onto threaded Cb-1 Zr plugs which were then installed similarly to the rod specimens. Information on the solute configuration used for each material studied is included in Table 2.

Table 3 shows the analysis of one batch of the purified sodium used in the solubility experiments. The values shown are typical of the product of the purification system, except perhaps for the oxygen level, which was as high as 4 wppm in some batches.
TABLE 2
METAL SOLUTE DESCRIPTION AND TREATMENT

<table>
<thead>
<tr>
<th>Solute</th>
<th>Source</th>
<th>Solute Configuration</th>
<th>Cleaning Process</th>
<th>Collector Material</th>
<th>Crucible-Collector Degassing</th>
<th>Analysis Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co</td>
<td>MRC™ &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Rods</td>
<td>5:3:2, HNO₃:H₂SO₄:H₂O + few drops HF, followed by H₂O and acetone wash</td>
<td>Cb - 1 Zr</td>
<td>350°C, 2 hours</td>
<td>Atomic absorption spectrometry</td>
</tr>
<tr>
<td>Cr</td>
<td>MRC &quot;MARZ Grade&quot; (Vapor deposit from iodide)</td>
<td>Rods</td>
<td>2:1, HCl:H₂O, followed by H₂O and acetone wash</td>
<td>Cb - 1 Zr</td>
<td>350°C, 2 hours</td>
<td>Radiochemistry</td>
</tr>
<tr>
<td>Mn</td>
<td>American Potash and Chemical Corp. &quot;Tronamang Extra Low-Hy&quot; (Electrolytic deposit)</td>
<td>Plates</td>
<td>SiC grit blast, acetone wash</td>
<td>Cb - 1 Zr</td>
<td>350°C, 2 hours</td>
<td>Atomic absorption spectrometry</td>
</tr>
<tr>
<td>Mo</td>
<td>MRC &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Crucibles</td>
<td>1:1, HNO₃:H₂O, followed by H₂O and acetone wash</td>
<td>Cb - 1 Zr</td>
<td>750°C, 2 hours</td>
<td>Spectrophotometry</td>
</tr>
<tr>
<td>Nb</td>
<td>MRC &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Crucibles</td>
<td>2:3, HCl:H₂O, followed by H₂O and acetone wash</td>
<td>MARZ Grade Ti</td>
<td>900°C, 2 hours</td>
<td>Spectrophotometry</td>
</tr>
<tr>
<td>Ni</td>
<td>MRC &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Crucibles</td>
<td>1:1, HNO₃:H₂O, followed by H₂O and acetone wash. Collector cleaned with HNO₃ after welding to crucible</td>
<td>MARZ Grade Ti</td>
<td>400°C, 2 hours</td>
<td>Atomic absorption</td>
</tr>
<tr>
<td>Ti</td>
<td>MRC &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Crucibles</td>
<td>HNO₃ - 3% HF, followed by H₂O and acetone wash. Collector reamed after welding</td>
<td>Fe</td>
<td>350°C, 2 hours</td>
<td>Spectrophotometry</td>
</tr>
<tr>
<td>V</td>
<td>MRC &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Rods</td>
<td>5:3:2, HNO₃:H₂SO₄:H₂O + few drops HF, followed by H₂O and acetone wash</td>
<td>Cb - 1 Zr</td>
<td>350°C, 2 hours</td>
<td>Spectrophotometry</td>
</tr>
<tr>
<td>Zr</td>
<td>MRC &quot;MARZ Grade&quot; (E-B zone refined)</td>
<td>Crucibles</td>
<td>1:3:4, HF:HNO₃:H₂O, followed by H₂O and acetone wash</td>
<td>Fe, with Nb transition piece</td>
<td>350°C, 2 hours</td>
<td>X-ray fluorescence</td>
</tr>
</tbody>
</table>

*MRC = Materials Research Corporation, Orangeburg, New York
### TABLE 3
ANALYSIS OF PURIFIED SODIUM

<table>
<thead>
<tr>
<th>Element</th>
<th>Level in Na (wppm)</th>
<th>Element</th>
<th>Level in Na (wppm)</th>
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<tbody>
<tr>
<td>Ag</td>
<td>&lt;1 D*</td>
<td>Li</td>
<td>&lt;1 ND</td>
</tr>
<tr>
<td>Al</td>
<td>&lt;1 ND†</td>
<td>Mg</td>
<td>&lt;5 ND</td>
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<td>B</td>
<td>&lt;1 ND</td>
<td>Mn</td>
<td>&lt;1 ND</td>
</tr>
<tr>
<td>Ba</td>
<td>&lt;5 ND</td>
<td>Mo</td>
<td>&lt;1 ND</td>
</tr>
<tr>
<td>Be</td>
<td>&lt;1 ND</td>
<td>Ni</td>
<td>&lt;5 ND</td>
</tr>
<tr>
<td>Bi</td>
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<td>O</td>
<td>0.6</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>Pb</td>
<td>&lt;1 ND</td>
</tr>
<tr>
<td>Ca</td>
<td>&lt;10 D</td>
<td>Rb</td>
<td>&lt;5 ND</td>
</tr>
<tr>
<td>Cd</td>
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</tr>
<tr>
<td>Co</td>
<td>&lt;5 ND</td>
<td>Sn</td>
<td>&lt;5 ND</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;1 ND</td>
<td>Ta</td>
<td>&lt;1 ND</td>
</tr>
<tr>
<td>Cs</td>
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<td>Ti</td>
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<td>Cu</td>
<td>&lt;5 D</td>
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<td>&lt;100 ND</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>Zr</td>
<td>&lt;10 ND</td>
</tr>
<tr>
<td>K</td>
<td>&lt;10 D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*D = Detected
†ND = Not detected

To permit the radiochemical determination of chromium in the experiments with this solute, the chromium rods were irradiated in the Shield Test Irradiation Reactor (STIR) to a level of about 500 dpm/μg Cr. The cleaning and degassing noted in Table 2 was done after the irradiation.
TABLE 4
RESULTS OF CHROMIUM SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>T (°C)</th>
<th>$\frac{10^3}{T^*(°K)}$</th>
<th>Na (g)</th>
<th>$\gamma$-S* AAS (μg)</th>
<th>Cr AAS (μg)</th>
<th>Cr AAS (wppm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>525</td>
<td>700</td>
<td>1.027</td>
<td>1.119</td>
<td>6</td>
<td>10</td>
<td></td>
<td>Series I, solute rods came loose from crucible</td>
</tr>
<tr>
<td>526</td>
<td>800</td>
<td>0.932</td>
<td>1.20</td>
<td>43</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>527</td>
<td>900</td>
<td>0.853</td>
<td>1.21</td>
<td>208</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>528</td>
<td>1000</td>
<td>0.786</td>
<td>1.2</td>
<td>10</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>700</td>
<td>1.027</td>
<td>1.97</td>
<td>2.3</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>800</td>
<td>0.932</td>
<td>1.94</td>
<td>19.4</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>533</td>
<td>900</td>
<td>0.853</td>
<td>1.89</td>
<td>6.5</td>
<td>3.4</td>
<td></td>
<td></td>
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<tr>
<td>534</td>
<td>1000</td>
<td>0.786</td>
<td>2.42</td>
<td>16.6</td>
<td>6.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>537</td>
<td>700</td>
<td>1.027</td>
<td>1.96</td>
<td>1.6</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>800</td>
<td>0.932</td>
<td>1.82</td>
<td>19.9</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>539</td>
<td>900</td>
<td>0.853</td>
<td>1.80</td>
<td>206</td>
<td>114</td>
<td></td>
<td></td>
</tr>
<tr>
<td>540</td>
<td>1000</td>
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<td>1.90</td>
<td>24.4</td>
<td>12.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>544</td>
<td>800</td>
<td>0.932</td>
<td>2.88</td>
<td>43</td>
<td>14</td>
<td>15</td>
<td>4.9</td>
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<tr>
<td>545</td>
<td>800</td>
<td>0.932</td>
<td>1.56</td>
<td>44</td>
<td>19</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>546</td>
<td>900</td>
<td>0.853</td>
<td>1.55</td>
<td>282</td>
<td>4</td>
<td>182</td>
<td>117</td>
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<tr>
<td>13B</td>
<td>700</td>
<td>1.027</td>
<td>1.50</td>
<td>1.7</td>
<td>14</td>
<td>0.7</td>
<td>9.5</td>
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<tr>
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<td>1.58</td>
<td>51</td>
<td>48</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>14B</td>
<td>900</td>
<td>0.853</td>
<td>1.86</td>
<td>50</td>
<td>73</td>
<td>27</td>
<td>39</td>
</tr>
<tr>
<td>15A</td>
<td>1000</td>
<td>0.786</td>
<td>1.83</td>
<td>93</td>
<td>125</td>
<td>51</td>
<td>68</td>
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<tr>
<td>36A</td>
<td>900</td>
<td>0.853</td>
<td>1.87</td>
<td>267</td>
<td>25</td>
<td>142</td>
<td>13</td>
</tr>
<tr>
<td>36B</td>
<td>1000</td>
<td>0.786</td>
<td>1.31</td>
<td>10</td>
<td>6</td>
<td>7.6</td>
<td>4.6</td>
</tr>
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<td>37A</td>
<td>700</td>
<td>1.027</td>
<td>1.72</td>
<td>&lt;2</td>
<td>115</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>37B</td>
<td>600</td>
<td>1.145</td>
<td>1.20</td>
<td>1</td>
<td>2</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>16B</td>
<td>700</td>
<td>1.027</td>
<td>1.77</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>17A</td>
<td>800</td>
<td>0.932</td>
<td>1.69</td>
<td>0</td>
<td>1.7</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>17B</td>
<td>900</td>
<td>0.853</td>
<td>1.65</td>
<td>0</td>
<td>2.4</td>
<td>0</td>
<td>1.4</td>
</tr>
<tr>
<td>18A</td>
<td>1000</td>
<td>0.786</td>
<td>1.72</td>
<td>0</td>
<td>2.3</td>
<td>0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Gamma-spectrometer results (plotted in Figure 1). AAS results are tabulated to permit comparison.
III. RESULTS

The results of the solubility-in-sodium experiments for the nine solutes included in this report are presented below in alphabetical order. Results from other laboratories are included and discussed where this is possible.

A. CHROMIUM

The first four experiments with chromium rod solute which had not been irradiated all gave chromium concentrations in the sodium of less than 4 wppm, when analyzed by atomic absorption spectrometry (AAS). However, subsequent experience showed that there was a high probability that the technique used to prepare the aqueous solution for analysis caused volatilization of an appreciable amount of chromium; therefore, these first experiments must be disregarded.

For the next series of experiments, the same high purity Cr rods were irradiated in the Shield Test and Irradiation Reactor (STIR) to an activity level of approximately 500 dpm/µg. Six sets of experiments using the irradiated Cr rods were completed. In the first group of experiments, equilibrated at 700 to 1000°C, the sodium was found to have small radioactive particles on the surface, and the Cr rods had all come loose from the threaded crucible during the opening of the outer capsule and the sample collector. Therefore, it was necessary to cut the collectors again, below the surface of the sodium, and to cut through the sodium, discarding the surface. The results for these four samples (Series I) showed the presence of 6, 43, 208, and 10 µg Cr. The high values are perhaps the result of particulate Cr in the "pipe" formed in the center of the collector as the sodium solidified. Nevertheless, the results showed the feasibility of the radiochemical technique for chromium solubility studies.

Results of five subsequent series (II through VI) of chromium solubility runs, using the same irradiated rods, but with refinements in technique which prevented the rods from coming loose from the crucibles, are shown in Table 4. The sodium from Series I, IV, and V experiments was submitted for chromium analysis by atomic absorption spectrometry. The results from Series I were very low, as with the group of experiments run with unirradiated solute rods, with only about 1 µg chromium found, although gamma-spectrometry had...
indicated as much as 200 µg. Volatilization of chromium during the preparation for analysis is the probable cause for the difference.

The chromium solute rods were reirradiated between the Series IV and Series V experiments. Four blank experiments were conducted in which capsules were identical to those used to obtain the results in Table 4 except that no solute rod was included. They were treated in exactly the same manner as the solubility runs reported. Analysis of these was also by gamma-spectrometer examination of the sodium in the sample collector, followed by dissolution and analysis for chromium by AAS. Gamma-spectrometry showed no $^{51}$Cr detected. AAS analysis showed about 1 wppm of chromium in the sodium. This latter result compares with a result of ≤1 wppm of Cr in the original sodium.

Although the chromium found by gamma-spectrometry in Series I experiments was not seen on subsequent dissolution and AAS analysis, the results of Series V show reasonable correspondence between the spectrometer and AAS results. Minor changes in the analytical procedure and sample preparation for AAS analysis are probably responsible for the improved agreement between the analysis techniques. The agreement between techniques is seen to be lacking in Series VI, however. While there are plausible explanations for this (e.g., external radioactive contamination on the sample collector) there is no evidence to explain the discrepancies.

The only other experimental work on the solubility of chromium in sodium has been conducted at Brookhaven National Laboratory (BNL), and has not been published. A preliminary result indicates a solubility of about 0.4 wppm at 650°C, using irradiated chromium as solute and determining the amount dissolved by radiochemistry. This point, with the radiochemical results from Table 4, is shown in Figure 1. The curve was calculated by a least squares procedure from the AI data, with the exception of Experiment Number 37A, which result is an order of magnitude greater than the other results at the same temperature. The equation for the curve shown is

$$\log_{10} S(\text{wppm Cr in Na}) = 5.876 - 5362/T(°K) \quad \ldots (1)$$

The value of $\Delta H$ (solution) calculated from Equation 1 is 24,670 cal/mole.
Figure 1. Chromium Concentration in Sodium
These experiments have not unequivocally defined the solubility of chromium in sodium. They are, however, the first to be reported on the subject, and show that chromium is similar in solubility to the other major constituents of stainless steel, nickel, and iron. It also appears that reasonable agreement may be obtained between AAS and radiochemical analyses, provided extreme care is exercised in the analytical procedures.

B. COBALT

The results of four experiments with cobalt solute are shown in Table 5. No explanation is offered for the very high result found in Experiment Number 49A. The other three results are near the limit of analytical sensitivity, and cannot be interpreted beyond indicating that there is detectable cobalt in the sodium, whereas none is detected in the purified sodium which was loaded into the crucible. Lee and Berkey\textsuperscript{(4)} have reported the results of solubility experiments with cobalt, in which spark source mass spectrometry was used as the analytical method. The temperature range of their experiments was 289 to 544°C. Their results showed no consistency in temperature dependence, but ranged from about 0.1 to 14 wppm in 28 analyses from four equilibrated samples, with most of the analyses falling between 0.1 and 1.0 wppm. Grand, et al.\textsuperscript{(5)} measured the solubility of cobalt in sodium by irradiating cobalt-saturated sodium and determining the cobalt concentration by radioactivity measurements. They reported 1.00 wppm at 525°C, 0.021 wppm at 425°C, and 0.028 wppm at 365°C. The results from the three laboratories are not inconsistent, although they do not serve to define the solubility of cobalt in sodium except within rather broad limits.

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>$\frac{10^3}{T(°K)}$</th>
<th>Na (g)</th>
<th>Co (µg)</th>
<th>Co (wppm)</th>
<th>Co in Crucible Etch (µg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49A</td>
<td>600</td>
<td>1.148</td>
<td>1.86</td>
<td>175</td>
<td>94</td>
<td>86</td>
</tr>
<tr>
<td>49B</td>
<td>700</td>
<td>1.027</td>
<td>2.01</td>
<td>8</td>
<td>4</td>
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<td>800</td>
<td>0.932</td>
<td>1.53</td>
<td>3</td>
<td>2</td>
<td>12</td>
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<td>50B</td>
<td>900</td>
<td>0.786</td>
<td>1.61</td>
<td>3</td>
<td>2</td>
<td>11</td>
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</table>

TABLE 5
RESULTS OF COBALT SOLUBILITY EXPERIMENTS

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### TABLE 6
RESULTS OF MANGANESE SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>$\frac{10^3}{T(°K)}$</th>
<th>Na (g)</th>
<th>Mn (μg)</th>
<th>Mn (wppm)</th>
<th>Mn in Crucible Etch (μg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>42B*</td>
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<td>0.932</td>
<td>1.55</td>
<td>312</td>
<td>201</td>
<td>Not analyzed</td>
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<td>43A†</td>
<td>900</td>
<td>0.853</td>
<td>0.93</td>
<td>50</td>
<td>54</td>
<td>Not analyzed</td>
</tr>
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<td>43B*</td>
<td>700</td>
<td>1.027</td>
<td>1.62</td>
<td>100</td>
<td>62</td>
<td>Not analyzed</td>
</tr>
<tr>
<td>44B</td>
<td>600</td>
<td>1.145</td>
<td>1.56</td>
<td>6.3</td>
<td>4</td>
<td>485</td>
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<td>700</td>
<td>1.027</td>
<td>2.13</td>
<td>3</td>
<td>1.3</td>
<td>120</td>
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<tr>
<td>46A</td>
<td>900</td>
<td>0.853</td>
<td>1.55</td>
<td>3</td>
<td>1.9</td>
<td>280</td>
</tr>
</tbody>
</table>

* Manganese solute embedded about 1/8 in. in sodium.
† Much sodium had escaped to outer capsule.

### TABLE 7
RESULTS OF MOLYBDENUM SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>$\frac{10^3}{T(°K)}$</th>
<th>Na (g)</th>
<th>Mo (μg)</th>
<th>Mo (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>282</td>
<td>1000</td>
<td>0.786</td>
<td>2.10</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>283</td>
<td>1000</td>
<td>0.786</td>
<td>2.30</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>284</td>
<td>900</td>
<td>0.853</td>
<td>2.15</td>
<td>&lt;2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>285</td>
<td>800</td>
<td>0.932</td>
<td>1.45</td>
<td>&lt;2</td>
<td>&lt;1.5</td>
</tr>
<tr>
<td>286</td>
<td>700</td>
<td>1.027</td>
<td>2.00</td>
<td>2.4</td>
<td>1.2</td>
</tr>
<tr>
<td>505</td>
<td>800</td>
<td>0.932</td>
<td>1.43</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>506</td>
<td>850</td>
<td>0.890</td>
<td>1.47</td>
<td>0.77</td>
<td>0.5</td>
</tr>
<tr>
<td>507</td>
<td>900</td>
<td>0.853</td>
<td>1.26</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>508</td>
<td>950</td>
<td>0.817</td>
<td>1.58</td>
<td>1.95</td>
<td>1.2</td>
</tr>
<tr>
<td>511</td>
<td>1005</td>
<td>0.783</td>
<td>1.65</td>
<td>2.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

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In addition to analyzing the sodium in the collector and the collector washings for cobalt, the walls of the crucibles were acid etched to remove any cobalt that may have entered the metal of the wall. The etch solutions were analyzed; the results are shown in Table 5. An appreciable amount of cobalt transferred through the sodium into the surface of the Cb - 1 Zr crucible. The crucible apparently acts as a sink for the isothermal transfer of cobalt, and very possibly affects the amount of cobalt found in the sodium. Solution-deposition kinetics, about which there is no information, are of importance here. It is notable that Experiment Number 49A, which showed a large amount of cobalt in the sodium sample, relative to the amount in the other experiments, also showed a markedly greater amount of transfer to the crucible.

C. MANGANESE

The first three experiments with manganese solute did not give satisfactory results. In Experiments 42B and 43B the solute specimen had broken loose from the mounting wire during opening and imbedded about 1/8 in. in the sodium, and in Experiment 43A a leak in the crucible-collector assembly permitted a substantial amount of sodium to transfer into the outer capsule. The samples were submitted for analysis to confirm that the analytical method would determine manganese when it was present in a reasonable amount. The results are shown in Table 6, which includes results of all experiments with manganese solute. As with cobalt, the results indicate that a detectable amount of solute is present in the equilibrated samples, whereas none was detected in the sodium before loading. No previous report of solubility of manganese in sodium was found.

The walls of the crucibles were etched to remove any manganese that may have transferred, and the etch solutions were analyzed. Results are shown in Table 6. It is seen that very much more manganese has transferred to the Cb - 1 Zr crucible than was present in the sodium at the termination of the experiments. As with cobalt, the crucible is a sink for the isothermal transfer of manganese through sodium. If the rate of deposition on the Cb - 1 Zr is fast compared to the rate of solution from the manganese, the values in Table 6 do not represent the solubility of manganese in sodium.

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D. MOLYBDENUM

The results of 10 experiments completed with molybdenum crucible solutes are shown in Table 7. The molybdenum concentration found was less than 2 wppm for the 10 experiments. All experiments were in the temperature range of 700 to 1005°C. More precise work is dependent on overcoming the apparent limitation in the analytical method. No other work on the solubility of molybdenum in sodium has been found in the available literature.

E. NICKEL

The solubility of nickel in sodium has been studied by Rodgers, Mausteller, and Batutis,\textsuperscript{6} Singer and Weeks,\textsuperscript{7} and Lee and Berkey,\textsuperscript{4} by conventional techniques, and by Kovacina and Miller\textsuperscript{8} using a radioactive tracer technique. The results from this latter work are below 0.01 wppm at 600°C, whereas all the other work showed apparent solubilities in the ppm range, or at least 100 times greater. The solubilities reported by Rodgers, et al.\textsuperscript{6} are generally higher than the others obtained by conventional techniques. The results reported by Singer and Weeks,\textsuperscript{2} by Lee and Berkey,\textsuperscript{4} and the present work all lie in between these earlier results, although the higher slope of Lee and Berkey's results makes an extrapolation of their work yield very large numbers. The results of the current experiments are shown in Table 8, and plotted in Figure 2, together with the data from References 4 and 7.

The solubility curve shown in Figure 2 was derived by a least squares treatment of seven of the points in Table 8, the values reported by Singer and Weeks (which are averages of from 2 to 11 determinations), and the average of the values at each temperature reported by Lee and Berkey. Four of the AI experimental points have been excluded on the basis of being unreasonably high, from one to two orders of magnitude above the other data. The equation for the curve is

\[
\log_{10} S(\text{wppm Ni in Na}) = 1.594 - \frac{1087}{T(°K)} \quad \text{(2)}
\]

The \(\Delta H\) (solution) calculated from Equation 2 is 5000 cal/mole.
TABLE 8
RESULTS OF NICKEL SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>$\frac{10^3}{T(°K)}$</th>
<th>Na (g)</th>
<th>Ni (μg)</th>
<th>Ni (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>273</td>
<td>1000</td>
<td>0.786</td>
<td>1.45</td>
<td>30.5</td>
<td>21</td>
</tr>
<tr>
<td>274</td>
<td>700</td>
<td>1.027</td>
<td>2.75</td>
<td>180</td>
<td>65</td>
</tr>
<tr>
<td>275</td>
<td>800</td>
<td>0.932</td>
<td>0.80</td>
<td>91</td>
<td>114</td>
</tr>
<tr>
<td>276</td>
<td>900</td>
<td>0.853</td>
<td>2.05</td>
<td>940</td>
<td>459</td>
</tr>
<tr>
<td>299</td>
<td>700</td>
<td>1.027</td>
<td>1.95</td>
<td>5.9</td>
<td>3.0</td>
</tr>
<tr>
<td>300</td>
<td>800</td>
<td>0.932</td>
<td>2.03</td>
<td>8.2</td>
<td>4.0</td>
</tr>
<tr>
<td>501</td>
<td>900</td>
<td>0.853</td>
<td>1.50</td>
<td>7.3</td>
<td>4.9</td>
</tr>
<tr>
<td>519</td>
<td>600</td>
<td>1.145</td>
<td>2.08</td>
<td>216</td>
<td>104</td>
</tr>
<tr>
<td>22A</td>
<td>650</td>
<td>1.083</td>
<td>1.95</td>
<td>5</td>
<td>2.6</td>
</tr>
<tr>
<td>22B</td>
<td>750</td>
<td>0.976</td>
<td>1.89</td>
<td>2</td>
<td>1.1</td>
</tr>
<tr>
<td>23A</td>
<td>850</td>
<td>0.890</td>
<td>2.04</td>
<td>5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

F. NIOBIUM:

The results of eight experiments completed with niobium crucible solutes are shown in Table 9, and together with the data reported by Kovacina and Miller (9) are plotted in Figure 3. Neither the AI data nor the NRL data shows very good internal agreement, but the two sets of data are reasonably consistent, as seen, and can be represented by

$$\log_{10} S(\text{wppm Nb in Na}) = 2.20 - 654/T(°K) \quad \ldots (3)$$

The $\Delta H$ (solution) derived from Equation 3 is 3000 cal/mole.

A radioactive tracer technique was used to determine the niobium concentration in the NRL work, and their solute was an alloy of niobium containing 1% zirconium. The sodium used in both sets of experiments reportedly contained less than 10 wppm $O_2$. The solubility values measured seem to be high, compared to those for other similar metals which dissolve in sodium by a simple solution process, but there is not enough oxygen available to explain the measured values in terms of oxide formation. Until more definitive work which
Figure 2. Nickel Concentration in Sodium
Figure 3. Niobium Concentration in Sodium
TABLE 9
RESULTS OF NIOBIUM SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>10^3 Na/T(°K)</th>
<th>Na (g)</th>
<th>Nb (µg)</th>
<th>Nb (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>521</td>
<td>600</td>
<td>1.145</td>
<td>1.87</td>
<td>53</td>
<td>28</td>
</tr>
<tr>
<td>547</td>
<td>700</td>
<td>1.027</td>
<td>1.67</td>
<td>120</td>
<td>72</td>
</tr>
<tr>
<td>548</td>
<td>800</td>
<td>0.932</td>
<td>1.58</td>
<td>138</td>
<td>88</td>
</tr>
<tr>
<td>522</td>
<td>800</td>
<td>0.932</td>
<td>1.75</td>
<td>55</td>
<td>31</td>
</tr>
<tr>
<td>549</td>
<td>900</td>
<td>0.853</td>
<td>1.95</td>
<td>173</td>
<td>88</td>
</tr>
<tr>
<td>19B</td>
<td>750</td>
<td>0.976</td>
<td>1.75</td>
<td>50</td>
<td>28.5</td>
</tr>
<tr>
<td>20A</td>
<td>850</td>
<td>0.890</td>
<td>1.78</td>
<td>108</td>
<td>66.3</td>
</tr>
<tr>
<td>20B</td>
<td>950</td>
<td>0.817</td>
<td>1.81</td>
<td>52</td>
<td>28.6</td>
</tr>
<tr>
<td>21A</td>
<td>150</td>
<td></td>
<td>1.76</td>
<td>39</td>
<td>22.2</td>
</tr>
</tbody>
</table>

shows otherwise is done on this system, it must be assumed that niobium is more soluble in sodium than are iron, nickel, chromium, molybdenum, titanium, cobalt, manganese, vanadium, and zirconium.

G. TITANIUM

The results of eight experiments completed with titanium crucible solutes are shown in Table 10. These results are plotted in Figure 4, although there is no foundation for drawing a "solubility curve" on the basis of the data. It is indeterminate if the values presented represent a solution equilibrium, or if there is some other phenomenon to explain the presence of titanium in the sodium after equilibration. The iron tubing from which the collectors were made contained less than 5 wppm Ti by emission spectrography, and 1.1 wppm Ti by spark source mass spectroscopy. Because the usual acid etch of the collector removed much less than 100 mg of iron, this process added an insignificant amount of titanium to the solution. No reports of other attempts to measure the solubility of titanium in sodium have been found in available literature.

H. VANADIUM

The results of five experiments with vanadium solute rods are shown in Table 11. The spectrophotometric method used for analyzing for vanadium is
TABLE 10
RESULTS OF TITANIUM SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>$\frac{10^3}{T(°K)}$</th>
<th>Na (g)</th>
<th>Ti (μg)</th>
<th>Ti (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27B</td>
<td>900</td>
<td>0.853</td>
<td>2.04</td>
<td>17</td>
<td>8.3</td>
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<td>28A</td>
<td>800</td>
<td>0.932</td>
<td>2.00</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>28B</td>
<td>700</td>
<td>1.027</td>
<td>1.97</td>
<td>12</td>
<td>6.1</td>
</tr>
<tr>
<td>29A</td>
<td>600</td>
<td>1.145</td>
<td>1.71</td>
<td>22</td>
<td>12.9</td>
</tr>
<tr>
<td>38-1</td>
<td>600</td>
<td>1.145</td>
<td>1.50</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>38-3</td>
<td>900</td>
<td>0.853</td>
<td>1.40</td>
<td>10</td>
<td>7.2</td>
</tr>
<tr>
<td>38-8</td>
<td>900</td>
<td>0.853</td>
<td>1.30</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>39-11</td>
<td>750</td>
<td>0.976</td>
<td>1.49</td>
<td>10</td>
<td>7</td>
</tr>
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</table>

TABLE 11
RESULTS OF VANADIUM SOLUBILITY EXPERIMENTS

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>T (°C)</th>
<th>$\frac{1000}{T(°K)}$</th>
<th>Na (g)</th>
<th>V (μg)</th>
<th>V (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>46B</td>
<td>600</td>
<td>1.145</td>
<td>1.58</td>
<td>4</td>
<td>2</td>
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<tr>
<td>47A</td>
<td>700</td>
<td>1.027</td>
<td>2.07</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>47B</td>
<td>800</td>
<td>0.932</td>
<td>1.72</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>48A</td>
<td>900</td>
<td>0.853</td>
<td>1.85</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>48B</td>
<td>700</td>
<td>1.027</td>
<td>2.50</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

not satisfactorily sensitive. In four of the five experiments vanadium was detected in the sodium, but just at the threshold of detectability, which is perhaps 5 wppm in the samples prepared.

The walls of the crucibles which contained the vanadium solute rods were etched, and the solution was analyzed for vanadium. From the results shown in Table 11, vanadium apparently did not transfer through the sodium from the solute rod to the Cb - 1 Zr crucible wall.

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Figure 4. Titanium Concentration in Sodium
I. ZIRCONIUM

The results of four experiments with zirconium solute crucibles are shown in Table 12 and plotted in Figure 5. It is notable that the concentration of zirconium is significantly higher than that of the other refractory metals and iron group metals reported, with the exception of niobium. The curve shown in Figure 5 was calculated from the three points shown, and fits the equation

\[ \log_{10} S(\text{wppm Zr in Na}) = 5.429 - 3464/T(\degree K) \]  

\[ \text{(4)} \]

The \( \Delta H \) (solution) indicated by Equation 4 is 16,000 cal/mole.

Although this work is not extensive, and the curve is based on only three points, it does provide a valid comparison with the results obtained with the other solutes studied.

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>( T ) (°C)</th>
<th>( 10^{3} \frac{T}{T(\degree K)} )</th>
<th>Na (g)</th>
<th>Zr (μg)</th>
<th>Zr (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>39A-2</td>
<td>750</td>
<td>0.976</td>
<td>1.35</td>
<td>104</td>
<td>77</td>
</tr>
<tr>
<td>39A-3</td>
<td>900</td>
<td>0.853</td>
<td>1.46</td>
<td>538</td>
<td>370</td>
</tr>
<tr>
<td>39B-1</td>
<td>600</td>
<td>1.145</td>
<td>1.70</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>39B-2</td>
<td>800</td>
<td>0.932</td>
<td>*</td>
<td>54</td>
<td>*</td>
</tr>
</tbody>
</table>

*Crucible-collector weld cracked, allowing sodium to escape into outer capsule during test.
Figure 5. Zirconium Concentration in Sodium
IV. SUMMARY AND EVALUATION

The work described resulted in analytical expressions for the solubility in sodium of chromium, nickel, niobium, and zirconium. These expressions, and the solubility values calculated from them at 700°C are as follows:

\[
\begin{align*}
\text{Cr:} & \quad \log_{10} S(\text{wppm Cr in Na}) = 5.876 - 5362/T(\text{°K}) \quad S_{700\text{°C}} = 2.3 \text{ wppm} \\
\text{Ni:} & \quad \log_{10} S(\text{wppm Ni in Na}) = 1.594 - 1087/T(\text{°K}) \quad S_{700\text{°C}} = 3 \text{ wppm} \\
\text{Nb:} & \quad \log_{10} S(\text{wppm Nb in Na}) = 2.20 - 654/T(\text{°K}) \quad S_{700\text{°C}} = 34 \text{ wppm} \\
\text{Zr:} & \quad \log_{10} S(\text{wppm Zr in Na}) = 5.429 - 3464/T(\text{°K}) \quad S_{700\text{°C}} = 74 \text{ wppm}
\end{align*}
\]

The equations were developed from data obtained over the temperature range of 600 to 1000°C. Results for the other solutes investigated, over the same temperature range, are summarized as follows:

<table>
<thead>
<tr>
<th>Solute</th>
<th>Concentration in Sodium (wppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Mn</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Mo</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Ti</td>
<td>10 ± 5</td>
</tr>
<tr>
<td>V</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

For these metals, with the probable exception of titanium, the amount of solute found in the sodium was near the limit of detection of the analytical method. It is almost certain that the quantity of solute found represents an increase over that present in the sodium originally, but the uncertainty in the analysis and the scatter of data prevent a more quantitative evaluation.

Other solubility-in-sodium experiments with metal solutes reported from this laboratory include similar work with bismuth,\(^{10}\) iron,\(^{1b}\) and copper.\(^{1a}\) The solubility of bismuth is several orders of magnitude greater than that of the other metals examined, and that of copper is intermediate, measuring approximately 300 wppm at 700°C. An estimate for iron is between 1 and 3 wppm at the same temperature.
It is not the purpose of this report to provide an exhaustive discussion of metal solubility in sodium and the factors affecting the reported measurements. It is appropriate, however, to extract a few generalizations from the work discussed above.

It has been possible to develop satisfactory solubility expressions for metals that are relatively soluble in sodium, such as bismuth and copper. These latter two metals also have oxides that are significantly less stable than those of the other metals listed. Although a rather successful effort was made to prevent oxygen contamination in the present experiments, it may be conjectured that the solubilities of the oxygenated species (metal oxides, or double oxides such as sodium chromite, ferrite, zirconate, etc.) may be a significant factor in the success of this type of solubility experiment. Detailed knowledge of the relative thermodynamic stabilities of the species known and postulated to be important in the various metal-sodium-oxygen systems would be helpful in interpreting the data. Experimental and chemical analysis techniques which would provide more specific information on the oxygen inventory, for example, are needed to obtain unequivocal solubility data for oxygen-reactive and/or very slightly soluble metals.
REFERENCES


3. H. S. Isaacs, Brookhaven National Laboratory, Personal Communication


