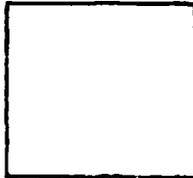


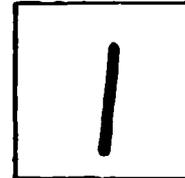
PHOTOGRAPH THIS SHEET

AD A951384

DTIC ACCESSION NUMBER



LEVEL



INVENTORY

TR NO. 6 DA-04-495-ORD-237

DOCUMENT IDENTIFICATION

SEPTEMBER 1, 1954

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR	
NTIS	GRA&I <input checked="" type="checkbox"/>
DTIC	TAB <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
(SEPT. 1954)	
BY	
DISTRIBUTION /	
AVAILABILITY CODES	
DIST	AVAIL AND/OR SPECIAL
A	

RELEASED

DTIC
ELECTED
SEP 30 1981
B

DATE ACCESSIONED

DISTRIBUTION STAMP

UNANNOUNCED

81 9 24 075

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

WATERTOWN ARSENAL
WATERTOWN, MASS.

LABORATORY

INDEXED

10/18/6
91-811016

HIGH PRESSURE OXIDATION OF METALS

MOLYBDENUM IN OXYGEN

by

*Robert C. Peterson and
W. Martin Fassell, Jr.*

TECHNICAL REPORT

VI

September 1, 1954

DEPARTMENT OF ARMY - PROJECT NO. 599-01-004
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT NO. TB2-0001
-AND TB 4-901

OFFICE OF ORDNANCE RESEARCH - PROJECT NO. 25

ARMY ORDNANCE CONTRACT
DA - 04 - 495 - ORD - 237

DEPARTMENT OF METALLURGY
UNIVERSITY OF UTAH
SALT LAKE CITY

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

AD A951384

G

HIGH PRESSURE OXIDATION OF METALS

MOLYBDENUM IN OXYGEN

by

Robert C. Peterson and W. Martin Fassell Jr.

ABSTRACT

The temperature and pressure dependence of the reaction of molybdenum in oxygen were investigated from 525 to 700°C at pressures from one atmosphere to 47.6 atms. (700 psia). Molybdenum was found to oxidize linearly from 525 to 650°C at all pressures investigated. No dependence was observed from 525 to 550°C at pressures above one atmosphere. From 550 to 700°C the oxidation rate of molybdenum was dependent on oxygen pressure. The pressure dependence from 550 - 650°C may be expressed by $v = k \theta$ where k is the specific rate constant and

$$\theta = \frac{k_1 C_{O_2}}{1 + k_1 C_{O_2}}$$

where k_1 is the equilibrium constant for the adsorption of oxygen at the surface site of reaction. An unusual pressure sensitive transition from a linear rate to some type of protective rate was observed at 650 - 700°C.

INTRODUCTION

Numerous papers have been published on oxidation of molybdenum and molybdenum alloys.⁽¹⁾ Some of the most significant investigations on the rate of reaction of molybdenum in oxygen are those by Gulbransen and his associates. Gulbransen and Wysong⁽²⁾ investigated the rate oxidations in oxygen using their microbalance technique from 250 - 450°C at low pressures (.076, 0.76, 7.6 cm. Hg.). They found that the metal follows the parabolic law under these conditions with an activation energy of 36.5 kcal/mole. Some deviation was noted toward a linear behavior at the higher temperatures.

Hickman and Gulbransen³⁾ investigated the types of films formed on molybdenum between 300 and 700°C by their electron diffraction technique. They found that in the low temperature range (300 - 400°C) MoO₃ becomes predominant in the surface oxide coating. Above 400°C, at the pressures used in their investigation, only MoO₂ was present. The absence of MoO₃ at high temperatures very possibly was due to the slow rate of conversion of MoO₂ to MoO₃ on the low oxygen concentration.

The present paper concerns the behavior of molybdenum from 500 to 700°C in oxygen at pressures ranging from one to 47.6 atmospheres (14.7 to 700 psia).

EXPERIMENTAL PROCEDURE

The equipment and the experimental technique used in this investigation have been reported in previous papers.^(4,5,6) The metal samples used were sheared from 20 mil. molybdenum sheet (General Electric Company, Cleveland Wire Works) into small platelets approximately 1.5 inches X 0.5 inches. Spectrographic analysis of the molybdenum metal indicated the following impurities present: 0.0001% Cu., 0.001% Ni. No analyses were made for absorbed or dissolved gases in the metal.

Prior to oxidation each sample was abraded lightly with No. 1 metallographic paper, washed in acetone and dried. Each individual observation was made at constant temperature and pressure.

EXPERIMENTAL RESULTS

The results to be described are based on the experimental observations of over 100 molybdenum samples in oxygen from 500 to 700°C at absolute oxygen pressures from one to 47.6 atmospheres (14.7 to 700 psia.). Molybdenum was found to oxidize according to the linear mechanism from 500 to 650°C at all pressures investigated. Figure 1 shows a typical weight gain versus time curve in this region. From 650 to 700°C deviations from linearity were found in the sense that the rate of oxidation decreased markedly with increasing time at the lower pressures. At higher pressures, however, this anomalous deviation from linearity was reduced or completely eliminated. For example, at 650°C and at atmospheric pressure the rate of oxidation decreases with increasing time.

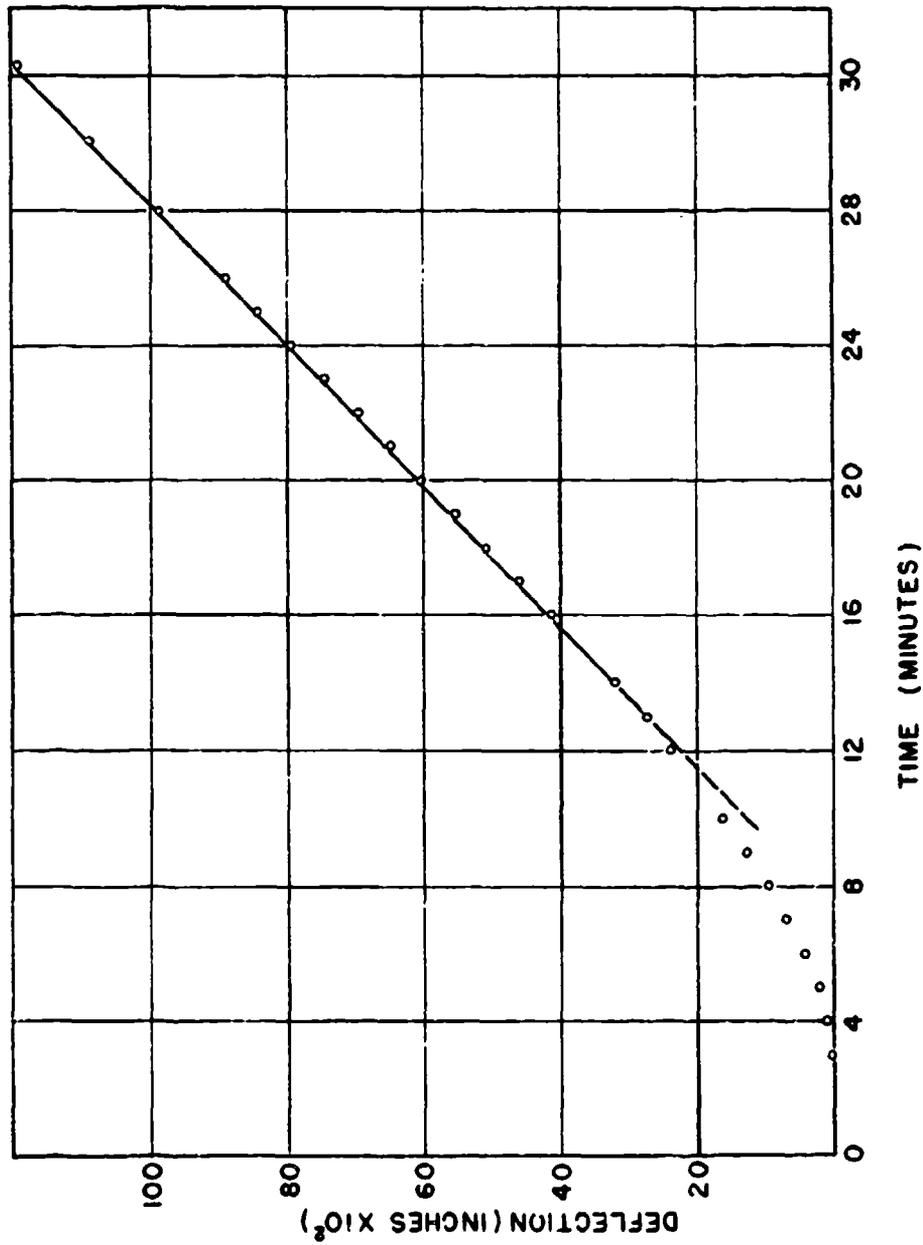


Fig. 1. TYPICAL LINEAR OXIDATION RATE OF MOLYBDENUM
IN OXYGEN AT 600°C. AND 200 psia.

If the pressure is increased to 50 psia, the metal returns to its linear behavior. At 700°C it was necessary to increase the pressure to 400 psia to cause the reversion to the linear rate. This peculiar behavior of molybdenum at 700°C with respect to oxygen pressure is shown in Figure 2. It should be mentioned at this point that to the authors' knowledge this is the first time that the reversion from a linear rate to rate law of higher order, i.e., parabolic, cubic or logarithmic, has been observed.

At temperatures below 500 to 525°C no variation in the rate of oxidation with respect to oxygen pressure was observed at the pressures investigated. At 550°C the rate of oxidation of molybdenum becomes dependent on the oxygen pressure. The experimental and theoretical oxidation rates as a function of oxygen pressure at various temperatures are shown in Figures 3 to 8.

DISCUSSION OF RESULTS

The experimental results presented above clearly demonstrate the following facts concerning the oxidation behavior of molybdenum under the imposed conditions. (1) molybdenum oxidizes linearly from 500 to 650°C at all pressures investigated. (2) at temperatures from 550 to 700°C the oxidation rate is a function of the oxygen pressure while below this temperature no pressure effects were observed. (3) from 650 to 700°C the metal shows a peculiar transition from some type of protective behavior at low pressures to linear behavior at high pressures; (4) at any given temperature from 550 to 650°C the rate of oxidation approaches a limiting rate as the pressure is increased.

X-ray diffraction studies made on the oxide films formed on the metal in situ indicated that the films were highly oriented by virtue of the fact that a number of the normal diffraction lines of MoO_3 were totally absent. However, when the oxide films were removed from the metal substrate and finely ground, the resulting d/n values correspond closely to the reported values for MoO_3 . The d/n values obtained for the oxide in situ and after removal are given in Table I. The slight shift in the d/n values of the oxide in situ suggests that possibly some residual strains were present in the oxides at room temperature. In no case were diffraction patterns observed for the lower oxides of molybdenum by X-ray techniques.

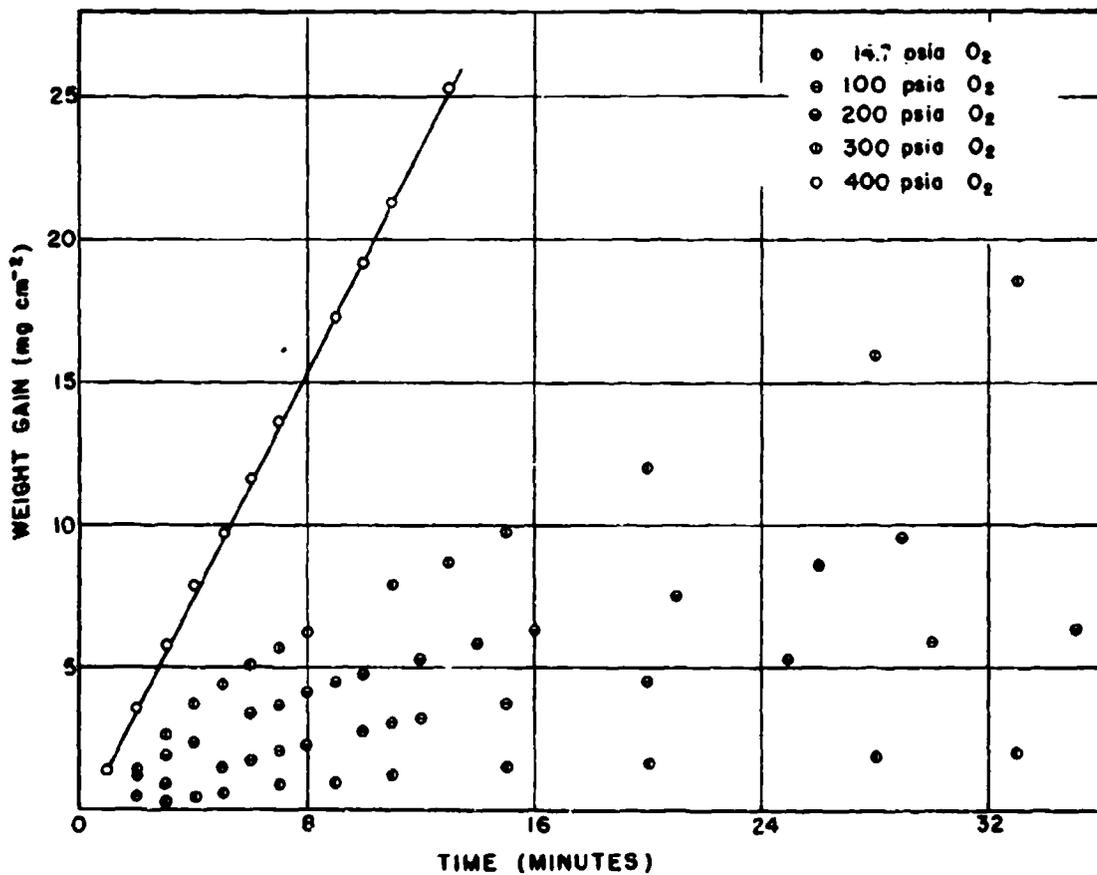


Fig. 2. OXIDATION RATE OF MOLYBDENUM IN OXYGEN AT 700° C.
SHOWING THE TRANSITION FROM PROTECTIVE TO LINEAR
RATES AT HIGH PRESSURES

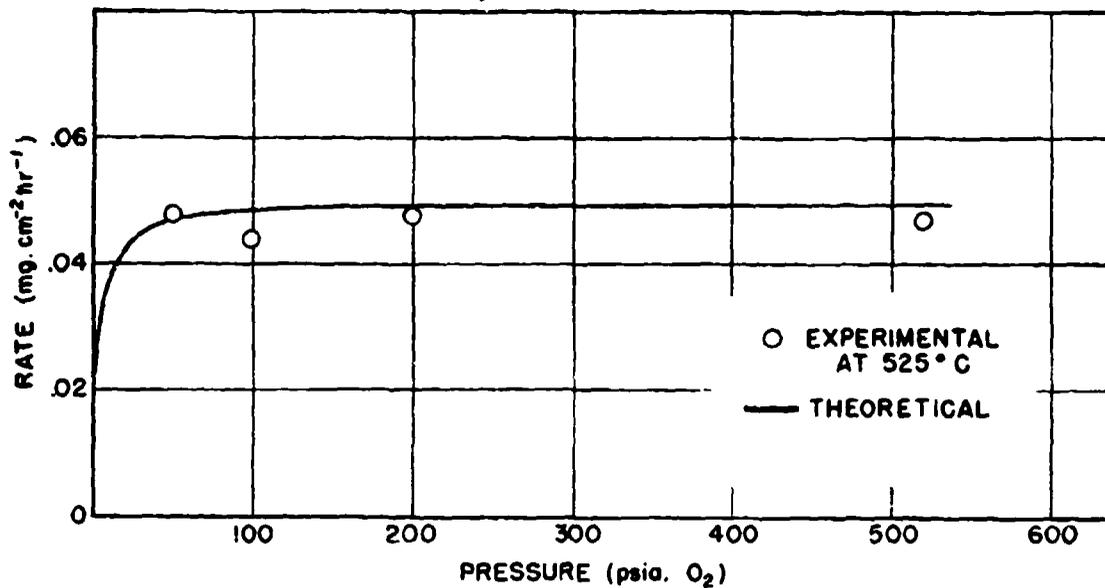


Fig.3. OXIDATION RATE OF MOLYBDENUM versus OXYGEN PRESSURE

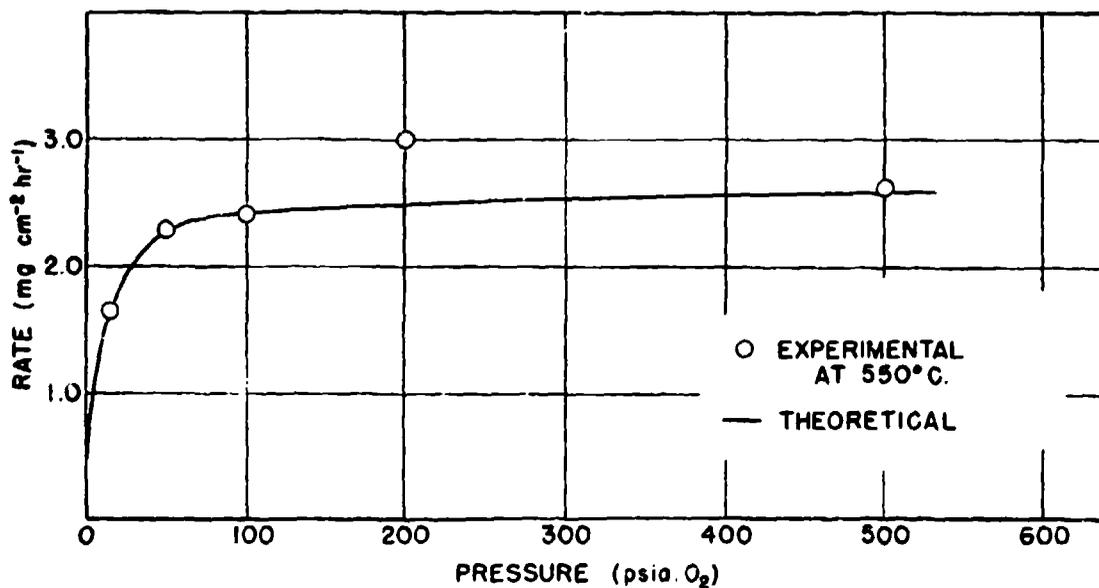


Fig.4. OXIDATION RATE OF MOLYBDENUM versus OXYGEN PRESSURE

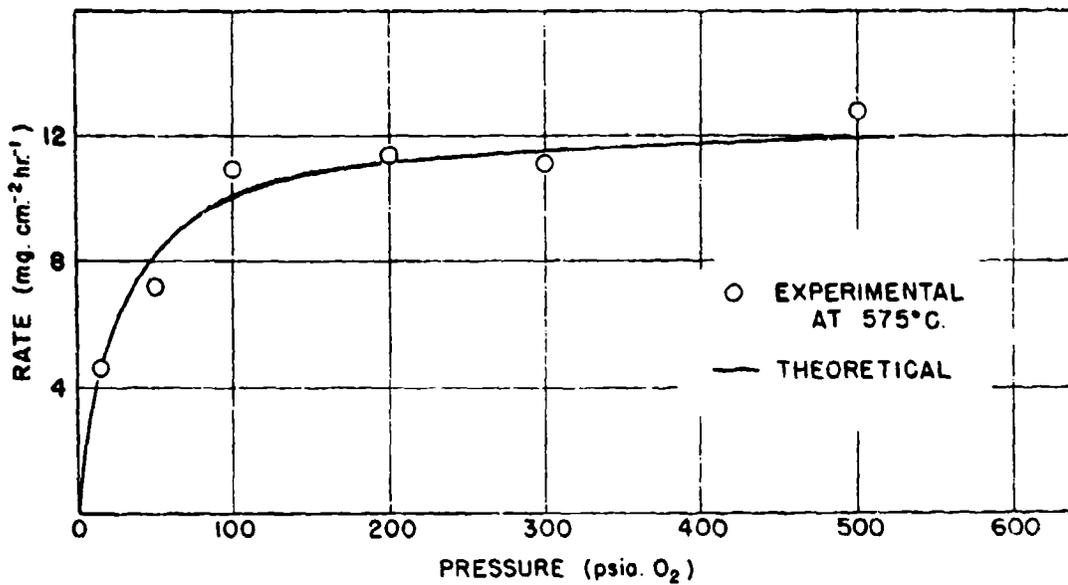


Fig.5. OXIDATION RATE OF MOLYBDENUM versus O₂ GEN PRESSURE

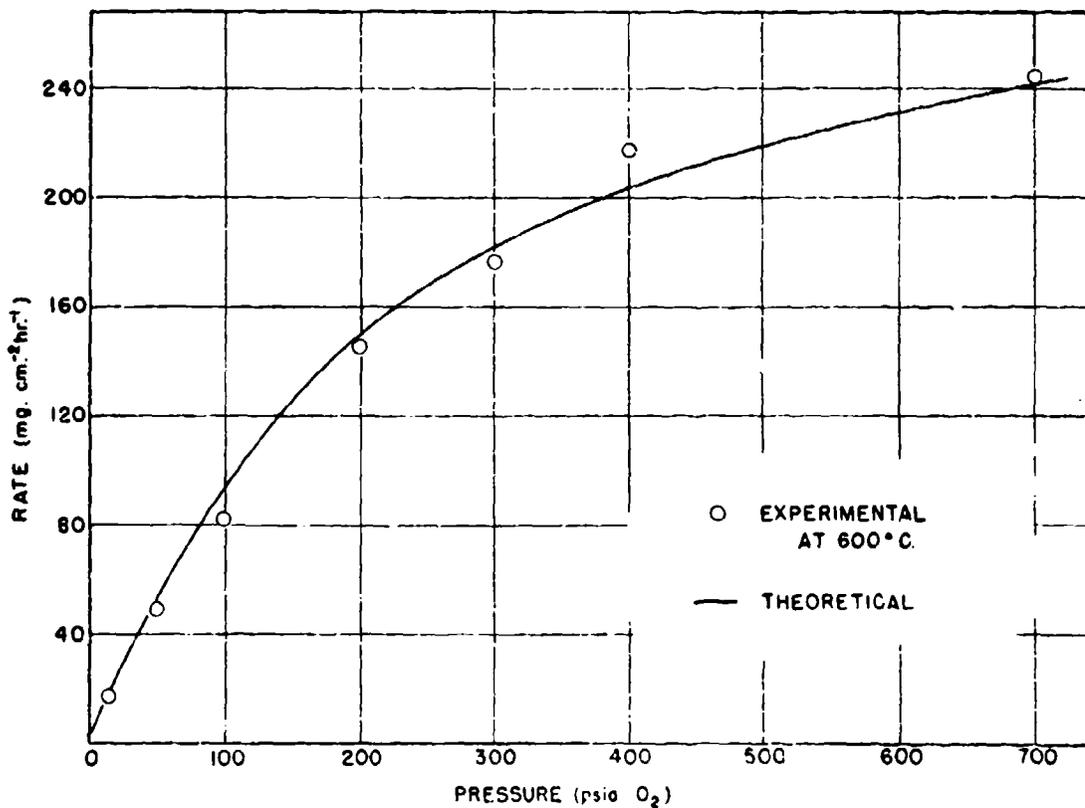


Fig.6. OXIDATION RATE OF MOLYBDENUM versus OXYGEN PRESSURE

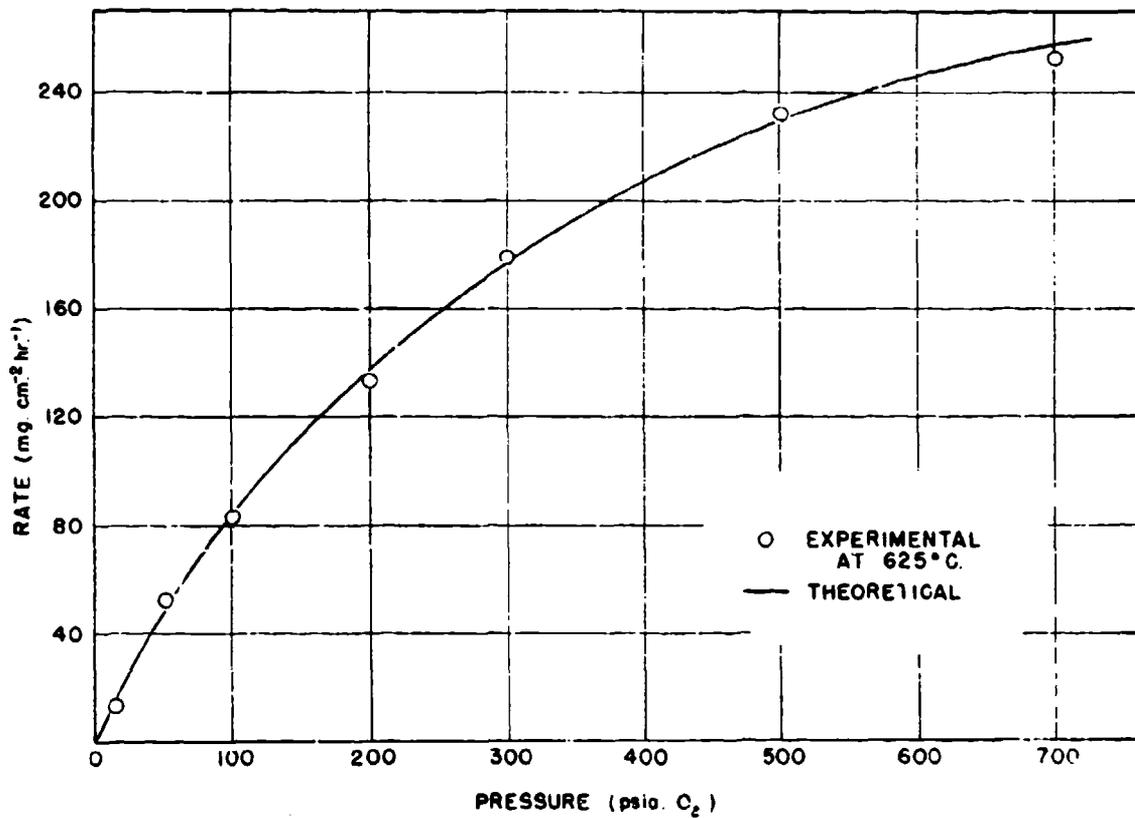


Fig. 7. OXIDATION RATE OF MOLYBDENUM versus OXYGEN PRESSURE

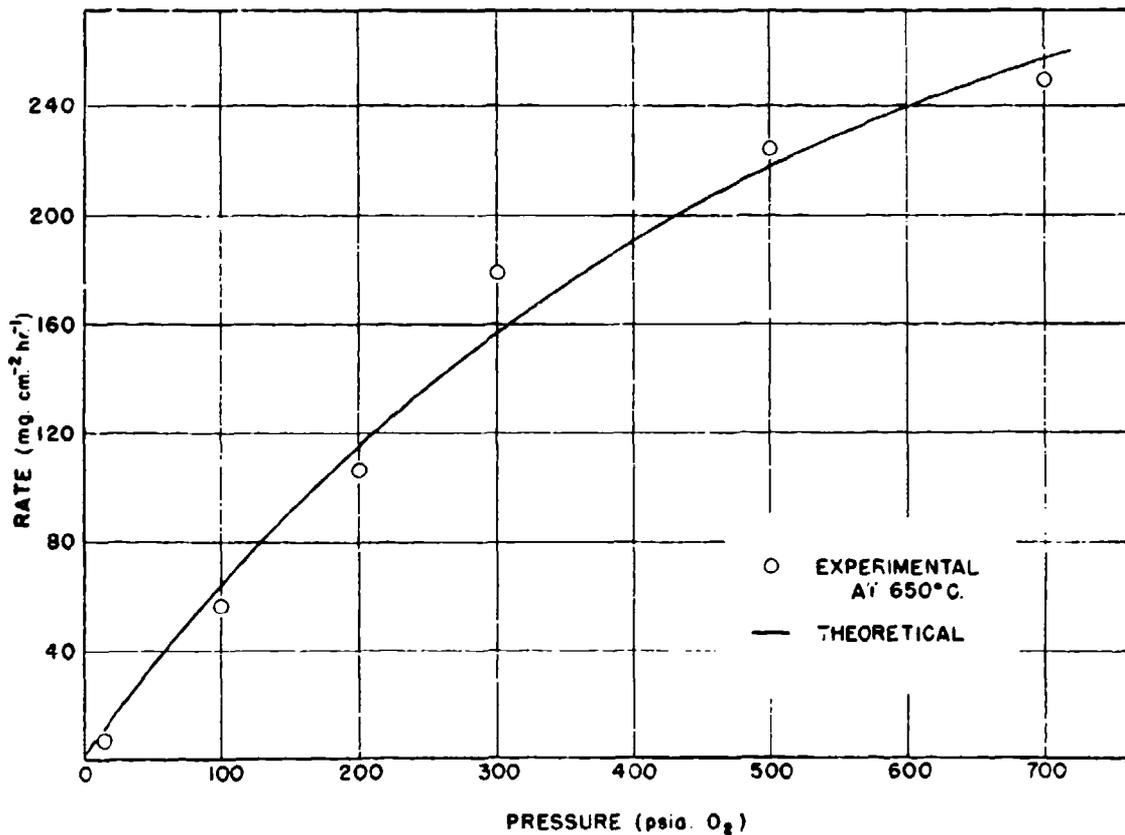


Fig. 8. OXIDATION RATE OF MOLYBDENUM versus OXYGEN PRESSURE

TABLE I
COMPARISON OF THE LATTICE PARAMETERS OF THE
OXIDE FILMS FORMED ON MOLYBDENUM METAL

OXIDE FILM IN SITU d/n	GROUND OXIDE FILM d/n	ASTM MoO ₃ d/n	ASTM MoO ₃ d/n
<u>4.1329</u>	7.5634	6.9	3.415
<u>3.7385</u>	<u>6.8624</u>	<u>3.80</u>	2.811
3.3759	<u>5.8176</u>	<u>3.46</u>	2.693
2.1709	<u>3.4530</u>	<u>3.25</u>	2.424
2.1462	3.2433	3.00	2.177
<u>1.9649</u>	<u>2.5493</u>	2.66	1.844
<u>1.9489</u>	<u>2.3037</u>	2.52	1.722
1.8039	1.9569	2.30	1.708
1.4269	1.7338	2.26	1.695
1.2914	1.5679	2.13	1.531
	1.5302	1.97	1.467
	1.3840	1.85	1.402
		1.73	1.390
		1.70	1.301
		1.67	1.287
			1.215

==== STRONG
 ——— MEDIUM
 NO LINE WEAK

Some question may exist concerning the possible sublimation of the MoO₃ during oxidation. A number of samples were oxidized to completion and a comparison was made between final and stoichiometric weight corresponding to MoO₃. No significant loss of the oxide could be detected up to and including 700°C. In addition no sublimed crystals were observed on the interior of the equipment.

Numerous attempts were made to secure data at 725°C. At this temperature ignition of the metal invariably occurred, preceded by 'self heating' of the metal sample. In fact even at 700°C some indications of self heating were observed but the furnace was sufficiently responsive to correct this condition, making rate measurements possible.

The results presented in the above figures and the conventional Arrhenius plot shown in Figure 9 indicate the complexity of the oxidation of molybdenum. In addition it has been shown by others that at low temperatures (below 450°C) molybdenum follows the parabolic law.

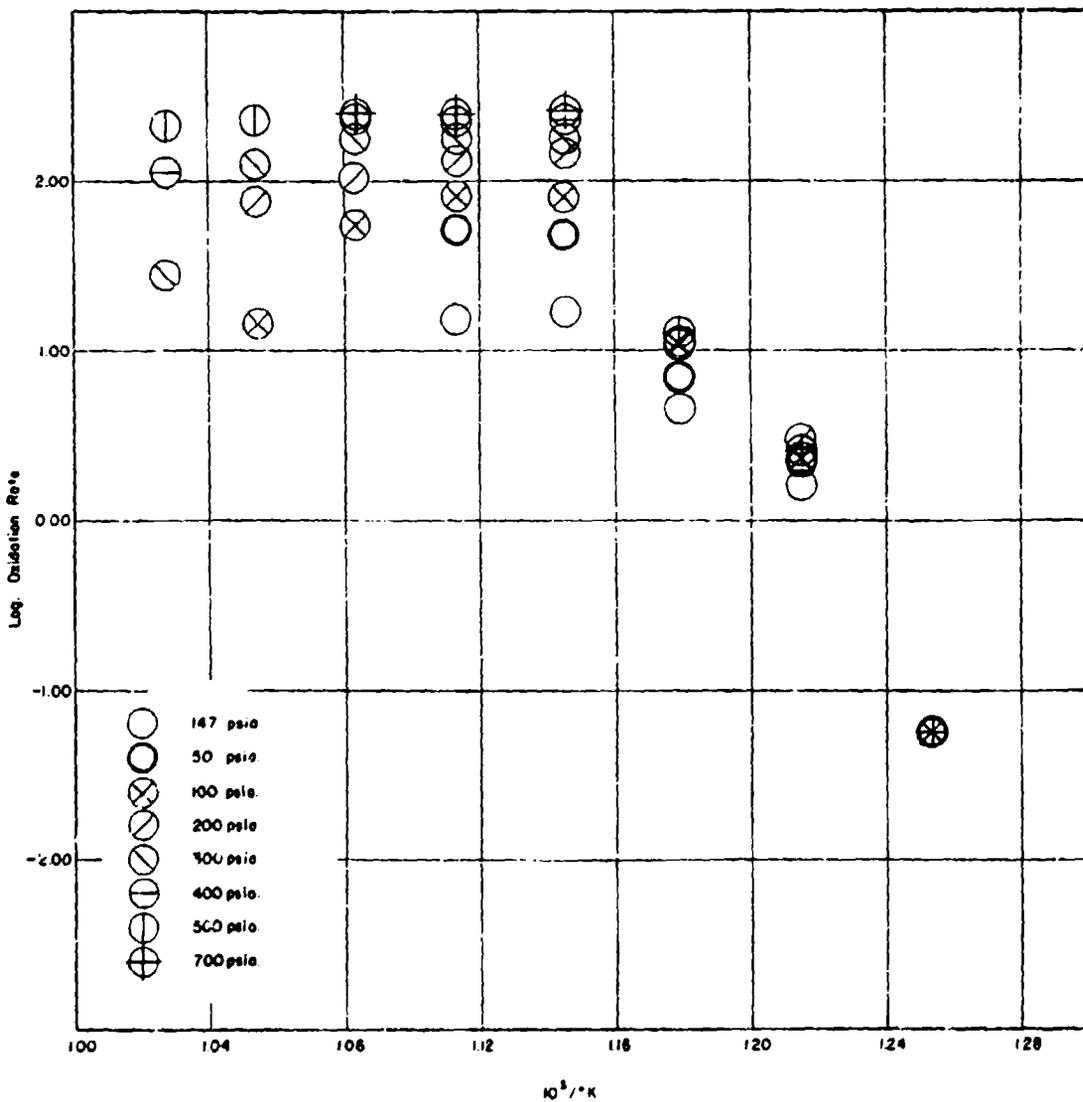


Fig. 9. ARRHENIUS PLOT OF THE EXPERIMENTAL OXIDATION RATES OF MOLYBDENUM IN OXYGEN

The present results indicate a shift to a linear rate at intermediate temperatures, which incidentally has become a fairly familiar pattern of many metals, followed by a pressure sensitive reversion to a protective mechanism at higher temperatures (650 to 700°C).

The exact nature of this protective mechanism is at present still unknown. Repeated attempts to apply the conventional protective type laws have not produced entirely satisfactory results. It may be significant to mention the fact that such a shift was predicted previously⁽⁷⁾ on the basis of a rather qualitative consideration of the relative rates at which the film forming oxide was produced and the rate at which it could be assimilated in the already present film. Briefly a possible explanation for the reversion to the protective mechanism for molybdenum is as follows: In the intermediate temperature region (from 500-650°C) where the linear rate law is followed, the rate of oxide formation is greater than the rate at which this oxide can be assimilated in existing crystallites by some type of growth mechanism. Therefore a high probability exists that nuclei will form, resulting in extremely small MoO_3 crystals throughout the oxide film, resulting in a relatively porous, non-protective film. As the temperature increases the rate of oxidation will increase according to the usual exponential relationships. Likewise, from the theoretical considerations of sintering, it is known that the growth process will increase exponentially. The question then becomes one of the relative effect of temperature on these two exponential functions. While quantitative data are lacking on MoO_3 , it might be expected that as the melting temperature of MoO_3 is approached, the rate of crystal growth will become large with the possibility that the oxide film could now 'fit in' the new oxide formed to the existing oxide crystallites. The shift from a protective mechanism to a linear mechanism with increased pressure at 700°C may then be considered to occur because of the increased rate of oxidation at higher pressures in this temperature region. Further work is in progress on this transition because of its possible theoretical implications.

THEORETICAL

The linear equation usually given to describe the oxidation of a metal is $w = kt$, where w is the weight gained and k is the rate. The value of k under the experimental conditions which are described in the paper is a function both of temperature and of the pressure of the gas phase of the system. The temperature dependence is usually given in the forms of the Arrhenius equation

$$V = A e^{-\frac{E}{RT}} \quad (1)$$

where V is the experimental rate, A the action constant, E is the activation energy, and R and T are the gas constant and absolute temperature. Fig. 9 shows a plot of the logarithm of the rate versus $1/T$. The large deviation from a straight line due to the effect of pressure is immediately obvious.

The linear equation can be re-written in the form,

$$w = \prod_i c_i f(T) \quad (2)$$

where the rate is implicitly a function of the product of the concentrations at the site of the reaction of the reacting species and of the temperature. Assuming that $f(T)$ is given by the Eyring (8) equation for the absolute rate of reaction, the question then becomes one of determining $\prod_i c_i$ in terms of the effective concentration of oxygen in the gas phase.

The rate is now in the form,

$$V = \prod_i c_i \mathcal{A} \frac{kT}{h} e^{-\frac{\Delta H^\ddagger}{RT}} e^{\frac{\Delta S^\ddagger}{R}} \quad (3)$$

where

$$\mathcal{A} \frac{kT}{h} e^{-\frac{\Delta H^\ddagger}{RT}} e^{\frac{\Delta S^\ddagger}{R}}$$

is the specific rate constant as given by Eyring.

In the present investigation it was found that the rate versus pressure curves shown in Figs. 3 to 8 could be fitted almost exactly with a type I Langmuir Adsorption Isotherm. This indicates that the concentration term $\prod_i c_i$ in Eq. (3) is proportional to θ , the fraction

of the available surface sites covered by adsorbed oxygen. In terms of Eq. (3) becomes,

$$V = k_0 \theta \mathcal{L} \frac{kT}{h} e^{-\frac{\Delta E^\ddagger}{RT}} e^{-\frac{\Delta S^\ddagger}{R}} \quad (4)$$

where k_0 is a proportionality constant with the dimensions of ML^{-2} and includes the correction factor for the true surface area involved in the oxidation reaction.

An expression for θ in terms of the gas phase concentration of oxygen can be obtained by considering the following equilibrium reaction between an absorption site, S_a , and O_2 in the gas phase,



The fraction of sites covered, θ , is proportional to $S_a - O_2 \text{ (ads)}$ and the fraction of bare sites, $1 - \theta$, to S_a . The equilibrium constant for Eq. (5) is then,

$$k_1 = \frac{\theta}{1 - \theta} \cdot \frac{1}{f_{O_2}} = e^{-\frac{\Delta F_1}{RT}} \quad (6)$$

where f_{O_2} is the fugacity of O_2 in the gas phase and ΔF_1 is the free energy of adsorption of oxygen on the surface. The standard state for this system is chosen as that which corresponds to one-half surface coverage and a pressure of one atmosphere. Oxygen can be considered an ideal gas under the experimental conditions herein described so that Eq. (6) can be rewritten,

$$k_1 = \frac{\theta}{1 - \theta} \cdot \frac{1}{C_{O_2}} \quad (7)$$

where C_{O_2} is now the effective concentration of O_2 in the gas phase. Solving for θ , we obtain,

$$\theta = \frac{k_1 C_{O_2}}{1 + k_1 C_{O_2}} \quad (8)$$

Substituting Eq. (8) in Eq. (4) and making the usual assumption that $\mathcal{L} = 1$, we have

$$V = k_0 \left[\frac{k_1 C_{O_2}}{1 + k_1 C_{O_2}} \right] \frac{kT}{h} e^{-\frac{\Delta E^\ddagger}{RT}} e^{-\frac{\Delta S^\ddagger}{R}} \quad (9)$$

TABLE II

$T^{\circ}C$	$T^{\circ}K$	$\frac{10^3}{T}$	k_1	$\log k_1$
525	798	1.2531	240	2.38
550	823	1.2151	128	2.107
575	848	1.1792	39.6	1.598
600	873	1.1455	4.5	.653
625	898	1.1136	2.75	.440
650	923	1.0834	1.35	.130

At constant temperature Eq. (9) can be written as,

$$V = k'_0 \left[\frac{k_1 C_{O_2}}{1 + k_1 C_{O_2}} \right] \quad (10)$$

and this in turn can be cast into linear form,

$$\frac{1}{V} = \frac{1}{k_0 k_1 C_{O_2}} + \frac{1}{k_0} \quad (11)$$

from which k_0 and k_1 can be determined by plotting reciprocal rate versus reciprocal concentration as is shown in Figure 10. Table II gives the values of the equilibrium constant of adsorption, k_1 , obtained in this manner.

Figure 11 shows a plot of $\log k_1$ versus reciprocal temperature from which the heat of adsorption, ΔH_1 , of O_2 on molybdenum was found to be 61.0 kcal/mole of oxygen with an entropy of adsorption ΔS_1 of 36.4 entropy units. Both ΔH_1 and ΔS_1 are considerably larger in this case than the corresponding values for the adsorption of oxygen which was involved in the oxidation of tantalum under similar conditions.⁽⁸⁾

From Eq. (9) it is evident that a plot of

$$\log V \left[\left(\frac{k_1 C_{O_2}}{1 + k_1 C_{O_2}} \right) \frac{kT}{h} \right]^{-1} \text{ vs. } \frac{1}{T^{\circ}K}$$

should yield a straight line. Figure 12 shows such a plot. In contrast to Fig. 9 where a large spread in the experimental values due to neglecting the surface concentration of O_2 is evident, the experimental points now fall reasonably well along two straight lines. The length of the vertical line within the circles in Fig. 12 indicates the experimental spread of the rates at various pressures.

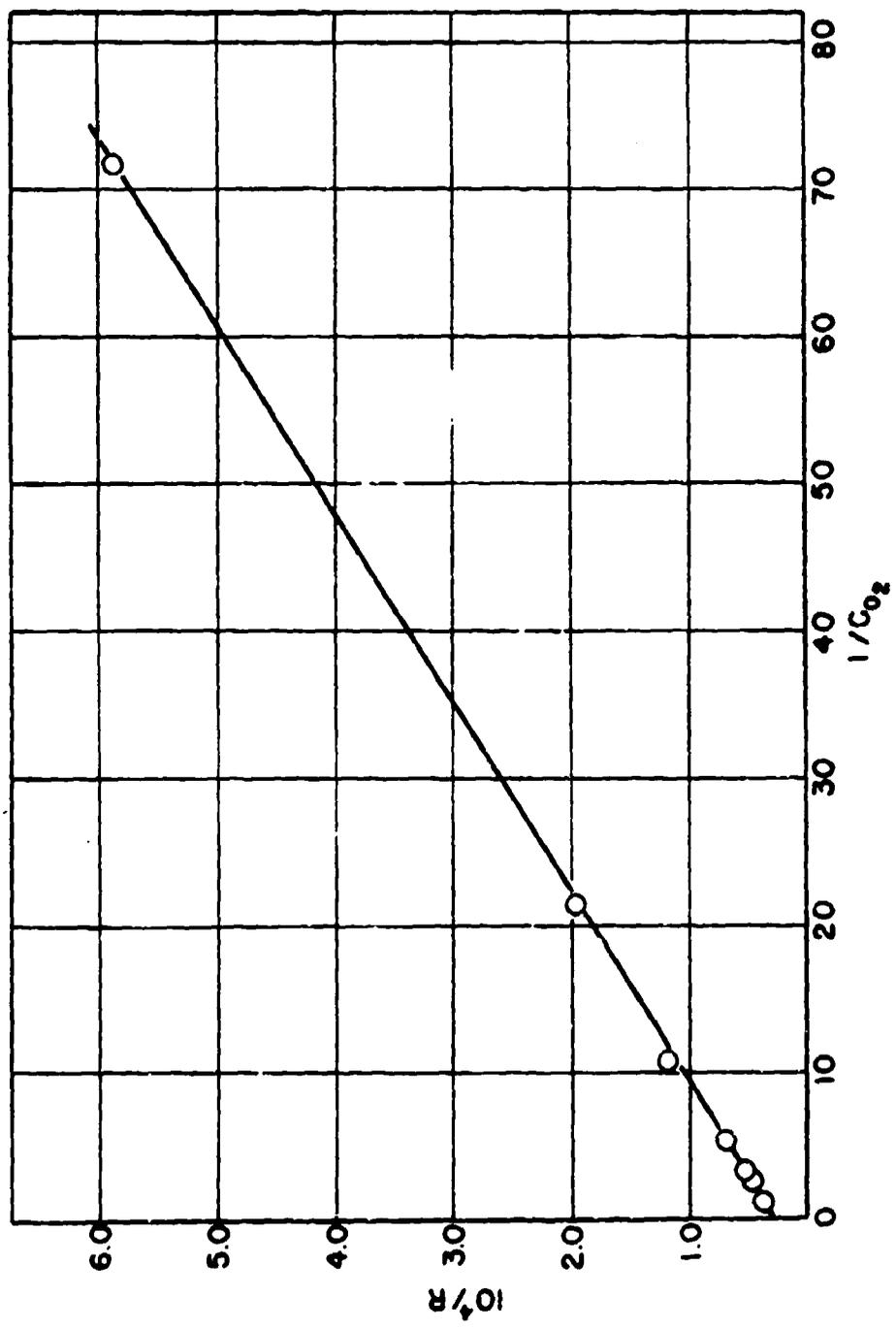


Fig. 10. TYPICAL CURVE USED TO EVALUATE k_1 AND k_0 IN EQUATION

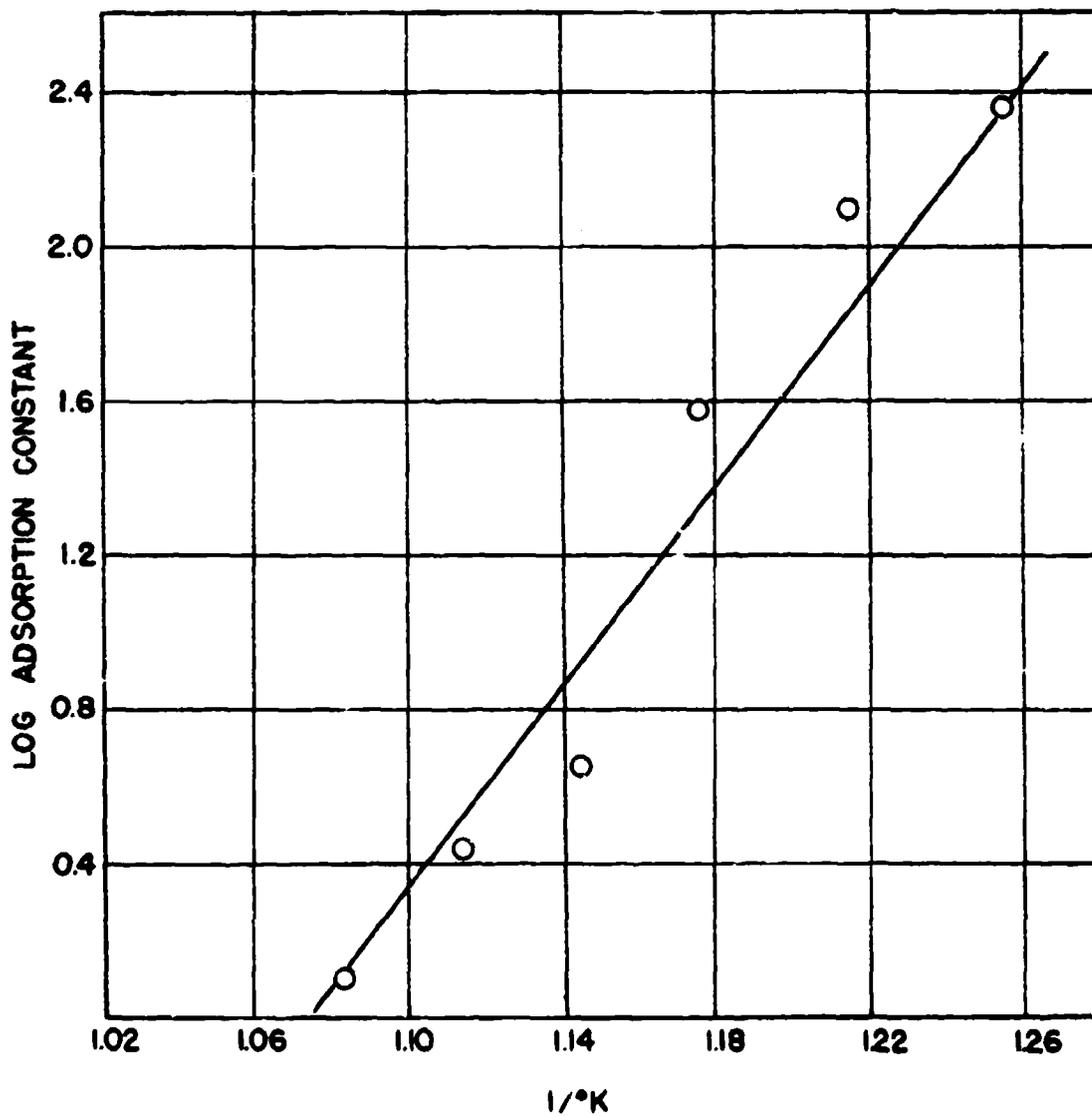


Fig. II. RELATIONSHIP BETWEEN EQUILIBRIUM CONSTANT OF ADSORPTION AND TEMPERATURE

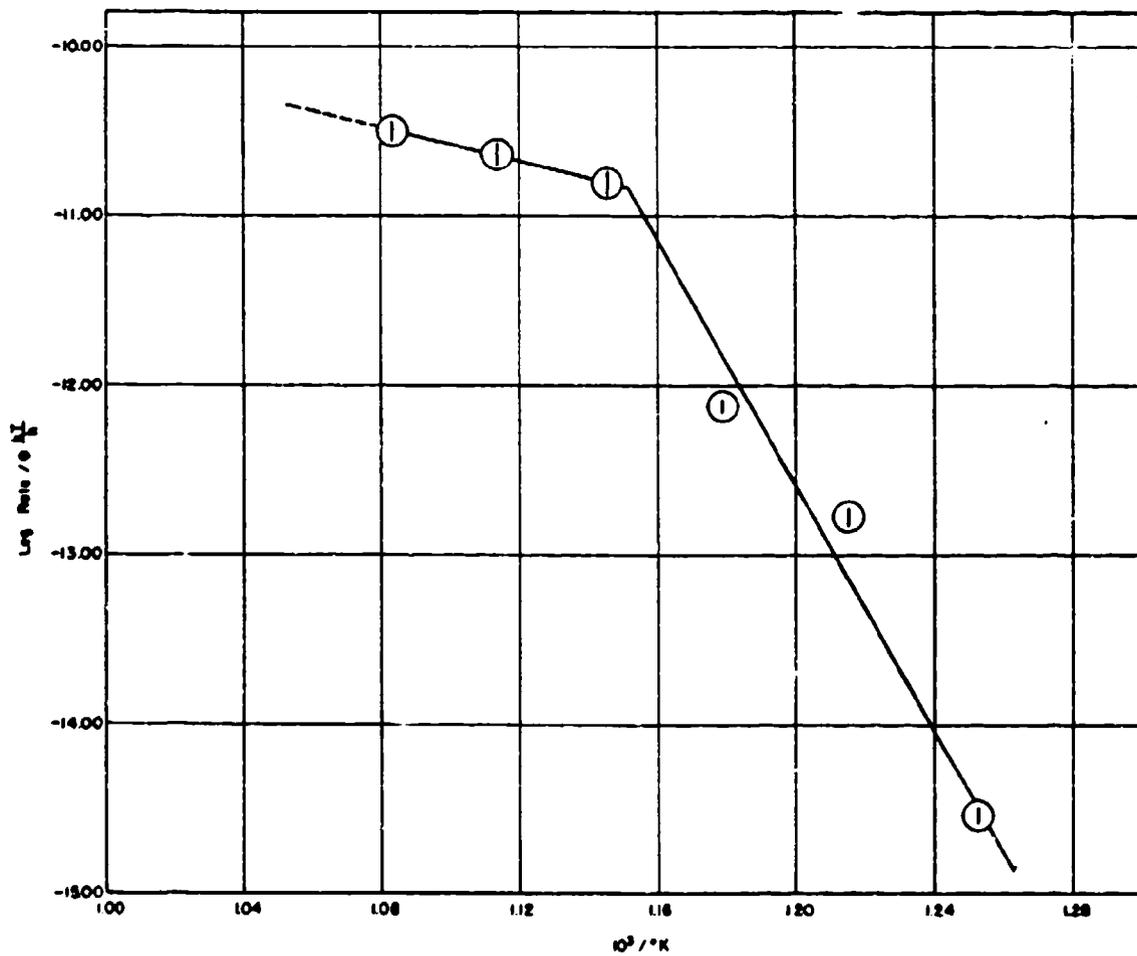


Fig.12. TOTAL ABSOLUTE RATE OF REACTION OF MOLYBDENUM IN OXYGEN versus RECIPROCAL TEMPERATURE

The heat of activation, ΔH^\ddagger , as determined from Fig. 12 in the temperature region from 525 to 625°C is 165 kcal/mole. In the temperature range from 625 to 700°C ΔH^\ddagger is approximately 23.3 kcal/mole. The extremely large value of ΔH^\ddagger in the first case above is indicative of the great sensitivity of the rate of reaction of molybdenum in oxygen to temperature changes. At equivalent concentrations of oxygen the rate at 625°C is greater by a factor of ten thousand than the rate at 525°C.

SUMMARY

In conclusion, the facts concerning the oxidation behavior of molybdenum in oxygen from 500 to 725°C at pressures ranging from 1 to 47.6 atmospheres pressure are as follows.

1. Molybdenum oxidizes according to the linear law from 500 to 650°C at all pressures investigated.
2. No pressure dependence of the oxidation rate was found from 500 to 525°C.
3. From 550 to 700°C the oxidation rate is sensitive to oxygen pressure. In this region the reaction rate may be expressed by the equation

$$V = k_0 A \left(\frac{k_1 C_{O_2}}{1 + k_1 C_{O_2}} \right) e^{-\frac{\Delta H^\ddagger}{RT}} e^{-\frac{\Delta S^\ddagger}{R}}$$

where ΔH^\ddagger has a value of 165 kcal/mole from 525 to 625°C and 23.3 kcal/mole from 625 to 700°C.

4. A peculiar pressure sensitive transition has been observed from 650 to 700°C wherein the mechanism shifts from some unknown type of protective behavior at low pressures to a linear mechanism at high pressures. It is believed that this is the first experimental observation of a shift from a linear rate to a protective rate with increasing temperature.
5. The oxide formed on the metal under the experimental conditions used was MoO_3 .

ACKNOWLEDGEMENT

The authors wish to express their appreciation to the Office of Ordnance Research, U. S. Army, for the funds that made this work possible and to Dr. John R. Lewis, Head Department of Metallurgy, for his support and interest in this project.

REFERENCES

1. Kubaschewski, O., and B. F. Hopkins, "Oxidation of Metals and Alloys," Academic Press Inc., 1953.
2. Gulbransen, E. A., and Wysong, W. S., Trans. AIME 175 (1948) 611-628.
3. Hickman, J. W., and Gulbransen, E. A., Trans. AIME 171 (1947) 344-361.
4. McKewan, W. M., and Fassell, W. M., Jr., Trans. AIME (1953) 1127-1130.
5. Fassell, W. M., Jr., and Peterson, R. C., "Equipment for High Temperature, High Pressure Solid Gas Reaction Rate Studies," Technical Report IV, August 10, 1953, Army Ord. Contract DA-04-495-ORD-237.
6. Peterson, R. C., Fassell, W. M., Jr., and Wadsworth, M. E., Journal of Metals. Sept. 1954. 1038 - 1044.
7. McKewan, W. M., and Fassell, W. M., Jr., "The Parabolic-Linear Oxidation Rate Transition Theory," Technical Report No. 1, Feb. 26, 1952, Army Ordnance Contract DA-04-495-ORD-237.
8. Glasstone, S., Laidler, K. J., Eyring, H., "Theory of Rate Processes," McGraw Hill Book Co., N. Y., 1941.

DISTRIBUTION LIST

Technical Reports

Army Ordnance

Contract No. DA-04-495-ORD-237

Director, Applied Physics Lab., Johns Hopkins University 8621 Georgia Ave. Silver Spring 19, Maryland.	(1 Copy)	NAC for Aeronautics 1724 F. Street, NW, Washington 25, D. C. Attn: Mr. E. B. Jackson, Chief, (1 Copy) Office of Aeronautical Intelligence.
Chief, Los Angeles District 55 So. Grand Ave. Pasadena 1, California	(1 Copy)	Scientific Information Section Research Branch, Research & Development Division, Office, Assistant Chief of Staff, G-4 Department of the Army, Washington 25, D. C.
Commanding General Air University Maxwell Air Force Base, Alabama. Attn: Air University Library.	(1 Copy)	(1 Copy)
Document Service Center, U.B. Building Dayton 2, Ohio. Attn: DSC-SD	()	Armed Services Tech. Information Agency, Document Service Center, Knott Building, Dayton 2, Ohio. (5 Copies) Attn: DSC-SD
Commanding General, Air Res. & Dev. Command, P.O. Box 1395, Baltimore 3, Maryland. Attn: RDR	(1 Copy)	The Library, United Aircraft Corp., 400 Main Street, East Hartford 8, Conn. (1 Copy)
Commanding General, Air Res. & Dev. Command, P. O. Box 1395, Baltimore 3, Maryland. Attn: RDD	(1 Copy)	Chief of Naval Research, % Reference Dept. Technical Information Division, Library of Congress, Washington 25, D. C. (3 Copies)
U.S. Atomic Energy Commission, Document Library, 19th & Constitution Ave. Washington 25, D. C.	(1 Copy)	Commander, U. S. Naval Ord. Test Station, Inyokern China Lake, California. Attn: Technical Library. (1 Copy)
Commanding General Air Material Command, Wright-Patterson Air Force Base, Dayton 2, Ohio. Attn: F. N. Bubb, Chief Scientist Flight Research Lab.	(1 Copy)	Chairman, Medical Res. & Dev. Bd. Office of the Surgeon General, Department of the Army, Main Building, Washington 25, D. C.
Office of Ordnance Research, Box CM, Duke Station, Durham, North Carolina.	(10 Copies)	Office of the Chief Signal Officer, Engineering & Tech. Division, Engineering Control Branch, Room 2B273, Pentagon Bldg. Washington 25, D. C. Attn: SIGGD
		Commanding Officer, Army Medical Research Laboratory, Fort Knox, Kentucky.

DISTRIBUTION LIST
Technical Reports
(Cont.)

Army Ordnance

Contract No. DA-04-495-ORD-237

<p>Office, Chief of Ordnance, Washington 25, D. C. Attn: ORDTA</p>	<p>(1 Copy)</p>	<p>Commanding Officer Engineer Res. & Dev. Laboratories, Fort Belvoir, Virginia</p>	<p>(1 Copy)</p>
<p>Office, Chief of Ordnance, Washington 25, D. C. Attn: ORDTB</p>	<p>(1 Copy)</p>	<p>Commander U. S. Naval Proving Ground Dahlgren, Virginia</p>	<p>(1 Copy)</p>
<p>Chief, Bureau of Ordnance (AD3) Department of the Navy Washington 25, D. C.</p>	<p>(1 Copy)</p>	<p>Commanding Officer, U.S. Naval Powder Factory, Indian Head, Maryland.</p>	
<p>U.S. Naval Ordnance Laboratory, White Oak, Silver Spring 19, Md. Attn: Library Division.</p>	<p>(1 Copy)</p>	<p>Director, National Bureau of Standards, Washington 25, D. C.</p>	<p>(1 Copy)</p>
<p>Corona Laboratories, National Bureau of Standards, Corona, California.</p>	<p>(1 Copy)</p>	<p>Commanding Officer, Frankford Arsenal, Bridesburg Station, Philadelphia 37, Penna.</p>	<p>(1 Copy)</p>
<p>Commanding General Aberdeen Proving Grounds, Md. Attn: BRL</p>	<p>(1 Copy)</p>	<p>Technical Information Service, P. O. Box 62 Oak Ridge, Tennessee Attn: Reference Branch</p>	<p>(1 Copy)</p>
<p>Commanding Officer, Redstone Arsenal, Huntsville, Alabama.</p>	<p>(1 Copy)</p>	<p>Commanding Officer Signal Corps Engineering Lab., Fort Monmouth, New Jersey, Attn: Director of Research.</p>	<p>(1 Copy)</p>
<p>Commanding Officer, Picatinny Arsenal, Dover, New Jersey.</p>	<p>(1 Copy)</p>	<p>Commanding Officer, Rock Island Arsenal Rock Island, Illinois.</p>	<p>(1 Copy)</p>
<p>Commanding General Research H Engineering Command, Army Chemical Center, Md.</p>	<p>(1 Copy)</p>	<p>The Director, Naval Research Lab. Washington 25, D. C. Attn: Code 2021</p>	<p>(1 Copy)</p>
<p>Chief, Ordnance Development Div., National Bureau of Standards, Washington 25, D. C.</p>	<p>(1 Copy)</p>	<p>Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena 3, California.</p>	<p>(1 Copy)</p>
<p>Commanding Officer, Watertown Arsenal, Watertown 72, Mass.</p>	<p>(4 Copies)</p>	<p>Technical Reports Library, SCEL, Evans Signal Corps Lab., Belmar, New Jersey.</p>	<p>(1 Copy)</p>
<p>Commandant, Army Medical Service Graduate Sch., Walter Reed Army Medical Center, Washington 12, D. C.</p>			