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THERMODYNAMIC PROPERTIES OF 65 ELEMENTS— THEIR OXIDES HALIDES CARBIDES AND NITRIDES

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THERMODYNAMIC PROPERTIES OF 65 ELEMENTS—THEIR OXIDES, HALIDES, CARBIDES, AND NITRIDES[1]

by

C. E. Wicks[2] and F. E. Block[3]

Introduction

THROUGH the utilization of two branches of scientific knowledge, extractive metallurgy has recently developed from an empirical art to a more exact science. Improved techniques for evaluating physical and chemical properties of materials have provided better definition and control of operating variables. Also, chemical thermodynamics have provided the requisite fundamental information needed to evaluate optimum conditions for conducting processes.

The value of thermochemical calculations in extractive metallurgy is in evaluating heat requirements and optimum conditions for conducting a chemical process. Quantitative knowledge of thermodynamic values characteristic of elements and compounds is almost mandatory in the control and improvement of established extractive metallurgical processes, as well as for the development of new or modified processes.

This Bureau of Mines bulletin was prepared to compile in readily usable form the heat content, heat-of-formation, and free-energy-of-formation data for 65 common elements and their respective oxides, halides, carbides, and nitrides. The bulletin was prepared to encourage the application of thermodynamics in the metallurgical field; consequently, the values have been presented in a simple, readily usable form and several examples of their applications have been shown.

The necessary theoretical basis of chemical thermodynamics is discussed in part 1 of this bulletin. It is assumed that the user will be at least acquainted with the fundamentals of chemical thermodynamics. Accordingly, all derivations of the various functions and their interrelations have been eliminated. These can be found in various textbooks. This part contains the essential formulas necessary for applying fundamental data to process problems, with the accompanying examples included mainly to illustrate their applications.

A survey of literature published through 1959 permitted assembly of all accepted measured and estimated thermodynamic values. These values are included in part 2 of this bulletin. To satisfy individual needs, these data have been presented in three separate forms: (1) Tables of heat content,

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heat of formation, and free energy of formation at various temperatures as well as values for phase changes; (2) equations relating the variation of the thermodynamic functions with temperature; and (3) graphical plots of the variation of free energy of formation with temperature. The stable form of elements and compounds at the reference base temperature of 298.15° K. was used as the standard state. An effort was made to differentiate between established and estimated values. Parenthesized values within the tabular data, and dotted lines on the graphs indicate regions where estimations were required.

It is important to emphasize that thermochemistry deals with equilibrium conditions only, and that many reactions are in practice subject to overriding kinetic limitations rather than free-energy relationships. It is impossible to evaluate or predict reaction rates from thermodynamic calculations. A simple parallel may be drawn from the fact that the knowledge of the amount of gasoline available to drive an automobile gives no indication of the length of time required to traverse a busy city. The driving force causing a reaction to proceed and the ultimate state of the reacting system can be calculated from reliable data, but the resistance to attainment is incapable of prediction without additional kinetic information.

SYMBOLS AND UNITS[4]

$a, b, c, r, s,$	Constants in various equations.
a_A, a_B, a_R, a_S	Activity for reactants and products.
A, B, R, S	Reactants and products in the general chemical reaction equation.
α, β, γ	Crystalline state of elements and compounds.
$B.P.$	Normal boiling point, ° K.
C_p	Heat capacity, calories per gram-mole per ° K.
$\mathcal{E}$	Electromotive force, volts.
$e.u.$	Entropy units, calories per gram-mole or atom per ° K.
ΔF_T	Free-energy change, calories per gram-mole or atom.
ΔF°_T	Standard free-energy change, calories per gram-mole or atom.
$\mathfrak{F}$	Faraday's constant, calories per volt equivalent.
H_T	Heat content, calories per gram-mole or atom.
ΔH_M	Heat of fusion, calories per gram-mole or atom.
ΔH_r	Heat of reaction, calories per gram-mole or atom.
ΔH_T	Heat of formation at given temperature, calories per gram-mole or atom.
ΔH_V	Heat of vaporization, calories per gram-mole or atom.
K	Equilibrium constant.
$M.P.$	Normal melting point, ° K.
N	Number of electrical equivalents involved.
P	Partial pressure, millimeters of mercury.
Q	Heat exchanged between system and surroundings, calories.
R	Gas constant, 1.987 calories per ° K. per gram-mole.
S_T	Entropy, calories per gram-mole per ° K.
T	Absolute temperature, ° K.
$T.P.$	Transition point

[4] The following symbols are used in the illustrations:
B—Boiling
D—Decomposition
M—Melting
S—Sublimation
T—Transition

PART 1.—THERMODYNAMIC FUNCTIONS AND THEIR APPLICATIONS

A knowledge of thermodynamic functions can provide an excellent guide in the control and improvement of established metallurgical processes. Screening programs based on thermodynamic calculations can also be used to indicate the most favorable approach to the development of new extractive metallurgical processes. Heat content, heat of reaction, and free energy of formation are the principle thermodynamic functions needed in evaluating heat balances and in predicting proposed chemical reactions.

HEAT CONTENT

Heat content is the basic thermodynamic function required for heat balances, as well as for many other useful chemical calculations. For a system undergoing an isobaric change, it can be shown from the first law of thermodynamics that

$$\triangle H = Q.$$

This simply states that whenever a process is carried out under constant pressure, the heat absorbed or evolved by the system, Q, is equal to the change in the heat content of the system, $\triangle H$.

Since the heat content is a function only of the state of the system, the change in heat content that occurs during any process is independent of the path by which the particular process takes place. Accordingly, the change in heat content depends only on the initial and final states and the heat absorbed or evolved in a metallurgical process can be calculated from values of the heat content at the initial and final states.

Because of the relative importance of this thermodynamic property, physical chemists and metallurgists have made relatively comprehensive experimental measurements of the heat contents of pure substances in their various physical states. Since it is difficult to evaluate absolute heat content values, the quantities generally determined experimentally are changes in heat content above an arbitrarily chosen base temperature. The temperature 298° K., or 25° C., has been conventionally accepted as the base temperature for metallurgical thermochemistry. Pure elements in their stable form have been assigned a zero heat content at this temperature. The heat content of compounds in their stable state at 298° K. is equal to the heat of formation from their elements at this temperature. The change in heat content, $(H_T - H_{298})$, is referred to as the heat content of a substance above the reference base temperature.

Considerable effort has gone into compiling, simplifying, and systematizing values for the heat contents of elements and compounds. Changes in heat content with temperature for pure substances may be represented in graphs or tabulations, or by empirical equations.

A change in heat content with temperature is directly related to the heat capacity, C_p, of the substance by the equation:

$$H_T - H_{298} = \int_{298}^{T} C_p dT.$$

Since C_p is normally expressed as

$$C_p = a + bT + cT^{-2},$$

the relationship for a given physical state becomes

$$H_T - H_{298} = aT + \frac{bT^2}{2} - cT^{-1} + d.$$

Because a heat capacity relationship holds only for a given physical state, that is, solid, liquid, or gas, it is important that the specific relationship be used only for the temperature range in which it is valid.

After a solid is heated to its melting point, additional heat must be supplied to melt it. The heat required for melting at constant pressure is equal to the increase in heat content and is known as the heat of fusion, ΔH_M. An equal quantity of heat is liberated when the reverse operation, solidification, takes place; that is,

Heat of fusion = heat of crystallization.

Similar heat effects accompany other changes in physical states of substances, such as heat

of transformation and heat of vaporization. Values of heat effects accompanying changes in state vary with the temperature and pressure under which the change is carried out. Accordingly, values usually reported are those for the normal melting temperature, transition temperature, or boiling temperature at 1 atmosphere pressure (14.7 p.s.i.a.).

The empirical heat content relationship for a substance that undergoes phase changes in being heated from 298° K. to some higher temperature can be represented by the equation:

$$H_T - H_{298} = \int_{298}^{T.P.} C_p(\alpha)\,dT + \Delta H_{Trans.} + \int_{T.P.}^{M.P.} C_p(\beta)\,dT + \Delta H_M + \int_{M.P.}^{B.P.} C_p(l)\,dT + \Delta H_V + \int_{B.P.}^{T} C_p(g)\,dT.$$

Obviously, the evaluation of heat content values by this empirical equation involves burdensome calculations. Fortunately, tables have been prepared in which heat content values at various temperatures are reported. Exhaustive compilations by Kelley (*78–83*),[5] Rossini (*112*), Brewer (*6–9*, *11*, *12*), Coughlin (*24*), and Stull (*130*) deserve particular mention.

The most frequent use of heat content data by the metallurgist is in determining the amount of heat evolved or absorbed when the temperature of a substance is changed during a process. For such calculations, heat content data in tabular form require only simple arithmetic interpolation to reveal the heat content at any temperature. Heat evolved or absorbed during a temperature change under constant pressure is found simply as the difference between the heat contents at the two temperatures.

EXAMPLE 1: Calculate the heat required to raise 1 gram-mole of calcium dichloride from 400° K. to 1,200° K. using values from tabulations in part 2 of this bulletin. (Calcium dichloride melts at 1,055° K.)

At 1,200° K., $H_{1,200} - H_{298} = 24{,}840$ calories per mole.

At 400° K., $H_{400} - H_{298} = 1{,}850$ calories per mole.

$$\Delta H = H_{1,200} - H_{400} = 22{,}990 \text{ calories per mole.}$$

The solution of this example, using the empirical equation, would require solving

$$\Delta H = H_{1,200} - H_{400} = \int_{400}^{1,055} C_p(s)\,dT + \Delta H_M + \int_{1,055}^{1,200} C_p(l)\,dT$$
$$= \int_{400}^{1,055} (17.18 + 3.04\times10^{-3}T - 0.60\times10^{5}T^{-2})\,dT + 6{,}780 + \int_{1,055}^{1,200} 24.70\,dT.$$

[5] Italicized numbers in parentheses refer to citations in the list of references at the end of this report.

HEAT OF REACTION AND HEAT OF FORMATION

Chemical reactions are accompanied by changes in energy distribution between the reacting system and its environment. These are indicated by the evolution or absorption of heat. Since a system generally becomes more stable as its heat content decreases, the reaction will normally proceed toward the state having the lower heat content. This results in a negative value for the heat of reaction, corresponding to an evolution of heat during the reaction.

When heat is generated, a reaction is referred to as exothermic, and when heat is absorbed, it is considered endothermic. Exothermic reactions are self-sustaining, once initiated, while endothermic reactions require additional energy if they are to continue.

By simple additions and/or subtractions, the heat involved in any chemical reaction may be determined. Consider the equation for a general reaction:

$$aA + bB \longrightarrow rR + sS.$$

The heat of reaction, ΔH_r, can be calculated by subtracting the algebraic sum of the heat content of the reactants from the algebraic sum of the heat content of the products. Total heat content of each substance participating will be equal to the product of its heat content at a given temperature and the number of atoms or moles participating in the reaction. For the above general reaction, this calculation can be represented empirically:

$$\Delta H_r = [r(H_R) + s(H_S)] - [a(H_A) + b(H_B)].$$

EXAMPLE 2: Determine the heat of reaction for the reduction of dichromium trioxide by calcium at (1) 298° K. and also at (2) 500° K.

Reaction: $Cr_2O_3 + 3\,Ca \longrightarrow 3\,CaO + 2\,Cr$

1. Heat of reaction at 298° K.

$\Delta H_{Cr_2O_3} = -272{,}650$ calories per mole.
$\Delta H_{Ca} = 0$ calories per atom.
$\Delta H_{CaO} = -151{,}790$ calories per mole.
$\Delta H_{Cr} = 0$ calories per atom.

$$\Delta H_{298} = [3(H_{CaO}) + 2(H_{Cr})] - [(H_{Cr_2O_3}) + 3(H_{Ca})]$$
$$= [3(-151{,}790) + 2(0)] - [(-272{,}650) + 3(0)]$$
$$= -455{,}370 + 272{,}650$$
$$= -182{,}720 \text{ calories per mole of } Cr_2O_3.$$

2. Heat of reaction at 500° K.—This can be evaluated by using the heat content, H_T, of each reaction participant, as will now be illustrated, or by simple addition of heats of formation as illustrated in example 3.

Substance	$H_{500}-H_{298}$	ΔH_{298}	$\Delta H_{500}=\Delta H_{298}+(H_{500}-H_{298})$
Cr_2O_3	5,540	−272,650	−267,110
Ca	1,330	0	1,330
CaO	2,230	−151,790	−149,560
Cr	1,280	0	1,280

$$\Delta H_{500}=[3(H_{CaO})+2(H_{Cr})]-[(H_{Cr_2O_3})+3(H_{Ca})]$$
$$=[3(-149,560)+2(1,280)]-[(-267,110)+3(1,330)]$$
$$=-448,680+2,560+267,110-3,990$$
$$=-183,000 \text{ calories per mole of } Cr_2O_3.$$

In the simpler case of the formation of a single compound from its elements,

$$aA+bB\longrightarrow cC,$$

the difference in heat contents,

$$\Delta H_T=c(H_C)-[a(H_A)+b(H_B)],$$

is called the heat of formation. Since the heat content of an element at 298° K. is defined as zero, the heat content of a compound at this base temperature is equal to the heat of formation from its elements at 298° K.

The additive property of heats of reaction has long been known as Hess' principle. Application of this concept permits the determination of the heat of reaction by simple addition or subtraction of heats of formation at any given temperature.

EXAMPLE 3: Determine the heat of reaction for the reduction of dichromium trioxide by calcium at 500° K.

Reaction: $Cr_2O_3+3\ Ca\longrightarrow 3\ CaO+2\ Cr$

1. $3\ Ca+3/2O_2\longrightarrow 3\ CaO$ $\Delta H_{500}=3(-151,650)=-454,950$ calories per 3 moles CaO.
2. $2\ Cr+3/2O_2\longrightarrow Cr_2O_3$ $\Delta H_{500}=-271,850$ calories per mole Cr_2O_3.

Subtracting (2) from (1): $Cr_2O_3+3\ Ca\longrightarrow 3\ CaO+2\ Cr$ $\Delta H_{500}=-183,100$ calories per mole.

HEAT BALANCE

Most unit processes for extracting and refining metals involve a transfer of heat energy to or from the surroundings. The necessity for maintaining optimum temperatures while conducting metallurgical reactions, the requirement for additional energy to sustain endothermic reactions, and the removal of heat energy to condense gaseous products illustrate a few of the processes in which heat transfer plays an important role. The supply and utilization of heat rank in importance with the supply and demand of raw materials when evaluating costs and when determining the feasibility of a process. Accordingly, a system of energy accounting, or heat balance, represents one of the indispensable tools that a metallurgist can use.

The law of conservation of energy is the basis for all heat balance calculations. This can be stated simply for a definite system as follows:

Energy input = energy output + energy accumulation;

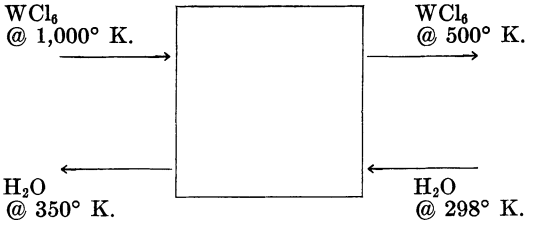
or in terms of heat:

Heat input = heat output + heat accumulation.

The heat balance must be based on an arbitrary fixed quantity, which may be a single batch of material charged into a reactor, a unit quantity of throughput, or the throughput for a fixed time interval.

Since the heat content function is independent of the path of a given process, only data dealing with the initial and final states of a complex process are required. These data consist primarily of the material balance, giving quantities of substances entering and leaving the process, information on the temperatures and physical states of the input and output substances, and a knowledge of any heat transferred to or from the system. With these data, heats of reaction as well as heat contents of all substances involved in a reaction can be evaluated. An accounting of all energy involved in a system can then be determined readily. A schematic diagram of a hypothetical system will facilitate analysis of the problem.

EXAMPLE 4: In the extraction of metals by chlorination, condensers are employed to recover a volatile chloride product. An evaluation of the heat duty on a condenser, and in turn, the evaluation of the cooling water requirements, illustrates the simplest form of a heat balance. Consider the condensation and solidification of 1 mole of tungsten hexachloride (WCl_6) as illustrated in the following diagram:



Heat lost by WCl_6 = Heat gained by water.

Heat lost by WCl_6
$= H_{1,000}-H_{298}=(50,000)$ calories per mole WCl_6,

$= H_{500}-H_{298}=(9,000)$ calories per mole WCl_6.

ΔH lost in cooling = (41,000) calories per mole WCl_6 from 1,000° to 500° K.

Because there are no tabulated values for the heat content of water at the desired temperature (350° K.) the empirical equation shown in

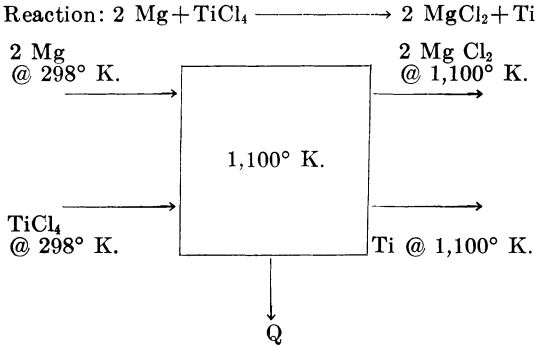
part 2 under Water (p. 54) for Zone 1 must be used:

$H_T - H_{298} = -5{,}376 + 18.03T$
$H_{350} - H_{298} = -5{,}376 + 18.03\ (350) = 934$ calories per mole H_2O.

Heat gained by 1 mole of water when heated from 298° to 350° K.=934 calories. Moles of water required to condense and solidify WCl_6= $\frac{(41{,}000)}{934}$ =43.9 moles H_2O.

A slightly more complex problem is encountered when a chemical reaction takes place within a process.

EXAMPLE 5: In the first stage of the Kroll process for the reduction of titanium tetrachloride by magnesium, temperatures of 1,100° K. are required to promote a reaction between molten magnesium and titanium tetrachloride. Determine the heat requirements for the reactor when the chloride and magnesium are introduced at room temperature, 298° K., and heated to 1,100° K., the reaction temperature.



This evaluation can be accomplished by following any desired path through the process, since the change in heat content is dependent on only the initial and final states. Calculations are often made using either the base temperature, 298° K., or the reaction temperature as the reference temperature. The following calculations illustrate each method:

1. Evaluate the heat input and output with reference to 298° K. The heat of reaction at 298° K. will be calculated as was done from the heats of formation of the compounds. In all calculations it must be remembered that the heat content of elements at 298° K. is zero.

ΔH reaction at 298° K. $= 2(\Delta H_{MgCl_2}$ at 298° K.$) - \Delta H_{TiCl_4}$ at 298° K.
$= 2(-153{,}200) - (-181{,}400)$
$= -125{,}000$ calories per mole $TiCl_4$.

Since the heat of reaction is negative, the reaction is exothermic; consequently, heat of reaction is a heat input term.

Heat balance: Heat input=heat output; Basis: 1 mole $TiCl_4$ reacting.

Heat input:

a. Reactants: Since each reactant is at 298° K., there will be no heat input due to the reactants.

b. Heat of reaction: −125,000 calories. Since the heat of reaction is exothermic, heat will be added to the system. Total heat input=125,000 calories.

Heat output:

a. Products: Titanium, $H_{1,100} - H_{298}$=5,630 calories; magnesium dichloride, $2(H_{1,100} - H_{298})$ =2(25,950)=51,900 calories.

b. Heat loss: Q. Total heat output=57,500 +Q. Since heat input=heat output, 125,000 =57,500+Q and Q=67,500 calories per mole of $TiCl_4$ reacted.

2. Evaluate the heat input and output with reference to the reaction temperature, 1,100° K. The heat of reaction at 1,100° K. will be calculated using heats of formation at 1,100° K.

ΔH reaction at 1,100° K. $= 2(\Delta H_{MgCl_2}$ at 1,100° K.$) - \Delta H_{TiCl_4}$ at 1,100° K.
$= 2(-141{,}750) - (-180{,}900)$
$= -102{,}600$ calories per mole.

The reaction is also exothermic at this elevated temperature; accordingly, the heat of reaction is a heat input term.

Heat input:

a. Reactants: Although the reactants are introduced into the process, their heat inputs are negative values because their temperatures are below the reference temperature of 1,100° K. Titanium tetrachloride: $H_{298} - H_{1,100} = -19{,}965$ calories; magnesium: $H_{298} - H_{1,100} = 2(-7{,}700)$ $= -15{,}400$ calories.

b. Heat of reaction: 102,600 calories. Total heat input=102,600−35,400=67,200 calories.

Heat output:

a. Products: Since each product is at the reference temperature, there will be no heat taken out by the products.

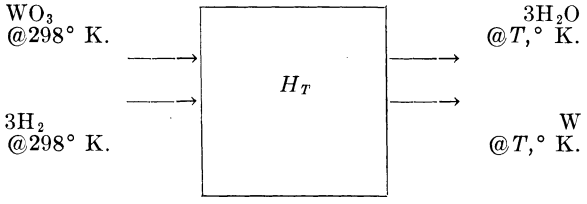
b. Heat loss: Q. Total heat output=Q. Since heat input=heat output, Q=67,200 calories per mole of $TiCl_4$ reacted.

The slight variation in answers is due to rounding off of all heat-of-formation values in order to report them only to their known reliability.

Another heat balance problem which commonly arises is the evaluation of the final temperature of the products when the reactor is assumed to be adiabatic (that is, insulated in a manner that eliminates any heat transfer in or out of the system) or when the heat input or removal is known.

EXAMPLE 6: Tungsten trioxide (WO_3) is reduced by hydrogen to tungsten metal when the reaction is conducted above 700° C. Determine whether the products produced in an electrically heated furnace are above the minimum 700° C. if 60,000 calories are added to the system for each mole of WO_3 reduced.

Reaction: $WO_3 + 3H_2 \longrightarrow W + 3H_2O$



60,000 calories

Since the reaction temperature is unknown, a reference temperature of 298° K. will be used. Heat of reaction at 298° K. will be calculated from heats of formation. The heat of formation for elements at their standard state is zero.

$$\begin{aligned}\Delta H_{298} &= 3(\Delta H_{H_2O}) - \Delta H_{WO_3} \\ &= 3(-68{,}320) - (-200{,}850) \\ &= -204{,}950 + 200{,}850 \\ &= -4{,}100 \text{ calories per mole } WO_3.\end{aligned}$$

Once again, the reaction is exothermic and the heat of reaction is a heat input term.

Heat balance: Heat input = heat output; basis: 1 mole of WO_3.

Heat input:

1. Reactants: Since each reactant is at the reference temperature, 298° K., there will be no heat input due to the reactants.
2. Heat of reaction: 4,100 calories.
3. Electrical input: 60,000 calories. Total heat input = 64,100 calories.

Heat output:

Products: Each product will carry out heat at the unknown temperature, T. From the equation for the reaction, the total heat output will be equal to three times the heat content of water plus the heat content of tungsten. It will equal the total heat input.

$$64{,}100 = 3(H_T - H_{298})H_2O + (H_T - H_{298})W.$$

The evaluation of the temperature requires a trial-and-error solution, assuming various temperatures until the correct temperature balances the above equation.

T,° K.	$3(H_T - H_{298})H_2O + (H_T - H_{298})W$	Total heat output
1,100	3(17,735)+5,010	58,200
1,200	3(18,768)+5,670	62,000
1,300	3(19,830)+6,340	65,800

The products will leave the reactor at a temperature between 1,200° and 1,300° K.

FREE ENERGY

The thermodynamic function which provides the means to evaluate the feasibility of a given chemical reaction under specified conditions is free energy. Any reaction or process that takes place is accompanied by a change in the free energy of the system, and this change is equal to the mechanical work done by or absorbed during the process. The magnitude of the change in free energy becomes a measure of the tendency for the reaction to proceed under stipulated conditions.

For the general chemical reaction,

$$aA + bB \longrightarrow rR + sS,$$

the change in free energy at a given temperature and pressure is given by the van't Hoff reaction isotherm,

$$\Delta F_T = -RT \ln K + RT \ln \frac{a_R^r \, a_S^s}{a_A^a \, a_B^b},$$

where K is the equilibrium constant of the reaction and a_R, a_S, a_A, and a_B are the activities of the various products and reactants at the given temperature, T. By definition, the activity of a pure liquid, solid, or gas is equal to unity. When all of the reactants and products are in their pure standard state, that is, all activities are unity, the change in the free energy is termed the standard free-energy change, ΔF_T°. The isotherm relationship becomes

$$\Delta F_T^\circ = -RT \ln K,$$

and for the van't Hoff reaction isotherm,

$$\Delta F_T = \Delta F_T^\circ + RT \ln \frac{a_R^r \, a_S^s}{a_A^a \, a_B^b}.$$

The direct relationship between the free-energy change and the equilibrium constant, K, is valid only when all of the activities are unity; that is, all reactants and products are in their pure state. In cases involving solutions, the activity correction factor should be considered. Since there is very little information available on the activities of substances in solution at high temperatures, it is generally necessary to assume that the activities of each component in liquid or solid solutions are equal to their mole fractions, and the activities of the components in gases are equal to their partial pressure.

Calculations involving free-energy changes are most frequently made to assess the feasi-

bility of chemical reactions. The simplest interpretation of the free-energy change is that reactions resulting in a loss of free energy are thermodynamically possible and are likely to proceed farther toward completion as the change in free energy becomes increasingly negative in value. It is important to emphasize that the free-energy change accounts only for the driving energy available and cannot predict the resistances to a particular reaction or process. Therefore, it is impossible to predict the reaction rates by the free-energy change.

When the free-energy change is zero, the reactants are in equilibrium with the products and the constant, K, becomes equal to the activity factor or equal to unity, if standard state activities are assumed. A positive change in free energy indicates a tendency for the reaction to go in the reverse direction to that in which it is written. If the free-energy change is more positive then 8,000 to 10,000 calories, there is a general tendency to dismiss the process as thermodynamically impossible under the conditions specified. Altering the conditions to operate at different temperatures, or at either higher or lower pressures, could alter the feasibility of the process. In addition, subsidiary reactions might alter the energy balance so as to bring it within the prescribed limits.

The free-energy change during a process is related to the heat content or enthalpy change by the following equation:

$$\Delta F_T = \Delta H_T - T\Delta S_T.$$

This empirical relationship states that the energy available for mechanical work is equal to the total heat energy evolved or absorbed less a term, $T\Delta S_T$, which accounts for energy lost due to irreversible factors such as friction. This latter term is a product of the temperature at which the process takes place and the change in entropy which occurs with the process. Because this bulletin is limited in scope, no attempt will be made to present a complete description of entropy or the second law of thermodynamics. In simple terms a change in entropy may be considered as a measure of the unavailability of energy in a system for performing useful work. An increase in entropy, therefore, would correspond to an increase in the unavailable energy in a system. Quantitatively, a change in entropy in any system is measured by the heat absorbed or evolved reversibly divided by the absolute temperature.

Since the change in heat content and entropy can be expressed directly in terms of heat capacity and temperature, an empirical equation may be written for the free-energy change:

$$\Delta F_T = \left[\Delta H_{298} + \int_{298}^{T} \Delta C_p dT\right] - T\left[\Delta S_{298} + \int_{298}^{T} \frac{\Delta C_p dT}{T}\right]$$

As in the case of heat content and the heat of formation, empirical equations and tabulations have been prepared for each substance to relate the free-energy change values and temperature.

The free-energy change for a given reaction can also be evaluated by simple arithmetic calculations, using values for the free energy of formation for each compound involved. This determination is identical to the heat-of-reaction calculation involving heats of formation. For the general chemical equation,

$$aA + bB \longrightarrow rR + sS,$$

the free-energy change due to the reaction is determined from the empirical relationship,

$$\Delta F_T = [r(\Delta F_R) + s(\Delta F_S)] - [a(\Delta F_A) + b(\Delta F_B)].$$

There is no free energy of formation for the elements.

The free-energy function is independent of the path of a given process. Accordingly, a knowledge of the initial and final states of a complex process or reaction permits the evaluation of the free-energy changes resulting from the process or reaction.

Probably the most important application of thermochemical calculations in extractive metallurgy involves the evaluation of the thermodynamic feasibility of a proposed reaction and the operating conditions under which the reaction should proceed.

EXAMPLE 7: When preparing yttrium metal, yttrium halides are reduced with active metals. Determine whether calcium and/or magnesium can be used as reducing agents if the reaction is conducted under 1 atmosphere pressure. If the reaction is feasible, evaluate the temperature range in which the reaction can be conducted.

The free-energy change associated with each reaction will be calculated, using the free energy of formation for each of the participating compounds.

1. Magnesium reduction:

$$3\ Mg + 2\ YCl_3 \longrightarrow 3\ MgCl_2 + 2Y.\quad \Delta F^\circ_T \text{ reaction} = 3(\Delta F^\circ_{MgCl_2}) - 2(\Delta F^\circ_{YCl_3}).$$

Products − Reactants = Reaction

T, ° K.	Products		Reactants		Reaction, ΔF°_T
	$\Delta F^\circ_{MgCl_2}$	$3(\Delta F^\circ_{MgCl_2})$	$\Delta F^\circ_{YCl_3}$	$2(\Delta F^\circ_{YCl_3})$	
298	−141,400	−424,200	(−215,200)	(−430,400)	(+6,200)
500	−133,500	−400,500	(−206,200)	(−412,400)	(+11,900)
1,000	−115,150	−345,500	(−183,700)	(−367,400)	(+21,900)
1,500	−99,650	−299,000	(−163,700)	(−327,400)	(+28,400)

Employing estimated free-energy values for yttrium trichloride, the magnesium reduction

does not seem to be feasible.

2. Calcium reduction:

$$3\,Ca+2\,YCl_3 \longrightarrow 3\,CaCl_2+2Y. \quad \Delta F^\circ_T \text{ reaction} = 3(\Delta F^\circ_{CaCl_2}) - 2(\Delta F^\circ_{YCl_3})$$

Products − Reactants = Reaction

T, ° K.	Products		Reactants		Reaction, ΔF°_T
	$\Delta F^\circ_{CaCl_2}$	$3(\Delta F^\circ_{CaCl_2})$	$\Delta F^\circ_{YCl_3}$	$2(\Delta F^\circ_{YCl_3})$	
298	−179,650	−538,900	(−215,200)	(−430,400)	(−108,500)
500	−172,500	−517,500	(−206,200)	(−412,400)	(−105,100)
1,000	−155,700	−467,100	(−183,700)	(−367,400)	(−100,000)
1,500	−142,400	−427,200	(−163,700)	(−327,400)	(−100,000)

The calcium reduction seems to be feasible over the entire temperature range. The optimum operating temperature must be determined by the kinetics involved. Operating temperatures greater than 1,055° K. are required to prevent the solidification of calcium dichloride, which might be expected to hinder the reaction.

When unit activities for the reactants and products can be assumed, the free-energy function is directly related to the equilibrium constant by the relationship:

$$\Delta F^\circ_T = -RT\,ln\,K.$$

Since the equilibrium constant, K, is defined in terms of the concentrations of substances participating in the reaction, the free-energy change can be used to evaluate the relationship existing between the equilibrium partial pressures of the gaseous participants. Consider the reduction of a metallic oxide:

$$MO_{x(c)} + R_{(c)} \longrightarrow xRO_{(g)} + M_{(c)}$$

The equilibrium constant, K, in terms of pressure will be

$$K_p = (P_{RO})^x.$$

Combining these two relations:

$$\Delta F^\circ_T = -RT\,ln\,(P_{RO})^x.$$

This relationship can be used to evaluate the pressure under which the reaction can be made to proceed.

EXAMPLE 8: Determine the equilibrium pressure of carbon dioxide when lead oxide is reduced by carbon at 1,000° K. according to the following reaction:

$$2PbO + C \longrightarrow Pb + CO_2$$

$$\Delta F^\circ_{\text{Reaction}} \text{ at } 1{,}000^\circ \text{ K.} = (\Delta F)^\circ_{CO_2} - 2(\Delta F^\circ_{PbO}) = (-94{,}600) - 2(-28{,}250) = -38{,}100 \text{ calories.}$$

The equilibrium constant, K, can be evaluated as follows:

$$\Delta F^\circ_{1,000} = -RT\,ln\,K,$$

$$ln\,K = \frac{-38{,}100}{-(1.987)(1{,}000)} = 19.18,$$

$$K = 2.14 \times 10^8.$$

Since carbon dioxide is the only gaseous participant at 1,000° K., the equilibrium constant, K, will be equal to the equilibrium pressure of carbon dioxide; that is, $P_{CO_2} = 2.14 \times 10^8$ atmospheres. It is obvious that the reaction can be conducted by operating below this pressure.

EXAMPLE 9: Evaluate the equilibrium partial pressure of carbon monoxide during the carbon reduction of dichromium trioxide at 1,400° K. according to the following reaction:

$$Cr_2O_3 + 3C \longrightarrow 2Cr + 3CO$$

$$\Delta F^\circ_{\text{Reaction}} \text{ at } 1{,}400^\circ \text{ K} = 3(\Delta F^\circ_{CO}) - (\Delta F^\circ_{Cr_2O_3}) = 3(-56{,}250) - (-185{,}050) = +16{,}300 \text{ calories;}$$

$$ln K = -\frac{\Delta F^\circ_{1,000}}{RT} = \frac{-16{,}300}{(1{,}987)(1{,}400)} = -5.87$$

$$K = 2.78 \times 10^{-3}.$$

This equilibrium constant is directly related to the equilibrium pressure of carbon monoxide:

$$K = (P_{CO})^3$$

$$P_{CO} = 0.14 \text{ atmosphere.}$$

These results indicate that dichromium trioxide can be reduced by carbon at 1,400° K. only when the partial pressure of carbon monoxide over the reaction is less than 0.14 atmosphere. This can be accomplished by operating under vacuum or by removing continuously the carbon monoxide produced in the reaction in a stream of inert gas.

Since the free-energy function measures the energy available to accomplish work during a process, it can be used to evaluate the electromotive force in an electrolytic cell.

$$\Delta F^\circ_T = -N\mathfrak{F}\mathcal{E}$$

Where $\mathfrak{F}$ is the Faraday and N is the number of electrical equivalents involved, $N\mathfrak{F}$ becomes the number of coulombs that pass if the reaction proceeds to completion and $\mathcal{E}$ is the electromotive force. With ΔF°_T expressed in calories and $\mathcal{E}$ in volts, the above equation becomes

$$\Delta F^\circ_T = -N23{,}062\mathcal{E}.$$

EXAMPLE 10: Evaluate the electromotive force required to decompose magnesium dichloride at 1,000° K.

$$\text{Reaction: } MgCl_2 \longrightarrow Mg + Cl_2$$

Because the charge on magnesium changes from +2 to 0,

$$\Delta F^\circ \text{reaction at } 1{,}000^\circ \text{ K.} = -(\Delta F^\circ_{MgCl_2}) = 115{,}150 \text{ calories}$$

$$\Delta F^\circ_{1,000} = -N(23{,}062)\mathcal{E}$$

$$115{,}150 = -(2)(23{,}062)\mathcal{E}$$

$$\mathcal{E}^\circ = -2.496 \text{ abs. volts.}$$

PART 2.—HEAT CONTENT, HEAT-OF-FORMATION AND FREE-ENERGY DATA

In the following pages are assembled tabular data and graphs of thermodynamic values for 65 elements, and their known oxides, halides, carbides, and nitrides. All data and equations are in terms of calorie-gram mole-° K. units. The tabular values incorporate a base temperature of 298.15° K. (25° C.). To avoid any possible confusion, the state of reference at this chosen base temperature is indicated specifically in each tabular heading.

In compiling these tabulations, data published previously by Kelley (*79–84*), Brewer (*6–9, 11, 12*), Coughlin (*24*), Stull (*130*), and Rossini, Wagman, Evans, Levine, and Jaffe (*112*) were of particular importance.

ALUMINUM AND ITS COMPOUNDS

Element, Al (*c*)

$S_{298}=6.77$ *e.u.*(*83*)

$M.P.=931.7°$ K.(*82*)

$\Delta H_M=2{,}570$ calories per atom

$B.P.=2{,}600°$ K.(*130*)

$\Delta H_V=67{,}950$ calories per atom

Zone I (*c*) (298°–931.7° K.)

$$C_p=4.94+2.96\times10^{-3}T(82)$$

$$H_T-H_{289}=-1{,}605+4.94T+1.48\times10^{-3}T^2$$

$$F_T-H_{289}=-1{,}605-4.94T\ln T-1.48\times10^{-3}T^2+27.19T$$

Zone II (*l*) (931.7°–1,300° K.)

$$C_p=7.00(82)$$

$$H_T-H_{298}=330+7.00T$$

$$F_T-H_{298}=330-7.00T\ln T+37.83T$$

Zone III (*l*) (1,300°–2,500° K.) (estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		6.77	6.77
400	600	8.49	6.99
500	1,230	9.91	7.45
600	1,890	11.11	7.96
700	2,580	12.17	8.48
800	3,310	13.15	9.01
900	4,060	14.03	9.53
1,000	7,330	17.53	10.20
1,100	8,030	18.19	10.89
1,200	8,730	18.80	11.52
1,300	9,430	19.36	(12.11)
1,400	(10,130)	(19.88)	(12.64)
1,500	(10,830)	(20.32)	(13.43)
1,600	(11,530)	(20.81)	(13.59)
1,700	(12,230)	(21.24)	(14.06)
1,800	(12,930)	(21.64)	(14.44)
1,900	(13,630)	(22.02)	(14.84)
2,000	(14,330)	(22.32)	(15.15)
2,500	(17,830)	(23.94)	(16.80)

Dialuminum Oxide, Al_2O (*g*)

$\Delta H^\circ_{298}=(-33{,}500)$ calories per mole (*8*)
$S_{298}=(68.2)$ *e.u.* (*24*)

Formation: $2Al+1/2O_2 \longrightarrow Al_2O$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−33,500	−42,500
400	(560)	(−34,500)	(−45,000)
500	(1,690)	(−35,000)	(−48,000)
600	(2,880)	(−35,500)	(−50,500)
700	(4,150)	(−36,000)	(−53,000)
800	(5,010)	(−37,000)	(−55,000)
900	(7,420)	(−36,500)	(−57,500)
1,000	(7,875)	(−43,000)	(−59,000)
1,100	(9,160)	(−43,500)	(−60,500)
1,200	(10,480	(−44,000)	(−62,000)
1,300	(11,800)	(−44,500)	(−63,500)
1,400	(13,120)	(−45,000)	(−65,000)
1,500	(14,500)	(−45,500)	(−66,500)
1,600	(15,780)	(−46,000)	(−68,000)
1,700	(17,130)	(−46,500)	(−69,500)
1,800	(18,470)	(−47,000)	(−70,500)

Aluminum Oxide, AlO (*g*)

$\Delta H^\circ_{298}=10{,}000$ calories per mole (*8*)
$S_{298}=51.40$ *e.u.* (*24*)

Formation: $Al+1/2O_2 \longrightarrow AlO$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298	----------	10,000	+4,000
400	(460)	(9,500)	(1,500)
500	(1,260)	(9,500)	(−500)
600	(2,000)	(9,000)	(−2,000)
700	(2,870)	(9,000)	(−4,000)
800	(3,700)	(8,500)	(−6,000)
900	(4,660)	(8,500)	(−8,000)
1,000	(5,550)	(5,500)	(−9,500)
1,100	(6,430)	(5,500)	(−11,000)
1,200	(7,250)	(5,000)	(−12,500)
1,300	(8,170)	(5,000)	(−14,000)
1,400	(9,000)	(4,500)	(−15,000)
1,500	(9,970)	(4,500)	(−16,500)
1,600	(10,750)	(4,000)	(−18,000)
1,700	(11,600)	(4,000)	(−19,500)
1,800	(12,500)	(3,500)	(−21,000)

Dialuminum Trioxide (Alumina), Al_2O_3 (c)

$\Delta H^\circ_{298}=-400{,}290$ calories per mole (*53*)
$S_{298}=12.16$ *e.u.* (*87*)
$M.P.=2{,}313°$ K.(*112*)
$\Delta H_M=26{,}000$ calories per mole

Zone I (*c*) (298°–1,800° K.)

$$C_p=27.43+3.06\times10^{-3}T-8.47\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-11{,}155+27.43T+1.53\times10^{-3}T^2+8.47\times10^{5}T^{-1}$$

Formation: $2Al+3/2O_2\longrightarrow Al_2O_3$

Zone I (298°–931.7° K.)

$$\Delta C_p=6.81-4.3\times610^{-3}T-7.87\times10^{5}T^{-2}$$
$$\Delta H_T=-405{,}200+6.81T-2.18\times10^{-3}T^2+7.87\times10^{5}T^{-1}$$
$$\Delta F_T=-405{,}200-6.81T\ln T+2.18\times10^{-3}T^2+3.93\times10^{5}T^{-1}+123.58T$$

Zone II (931.7°–1,300° K.)

$$\Delta C_p=2.69+1.56\times10^{-3}T-7.87\times10^{5}T^{-2}$$
$$\Delta H_T=-408{,}660+2.69T+0.78\times10^{-3}T^2+7.87\times10^{5}T^{-1}$$
$$\Delta F_T=-408{,}660-2.69T\ln T-0.78\times10^{-3}T^2+3.93\times10^{5}T^{-1}+102.38T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	12.16	−400,300	−378,000
400	2,200	18.48	−400,400	−370,300
500	4,600	23.83	−400,300	−362,800
600	7,220	28.60	−400,200	−355,300
700	9,990	32.86	−399,900	−347,800
800	12,840	36.67	−399,700	−340,400
900	15,750	40.08	−399,500	−332,900
1,000	18,710	43.22	−404,400	−325,200
1,100	21,710	46.07	−404,000	−317,200
1,200	24,740	48.71	−403,600	−309,400
1,300	27,790	51.15	−403,200	−301,500
1,400	30,850	53.42	(−402,800)	(−293,800)
1,500	33,920	55.54	(−402,500)	(−286,100)
1,600	37,000	57.52	(−402,000)	(−278,100)
1,700	40,090	59.39	(−401,700)	(−270,600)
1,800	43,190	61.17	(−401,300)	(−263,100)

Aluminum Fluoride, AlF (c)

$\Delta H^\circ_{298}=(-84{,}000)$ calories per mole (*11*)
$S_{298}=(12)$ *e.u.* (*11*)
$M.P.=(1{,}100°)$ K. (*6*)
$\Delta H_M=5{,}000$ calories per mole
$B.P.=1{,}650°$ K. (*6*)
$\Delta H_V=38{,}000$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p=8.9-1.45\times10^{5}T^{-2}\ (82)$$

Aluminum Trifluoride, AlF_3 (c)

$\Delta H^\circ_{298}=-323{,}000$ calories per mole (*11*)
$S_{298}=23.8$ *e.u.* (*11*)
$S.P.=1{,}545°$ K. (*6*)
$\Delta H_{subl}=77{,}000$ calories per mole

Zone I (*c*) (298°–1,100° K.)

$$C_p=15.64+11.28\times10^{-3}T\ (82)$$
$$H_T-H_{298}=-5{,}164+15.64T+5.64\times10^{-3}T^2$$

Formation: $Al+3/2F_2\longrightarrow AlF_3$

Zone I (298°–931.7° K.)

$$\Delta C_p=-1.73+7.66\times10^{-3}T+1.20\times10^{5}T^{-2}$$
$$\Delta H_T=-322{,}400-1.73T+3.83\times10^{-3}T^2-1.20\times10^{5}T^{-1}$$
$$\Delta F_T=-322{,}400+1.73T\ln T-3.83\times10^{-3}T^2-0.60\times10^{5}T^{-1}+45.83T$$

Zone II (931.7°–1,100° K.)

$$\Delta C_p=-3.79+10.62\times10^{-3}T+1.20\times10^{5}T^{-2}$$
$$\Delta H_T=-323{,}500-3.79T+5.31\times10^{-3}T^2-1.20\times10^{5}T^{-1}$$
$$\Delta F_T=-323{,}500+3.79T\ln T-5.31\times10^{-3}T^2-0.60\times10^{5}T^{-1}+34.32T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	23.8	−323,000	−306,400
400	1,980	29.51	−322,800	−300,700
500	4,050	34.12	−322,550	−295,200
600	6,250	38.12	−322 400	−289,900
700	8,620	41.78	−321,850	−284,400
800	11,060	45.04	−321,450	−279,100
900	13,510	47.93	−321,000	−273,800
1,000	15,980	50.52	−322,100	−268,300
1,100	18,500	52.92	−322,600	−252,900

Aluminum Trichloride, $AlCl_3$ (c)

$\Delta H^\circ_{298}=-166{,}800$ calories per mole (*11*)
$S_{298}=40.5$ *e.u.* (*11*)
$M.P.=465.6°$ K. (*6*)
$\Delta H_M=8{,}500$ calories per mole
$B.P.=720°$ K. (*6*)
$\Delta H_V=15{,}610$ calories per mole

Zone I (*c*) (298°–465.6° K.)

$$C_p=13.25+28.00\times10^{-3}T\ (82)$$
$$H_T-H_{298}=-5{,}195+13.25T+14.00\times10^{-3}T^2$$

Zone II (*l*) (465.6°–720° K.)

$$C_p=31.2\ (82)$$
$$H_T-H_{298}=-2{,}020+31.2T$$

Zone III (*g*) (720°–1,800° K.)

$$C_p=19.8-2.69\times10^{5}T^{-2}\ (94)$$
$$H_T-H_{298}=20{,}320+19.8T+2.69\times10^{5}T^{-1}$$

Formation: $Al+3/2Cl_2\longrightarrow Al\ Cl_3$

Zone I (298°–466° K.)

$$\Delta C_p=-4.92+24.95\times10^{-3}T+1.02\times10^{5}T^{-2}$$
$$\Delta H_T=-166{,}100-4.92T+12.47\times10^{-3}T^2-1.02\times10^{5}T^{-1}$$
$$\Delta F_T=-166{,}100+4.92T\ln T-12.47\times10^{-3}T^2-0.51\times10^{5}T^{-1}+20.31T$$

Zone II (466°–720° K.)

$$\Delta C_p=13.03-3.05\times10^{-3}T+1.02\times10^{5}T^{-2}$$
$$\Delta H_T=-163{,}000+13.03T-1.52\times10^{-3}T^2-1.02\times10^{5}T^{-1}$$

$\Delta F_T = -163{,}000 - 13.03 T \ln T + 1.52 \times 10^{-3} T^2 - 0.51 \times 10^5 T^{-1} + 118.0 T$

Zone III (720°–931.7° K.)

$\Delta C_p = 1.63 - 3.05 \times 10^{-3} T - 1.67 \times 10^5 T^{-2}$
$\Delta H_T = -140{,}500 + 1.63 T - 1.52 \times 10^{-3} T^2 + 1.65 \times 10^5 T^{-1}$
$\Delta F_T = -140{,}500 - 1.63 T \ln T + 1.52 \times 10^{-3} T^2 + 0.83 \times 10^5 T^{-1} + 9.48 T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		40.5	−166,800	−153,000
400	2,340	47.23	−166,300	−148,300
500	13,580	71.58	−157,000	−144,500
600	16,700	75.3	−155,800	−141,000
700	19,820	80.0	−154,700	−138,600
800	36,490	105.0	−140,000	−140,700
900	38,440	107.3	−140,200	−141,000
1,000	40,390	109.5	−142,400	−141,200
1,100	42,340	111.3	−142,700	−141,800
1,200	44,300	112.9	−143,000	−142,300
1,300	46,275	114.5	−142,900	−143,000
1,400	48,230	115.9	(−143,100)	(−143,800)
1,500	50,200	117.3	(−143,400)	(−144,600)
1,600	52,170	118.5	(−142,700)	(−145,300)
1,700	54,140	119.7	(−143,900)	(−146,000)
1,800	56,110	120.9	(−144,100)	(−146,500)

Aluminum Tribromide, $AlBr_3$ (*c*)

$\Delta H^\circ_{298} = -127{,}000$ calories per mole (*11*)
$S_{298} = (49)$ *e.u.* (*11*)
$M.P. = 370.6°$ K. (*82*)
$\Delta H_M = 2{,}710$ calories per mole
$B.P. = 739°$ K. (*6*)
$\Delta H_V = 16{,}080$ calories per mole

Zone I (*c*) (298°–370.6° K.)

$C_p = 18.74 + 18.66 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -6{,}420 + 18.74 T + 9.33 \times 10^{-3} T^2$

Zone II (*l*) (370.6°–500° K.)

$C_p = 29.5$ (*82*)
$H_T - H_{298} = -6{,}410 + 29.5 T$

Formation: $Al + 3/2 Br_2 \longrightarrow AlBr_3$

Zone I (298°–331° K.)

$\Delta C_p = -11.85 + 15.7 \times 10^{-3} T$
$\Delta H_T = -124{,}200 - 11.85 T + 7.85 \times 10^{-3} T^2$
$\Delta F_T = -124{,}200 + 11.85 T \ln T - 7.85 \times 10^{-3} T^2 - 62.35 T$

Zone II (331°–500° K.)

$\Delta C_p = 11.0 - 2.96 \times 10^{-3} T + 0.55 \times 10^5 T^{-2}$
$\Delta H_T = -139{,}200 + 11.0 T - 1.48 \times 10^{-3} T^2 - 0.55 \times 10^5 T^{-1}$
$\Delta F_T = -139{,}200 - 11.0 T \ln T + 1.48 \times 10^{-3} T^2 - 0.27 \times 10^5 T^{-1} + 114.2 T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T	ΔF_T
298		(49.0)	−127,000	(−123,300)
400	5,390	(64.0)	−135,200	(−119,800)
500	8,340	(70.58)	−134,200	(−116,000)

Aluminum Triiodide, AlI_3 (*c*)

$\Delta H^\circ_{298} = -74{,}400$ calories per mole (*21*)
$S_{298} = (46)$ *e.u.* (*21*)
$M.P. = 464°$ K. (*82*)
$\Delta H_M = 3{,}980$ calories per mole
$B.P. = 695°$ K. (*6*)
$\Delta H_V = 18{,}500$ calories per mole

Zone I (*c*) (298°–464° K.)

$C_p = 16.88 + 22.66 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -6{,}040 + 16.88 T + 11.33 \times 10^{-3} T^2$

Zone II (*l*) (464°–500° K.)

$C_p = 29.0$ (*82*)
$H_T - H_{298} = -5{,}250 + 29.0 T$

Formation: $Al + 3/2 I_2 \longrightarrow AlI_3$

Zone I (298°–386.8° K.)

$\Delta C_p = -2.44 + 1.85 \times 10^{-3} T$
$\Delta H_T = -73{,}800 - 2.44 T + 0.92 \times 10^{-3} T^2$
$\Delta F_T = -73{,}800 + 2.44 T \ln T - 0.92 \times 10^{-3} T^2 - 13.24 T$

Zone II (386.8°–464° K.)

$\Delta C_p = -16.86 + 19.7 \times 10^{-3} T$
$\Delta H_T = -68{,}600 - 16.86 T + 9.85 \times 10^{-3} T^2$
$\Delta F_T = -68{,}600 + 16.86 T \ln T - 9.85 \times 10^{-3} T^2 - 19.76 T$

Zone III (464°–500° K.)

$\Delta C_p = 10.73 - 2.96 \times 10^{-3} T$
$\Delta H_T = -73{,}000 + 10.73 T - 1.48 \times 10^{-3} T^2$
$\Delta F_T = -73{,}000 - 10.73 T \ln T + 1.48 \times 10^{-3} T^2 + 65.13 T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T	ΔF_T
298		(46.0)	−74,400	(−73,600)
400	2,525	(53.26)	−73,500	(−73,400)
500	9,250	(67.97)	−68,200	(−73,400)

Tetraaluminum Tricarbide, Al_4C_3 (*c*)

$\Delta H^\circ_{298} = -39{,}900$ calories per mole (*9*)
$S_{298} = 25.2$ *e.u.* (*9*)

Zone I (*c*) (298°–600° K.)

$C_p = 24.08 + 31.6 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -8{,}585 + 24.08 T + 15.8 \times 10^{-3} T^2$

Formation: $4Al + 3C \longrightarrow Al_4C_3$

Zone I (298°–600° K.)

$\Delta C_p = -8.02 + 16.7 \times 10^{-3} T + 6.30 \times 10^5 T^{-2}$
$\Delta H_T = -36{,}150 - 8.02 T + 8.35 \times 10^{-3} T^2 - 6.30 \times 10^5 T^{-1}$
$\Delta F_T = -36{,}150 + 8.02 T \ln T - 8.35 \times 10^{-3} T^2 - 3.15 \times 10^5 T^{-1} - 46.2 T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		25.2	−39,900	−38,100
400	3,560	35.5	−39,500	−37,600
500	7,430	44.1	−39,100	−37,150
600	11,530	51.55	−38,800	−36,800

Aluminum Nitride, AlN (*c*)

$\Delta H°_{298} = -64{,}000$ calories per mole (*9*)
$S_{298} = 3.8$ *e.u.* (*9*)
$M.P. = 2{,}500°$ K. (*9*)

Zone I (*c*) (298°–900° K.)

$$C_p = 5.47 + 7.80 \times 10^{-3} T \ (82)$$
$$H_T - H_{298} = -1{,}980 + 5.47T + 3.90 \times 10^{-3} T^2$$

Formation: $Al + 1/2\ N_2 \longrightarrow AlN$

Zone I (298°–900° K.)

$$\Delta C_p = -2.8 + 4.33 \times 10^{-3} T$$
$$\Delta H_T = -63{,}400 - 2.8T + 2.16 \times 10^{-3} T^2$$
$$\Delta F_T = -63{,}400 + 2.8T \ln T - 2.16 \times 10^{-3} T^2 + 8.4T$$

T, ° K.	$H_T - H_{298}$	S_T	$\Delta H°_T$	$\Delta F°_T$
298		3.8	−64,000	−56,300
400	600	6.19	−64,100	−53,600
500	1,230	8.24	−64,200	−51,000
600	1,890	10.04	−64,200	−48,300
700	2,580	11.64	−64,200	−45,700
800	3,310	13.1	−64,200	−43,200
900	4,060	14.46	−64,200	−40,400

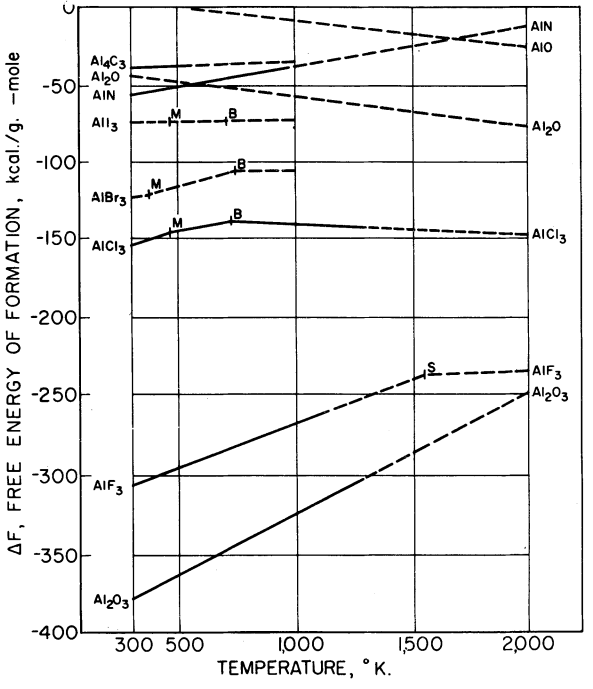


FIGURE 1.—Aluminum.

ANTIMONY AND ITS COMPOUNDS

Element, Sb (*c*)

$S_{298} = 10.5$ *e.u.* (*83*)
$M.P. = 903°$ K. (*82*)
$\Delta H_M = 4{,}740$ calories per atom
$B.P. = 1{,}713°$ K. (*112*)
$\Delta H_V = (46{,}700)$ calories per atom (*94*)

Zone I (*c*) (298°–903° K.)

$$C_p = 5.5i + 1.74 \times 10^{-3} T \ (82)$$
$$H_T - H_{298} = -1{,}720 + 5.51T + 0.87 \times 10^{-3} T^2$$
$$F_T - H_{298} = -1{,}720 - 5.51T \ln T - 0.87 \times 10^{-3} T^2 + 26.93T$$

Zone II (*l*) (903°–1,300° K.)

$$C_p = 7.50 \ (82)$$
$$H_T - H_{298} = +1{,}940 + 7.50T$$
$$F_T - H_{298} = +1{,}940 - 7.50T \ln T + 35.62T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		10.5	10.5
400	625	12.3	10.75
500	1,250	13.69	11.20
600	1,890	14.86	11.71
700	2,550	15.88	12.24
800	3,240	16.80	12.75
900	3,950	17.64	13.26
1,000	9,440	23.68	14.24
1,100	10,190	24.39	15.12
1,200	10,940	25.04	15.92
1,300	11,690	25.64	16.65
1,400	(12,440)	(26.2)	(17.26)
1,500	(13,190)	(26.8)	(17.91)
1,600	(13,940)	(27.3)	(18.47)
1,700	(14,690)	(27.8)	(19.01)
1,800		(28.9)	(20.35)
1,900		(29.3)	(20.80)
2,000		(39.3)	(21.43)

Diantimony Trioxide (Orthorhombic), Sb_2O_3 (*c*)

$\Delta H°_{298} = -168{,}500$ calories per mole (*113*)
$S_{298} = 29.4$ *e.u.* (*83*)
$M.P. = 928°$ K. (*24*)
$\Delta H_M = 13{,}500$ calories per mole
$B.P. = 1{,}698°$ K. (*24*)
$\Delta H_V = 8{,}910$ calories per mole

Zone I (*c*) (298°–929° K.)

Estimated equation:
$$C_p = 19.1 + 17.1 \times 10^{-3} T \ (82)$$
$$H_T - H_{298} = -6{,}450 + 19.1T + 8.55 \times 10^{-3} T^2$$

Formation: $2Sb + 3/2O_2 \longrightarrow Sb_2O_3$

(estimated (*24*))

T, ° K.	$H_T - H_{298}$	$\Delta H°_T$	$\Delta F°_T$
298		−168,500	−149,100
400	(2,220)	(−168,300)	(−142,500)
500	(5,180)	(−168,000)	(−136,100)
600	(7,800)	(−167,600)	(−129,700)
700	(10,980)	(−167,100)	(−123,500)
800	(14,260)	(−166,400)	(−117,300)
900	(17,700)	(−165,600)	(−111,200)
1,000	(35,020)	(−160,500)	(−105,200)
1,100	(38,990)	(−159,200)	(−99,800)
1,200	(42,940)	(−158,000)	(−94,400)
1,300	(46,990)	(−156,700)	(−89,200)
1,400	(50,950)	(−155,500)	(−84,000)
1,500	(55,100)	(−154,300)	(−79,000)
1,600	(58,940)	(−153,100)	(−74,000)
1,700	(61,880)	(−153,000)	(−69,100)
1,800		(−236,600)	(−60,000)
1,900		(−236,900)	(−50,200)
2,000		(−237,200)	(−40,300)

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Diantimony Trioxide (Cubic, Orthorhombic), Sb_2O_3 (c)

$\Delta H^\circ_{298} = -169{,}900$ calories per mole (*111*)
$S_{298} = 27.7$ *e.u.* (*24*)
$T.P. = 842°$ K. (*24*)
$\Delta H_T = 1{,}390$ calories per mole
$M.P. = 928°$ K. (*24*)
$\Delta H_M = 13{,}500$ calories per mole
$B.P. = 1{,}698°$ K. (*24*)
$\Delta H_V = 8{,}910$ calories per mole

Zone I (298°–842° K.)

Estimated equation:

$C_p = 19.1 + 17.1 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -6{,}450 + 19.1T + 8.55 \times 10^{-3} T^2$ (*82*)

Formation: $2Sb + 3/2O_2 \longrightarrow Sb_2O_3$ (estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−169, 900	−150, 000
400	(2, 220)	(−169, 700)	(−143, 200)
500	(5, 180)	(−169, 400)	(−136, 600)
600	(7, 800)	(−169, 000)	(−130, 100)
700	(11, 080)	(−168, 400)	(−123, 700)
800	(14, 260)	(−167, 800)	(−117, 400)
900	(19, 100)	(−165, 600)	(−111, 200)
1,000	(36, 420)	(−160, 500)	(−105, 200)
1,100	(40, 390)	(−159, 200)	(−99, 800)
1,200	(44, 340)	(−158, 000)	(−94, 400)
1,300	(48, 390)	(−156, 700)	(−89, 200)
1,400	(52, 350)	(−155, 500)	(−84, 000)
1,500	(56, 500)	(−154, 300)	(−79, 000)
1,600	(60, 340)	(−153, 100)	(−74, 000)
1,700	(63, 280)	(−143, 000)	(−69, 100)
1,800		(−236, 600)	(−60, 000)
1,900		(−236, 900)	(−50, 200)
2,000		(−237, 200)	(−40, 300)

Diantimony Tetraoxide, Sb_2O_4 (c)

$\Delta H^\circ_{298} = (-209{,}000)$ calories per mole (*24*)
$S_{298} = 30.4$ *e.u.* (*24*)
Decomposes = 1,203° K. (*24*)

Formation: $2Sb + 2O_2 \longrightarrow Sb_2O_4$ (estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−209, 000)	(−182, 500)
400	(2, 700)	(−209, 000)	(−173, 500)
500	(5, 900)	(−208, 500)	(−164, 500)
600	(9, 200)	(−208, 000)	(−156, 000)
700	(12, 600)	(−207, 500)	(−147, 500)
800	(16, 000)	(−207, 000)	(−138, 500)
900	(19, 600)	(−206, 500)	(−130, 000)
1,000	(23, 200)	(−215, 500)	(−120, 500)
1,100	(27, 400)	(−214, 500)	(−111, 500)
1,200	(31, 400)	(−213, 500)	(−102, 000)

Diantimony Pentaoxide, Sb_2O_5 (c)

$\Delta H_{298} = (-229{,}000)$ calories per mole (*24*)
$S_{298} = 31.3$ *e.u.* (*24*)
Decomposes = 673° K. (*24*)

Formation: $2Sb + 5/2O_2 \longrightarrow Sb_2O_5$ (estimated (*24*))

T, ° K	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−229, 000)	(−195, 500)
400	(3, 050)	(−229, 000)	(−183, 500)
500	(6, 650)	(−228, 500)	(−172, 500)
600	(10, 800)	(−227, 500)	(−161, 500)

Antimony Trifluoride, SbF_3 (c)

$\Delta H^\circ_{298} = -216{,}600$ calories per mole (*11*)
$S_{298} = (38)$ *e.u.* (*11*)
$M.P. = 565°$ K. (*6*)
$B.P. = 649°$ K. (*6*)
$\Delta H_V = (14{,}000)$ calories per mole

Formation: $Sb + 3/2F_2 \longrightarrow SbF_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−216, 600	(−203, 200)
500	(6, 000)	(−213, 600)	(−193, 100)

Antimony Trichloride, $SbCl_3$ (c)

$\Delta H^\circ_{298} = -91{,}400$ calories per mole (*11*)
$S_{298} = 44.7$ *e.u.* (*11*)
$M.P. = 346.4°$ K. (*6*)
$\Delta H_M = 3{,}030$ calories per mole
$B.P. = 494°$ K. (*6*)
$\Delta H_V = 10{,}362$ calories per mole

Zone I (*c*) (298°–346° K.)

$C_p = 10.3 + 51.1 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -5{,}300 + 10.3T + 25.55 \times 10^{-3} T^2$

Formation: $Sb + 3/2Cl_2 \longrightarrow SbCl_3$ (estimated(*11*))

Zone I (298°–346° K.)

$\Delta C_p = -8.44 + 49.26 \times 10^{-3} T + 1.02 \times 10^5 T^{-2}$
$\Delta H_T = -90{,}700 - 8.44T + 24.63 \times 10^{-3} T^2 - 1.02 \times 10^5 T^{-1}$
$\Delta F_T = -90{,}700 + 8.44 T \ln T - 24.63 \times 10^{-3} T^2 - 0.51 \times 10^5 T^{-1} + 3.4T$

T, ° K.	$H_T - H_{298}$	ΔH_T	ΔF_T
298		−91, 400	−77, 800
500	(17, 400)	(−78, 000)	(−71, 100)

Antimony Tribromide, $SbBr_3$ (c)

$\Delta H^\circ_{298} = (-59{,}900)$ calories per mole (*11*)
$S_{298} = 53.5$ *e.u.* (*11*)
$M.P. = 370°$ K. (*6*)
$\Delta H_M = 3{,}510$ calories per mole
$B.P. = 561°$ K. (*6*)
$\Delta H_V = (12{,}000)$ calories per mole

Formation: $Sb + 3/2Br_2 \longrightarrow SbBr_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−59, 900	(−56, 000)
500	(7, 000)	(−68, 400)	(−51, 300)

Antimony Triiodide, SbI_3 (c)

$\Delta H^\circ_{298} = (-22{,}800)$ calories per mole (*11*)
$S_{298} = (57)$ *e.u.* (*11*)
$M.P. = 444°$ K. (*6*)
$B.P. = 700°$ K. (*6*)
$\Delta H_V = (15{,}000)$ calories per mole

Formation: $Sb+3/2I_2 \longrightarrow SbI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−22, 800)	(−24, 100)
500	(7, 000)	(−42, 000)	(−25, 500)

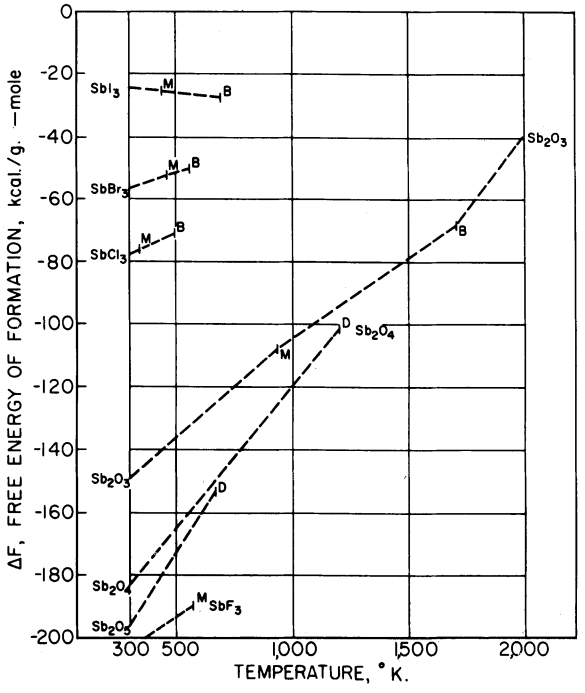

FIGURE 2.—Antimony.

ARSENIC AND ITS COMPOUNDS

Element, As (*c*)

$S_{298}=8.40$ *e.u.* (*83*)
S.P.$=886°$ K. (*130*)
$\Delta H_{subl}=7{,}630$ calories per atom

Zone I (*c*) (298°–883° K.)

$C_p=5.23+2.22\times10^{-3}T$ (*82*)
$H_T-H_{298}=-1{,}658+5.23T+1.11\times10^{-3}T^2$
$F_T-H_{298}=-1{,}658-5.23T\ln T-1.11\times10^{-3}T^2+27.28T$
Above 883° K., diatomic gas (estimated (*124*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		8.40	8.4
400	610	10.16	8.64
500	1, 240	11.54	9.06
600	1, 880	12.73	9.60
700	2, 540	13.75	10.12
800	3, 230	14.68	10.64
900	(26, 630)	(33.39)	(3.81)
1,000	(27, 070)	(33.86)	(6.79)
1,100	(27, 520)	(34.28)	(9.27)
1,200	(27, 960)	(34.67)	(11.37)
1,300	(28, 410)	(35.03)	(13.18)
1,400	(28, 850)	(35.36)	(14.76)
1,500	(29, 300)	(35.67)	(16.14)
1,600	(29, 740)	(35.95)	(17.37)
1,700	(30, 190)	(36.22)	(18.47)
1,800	(30, 640)	(36.48)	(19.46)
1,900	(31, 080)	(36.72)	(20.37)
2,000	(31, 530)	(36.95)	(21.19)

Diarsenic Trioxide (Orthorhombic), As_2O_3 (*c*)

$\Delta H_{298}^\circ=157{,}000$ calories per mole (*114*)
$S_{298}=25.6$ *e.u.* (*112*)
T.P.$=506°$ K. (*24*)
$\Delta H_T=4{,}110$ calories per mole
M.P.$=542°$ K. (*24*)
$\Delta H_M=7{,}930$ calories per mole
B.P.$=730.3°$ K. (*24*)
$\Delta H_V=14{,}300$ calories per mole of As_4O_6

Formation: $2As+3/2O_2 \longrightarrow As_2O_3$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−157, 000	−137, 700
400	(2, 550)	(−156, 750)	(−131, 150)
500	(5, 610)	(−156, 050)	(−124, 800)
600	(17, 225)	(−146, 850)	(−119, 500)
700	(21, 200)	(−145, 350)	(−115, 100)
800	(31, 100)	(−138, 050)	(−111, 500)
900	(36, 500)	(−154, 000)	(−107, 850)
1,000	(38, 200)	(−154, 000)	(−102, 700)
1,100	(39, 800)	(−154, 050)	(−97, 600)
1,200	(41, 500)	(−154, 050)	(−92, 450)
1,300	(43, 000)	(−154, 150)	(−87, 300)
1,400	(44, 700)	(−154, 200)	(−82, 200)
1,500	(46, 500)	(−154, 300)	(−77, 050)
1,600	(48, 000)	(−154, 400)	(−71, 900)
1,700	(49, 700)	(−154, 500)	(−66, 700)
1,800	(51, 400)	(−154, 650)	(−61, 550)
1,900	(52, 900)	(−154, 800)	(−56, 400)
2,000	(54, 500)	(−154, 950)	(−51, 200)

Diarsenic Trioxide (Monoclinic), As_2O_3 (*c*)

$\Delta H_{298}^\circ=-152{,}900$ calories per mole (*114*)
$S_{298}=33.6$ *e.u.* (*24*)
M.P.$=586°$ K. (*24*)
$\Delta H_M=4{,}000$ calories per mole
B.P.$=730.3°$ K. (*24*)
$\Delta H_V=14{,}300$ calories per mole of As_4O_6

Formation: $2As+3/2O_2 \longrightarrow As_2O_3$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−152, 900	−136, 000
400	(2, 600)	(−152, 600)	(−130, 300)
500	(5, 550)	(−152, 000)	(−124, 800)
600	(13, 200)	(−146, 800)	(−119, 500)
700	(17, 100)	(−145, 300)	(−115, 100)
800	(26, 900)	(−138, 100)	(−111, 500)
900	(32, 400)	(−154, 000)	(−107, 800)
1,000	(34, 100)	(−154, 000)	(−102, 700)
1,100	(35, 700)	(−154, 000)	(−97, 600)
1,200	(37, 300)	(−154, 100)	(−92, 500)
1,300	(39, 000)	(−154, 100)	(−87, 300)
1,400	(40, 600)	(−154, 200)	(−82, 200)
1,500	(42, 400)	(−154, 300)	(−77, 000)
1,600	(43, 900)	(−154, 400)	(−71, 900)
1,700	(45, 600)	(−154, 500)	(−66, 700)
1,800	(47, 200)	(−154, 600)	(−61, 600)
1,900	(48, 800)	(−154, 800)	(−56, 400)
2,000	(50, 600)	(−155, 000)	(−51, 200)

Diarsenic Tetraoxide, As_2O_4 (*c*)

$\Delta H_{298}^\circ=-175{,}500$ calories per mole (*14*)
$S_{298}=(36)$ *e.u.* (*24*)

Formation: $2As+2O_2 \longrightarrow As_2O_4$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−175, 500	−149, 000
400	(2, 700)	(−175, 500)	(−140, 000)
500	(5, 900)	(−175, 000)	(−131, 000)
600	(9, 200)	(−174, 500)	(−122, 000)
700	(12, 500)	(−174, 000)	(−113, 500)
800	(17, 000)	(−172, 500)	(−105, 000)
900	(22, 500)	(−186, 500)	(−96, 000)
1,000	(26, 200)	(−184, 500)	(−86, 000)
1,100	(30, 300)	(−182, 000)	(−76, 500)
1,200	(35, 000)	(−179, 000)	(−67, 000)
1,300	(39, 700)	(−176, 000)	(−58, 000)
1,400	(44, 900)	(−172, 500)	(−49, 000)
1,500	(50, 300)	(−169, 000)	(−40, 000)

Diarsenic Pentaoxide, As_2O_5 (*c*)

$\Delta H_{298}^\circ = -218{,}500$ calories per mole (*112*)
$S_{298} = 25.2$ *e.u.* (*112*)

Formation: $2As + 5/2O_2 \longrightarrow As_2O_5$ (estimated (*24*))

T, ° K.	$H - H_{298}$	ΔH_T°	ΔF_T°
298		−218, 500	−184, 500
400	(3, 000)	(−218, 500)	(−173, 000)
500	(6, 600)	(−219, 000)	(−161, 500)
600	(9, 800)	(−219, 000)	(−150, 000)
700	(12, 500)	(−218, 500)	(−138, 500)
800	(15, 900)	(−218, 500)	(−127, 000)
900	(23, 100)	(−233, 500)	(−115, 500)
1,000	(26, 600)	(−232, 500)	(−102, 500)
1,100	(30, 000)	(−231, 500)	(−89, 500)
1,200	(33, 500)	(−230, 500)	(−76, 500)
1,300	(37, 600)	(−229, 000)	(−63, 500)
1,400	(41, 700)	(−227, 500)	(−51, 000)
1,500	(46, 000)	(−226, 000)	(−38, 500)
1,600	(49, 800)	(−224, 500)	(−26, 000)
1,700	(54, 500)	(−222, 500)	(−13, 500)
1,800	(59, 200)	(−220, 500)	(−1, 500)
1,900	(64, 400)	(−218, 000)	(+10, 500)
2,000	(69, 400)	(−216, 000)	(+22, 500)

Arsenic Trifluoride, AsF_3 (*l*)

$\Delta H_{298}^\circ = -218{,}300$ calories per mole (*112*)
$S_{298} = 69.08$ *e.u.* (*112*)
$\Delta F_{298}^\circ = -214{,}700$ calories per mole
$M.P. = 267.2°$ K. (*112*)
$\Delta H_M = 2{,}486$ calories per mole
$B.P. = 333°$ K. (*94*)
$\Delta H_V = 7{,}100$ calories per mole

Arsenic Trichloride, $AsCl_3$ (*l*)

$\Delta H_{298}^\circ = -80{,}200$ calories per mole (*112*)
$S_{298} = 55.8$ *e.u.* (*112*)
$\Delta F_{298}^\circ = -70{,}400$ calories per mole
$M.P. = 257°$ K. (*112*)
$\Delta H_M = 2{,}420$ calories per mole
$B.P. = 403°$ K. (*112*)
$\Delta H_V = 7{,}500$ calories per mole

Arsenic Tribromide, $AsBr_3$ (*c*)

$\Delta H_{298}^\circ = -46{,}610$ calories per mole (*112*)
$S_{298} = (53)$ *e.u.* (*112*)
$M.P. = 304°$ K. (*112*)
$\Delta H_M = 2{,}810$ calories per mole
$B.P. = 494°$ K. (*112*)
$\Delta H_V = 10{,}000$ calories per mole

Formation: $As + 3/2Br_2 \longrightarrow AsBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−46, 600	(−43, 600)
500	(19, 000)	(−43, 000)	(−36, 800)

Arsenic Triiodide, AsI_3 (*c*)

$\Delta H_{298}^\circ = -13{,}700$ calories per mole (*112*)
$S_{298} = (55)$ *e.u.* (*11*)
$M.P. = 415°$ K. (*6*)
$\Delta H_M = 2{,}200$ calories per mole
$B.P. = 687°$ K. (*6*)
$\Delta H_V = 14{,}200$ calories per mole

Formation: $As + 3/2I_2 \longrightarrow AsI_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−13, 700	(−15, 000)
500	(9, 000)	(−31, 000)	(−13, 900)

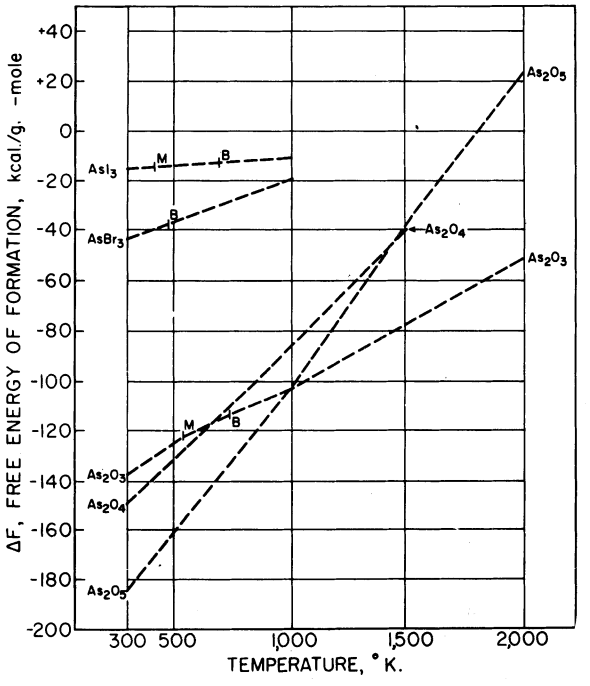

FIGURE 3.– Arsenic.

BARIUM AND ITS COMPOUNDS

Element, Ba (*c*)

$S_{298} = 16.0$ *e.u.* (*83*)
$M.P. = 983°$ K. (*93*)
$\Delta H_M = 1{,}830$ calories per atom
$B.P. = 1{,}911°$ K. (*130*)
$\Delta H_V = 35{,}700$ calories per atom

Zone I (*c*) (298°–983° K.)

$$C_p = 5.55 + 1.50 \times 10^{-3} T \quad (82)$$
$$H_T - H_{298} = -1{,}720 + 5.55T + 0.75 \times 10^{-3} T^2$$
$$F_T - H_{298} = 1{,}720 - 5.55 T \ln T - 0.75 \times 10^{-3} T^2 + 21.55T$$

Zone II (*l*) (983°–1,125° K.)

$$C_p = 11.5 \quad (82)$$
$$H_T - H_{298} = -4{,}250 + 11.5T$$
$$F_T - H_{298} = -4{,}250 - 11.5 T \ln T + 64.6T$$

Above 1,125° K. (estimated (*130*))

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		16.0	16.0
400	620	17.8	16.25
500	1,240	19.25	16.77
600	1,880	20.4	17.26
700	2,430	21.4	17.93
800	3,200	22.3	18.30
900	3,880	23.1	18.80
1,000	7,247	26.38	19.15
1,100	7,990	27.10	19.83
1,200	(8,750)	(27.75)	(20.47)
1,300	(9,500)	(28.35)	(21.05)
1,400	(10,250)	(28.91)	(21.60)
1,500	(11,000)	(20.42)	(22.09)
1,600	(11,750)	(29.91)	(22.57)
1,700	(13,000)	(30.36)	(23.01)
1,800	(13,250)	(30.79)	(23.44)
1,900	(14,000)	(31.20)	(23.84)

Barium Oxide, BaO (*c*)

$\Delta H^\circ_{298} = -133{,}400$ calories per mole (*50*)
$S_{298} = 16.8$ *e.u.* (*83*)
M.P. = 2,196° K. (*8*)
$\Delta H_M = 13{,}800$ calories per mole
B.P. = 3,000° K. (*8*)

Zone I (*c*) (298°-1,300° K.)

$$C_p = 12.74 + 1.040 \times 10^{-3} T - 1.984 \times 10^5 T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}500 + 12.74T + 0.52 \times 10^{-3} T^2 + 1.984 \times 10^5 T^{-1}$$

Formation: $Ba + 1/2O_2 \longrightarrow BaO$

Zone I (298°–983° K.)

$$\Delta C_p = 3.63 - 0.96 \times 10^{-3} T - 1.78 \times 10^5 T^{-2}$$
$$\Delta H_T = -135{,}000 + 3.63T - 0.48 \times 10^{-3} T^2 + 1.78 \times 10^5 T^{-1}$$
$$\Delta F_T = -135{,}000 - 3.63 T \ln T + 0.48 \times 10^{-3} T^2 + 0.89 \times 10^5 T^{-1} + 48.77T$$

Zone II (983°–1,125° K.)

$$\Delta C_p = -2.32 + 0.54 \times 10^{-3} T - 1.78 \times 10^5 T^{-2}$$
$$\Delta H_T = -132{,}700 - 2.32T + 0.27 \times 10^{-3} T^2 + 1.78 \times 10^5 T^{-1}$$
$$\Delta F_T = -132{,}700 + 2.32 T \ln T - 0.27 \times 10^{-3} T^2 + 0.89 \times 10^5 T^{-1} + 4.8T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		16.8	−133,400	−126,300
400	1,200	20.3	−133,200	−124,000
500	2,400	22.9	−133,000	−121,650
600	3,700	25.3	−132,700	−119,400
700	4,900	27.2	−132,400	−117,100
800	6,300	29.0	−132,200	−115,000
900	7,600	30.7	−132,000	−113,100
1,000	8,950	32.0	−134,600	−111,100
1,100	10,300	33.2	−134,200	−108,500
1,200			(−133,500)	(−106,000)
1,300			(−133,500)	(−103,500)
1,400			(−133,500)	(−101,500)
1,500	(15,900)		(−133,500)	(−99,000)
1,600			(−133,000)	(−96,500)
1,700			(−132,500)	(−94,500)
1,800			(−132,500)	(−92,000)
1,900			(−132,000)	(−90,000)
2,000	(23,150)		(−167,000)	(−86,000)

Barium Dioxide, BaO_2 (*c*)

$\Delta H^\circ_{298} = -151{,}890 \pm 250$ calories per mole (*139*)
$S_{298} = 22.62$ *e.u.* (*24*)

Formation: $Ba + O_2 \longrightarrow BaO_2$ (estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−152,000	−139,500
400	(1,300)	(−152,000)	(−135,500)
500	(3,200)	(−151,500)	(−131,000)
600	(5,100)	(−151,000)	(−127,000)
700	(6,400)	(−151,000)	(−123,000)
800	(8,500)	(−150,500)	(−119,500)
900	(9,500)	(−150,000)	(−115,500)
1,000	(11,900)	(−152,000)	(−111,500)
1,100	(13,000)	(−151,500)	(−107,500)
1,200		(−151,500)	(−103,500)
1,300		(−151,000)	(−99,500)
1,400		(−150,500)	(−95,500)
1,500	(22,000)	(−150,500)	(−91,500)

Barium Difluoride, BaF_2 (*c*)

$\Delta H^\circ_{298} = -286{,}900$ calories per mole (*112*)
$S_{298} = 23.03$ *e.u.* (*83*)
M.P. = 1,593° K. (*112*)
$\Delta H_M = 3{,}000$ calories per mole
B.P. = 2,473° K. (*94*)
$\Delta H_V = 70{,}000$ calories per mole

Zone I (*c*) (298°–1,300° K.)

$$C_p = 13.98 + 10.20 \times 10^{-3} T \quad (82)$$
$$H_T - H_{298} = -4{,}600 + 13.98T + 5.10 \times 10^{-3} T^2$$

Formation: $Ba + F_2 \longrightarrow BaF_2$

Zone I (298°–983° K.)

$$\Delta C_p = 0.14 + 8.26 \times 10^{-3} T + 0.80 \times 10^5 T^{-2}$$
$$\Delta H_T = -287{,}000 + 0.14T + 4.13 \times 10^{-3} T^2 - 0.80 \times 10^5 T^{-1}$$
$$\Delta F_T = -287{,}000 - 0.14 T \ln T - 4.13 \times 10^{-3} T^2 - 0.40 \times 10^5 T^{-2} + 44.48T$$

Zone II (983°–1,125° K.)

$$\Delta C_p = -5.81 + 9.76 \times 10^{-3} T + 0.80 \times 10^5 T^{-2}$$
$$\Delta H_T = -284{,}800 - 5.81T + 4.88 \times 10^{-3} T^2 - 0.80 \times 10^5 T^{-1}$$
$$\Delta F_T = -284{,}800 + 5.81 T \ln T - 4.88 \times 10^{-3} T^2 - 0.40 \times 10^5 T^{-1} + 1.91T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		23.03	−286,900	−274,500
400	1,850	28.36	−286,450	−270,350
500	3,700	32.48	−286,000	−266,300
600	5,650	36 04	−285,550	−262,450
700	7,650	39.12	−284,950	−257,550
800	9,700	41.85	−284,500	−254,900
900	11,900	44.44	−283,850	−251,250
1,000	14,200	46.86	−285,800	−247,700
1,100	16,700	49.25	−284,800	−243,900
1,200	(19,500)		(−283,770)	(−241,600)
1,300	(22,200)		(−283,110)	(−238,200)

Barium Dichloride, $BaCl_2$ (*c*)

$\Delta H^\circ_{298} = -205{,}300$ calories per mole (*11*)
$S_{298} = (29)$ *e.u.* (*11*)
M.P. = 1,233° K. (*6*)
$\Delta H_M = 5{,}370$ calories per mole
B.P. = 2,100° K. (*6*)
$\Delta H_V = (50{,}000)$ calories per mole

Zone I (*c*) (298°–1, 198° K.)

$$C_p = 17.0 + 3.34\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -5{,}200 + 17.0T + 1.67\times10^{-3}T^2$$

Formation: $Ba + Cl_2 \longrightarrow BaCl_2$

Zone I (298°–983° K.)

$$\Delta C_p = 2.63 + 1.78\times10^{-3}T + 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -206{,}000 + 2.63T + 0.89\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -206{,}000 - 2.63T\ln T - 0.89\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 58.13T$$

Zone II (983°–1,125° K.)

$$\Delta C_p = -3.32 + 3.28\times10^{-3}T + 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -203{,}400 - 3.32T + 1.64\times10^{-3}T^2 - 0.68\times10^{5}T^{-}$$
$$\Delta F_T = -203{,}400 + 3.32T\ln T - 1.64\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 14.68T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		(29.0)	−205,300	(−193,300)
400	1,900	(34.64)	−204,900	(−189,300)
500	3,700	(38.67)	−204,500	(−185,300)
600	5,600	(42.1)	−204,100	(−181,300)
700	7,500	(44.94)	−203,650	(−178,700)
800	9,500	(47.57)	−203,300	(−174,000)
900	11,500	(49.9)	−202,900	(−170,500)
1,000	13,500	(51.84)	−205,100	(−166,700)
1,100	15,500	(54.3)	−204,600	(−163,500)
1,500	(24,050)			(−149,000)
2,000	(35,500)			(−133,000)

Barium Dibromide, $BaBr_2$ (*c*)

$\Delta H_{298}^\circ = -180{,}000$ calories per mole (*11*)
$S_{298} = (35)$ *e.u.* (*11*)
$M.P. = 1{,}120°$ K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = 2{,}100°$ K. (*6*)
$\Delta H_V = (50{,}000)$ calories per mole

Formation: $Ba + Br_2 \longrightarrow BaBr_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		(35)	−180,000	(−175,000)
500	(3,800)	(45)	(−187,000)	(−167,000)
1,000	(13,700)	(58)	(−187,000)	(−148,000)
1,500	(31,400)	(73)	(−178,000)	(−131,500)

Barium Diiodide, BaI_2 (*c*)

$\Delta H_{298}^\circ = -144{,}600 \pm 1{,}000$ calories per mole (*11*)
$S_{298} = 39$ *e.u.* (*11*)
$M.P. = 984°$ K. (*6*)
$\Delta H_M = (6{,}800)$ calories per mole
$B.P. = (2{,}000°)$ K. (*6*)
$\Delta H_V = (45{,}000)$ calories per mole

Formation: $Ba + I_2 \longrightarrow BaI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		(39)	−144,600	(−143,000)
500	(3,800)	(49)	(−158,700)	(−140,000)
1,000	(20,700)	(70)	(−151,500)	(−121,500)
1,500	(32,700)	(80)	(−148,500)	(−105,500)

Tribarium Dinitride, Ba_3N_2 (*c*)

$\Delta H_{298}^\circ = -90{,}600$ calories per mole (*9*)
$S_{298} = 36.4$ *e.u.* (*9*)
Decomposes = 1,270° K. (*9*)

Formation: $3Ba + N_2 \longrightarrow Ba_3N_2$ (estimated (*9*))

T, ° K.	ΔF_T°
298	(−73,400)
500	(−61,900)
1,000	(−33,200)

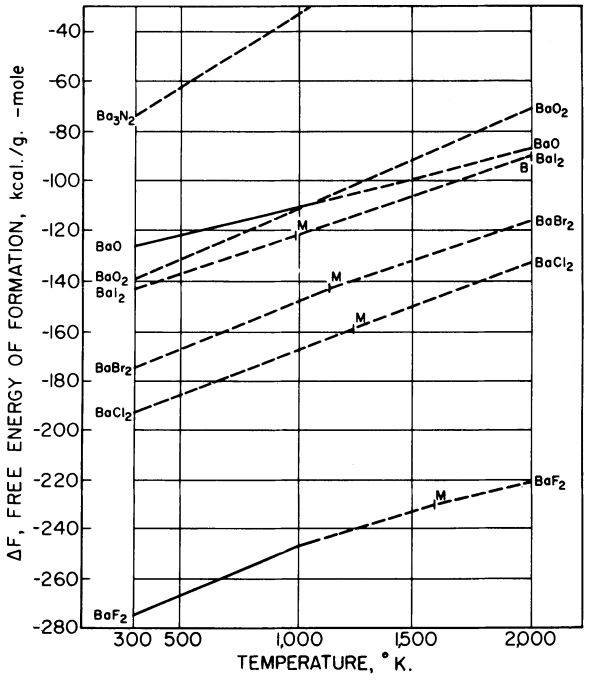

FIGURE 4.—Barium.

BERYLLIUM AND ITS COMPOUNDS

Element, Be (*c*)

$S_{298} = 2.28$ *e.u.* (*83*)
$M.P. = 1{,}556°$ K. (*112*)
$\Delta H_M = 2{,}300$ calories per atom
$B.P. = 3{,}243°$ K. (*138*)
$\Delta H_V = 53{,}490$ calories per atom

Zone I (*c*) (298°–1,300° K.)

$$C_p = 3.40 + 2.90\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -1{,}143 + 3.40T + 1.45\times10^{-3}T^2$$
$$F_T - H_{298} = -1{,}143 - 3.40T\ln T - 1.45\times10^{-3}T^2 + 21.34T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		2.28	2.28
400	415	3.48	2.44
500	900	4.56	2.76
600	1,415	5.50	3.14
700	1,965	6.14	3.33
800	2,535	7.10	3.93
900	3,135	7.81	4.33
1,000	3,745	8.45	4.70
1,100	4,365	9.04	5.07
1,200	4,990	9.59	5.43
1,300	5,615	10.09	5.77
1,400	(6,460)	(10.72)	(6.11)
1,500	(7,220)	(11.25)	(6.44)

Beryllium Oxide, BeO (*c*)

$\Delta H^\circ_{298}=-143{,}100$ calories per mole (*22*)
$S_{298}=3.37$ *e.u.* (*83*)
$M.P.=2{,}823°$ K. (*42*)
$\Delta H_M=17{,}000$ calories per mole
$B.P.=4{,}533°$ K. (*42*)
$\Delta H_V=117{,}000$ calories per mole

Zone I (*c*) (298°–1,200° K.)

$$C_p=8.45+4.00\times10^{-3}T-3.17\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-3{,}760+8.45T+2.00\times10^{-3}T^2+3.17\times10^{5}T^{-1}$$

Zone II (*c*) (1,200°–2,000° K.) (estimated (*24*))

Formation: $Be+1/2O_2\longrightarrow BeO$

Zone I (298°–1,000° K.)

$$\Delta C_p=+1.47+0.60\times10^{-3}T-2.97\times10^{5}T^{-2}$$
$$\Delta H_T=-144{,}560+1.47T+0.30\times10^{-3}T^2+2.97\times10^{5}T^{-1}$$
$$\Delta F_T=-144{,}560-1.47T\ln T-0.30\times10^{-3}T^2+1.48\times10^{5}T^{-1}+35.15T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		3.37	−143,100	−136,100
400	730	5.46	−143,150	−133,700
500	1,580	7.35	−143,250	−131,400
600	2,540	9.10	−143,100	−128,800
700	3,600	10.73	−142,900	−126,800
700	4,700	12.20	−142,800	−124,350
900	5,830	13.53	−142,700	−122,000
1,000	7,010	14.77	−142,550	−119,750
1,100	8,240	15.95	−142,300	−117,450
1,200	9,510	17.05	−142,100	−115,250
1,300	(10,870)		(−141,900)	(−112,850)
1,400	(12,200)		(−141,700)	(−111,150)
1,500	(13,630)		(−140,500)	(−109,250)
2,000	(21,300)		(−142,900)	(−97,000)

Beryllium Difluoride, BeF_2 (*c*)

$\Delta H^\circ_{298}=(-227{,}000)$ calories per mole (*11*)
$S_{298}=(17)$ *e.u.* (*11*)
$M.P.=1{,}070°$ K. (*6*)
$\Delta H_M=(6{,}000)$ calories per mole
$B.P.=(1{,}600°)$ K. (*6*)
$\Delta H_V=(40{,}000)$ calories per mole

Formation: $Be+F_2\longrightarrow BeF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(17)	−227,000	(−216,900)
500	(3,400)	(25.5)	(−226,000)	(−210,500)
1,000	(12,000)	(38)	(−224,500)	(−195,000)
1,500	(29,000)	(52.7)	(−215,500)	(−183,500)

Beryllium Dichloride, $BeCl_2$ (*c*)

$\Delta H^\circ_{298}=-112{,}600$ calories per mole (*11*)
$S_{298}=(23)$ *e.u.* (*11*)
$M.P.=678°$ K. (*6*)
$\Delta H_M=(3{,}000)$ calories per mole
$B.P.=(820°)$ K. (*6*)
$\Delta H_V=(25{,}000)$ calories per mole

Formation: $Be+Cl_2\longrightarrow BeCl_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(23)	−112,600	(−102,900)
500	(3,400)	(26.4)	(−112,000)	(−96,600)
1,000	(42,000)	(40)	(−80,500)	(−84,600)

Beryllium Dibromide, $BeBr_2$ (*c*)

$\Delta H^\circ_{298}=-79{,}400$ calories per mole (*11*)
$S_{298}=(29)$ *e.u.* (*11*)
$M.P.=761°$ K. (*6*)
$\Delta H_M=(4{,}500)$ calories per mole
$B.P.=(800°)$ K. (*6*)
$\Delta H_V=(22{,}000)$ calories per mole

Formation: $Be+Br_2\longrightarrow BeBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(29)	−79,400	(−76,500)
500	(3,400)	(37.5)	(−86,500)	(−70,500)
1,000	(39,000)	(58.0)	(−58,000)	(−59,000)

Beryllium Diiodide, BeI_2 (*c*)

$\Delta H^\circ_{298}=(-39{,}400)$ calories per mole (*11*)
$S_{298}=(31)$ *e.u.* (*11*)
$M.P.=753°$ K. (*6*)
$\Delta H_M=(4{,}500)$ calories per mole
$B.P.=760°$ K. (*6*)
$\Delta H_V=(19{,}000)$ calories per mole

Formation: $Be+I_2\longrightarrow BeI_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(31)	(−39,400)	(−39,400)
500	(3,400)	(39.5)	(−53,500)	(−33,200)
1,000	(36,000)	(60)	(−28,300)	(−20,700)

Triberyllium Dinitride, Be_3N_2 (*c*)

$\Delta H^{\circ}_{298} = -133{,}500$ calories per mole (*81*)
$S_{298} = 12.0$ *e.u.* (*81*)
$M.P. = 2{,}470°$ K. (*9*)

Zone I (*c*) (298°–800° K.)

$$C_p = 7.32 + 30.8 \times 10^{-3} T \text{ (82)}$$
$$H_T - H_{298} = -3{,}550 + 7.32T + 15.4 \times 10^{-3} T^2$$

Formation: $3Be + N_2 \longrightarrow Be_3N_2$

Zone I (298°–800° K.)

$$\Delta C_p = -9.54 + 21.08 \times 10^{-3} T$$
$$\Delta H_T = -131{,}600 - 9.54T + 10.54 \times 10^{-3} T^2$$
$$\Delta F_T = -131.600 + 9.54 T \ln T - 10.54 \times 10^{-3} T^2 - 18.14T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		12.0	−133,506	−121,400
400	1,840	17.29	−133,600	−117,200
500	3,930	21.94	−133,700	−113,100
600	6,420	26.47	−133,450	−109,000
700	9,200	30.75	−133,000	−105,400
800	12,130	34.66	−132,500	−101,000
900	(15,500)		(−131,600)	(−98,200)
1,000	(19,200)		(−130,600)	(−94,500)
1,500	(42,200)		(−122,100)	(−77,900)
2,000	(72,700)		(−108,500)	(−65,100)

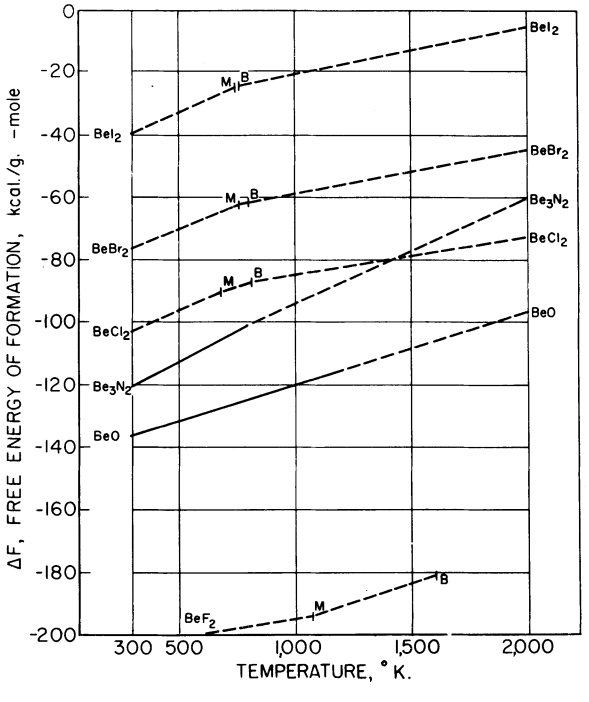

FIGURE 5.—Beryllium.

BISMUTH AND ITS COMPOUNDS

Element, Bi (*c*)

$S_{298} = 13.6$ *e.u.* (*83*)
$M.P. = 544.5°$ K. (*82*)
$\Delta H_M = 2{,}600$ calories per atom
$B.P. = 1{,}832°$ K. (*130*)
$\Delta H_V = 36{,}200$ calories per atom

Zone I (*c*) (298°–544.5° K.)

$$C_p = 4.49 + 5.40 \times 10^{-3} T \text{ (82)}$$
$$H_T - H_{298} = -1{,}579 + 4.49T + 2.70 \times 10^{-3} T^2$$
$$F_T - H_{298} = -1{,}579 - 4.49 T \ln T - 2.70 \times 10^{-3} T^2 + 18.08T$$

Zone II (*l*) (544.5°–1,800° K.)

$$C_p = 7.50 \text{ (82)}$$
$$H_T - H_{298} = 180 + 7.50T$$
$$F_T - H_{298} = 180 - 7.50 T \ln T + 32.34T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		13.6	13.6
400	650	15.47	13.84
500	1,340	17.01	14.33
600	4,680	23.14	15.34
700	5,430	24.30	16.54
800	6,180	25.30	17.58
900	6,930	26.18	18.48
1,000	7,680	26.97	19.29
1,100	8,430	27.67	20.01
1,200	9,180	28.32	20.67
1,300	9,930	28.92	21.29
1,400	10,680	29.47	21.85
1,500	11,430	29.99	22.37
1,600	12,180	30.48	22.87
1,700	12,930	30.93	23.32
1,800	13,680	31.36	23.76
1,900	(55,460)	(53.87)	(24.68)
2,000	(55,970)	(54.13)	(26.15)

Bismuth Oxide, BiO (*c*)

$\Delta H^{\circ}_{298} = -49{,}850$ calories per mole (*112*)
$S_{298} = (16.4)$ *e.u.* (*24*)

Formation: $Bi + 1/2O_2 \longrightarrow BiO$
(estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−49,850	(−43,500)
400	(1,400)	(−49,500)	(−41,000)
500	(2,400)	(−49,500)	(−39,000)
600	(4,100)	(−51,500)	(−36,500)
700	(5,300)	(−51,500)	(−34,000)
800	(6,400)	(−51,500)	(−31,500)
900	(8,100)	(−51,000)	(−29,000)
1,000	(9,200)	(−51,000)	(−26,500)
1,100	(10,900)	(−50,500)	(−24,500)
1,200	(12,000)	(−50,500)	(−22,000)
1,300	(13,200)	(−50,500)	(−19,500)
1,400	(15,000)	(−50,000)	(−17,000)
1,500	(16,300)	(−50,000)	(−15,000)
1,600	(17,400)	(−49,500)	(−12,500)

Dibismuth Trioxide, Bi_2O_3 (*c*)

$\Delta H^\circ_{298} = -137{,}900$ calories per mole (*112*)
$S_{298} = 36.2$ *e.u.* (*83*)
M.P. = 1,090° K. (*112*)
$\Delta H_M = 6{,}800$ calories per mole
B.P. = (2,160°) K. (*94*)

Zone I (*c*) (298°–800° K.)

$C_p = 24.74 + 8.00 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -7{,}732 + 24.74T + 4.00 \times 10^{-3} T^2$

Formation: $2Bi + 3/2O_2 \longrightarrow Bi_2O_3$

Zone I (298°–800° K.)

$\Delta C_p = 5.02 - 4.30 \times 10^{-3} T + 0.60 \times 10^5 T^{-2}$
$\Delta H_T = -139{,}000 + 5.02T - 2.15 \times 10^{-3} T^2 - 0.60 \times 10^5 T^{-1}$
$\Delta F_T = -139{,}000 - 5.02T \ln T + 2.15 \times 10^{-3} T^2 - 0.30 \times 10^5 T^{-1} + 96.5T$

Above 800° K. (estimated (*24*))

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		36.2	−137,900	−118,700
400	2,770	44.2	−137,500	−112,150
500	5,630	50.56	−137,100	−105,800
600	8,550	55.89	−142,000	−99,100
700	11,550	60.51	−141,700	−92,000
800	14,620	64.61	−141,300	−84,850
900	(18,170)	(68.36)	(−140,500)	(−77,500)
1,000	(21,000)	(71.78)	(−140,300)	(−70,850)
1,100			(−132,500)	(−64,500)
1,200			(−131,500)	(−58,000)
1,300			(−130,500)	(−52,000)
1,400			(−129,000)	(−46,000)
1,500			(−128,000)	(−40,000)
1,600			(−126,500)	(−34,500)

Bismuth Trifluoride, BiF_3 (*c*)

$\Delta H^\circ_{298} = (-216{,}000)$ calories per mole (*11*)
$S_{298} = (34)$ *e.u.* (*11*)
M.P. = 1,000° K. (*6*)
$\Delta H_M = (6{,}200)$ calories per mole
B.P. = (1,300°) K. (*6*)
$\Delta H_V = (28{,}000)$ calories per mole

Formation: $Bi + 3/2F_2 \longrightarrow BiF_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−216,000)	(−200,000)
500	(6,000)	(−213,500)	(−188,500)

Bismuth Trichloride, $BiCl_3$ (*c*)

$\Delta H^\circ_{298} = -90{,}500$ calories per mole (*11*)
$S_{298} = 45.8$ *e.u.* (*11*)
M.P. = 502° K. (*6*)
$\Delta H_M = 2{,}600$ calories per mole
B.P. = 714° K. (*6*)
$\Delta H_V = 17{,}354$ calories per mole

Formation: $Bi + 3/2Cl_2 \longrightarrow BiCl_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−90,500	−76,000
500	(7,000)	(−87,500)	(−66,500)

Bismuth Tribromide, $BiBr_3$ (*c*)

$\Delta H^\circ_{298} = (-60{,}000)$ calories per mole (*11*)
$S_{298} = (54)$ *e.u.* (*11*)
M.P. = 491° K. (*6*)
$\Delta H_M = (4{,}000)$ calories per mole
B.P. = 734° K. (*6*)
$\Delta H_V = 18{,}024$ calories per mole

Formation: $Bi + 3/2Br_2 \longrightarrow BiBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−60,000)	(−55,800)
500	(7,000)	(−68,600)	(−47,500)

Bismuth Triiodide, BiI_3 (*c*)

$\Delta H^\circ_{298} = = 23{,}700$ calories per mole (*11*)
$S_{298} = (55)$ *e.u.* (*11*)
M.P. = 681° K. (*6*)
Decomposes = 773° K. (*6*)

Formation: $Bi + 3/2I_2 \longrightarrow BiI_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−23,700	(−23,500)
500	(6,000)	(−44,000)	(−20,000)

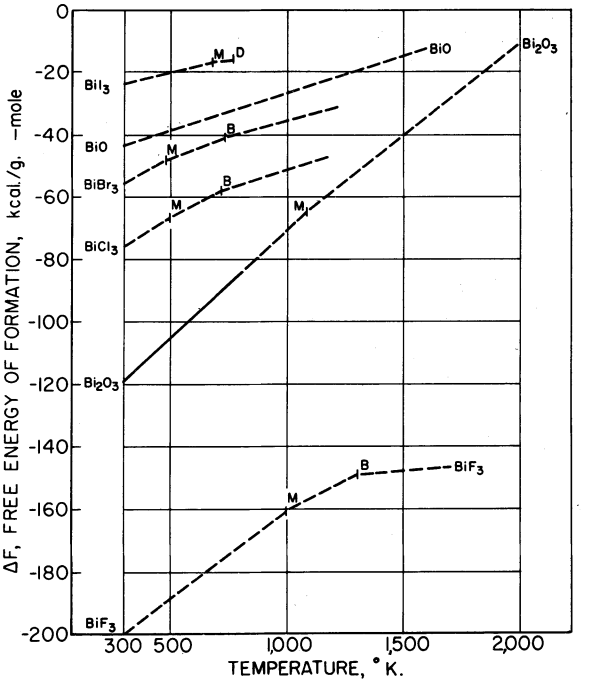

FIGURE 6.—Bismuth.

BORON AND ITS COMPOUNDS

Element, B (*c*)

$S_{298}=1.4$ *e.u.* (*76*)
$M.P.=2{,}300°$ K. (*24*)
$\Delta H_M=5{,}300$ calories per atom

Zone I (*c*) (298°–1,200° K.)

$$C_p=1.54+4.40\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-655+1.54T+2.20\times10^{-3}T^2$$
$$F_T-H_{298}=-655-1.54T\ln T-2.20\times10^{-3}T^2+10.21T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		1.4	1.4
400	300	2.27	1.52
500	660	3.07	1.75
600	1,080	3.83	2.03
700	1,540	4.54	2.34
800	2,040	5.20	2.65
900	2,570	5.82	2.96
1,000	3,130	6.41	3.28
1,100	3,700	6.94	3.57
1,200	4,270	7.45	3.90
1,500	(6,600)	(9.15)	(4.88)
2,000	(11,225)	(11.15)	(6.21)

Boron Oxide, BO (*g*)

$\Delta H^\circ_{298}=5{,}300$ calories per mole (*112*)
$S_{298}=48.60$ *e.u.* (*83*)
$\Delta F^\circ_{298}=11{,}600$ calories per mole

Diboron Trioxide, B_2O_3 (*c*)

$\Delta H^\circ_{298}=-305{,}400$ calories per mole (*112*)
$S_{298}=13.04$ *e.u.* (*83*)
$M.P.=723°$ K. (*82*)
$\Delta H_M=5{,}500$ calories per mole
$B.P.=2{,}300°$ K. (*42*)
$\Delta H_V=(70{,}000)$ calories per mole

Zone I (*c*) (298°–723° K.)

$$C_p=8.73+25.40\times10^{-3}T-1.31\times10^5T^{-2} \quad (82)$$
$$H_T-H_{298}=-4{,}170+8.73T+12.70\times10^{-3}T^2+1.31\times10^5T^{-1}$$

Zone II (*l*) (723°–1,800° K.)

$$C_p=30.50 \quad (82)$$
$$H_T-H_{298}=-7{,}590+30.50T$$

Formation: $2B+3/2O_2\longrightarrow B_2O_3$

Zone I (298°–723° K.)

$$\Delta C_p=-5.09+15.1\times10^{-3}T-0.71\times10^5T^{-2}$$
$$\Delta H_T=-304{,}690-5.09T+7.55\times10^{-3}T^2+0.71\times10^5T^{-1}$$
$$\Delta F_T=-304{,}690+5.09T\ln T-7.55\times10^{-3}T^2+0.355\times10^5T^{-1}+34.3T$$

Zone II (723°–1,200° K.)

$$\Delta C_p=16.68T-10.3\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-308{,}150+16.68T-5.15\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-308{,}150-16.68T\ln T+5.15\times10^{-3}T^2-0.30\times10^5T^{-1}+173.25T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		13.04	−305,400	−286,400
400	1,640	17.75	−305,400	−279,900
500	3,700	22.33	−305,200	−273,400
600	5,860	26.27	−305,000	−267,000
700	8,350	30.10	−304,600	−261,200
800	16,810	41.65	−298,350	−254,900
900	19,860	45.24	−297,600	−249,700
1,000	22,910	48.45	−296,900	−244,500
1,100	25,960	51.36	−296,250	−239,150
1,200	29,010	54.02	−295,600	−234,000
1,300	32,060	56.45	(−295,200)	(−229,500)
1,400	35,110	58.71	(−294,900)	(−224,600)
1,500	38,160	60.82	(−294,700)	(−219,300)
1,600	41,210	62.79	(−294,500)	(−214,300)
1,700	44,260	64.64	(−294,200)	(−209,400)

Boron Trifluoride, BF_3 (*g*)

$\Delta H^\circ_{298}=-273{,}500$ calories per mole (*42*)
$S_{298}=60.70$ *e.u.* (*112*)
$M.P.=145°$ K. (*6*)
$\Delta H_M=480$ calories per mole
$B.P.=172.2°$ K. (*6*)
$\Delta H_V=4{,}620$ calories per mole

Zone I (*g*) (298°–1,000° K.)

$$C_p=12.44+6.70\times10^{-3}T-2.12\times10^5T^{-2} \quad (82)$$
$$H_T-H_{298}=-4{,}720+12.44T+3.35\times10^{-3}T^2+2.12\times10^5T^{-1}$$

Formation: $B+3/2F_2\longrightarrow BF_3$

Zone I (298°–1,000° K.)

$$\Delta C_p=-1.54+1.64\times10^{-3}T-0.92\times10^5T^{-2}$$
$$\Delta H_T=-273{,}420-1.54T+0.82\times10^{-3}T^2+0.92\times10^5T^{-1}$$
$$\Delta F_T=-273{,}420+1.54T\ln T-0.82\times10^{-3}T^2+0.46\times10^5T^{-1}+4.54T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		60.70	−273,500	−269,400
400	1,320	64.50	−273,660	−267,950
500	2,765	67.72	−273,780	−266,500
600	4,320	70.55	−273.890	−265,000
700	5,965	73.08	−273,970	−263,500
800	7,695	75.36	−274,050	−262,050
900	9,430	77.43	−274,110	−260,550
1,000	11,230	79.33	−274,175	−259,050
1,100	(13,240)		(−274,050)	(−257,600)
1,200	(15,160)		(−274,010)	(−256,100)
1,300			(−273,960)	(−255,200)
1,400			(−273,900)	(−253,650)
1,500	(21,640)		(−273,820)	(−252,050)
1,600			(−273,720)	(−250,450)
1,700			(−273,640)	(−248,900)
1,800			(−273,480)	(−247,300)
1,900			(−273,330)	(−245,700)
2,000	(33,560)		(−273,170)	(−244,050)

Boron Trichloride, BCl_3 (*g*)

$\Delta H^\circ_{298}=-94{,}500$ calories per mole (*112*)
$S_{298}=69.29$ *e.u.* (*112*)
$M.P.=166°$ K. (*6*)
$\Delta H_M=(500)$ calories per mole
$B.P.=285.6°$ K. (*6*)
$\Delta H_V=5{,}700$ calories per mole

Zone I (*g*) (298°–1,000° K.)

$$C_p = 16.86 + 2.86\times10^{-3}T - 2.44\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -5{,}970 + 16.86T + 1.43\times10^{-3}T^2 + 2.44\times10^{5}T^{-1}$$

Formation: $B + 3/2Cl_2 \longrightarrow BCl_3$

Zone I (298°–1,000° K.)

$$\Delta C_p = 2.09 - 1.63\times10^{-3}T - 1.42\times10^{5}T^{-2}$$
$$\Delta H_T = -95{,}525 + 2.09T - 0.815\times10^{-3}T^2 + 1.42\times10^{5}T^{-1}$$
$$\Delta F_T = -95{,}525 - 2.09T\ln T + 0.815\times10^{-3}T^2 + 0.71\times10^{5}T^{-1} + 26.68T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		69.29	−94,500	−90,800
400	1,610	73.93	−94,450	−89,450
500	3,295	77.68	−94,395	−88,250
600	5,065	80.91	−94,330	−87,050
700	6,885	83.71	−94,285	−85,900
800	8,745	86.19	−94,240	−84,550
900	10,630	88.41	−94,205	−83,500
1,000	12,530	90.41	−94,190	−82,150
1,100	(14,530)		(−94,080)	(−81,250)
1,200	(16,500)		(−94,080)	(−80,150)
1,300			(−94,090)	(−79,050)
1,400			(−94,100)	(−77,750)
1,500	(22,700)		(−94,130)	(−76,650)
1,600			(−94,200)	(−75,550)
1,700			(−94,250)	(−74,300)
1,800			(−94,330)	(−73,100)
1,900			(−94,420)	(−71,850)
2,000	(33,600)		(−94,530)	(−70,600)

Boron Tribromide, BBr_3 (*l*)

$\Delta H_{298}^\circ = -57{,}900$ calories per mole (*120*)
$S_{298} = 53.9$ *e.u.* (*11*)
$M.P. = 227°$ K. (*6*)
$\Delta H_M = (700)$ calories per mole
$B.P. = 364.4°$ K. (*6*)
$\Delta H_V = 7{,}298$ calories per mole

Zone I (*g*) (364.4°–1,000° K.)

$$C_p = 17.83 + 2.04\times10^{-3}T - 1.95\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = 7{,}160 + 17.83T + 1.02\times10^{-3}T^2 + 1.95\times10^{5}T^{-1}$$

Formation: $B + 3/2Br_2 \longrightarrow BBr_3$

Zone I (400°–1,000° K.)

$$\Delta C_p = 2.73 - 2.36\times10^{-3}T - 1.40\times10^{5}T^{-2}$$
$$\Delta H_T = -57{,}460 + 2.73T - 1.18\times10^{-3}T^2 + 1.40\times10^{5}T^{-1}$$
$$\Delta F_T = -57{,}460 - 2.73T\ln T + 1.18\times10^{-3}T^2 + 0.70\times10^{5}T^{-1} + 32.81T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		53.9	−57,900	−57,200
400	14,960	82.46	−56,200	−50,500
500	16,740	86.43	−56,120	−49,100
600	18,575	89.77	−56,030	−47,700
700	20,450	92.66	−55,960	−46,300
800	22,350	95.19	−55,900	−45,000
900	24,270	97.45	−55,860	−43,600
1,000	26,200	99.49	−55,840	−42,300
1,100	(28,450)			(−40,900)
1,200	(30,450)			(−39,500)
1,300	(32,500)			(−38,100)
1,400	(34,700)			(−36,700)
1,500	(36,600)		(−55,900)	(−35,400)
2,000	(46,600)		(−56,850)	(−28,600)

Boron Triiodide BI_3 (*c*)

$\Delta H_{298}^\circ = (-27{,}600)$ calories per mole (*11*)
$S_{298} = (55)$ *e.u.* (*11*)
$\Delta F_{298}^\circ = (-31{,}100)$ calories per mole
$M.P. = 316°$ K. (*6*)
$\Delta H_M = (1{,}000)$ calories per mole
$B.P. = 483°$ K. (*6*)
$\Delta H_V = (10{,}000)$ calories per mole

Tetraboron Carbide, B_4C (*c*)

$\Delta H_{298} = -13{,}800$ calories per mole (*122*)
$S_{298} = 6.47$ *e.u.* (*83*)
$M.P. = 2{,}623°$ K. (*9*)

Zone I (*c*) (298°–1,200° K.)

$$C_p = 22.99 + 5.40\times10^{-3}T - 10.72\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -10{,}690 + 22.99T + 2.70\times10^{-3}T^2 + 10.72\times10^{5}T^{-1}$$

Formation: $4B + C \longrightarrow B_4C$

Zone I (298°–1,200° K.)

$$\Delta C_p = 12.73 - 13.22\times10^{-3}T - 8.62\times10^{5}T^{-2}$$
$$\Delta H_T = -20{,}000 + 12.73T - 6.61\times10^{-3}T^2 + 8.62\times10^{5}T^{-1}$$
$$\Delta F_T = -20{,}000 - 12.73T\ln T + 6.61\times10^{-3}T^2 + 4.31\times10^{5}T^{-1} + 87.7T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		6.47	−13,800	−13,300
400	1,620	10.82	−13,600	−13,150
500	3,610	15.65	−13,450	−13,100
600	5,850	19.54	−13,300	−13,100
700	8,340	23.38	−13,150	−13,050
800	10,760	26.77	−13,050	−13,000
900	13,325	29.52	−13,000	−12,950
1,000	16,070	32.55	−13,000	−12,900
1,100	18,800	35.20	−12,950	−12,850
1,200	21,665	37.66	−12,900	−12,750
1,500	30,550	44.35	(−12,800)	(−12,500)
2,000	(46,550)	(53.64)		

Boron Nitride, BN (*c*)

$\Delta H_{298}^\circ = -60{,}700$ calories per mole (*33*)
$S_{298} = 3.67$ *e.u.* (*33*)
$S.P. = 3{,}270°$ K. (*9*)

Zone I (*c*) (298°–1,200° K.)

$$C_p = 3.64 + 7.24\times10^{-3}T \quad (78)$$
$$H_T - H_{298} = -1{,}380 + 3.64T + 3.62\times10^{-3}T^2$$

Formation: $B + 1/2N_2 \longrightarrow BN$

Zone I (298°–1,200° K.)

$$\Delta C_p = -1.23 + 2.33\times10^{-3}T$$
$$\Delta H_T = -60{,}950 - 1.23T + 1.16\times10^{-3}T^2$$
$$\Delta F_T = -60{,}950 + 1.23T\ln T - 1.16\times10^{-3}T^2 + 9.94T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		7.34	−60,700	−55,650
400	630	9.16	−60,700	−53,900
500	1,340	10.74	−60,700	−52,200
600	2,070	12.06	−60,750	−50,500
700	2,900	13.34	−60,750	−48,800
800	3,840	14.60	−60,750	−47,150
900	4,840	15.78	−60,600	−45,400
1,000	5,900	16.90	−60,500	−43,750
1,100	6,980	17.92	−60,400	−42,100
1,200	8,100	18.88	−60,250	−40,300

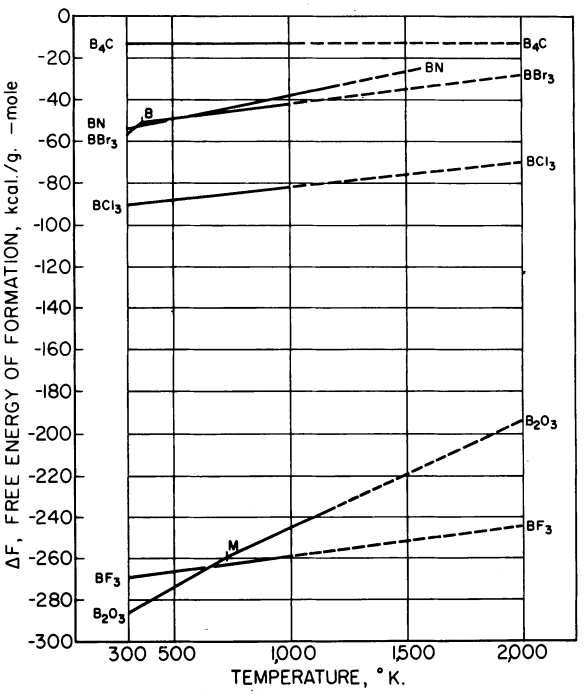

FIGURE 7.—Boron.

BROMINE

Element, Br_2 (l)

$S_{298}=36.4$ *e.u.* (*83*)
$M.P.=265.7°$ K. (*112*)
$\Delta H_M=2{,}580$ calories per atom
$B.P.=331°$ K. (*112*)
$\Delta H_V=7{,}418$ calories per atom

Zone I (l) (298°–331° K.)

$$C_p=17.1 \quad (82)$$
$$H_T-H_{298}=-5{,}090+17.1T$$
$$F_T-H_{298}=-5{,}090-17.1T\ln T+77.6T$$

Zone II (g) (331°–1,600° K.)

$$C_p=9.04-0.37\times10^5T^{-2} \quad (82)$$
$$H_T-H_{298}=4{,}940+9.04T+0.37\times10^5T^{-1}$$
$$F_T-H_{298}=4{,}940-9.04T\ln T+0.185\times10^5T^{-1}+0.51T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		36.4	36.4
400	8,648	62.74	41.12
500	9,531	64.71	45.65
600	10,420	66.33	48.96
700	11,313	67.71	51.55
800	12,209	68.91	53.65
900	13,109	69.96	55.39
1,000	14,011	70.91	56.90
1,100	14,900	71.85	58.30
1,200	15,819	72.56	59.37
1,300	16,720	73.24	60.38
1,400	17,635	73.96	61.36
1,500	18,530	74.54	62.19
1,600	19,457	75,18	63.02
1,700	(20,340)	(75.74)	(63.78)
1,800	(21,240)	(76.29)	(64.49)
1,900	(22,140)	(76.74)	(65.08)
2,000	(23,040)	(77.24)	(65.72)

CADMIUM AND ITS COMPOUNDS

Element, Cd (c)

$S_{298}=12.37$ *e.u.* (*28*)
$M.P.=594°$ K. (*82*)
$\Delta H_M=1{,}450$ calories per atom
$B.P.=1{,}038°$ K. (*7*)
$\Delta H_V=23{,}870$ calories per atom

Zone I (c) (298°–594° K.)

$$C_p=5.31+2.94\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-1{,}714+5.31T+1.47\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}714-5.31T\ln T-1.47\times10^{-3}T^2+24.07T$$

Zone II (l) (594°–1,038° K.)

$$C_p=7.10 \quad (82)$$
$$H_T-H_{298}=-810+7.10T$$
$$F_T-H_{298}=-810-7.10T\ln T+32.99T$$

Zone III (g) (1,038°–2,000° K.)

$$C_p=(5.0) \quad (141)$$
$$H_T-H_{298}=+25{,}370+5.0T$$
$$F_T-H_{298}=+25{,}370-5.0T\ln T-6.57T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		12.37	12.37
400	645	14.23	12.62
500	1,310	15.71	13.08
600	3,450	19.41	13.67
700	4,160	20.50	14.57
800	4,870	21.45	15.36
900	5,580	22.29	16.09
1,000	6,290	23.04	16.75
1,100	(30,700)	(46.55)	(18.62)
1,200	(31,200)	(46.98)	(20.96)
1,300	(31,700)	(47.38)	(22.98)
1,400	(32,200)	(47.75)	(24.74)
1,500	(32,700)	(48.09)	(26.28)
1,600	(33,200)	(48.41)	(27.65)
1,700	(33,700)	(48.72)	(28.90)
1,800	(34,200)	(49.00)	(30.00)
1,900	(34,700)	(49.27)	(31.01)
2,000	(35,200)	(49.52)	(31.92)

Cadmium Oxide, CdO (*c*)

$\Delta H^\circ_{298} = -61{,}200$ calories per mole (*98*)
$S_{298} = 13.1$ *e.u.* (*24*)

Formation: $Cd + 1/2O_2 \longrightarrow CdO$
(estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−61, 200	−54, 100
400	(1, 100)	(−61, 100)	(−51, 700)
500	(2, 150)	(−61, 100)	(−47, 000)
600	(3, 250)	(−62, 500)	(−44, 400)
700	(4, 350)	(−62, 500)	(−41, 800)
800	(5, 450)	(−62, 500)	(−39, 200)
900	(6, 600)	(−62, 500)	(−36, 700)
1, 000	(7, 800)	(−62, 400)	(−32, 700)
1,100	(9, 050)	(−86, 100)	(−27, 800)
1, 500	(14, 150)	(−84, 800)	(−8, 700)

Cadmium Difluoride, CdF_2 (*c*)

$\Delta H^\circ_{298} = -167{,}000$ calories per mole (*11*)
$S_{298} = (22)$ *e.u.* (*11*)
$M.P. = 1{,}383°$ K. (*6*)
$\Delta H_M = 5{,}400$ calories per mole
$B.P. = 2{,}023°$ K. (*6*)
$\Delta H_V = 52{,}000$ calories per mole

Formation: $Cd + F_2 \longrightarrow CdF_2$
(estimated (11))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−167, 000	(−155, 400)
500	(4, 000)	(−165, 900)	(−147, 000)
1, 000	(14, 000)	(−165, 000)	(−129, 000)
1, 500	(32, 000)		

Cadmium Dichloride, $CdCl_2$ (*c*)

$\Delta H^\circ_{298} = -93{,}000$ calories per mole (*112*)
$S_{298} = 31.2$ *e.u.* (*83*)
$M.P. = 841°$ K. (*6*)
$\Delta H_M = 5{,}300$ calories per mole
$B.P. = 1{,}240°$ K. (*6*)
$\Delta H_V = 29{,}860$ calories per mole

Zone I (298°–800° K.)

$C_p = 14.64 + 9.60 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -4{,}790 + 14.64T + 4.80 \times 10^{-3} T^2$

Formation: $Cd + Cl_2 \longrightarrow CdCl_2$

Zone I (298°–594 K.)

$\Delta C_p = 0.51 + 6.60 \times 10^{-3} T + 0.68 \times 10^5 T^{-2}$
$\Delta H_T = -93{,}215 + 0.51T + 3.30 \times 10^{-3} T^2 - 0.68 \times 10^5 T^{-1}$
$\Delta F_T = -93{,}215 - 0.51 T \ln T - 3.30 \times 10^{-3} T^2 - 0.34 \times 10^5 T^{-1} + 39.48T$

Zone II (594°–800° K.)

$\Delta C_p = -1.28 + 9.54 \times 10^{-3} T + 0.68 \times 10^5 T^{-2}$
$\Delta H_T = -94{,}100 - 1.28T + 4.77 \times 10^{-3} T^2 - 0.68 \times 10^5 T^{-1}$
$\Delta F_T = -94{,}100 + 1.28 T \ln T - 4.77 \times 10^{-3} T^2 - 0.34 \times 10^5 T^{-1} + 30.5T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		31. 2	−93, 000	−82, 700
400	1, 780	36. 33	−92, 700	−79, 200
500	3, 720	40. 66	−92, 300	−75, 900
600	5, 750	44. 36	−93, 250	−72, 650
700	7, 840	47. 58	−92, 750	−69, 300
800	9, 990	50. 45	−92, 200	−65, 900
1,000	(20, 000)		(−85, 350)	(−60, 700)
1, 500	(62, 000)		(−74, 000)	(−47, 900)

Cadmium Dibromide, $CdBr_2$ (*c*)

$\Delta H^\circ_{298} = -75{,}800$ calories per mole (*11*)
$S_{298} = 34.4$ *e.u.* (*83*)
$M.P. = 841°$ K. (*6*)
$\Delta H_M = 5{,}000$ calories per mole
$B.P. = 1{,}136°$ K. (*6*)
$\Delta H_V = 27{,}000$ calories per mole

Formation: $Cd + Br_2 \longrightarrow CdBr_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−75, 800	−71, 500
500	(4, 000)	(−82, 650)	(−64, 250)
1,000	(20, 000)	(−76, 100)	(−47, 000)
1,500	(59, 000	(−68, 200)	

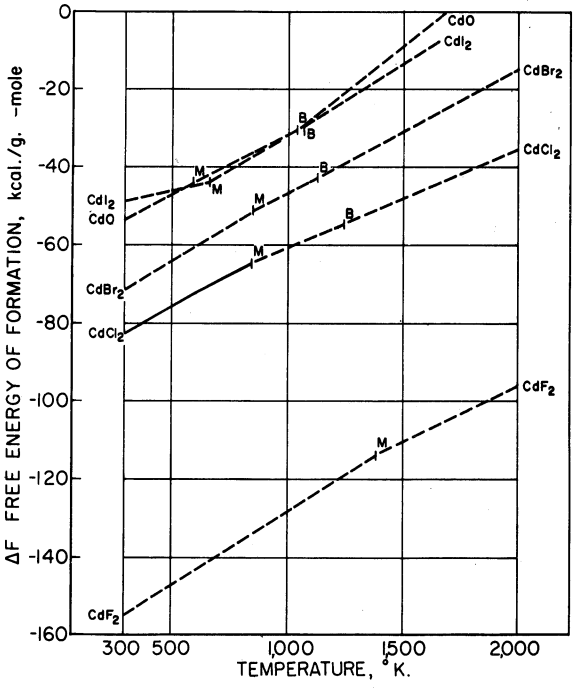

FIGURE 8.—Cadmium.

Cadmium Diiodide, CdI_2 (*c*)

$\Delta H^\circ_{298} = -48{,}750$ calories per mole (*11*)
$S_{298} = 39.5$ *e.u.* (*11*)
$M.P. = 660°$ K. (*6*)
$\Delta H_M = 3{,}660$ calories per mole
$B.P. = 1{,}069°$ K. (*6*)
$\Delta H_V = 25{,}400$ calories per mole

Formation: $Cd + I_2 \longrightarrow CdI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−48,750	−49,000
500	(4,000)	(−62,700)	(−46,300)
1,000	(19,000)	(−56,200)	(−32,000)
1,500	(56,400)	(−50,800)	(−13,000)

CALCIUM AND ITS COMPOUNDS

Element, Ca (*c*)

$S_{298} = 9.95$ *e.u.* (*83*)
$T.P. = 673°$ K. (*82*)
$\Delta H_T = 115$ calories per atom
$M.P. = 1{,}124°$ K. (*80*)
$\Delta H_M = 2{,}230$ calories per atom
$B.P. = 1{,}760°$ K. (*130*)
$\Delta H_V = 35{,}840$ calories per atom

Zone I (α) (298°–673° K.)

$C_p = 5.24 + 3.50 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -1{,}718 + 5.24T + 1.75 \times 10^{-3} T^2$
$F_T - H_{298} = -1{,}718 - 5.24 T \ln T - 1.75 \times 10^{-3} T^2 + 26.13 T$

Zone II (β) (673°–1,124° K.)

$C_p = 6.29 + 1.40 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -1{,}834 + 6.29T + 0.70 \times 10^{-3} T^2$
$F_T - H_{298} = -1{,}834 - 6.29 T \ln T - 0.70 \times 10^{-3} T^2 + 32.49 T$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		9.95	9.95
400	650	11.82	10.20
500	1,330	13.34	10.88
600	2,060	14.67	11.23
700	2,910	15.97	11.81
800	3,650	16.96	12.41
900	4,390	17.83	12.94
1,000	5,160	18.64	13.48
1,100	5,930	19.38	13.97
1,200	(8,880)	(21.88)	(14.47)
1,300	(9,630)	(22.58)	(15.18)
1,400	(10,380)	(23.08)	(15.58)
1,500	(11,210)	(23.69)	(16.20)

Calcium Oxide, CaO (*c*)

$\Delta H^\circ_{298} = -151{,}790$ calories per mole (*57*)
$S_{298} = 9.5$ *e.u.* (*83*)
$M.P. = 2{,}873°$ K. (*112*)
$\Delta H_M = 12{,}000$ calories per mole
$B.P. = 3{,}800°$ K. (*94*)

Zone I (*c*) (298°–1,800° K.)

$C_p = 11.67 + 1.08 \times 10^{-3} T - 1.56 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -4{,}050 + 11.67T + 0.54 \times 10^{-3} T^2 + 1.56 \times 10^5 T^{-1}$

Formation: $Ca + 1/2O_2 \longrightarrow CaO$

Zone I (298°–673° K.)

$\Delta C_p = 2.85 - 2.92 \times 10^{-3} T - 1.36 \times 10^5 T^{-2}$
$\Delta H_T = -152{,}950 + 2.85T - 1.46 \times 10^{-3} T^2 + 1.36 \times 10^5 T^{-1}$
$\Delta F_T = -152{,}950 - 2.85 T \ln T + 1.46 \times 10^{-3} T^2 + 0.68 \times 10^5 T^{-1} + 43.87 T$

Zone II (673°–1,124° K.)

$\Delta C_p = 1.80 - 0.82 \times 10^{-3} T - 1.36 \times 10^5 T^{-2}$
$\Delta H_T = -152{,}850 + 1.80T - 0.41 \times 10^{-3} T^2 + 1.36 \times 10^5 T^{-1}$
$\Delta F_T = -152{,}850 - 1.80 T \ln T + 0.41 \times 10^{-3} T^2 + 0.68 \times 10^5 T^{-1} + 37.57 T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		9.5	−151,790	−144,350
400	1,100	12.67	−151,700	−141,850
500	2,230	15.19	−151,650	−139,400
600	3,400	17.32	−151,550	−136,950
700	4,600	19.17	−151,600	−134,500
800	5,820	20.80	−151,500	−132,050
900	7,040	22.23	−151,450	−129,650
1,000	8,270	23.53	−151,400	−127,200
1,100	9,520	24.72	−151,300	−124,700
1,200	10,800	25.84	(−153,400)	(−122,400)
1,300	12,110	26.88	(−153,300)	(−119,900)
1,400	13,430	27.86	(−153,200)	(−117,250)
1,500	14,760	28.78	(−153,100)	(−114,500)

Calcium Dioxide, CaO_2 (*c*)

$\Delta H^\circ_{298} = (-156{,}500)$ calories per mole (*24*)
$S_{298} = (15.4)$ *e.u.* (*24*)
Decomposes = 548° K. (*8*)

(estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−156,500)	(−143,500)
400	(1,875)	(−156,000)	(−139,500)
500	(3,800)	(−155,500)	(−135,000)

Calcium Difluoride, CaF_2 (*c*)

$\Delta H^\circ_{298} = -290{,}200$ calories per mole (*112*)
$S_{298} = 16.48$ *e.u.* (*134*)
$T.P. = 1{,}424°$ K. (*82*)
$\Delta H_T = 1{,}140$ calories per mole
$M.P. = 1{,}691°$ K. (*82*)
$\Delta H_M = 6{,}780$ calories per mole
$B.P. = 2{,}145°$ K. (*112*)
$\Delta H_V = 83{,}000$ calories per mole

Zone I (α) (298°–1,424° K.)

$C_p = 14.30 + 7.28 \times 10^{-3} T + 0.47 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -4{,}400 + 14.30T + 3.64 \times 10^{-3} T^2 - 0.47 \times 10^5 T^{-1}$

Zone II (β) (1,424°–1,691° K.)

$$C_p = 25.81 + 2.50\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -14{,}900 + 25.81T + 1.25\times10^{-3}T^2$$

Zone III (l) (1,691°–1,800° K.)

$$C_p = 23.90 \quad (82)$$
$$H_T - H_{298} = -1{,}000 + 23.90T$$

Formation: $Ca + F_2 \longrightarrow CaF_2$

Zone I (298°–673° K.)

$$\Delta C_p = 0.77 + 3.34\times10^{-3}T + 1.27\times10^{5}T^{-2}$$
$$\Delta H_T = -290{,}150 + 0.77T + 1.67\times10^{-3}T^2 - 1.27\times10^{5}T^{-1}$$
$$\Delta F_T = -290{,}150 - 0.77T\ln T - 1.67\times10^{-3}T^2 - 0.63\times10^{5}T^{-1} + 47.48T$$

Zone II (673°–1,124° K.)

$$\Delta C_p = -0.28 + 5.44\times10^{-3}T + 1.27\times10^{5}T^{-2}$$
$$\Delta H_T = -290{,}010 - 0.28T + 2.72\times10^{-3}T^2 - 1.27\times10^{5}T^{-1}$$
$$\Delta F_T = -290{,}010 + 0.28T\ln T - 2.72\times10^{-3}T^2 - 0.63\times10^{5}T^{-1} + 41.11T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		16.48	−290,200	−277,700
400	1,760	21.54	−289,900	−273,500
500	3,540	25.52	−289,600	−269,400
600	5,400	28.91	−289,300	−265,300
700	7,320	31.87	−289,050	−261,400
800	9,280	34.49	−288,700	−257,500
900	11,300	36.86	−288,250	−253,500
1,000	13,380	39.06	−287,850	−249,750
1,100	15,550	41,12	−287,300	−246,000
1,200	17,850	43.12	(−288,750)	(−242,150)
1,300	20,230	45,03	(−287,800)	(−238,300)
1,400	22,680	46.84	(−286,850)	(−234,600)
1,500	26,660	49.60	(−284,990)	(−230,900)

Calcium Dichloride, $CaCl_2$ (c)

$\Delta H_{298}^\circ = -190{,}400$ calories per mole (*94*)
$S_{298} = 27.2$ *e.u.* (*83*)
$M.P. = 1{,}055°$ K. (*82*)
$\Delta H_M = 6{,}780$ calories per mole
$B.P. = (2{,}300°)$ K. (*6*)
$\Delta H_V = (55{,}000)$ calories per mole

Zone I (c) (298°–1,055° K.)

$$C_p = 17.18 + 3.04\times10^{-3}T - 0.60\times10^{5}T^{-2} \quad (83)$$
$$H_T - H_{298} = -5{,}460 + 17.18T + 1.52\times10^{-3}T^2 + 0.60\times10^{5}T^{-1}$$

Zone II (l) (1,055°–1,700° K.)

$$C_p = 24.70 \quad (83)$$
$$H_T - H_{298} = -4{,}880 + 24.70T$$

Formation: $Ca + Cl_2 \longrightarrow CaCl_2$

Zone I (298°–673° K.)

$$\Delta C_p = 3.12 - 0.52\times10^{-3}T + 0.08\times10^{5}T^{-2}$$
$$\Delta H_T = -191{,}280 + 3.12T - 0.26\times10^{-3}T^2 - 0.08\times10^{5}T^{-1}$$
$$\Delta F_T = -191{,}280 - 3.12T\ln T + 0.26\times10^{-3}T^2 - 0.04\times10^{5}T^{-1} + 56.41T$$

Zone II (673°–1,055° K.)

$$\Delta C_p = 2.07 + 1.58\times10^{-3}T + 0.08\times10^{5}T^{-2}$$
$$\Delta H_T = -191{,}150 + 2.07T + 0.79\times10^{-3}T^2 - 0.08\times10^{5}T^{-1}$$
$$\Delta F_T = -191{,}150 - 2.07T\ln T - 0.79\times10^{-3}T^2 - 0.04\times10^{5}T^{-1} + 50.32T$$

Zone III (1,055°–1,124° K.)

$$\Delta C_p = 9.59 - 1.46\times10^{-3}T - 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -190{,}500 + 9.59T - 0.73\times10^{-3}T^2 + 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -190{,}500 - 9.59T\ln T + 0.73\times10^{-3}T^2 + 0.34\times10^{5}T^{-1} + 100.69T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		27.2	−190,400	−179,650
400	1,850	32.53	−190,050	−175,950
500	3,700	36.66	−189,700	−172,500
600	5,540	40.02	−189,450	−169,050
700	7,400	42.88	−189,350	−165,750
800	9,290	45.4	−189,050	−162,350
900	11,230	47.69	−188,750	−159,150
1,000	13,270	49.84	−188,350	−155,700
1,100	22,340	58.44	−180,800	−152,800
1,200	24,840	60.62	(−182,300)	(−150,300)
1,300	27,320	62.6	(−181,500)	(−147,700)
1,400	29,780	64.42	(−180,600)	(−145,100)
1,500	32,210	66.10	(−179,770)	(−142,400)

Calcium Dibromide, $CaBr_2$ (c)

$\Delta H_{298}^\circ = -161{,}300$ calories per mole (*114*)
$S_{298} = (31)$ *e.u.* (*114*)
$M.P. = 1{,}033°$ K. (*6*)
$\Delta H_M = 4{,}180$ calories per mole
$B.P. = (2{,}100°)$ K. (*6*)
$\Delta H_V = (50{,}000)$ calories per mole

Formation: $Ca + Br_2 \longrightarrow CaBr_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−161,300	(−157,500)
500	(3,500)	(−168,700)	(−150,350)
1,000	(13,900)	(−166,600)	(−133,500)
1,500	(30,100)	(−160,900)	(−119,500)

Calcium Diiodide, CaI_2 (c)

$\Delta H_{298}^\circ = -127{,}500$ calories per mole (*112*)
$S_{298} = (34)$ *e.u.* (*112*)
$M.P. = 1{,}013°$ K. (*6*)
$\Delta H_M = (5{,}000)$ calories per mole
$B.P. = (1{,}500°)$ K. (*6*)
$\Delta H_V = (35{,}000)$ calories per mole

Formation: $Ca + I_2 \longrightarrow CaI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−127,500	(−126,400)
500	(3,900)	(−141,600)	(−124,000)
1,000	(14,100)	(−139,700)	(−106,000)
1,500	(31,100)	(−132,200)	(−91,000)

Calcium Dicarbide, CaC_2 (*c*)

$\Delta H^\circ_{298} = -15{,}000$ calories per mole (*112*)
$S_{298} = 16.8$ *e.u.* (*83*)
$T.P. = 720°$ K. (*82*)
$\Delta H_T = 1{,}330$ calories per mole
$M.P. = 2{,}573°$ K. (*9*)

Zone I (α) (298°–720° K.)

$$C_p = 16.40 + 2.84\times10^{-3}T - 2.07\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -5{,}700 + 16.40T + 1.42\times10^{-3}T^2 + 2.07\times10^{5}T^{-1}$$

Zone II (β) (720°–1,300° K.)

$$C_p = 15.40 + 2.00\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -3{,}150 + 15.40T + 1.00\times10^{-3}T^2$$

Formation: $Ca + 2C \longrightarrow CaC_2$

Zone I (298°–673° K.)

$$\Delta C_p = 2.96 - 2.7\times10^{-3}T + 2.13\times10^{5}T^{-2}$$
$$\Delta H_T = -15{,}000 + 2.96T - 1.35\times10^{-3}T^2 - 2.13\times10^{5}T^{-1}$$
$$\Delta F_T = -15{,}000 - 2.96T\ln T + 1.35\times10^{-3}T^2 - 1.07\times10^{5}T^{-1} + 13.72T$$

Zone II (673°–720° K.)

$$\Delta C_p = 1.91 - 0.60\times10^{-3}T + 2.13\times10^{5}T^{-2}$$
$$\Delta H_T = -14{,}700 + 1.91T - 0.30\times10^{-3}T^2 - 2.13\times10^{5}T^{-1}$$
$$\Delta F_T = -14{,}700 - 1.91T\ln T + 0.30\times10^{-3}T^2 - 1.06\times10^{5}T^{-1} + 7.02T$$

Zone III (720°–1,124° K.)

$$\Delta C_p = 0.91 - 1.44\times10^{-3}T + 4.20\times10^{5}T^{-2}$$
$$\Delta H_T = -12{,}320 + 0.91T - 0.72\times10^{-3}T^2 - 4.20\times10^{5}T^{-1}$$
$$\Delta F_T = -12{,}320 - 0.91T\ln T + 0.72\times10^{-3}T^2 - 2.10\times10^{5}T^{-1} - 3.17T$$

T ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		16.8	−15,000	−16,200
400	1,600	21.41	−14,550	−16,700
500	3,260	25.11	−14,200	−17,300
600	5,000	28.27	−13,950	−17,950
700	6,760	30.99	−13,900	−18,600
800	9,790	35.12	−12,500	−19,450
900	11,510	37.14	−12,500	−20,300
1,000	13,250	38.98	−12,550	−21,200
1,100	15,010	40.65	−12,600	−22,100
1,200	16,780	42.19	(−14,800)	(−22,900)

Tricalcium Dinitride, Ca_3N_2 (*c*)

$\Delta H^\circ_{298} = -108{,}200$ calories per mole (*9*)
$S_{298} = 25.4$ *e.u.* (*9*)
$M.P. = 1{,}468°$ K. (*112*)

Zone I (*c*) (298°–800° K.)

$$C_p = 20.44 + 22.00\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -7{,}100 + 20.44T + 11.00\times10^{-3}T^2$$

Formation: $3Ca + N_2 \longrightarrow Ca_3N_2$

Zone I (298°–673° K.)

$$\Delta C_p = -1.94 + 10.48\times10^{-3}T$$
$$\Delta H_T = -108{,}100 - 1.94T + 5.24\times10^{-3}T^2$$
$$\Delta F_T = -108{,}100 + 1.94T\ln T - 5.24\times10^{-3}T^2 + 40.46T$$

Zone II (673°–800° K.)

$$\Delta C_p = -5.09 + 16.78\times10^{-3}T$$
$$\Delta H_T = -107{,}670 - 5.09T + 8.39\times10^{-3}T^2$$
$$\Delta F_T = -107{,}670 + 5.09T\ln T - 8.39\times10^{-3}T^2 + 21.28T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		25.4	−108,200	−93,200
400	2,850	33.61	−108,100	−88,100
500	5,900	40.41	−107,700	−83,200
600	9,150	46.33	−107,350	−78,350
700	12,650	51.72	−107,100	−73,550
800	16,300	56.59	−106,500	−68,750

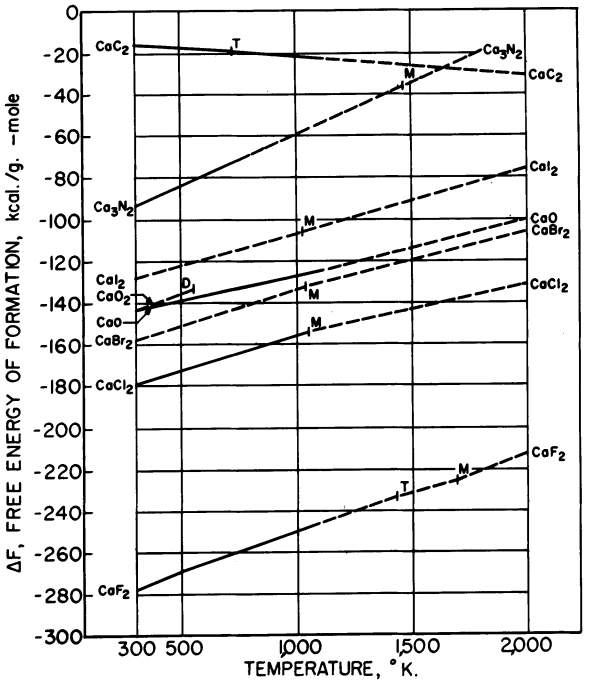

FIGURE 9.—Calcium.

CARBON AND ITS COMPOUNDS

Element, C (*c*)

$S_{298} = 1.366$ *e.u.* (*83*)
$S.P. = 4{,}620°$ K. (*130*)

Zone I (*c*) (298°–2,300° K.)

$$C_p = 4.10 + 1.02\times10^{-3}T - 2.10\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -1{,}972 + 4.10T + 0.51\times10^{-3}T^2 + 2.10\times10^{5}T^{-1}$$
$$F_T - H_{298} = -1{,}972 - 4.10T\ln T - 0.51\times10^{-3}T^2 + 1.05\times10^{5}T^{-1} + 27.72T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		1.36	1.36
400	250	2.08	1.42
500	570	2.79	1.65
600	950	3.48	1.90
700	1,370	4.13	2.17
800	1,830	4.74	2.43
900	2,310	5.31	2.74
1,000	2,810	5.83	3.02
1,100	3,320	6.32	3.10
1,200	3,850	6.78	3.58
1,300	4,390	7.21	3.84
1,400	4,930	7.61	4.10
1,500	5,480	7.99	4.33
1,600	6,040	8.35	4.57
1,700	6,610	8.69	4.81
1,800	7,190	9.02	5.02
1,900	7,780	9.34	5.25
2,000	8,380	9.65	5.46

Carbon Monoxide, CO (*g*)

$\Delta H^\circ_{298} = -26{,}416$ calories per mole (*112*)
$S_{298} = 47.31$ *e.u.* (*83*)
$M.P. = 68.10°$ K. (*112*)
$\Delta H_M = 200$ calories per mole
$B.P. = 81.66°$ K. (*112*)
$\Delta H_V = 1{,}444$ calories per mole

Zone I (*g*) (298°–2,500° K.)

$$C_p = 6.79 + 0.98\times10^{-3}T - 0.11\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -2{,}100 + 6.79T + 0.49\times10^{-3}T^2 + 0.11\times10^{5}T^{-1}$$

Formation: $C + 1/2O_2 \longrightarrow CO$

Zone I (298°–2,000° K.)

$$\Delta C_p = -0.89 - 0.54\times10^{-3}T + 2.19\times10^{5}T^{-2}$$
$$\Delta H_T = -25{,}380 - 0.89T - 0.27\times10^{-3}T^2 - 2.19\times10^{5}T^{-1}$$
$$\Delta F_T = -25{,}380 + 0.89T\ln T + 0.27\times10^{-3}T^2 - 1.10\times10^{5}T^{-1} - 28.84T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298	----------	47.31	−26,400	−32,800
400	711	49.36	−26,300	−35,000
500	1,418	50.94	−26,200	−37,100
600	2,137	52.25	−26,350	−39,350
700	2,874	53.38	−26,400	−41,550
800	3,628	54.39	−26,500	−43,700
900	4,400	55.30	−26,600	−45,850
1,000	5,186	56.13	−26,750	−47,950
1,100	5,960	56.94	−26,900	−50,100
1,200	6,798	57.59	−27,000	−52,150
1,300	7,460	58.23	−27,300	−54,350
1,400	8,370	58.83	−27,350	−56,250
1,500	9,291	59.45	−27,450	−58,400
1,600	10,020	60.03	−27,650	−60,600
1,700	10,850	60.53	−27,850	−62,650
1,800	11,700	60.92	−28,000	−64,650
1,900	12,580	61.42	−28,250	−66,750
2,000	13,570	61.91	−28,450	−68,750

Carbon Dioxide, CO_2 (*g*)

$\Delta H^\circ_{298} = -94{,}052$ calories per mole (*112*)
$S_{298} = 51.05$ *e.u.* (*83*)
$S.P. = 194.7°$ K. (*112*)
$\Delta H_{subl} = 6{,}031$ calories per mole

Zone I (*g*) (298°–2,500° K.)

$$C_p = 10.55 + 2.16\times10^{-3}T - 2.04\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -3{,}926 + 10.55T + 1.08\times10^{-3}T^2 + 2.04\times10^{5}T^{-1}$$

Formation: $C + O_2 \longrightarrow CO_2$

Zone I (298°–2,000° K.)

$$\Delta C_p = -0.71 + 0.14\times10^{-3}T + 0.46\times10^{5}T^{-2}$$
$$\Delta H_T = -93{,}650 - 0.71T + 0.07\times10^{-3}T^2 - 0.46\times10^{5}T^{-1}$$
$$\Delta F_T = -93{,}650 + 0.71T\ln T - 0.07\times10^{-3}T^2 - 0.23\times10^{5}T^{-1} - 5.56T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298	----------	51.05	−94,050	−94,250
400	958	53.76	−94,050	−94,300
500	1,987	56.10	−94,100	−94,400
600	3,088	58.11	−94,150	−94,450
700	4,248	59.89	−94,150	−94,500
800	5,458	61.51	−94,200	−94,500
900	6,708	62.98	−94,250	−94,550
1,000	7,993	64.33	−94,400	−94,600
1,100	9,308	65.59	−94,250	−94,600
1,200	10,650	66.75	−94,300	−94,650
1,300	12,010	67.84	−94,300	−94,700
1,400	13,380	68.86	−94,300	−94,750
1,500	14,780	69.82	−94,400	−94,750
1,600	15,850	70.39	−94,700	−94,800
1,700	17,240	71.34	−94,750	−94,850
1,800	18,690	72.09	−94,800	−94,900
1,900	20,100	72.85	−94,850	−94,900
2,000	21,920	73.93	−94,850	−95,000

Carbon Tetrafluoride, CF_4 (*g*)

$\Delta H^\circ_{298} = -162{,}500$ calories per mole (*106*)
$S_{298} = 62.8$ *e.u.* (*80*)
$M.P. = 89.47°$ K. (*106*)
$\Delta H_M = 167$ calories per mole
$B.P. = 145.14°$ K. (*106*)
$\Delta H_V = 3{,}010$ calories per mole

Zone I (*g*) (298°–1,200° K.)

$$C_p = 16.64 + 7.84\times10^{-3}T - 4.00\times10^{5}T^{-2} \quad (79)$$
$$H_T - H_{298} = -6{,}650 + 16.64T + 3.92\times10^{-3}T^2 + 4.00\times10^{5}T^{-1}$$

Formation: $C + 2F_2 \longrightarrow CF_4$

Zone I (298°–1,200° K.)

$$\Delta C_p = -4.04 + 5.94\times10^{-3}T - 0.30\times10^{5}T^{-2}$$
$$\Delta H_T = -161{,}700 - 4.04T + 2.97\times10^{-3}T^2 + 0.30\times10^{5}T^{-1}$$
$$\Delta F_T = -161{,}700 + 4.04T\ln T - 2.97\times10^{-3}T^2 + 0.15\times10^{5}T^{-1} + 10.8T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298	----------	62.8	−162,500	−151,850
400	1,615	67.47	−162,600	−148,100
500	3,430	71.49	−162,700	−144,450
600	5,410	75.10	−162,900	−140,900
700	7,520	78.35	−162,900	−137,200
800	9,720	81.28	−162,850	−133,550
900	11,995	83.96	−162,800	−129,900
1,000	14,315	86.41	−162,700	−126,250
1,100	16,760	88.72	−162,500	−122,900
1,200	19,085	90.75	−162,500	−119,000
1,500	(27,400)	----------	(−160,500)	(−107,700)
2,000	(42,650)	----------	(−156,900)	(−85,100)

Carbon Tetrachloride, CCl_4 (*l*)

$\Delta H^\circ_{298} = -33{,}200$ calories per mole (*112*)
$S_{298} = 51.3$ *e.u.* (*83*)
$M.P. = 249.1°$ K. (*112*)
$\Delta H_M = 644$ calories per mole
$B.P. = 350°$ K. (*112*)
$\Delta H_V = 7{,}283$ calories per mole

Zone I (g) (350°–1,000° K.)

$$C_p = 23.34 + 2.30\times10^{-3}T - 3.60\times10^{5}T^{-2} \quad (83)$$
$$H_T - H_{298} = -1,560 + 23.34T + 1.15\times10^{-3}T^2 + 3.60\times10^{5}T^{-1}$$

Formation: $C + 2Cl_2 \longrightarrow CCl_4$

Zone I (350°–1,000° K.)

$$\Delta C_p = 1.6 + 1.16\times10^{-3}T - 0.14\times10^{5}T^{-2}$$
$$\Delta H_T = -27,020 + 1.6T + 0.58\times10^{-3}T^2 + 0.14\times10^{5}T^{-1}$$
$$\Delta F_T = -27,020 - 1.6T\ln T - 0.58\times10^{-3}T^2 + 0.07\times10^{5}T^{-1} + 45.44T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298	----------	51.3	−33,200	−16,300
400	8,845	79.98	−26,300	−12,750
500	11,100	84.99	−26,050	−9,400
600	13,450	89.29	−25,800	−6,150
700	15,860	92.99	−25,550	−2,950
800	18,310	96.26	−25,300	+450
900	20,790	99.18	−25,050	+3,500
1,000	23,290	101.82	−24,850	+6,850
1,500	(36,250)	----------	(−23,600)	(+22,300)
2,000	(49,900)	----------	(−22,350)	(+37,300)

Carbonyl Chloride (Phosgene), $COCl_2$ (g)

$\Delta H_{298}^\circ = -53,300$ calories per mole (*112*)
$S_{298} = 69.13$ *e.u.* (*38*)
$M.P. = 145.34°$ K. (*38*)
$\Delta H_M = 1,371$ calories per mole
$B.P. = 280.7°$ K. (*38*)
$\Delta H_V = 5,825$ calories per mole

Zone I (g) (298°–1,000° K.)

$$C_p = 15.60 + 3.46\times10^{-3}T - 1.91\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -5,446 + 15.60T + 1.73\times10^{-3}T^2 + 1.91\times10^{5}T^{-1}$$

Formation: $C + 1/2O_2 + Cl_2 \longrightarrow COCl_2$

Zone I (298°–1,000° K.)

$$\Delta C_p = -0.90 + 1.88\times10^{-3}T + 1.07\times10^{5}T^{-2}$$
$$\Delta H_T = -52,700 - 0.90T + 0.94\times10^{-3}T^2 - 1.07\times10^{5}T^{-1}$$
$$\Delta F_T = -52,700 + 0.90T\ln T - 0.94\times10^{-3}T^2 - 0.54\times10^{5}T^{-1} + 3.92T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298	----------	69.13	−53,300	−50,300
400	1,545	73.58	−53,200	−49,300
500	3,165	77.19	−53,100	−48,300
600	4,855	80.27	−53,050	−47,300
700	6,600	82.96	−53,000	−46,400
800	8,400	85.36	−52,900	−45,450
900	10,210	87.49	−52,900	−44,500
1,000	12,060	89.44	−52,800	−43,500
1,500	(22,000)	----------	(−51,800)	(−39,400)
2,000	(32,800)	----------	(−50,600)	(−35,400)

Carbon Tetrabromide, CBr_4 (c)

$\Delta H_{298}^\circ = (-500)$ calories per mole (*11*)
$S_{298} = (56)$ *e.u.* (*11*)
$T.P. = 320°$ K. (*82*)
$\Delta H_T = 1,430$ calories per mole
$M.P. = 363°$ K. (*82*)
$\Delta H_M = 950$ calories per mole
$B.P. = 463°$ K. (*6*)
$\Delta H_V = (9,700)$ calories per mole

Zone I (α) (298°–320° K.)

$$C_p = 34.5 \quad (82)$$
$$H_T - H_{298} = -10,287 + 34.5T$$

Zone II (β) (320°–363° K.)

$$C_p = 43.0 \quad (82)$$
$$H_T - H_{298} = -11,580 + 43.0T$$

Zone III (l) (363°–463° K.)

$$C_p = 36.7 \quad (82)$$
$$H_T - H_{298} = -8,340 + 36.7T$$

Zone IV (g) (463°–1,000° K.)

$$C_p = 25.03 + 0.60\times10^{-3}T - 3.03\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = 5,200 + 25.03T + 0.30\times10^{-3}T^2 + 3.03\times10^{5}T^{-1}$$

Formation: $C + 2Br_2 \longrightarrow CBr_4$

Zone I (298°–320° K.)

$$\Delta C_p = -3.8 - 1.02\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = 1,877 - 3.8T - 0.51\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = 1,877 + 3.8T\ln T + 0.51\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} - 10.1T$$

Zone II (331°–363° K.)

$$\Delta C_p = 20.86 - 1.02\times10^{-3}T + 2.84\times10^{5}T^{-2}$$
$$\Delta H_T = -20,000 + 20.86T - 0.51\times10^{-3}T^2 - 2.84\times10^{5}T^{-1}$$
$$\Delta F_T = -20,000 - 20.86T\ln T + 0.51\times10^{-3}T^2 - 1.42\times10^{5}T^{-1} + 201.0T$$

Zone III (363°–463° K.)

$$\Delta C_p = -14.55 - 1.02\times10^{-3}T + 2.84\times10^{5}T^{-2}$$
$$\Delta H_T = -16,730 + 14.55T - 0.51\times10^{-3}T^2 - 2.84\times10^{5}T^{-1}$$
$$\Delta F_T = -16,730 - 14.55T\ln T + 0.51\times10^{-3}T^2 - 1.42\times10^{5}T^{-1} + 154.2T$$

Zone IV (463°–1,000° K.)

$$\Delta C_p = 2.89 - 0.42\times10^{-3}T - 0.19\times10^{5}T^{-2}$$
$$\Delta H_T = -3,310 + 2.89T - 0.21\times10^{-3}T^2 + 0.19\times10^{5}T^{-1}$$
$$\Delta F_T = -3,310 - 2.89T\ln T + 0.21\times10^{-3}T^2 + 0.1\times10^{5}T^{-1} + 52.9T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298	----------	(56)	(−500)	(+5,000)
400	6,340	(74.02)	(−11,700)	(9,700)
500	18,400	(100.0)	(−1,840)	(15,400)
600	20,840	(104.7)	(−1,450)	(18,300)
700	23,300	(108.5)	(−1,200)	(20,700)
800	25,790	(111.7)	(−950)	(23,750)
900	28,310	(114.8)	(−700)	(26,700)
1,000	30,840	(117.4)	(−500)	(29,700)
1,500	(42,000)	----------	(+1,750)	(46,100)
2,000	(68,100)	----------	(2,800)	(62,500)

Carbon Tetraiodide, CI_4 (c)

$\Delta H_{298}^\circ = (39,700)$ calories per mole (*11*)
$S_{298} = (60)$ *e.u.* (*11*)
$M.P. = 444°$ K. (*6*)
$\Delta H_M = (1,150)$ calories per mole
$B.P. = (580°)$ K. (*6*)
$\Delta H_V = (12,000)$ calories per mole

Formation: $C + 2I_2 \longrightarrow CI_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(39,700)	(29,800)
500	(10,000)	(30,100)	(40,500)

Cyanogen, C_2N_2 (*g*)

$\Delta H_{298}^\circ = 73{,}600$ calories per mole (*112*)
$S_{298} = 57.86$ *e.u.* (*112*)
$M.P. = 245.3°$ K. (*112*)
$\Delta H_M = 1{,}938$ calories per mole
$B.P. = 252°$ K. (*112*)
$\Delta H_V = 5{,}576$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 14.90 + 3.20\times10^{-3}T - 2.04\times10^{-5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -5{,}270 + 14.90T + 1.60\times10^{-3}T^2 + 2.04\times10^5T^{-1}$$

Formation: $2C + N_2 \longrightarrow C_2N_2$

Zone I (298°–2,000° K.)

$$\Delta C_p = 0.04 + 0.14\times10^{-3}T + 2.16\times10^5T^{-2}$$
$$\Delta H_T = 74{,}250 + 0.04T + 0.07\times10^{-3}T^2 - 2.16\times10^5T^{-1}$$
$$\Delta F_T = 74{,}250 - 0.04T\ln T - 0.07\times10^{-3}T^2 - 1.08\times10^5T^{-1} - 10.45T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		57.86	+73,600	+71,800
400	1,445	62.02	73,800	69,800
500	2,965	65.41	74,000	68,800
600	4,560	68.32	74,100	67,700
700	6,220	70.88	74,200	66,650
800	7,930	73.16	74,250	65,550
900	9,695	75.24	74,300	64,500
1,000	11,500	77.14	74,350	63,400
1,100	13,250	78.75	74,300	62,350
1,200	15,205	80.51	74,400	61,200
1,300	16,990	82.08	74,400	60,100
1,400	19,015	83.46	74,450	59,100
1,500	20,900	84.34	74,450	57,900
1,600	22,900	86.24	74,450	56,400
1,700	24,820	87.34	74,450	55,400
1,800	26,840	88.34	74,450	54,750
1,900	28,900	89.47	74,450	53,500
2,000	30,810	90.45	74,450	52,500

Cyanogen Chloride, CNCl (*g*)

$\Delta H_{298}^\circ = 34{,}500$ calories per mole (*112*)
$S_{298} = 56.31$ *e.u.* (*112*)
$M.P. = 266.3°$ K. (*112*)
$\Delta H_M = 2{,}720$ calories per mole
$B.P. = 286.1°$ K. (*112*)
$\Delta H_V = 6{,}290$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 11.88 + 1.64\times10^{-3}T - 1.49\times10^5T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}115 + 11.88T + 0.82\times10^{-3}T^2 + 1.49\times10^5T^{-1}$$

Formation: $C + 1/2Cl_2 + 1/2N_2 \longrightarrow CNCl$

Zone I (298°–2,000° K.)

$$\Delta C_p = 0.04 + 0.08\times10^{-3}T + 0.95\times10^5T^{-2}$$
$$\Delta H_T = 34{,}800 + 0.04T + 0.04\times10^{-3}T^2 - 0.95\times10^5T^{-1}$$
$$\Delta F_T = 34{,}800 - 0.04T\ln T - 0.04\times10^{-3}T^2 - 0.47\times10^5T^{-1} - 5.66T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		56.31	34,500	32,900
400	1,135	59.58	34,600	32,350
500	2,315	62.21	34,700	31,800
600	3,540	64.45	34,750	31,150
700	4,805	66.39	34,800	30,550
800	6,100	68.12	34,800	29,800
900	7,425	69.68	34,850	29,350
1,000	8,770	71,10	34,850	28,750
1,100	10,060	72,35	34,900	28,150
1,200	11,515	73.60	34,900	27,500
1,300	12,850	74.56	34,900	27,000
1,400	14,310	75.76	34,950	26,400
1,500	15,690	76.68	34,950	25,700
1,600	17,145	77.65	34,950	25,000
1,700	18,645	78.55	34,950	24,350
1,800	20,010	79.34	34,950	23,800
1,900	21,475	80.21	34,950	23,100
2,000	22,890	80.85	34,950	22,650

Cyanogen Bromide, CNBr (*l*)

$S_{298} = 59.05$ *e.u.* (*112*)
$S.P. = 334°$ K. (*112*)
$\Delta H_{subl.} = 11{,}300$ calories per mole

Zone I (*g*) (334°–2,000° K.)

$$C_p = 12.20 + 1.42\times10^{-3}T - 1.34\times10^5T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}150 + 12.20T + 0.71\times10^{-3}T^2 + 1.34\times10^5T^{-1}$$

Formation: $C + 1/2Br_2 + 1/2N_2 \longrightarrow CNBr$

T °, K.	H_T-H_{298}	S_T
298		59.05
400	1,175	52.44
500	2,380	55.13
600	3,630	57.40
700	4,910	59.37
800	6,220	61.12
900	7,550	62.69
1,000	8,910	64.12
1,200	11,665	66.63
1,400	14,475	68.79
1,600	17,310	70.69
1,800	20,185	72.38
2,000	23,095	73.91

Cyanogen Iodide, CNI (*c*)

$\Delta H_{298}^\circ = 40{,}400$ calories per mole (*112*)
$S_{298} = 30.8$ *e.u.* (*112*)
$S.P. = 413°$ K. (*112*)
$\Delta H_{subl} = 14{,}200$ calories per mole

Zone I (*g*) (413°-2,000° K.)

$$C_p = 12.30 + 1.38\times10^{-3}T - 1.04\times10^5T^{-2} \quad (82)$$
$$H_T - H_{298} = 10{,}100 + 12.30T + 0.69\times10^{-3}T^2 + 1.04\times10^5T^{-1}$$

Formation: $C + 1/2N_2 + 1/2I_2 \longrightarrow CNI$

Zone I (456°–1,500° K.)

$$\Delta C_p = 0.43 - 0.15\times10^{-3}T + 1.06\times10^5T^{-2}$$
$$\Delta H_T = 47{,}450 + 0.43T - 0.075\times10^{-3}T^2 - 1.06\times10^5T^{-1}$$
$$\Delta F_T = 47{,}450 - 0.43T\ln T + 0.075\times10^{-3}T^2 - 0.53\times10^5T^{-1} - 7.0T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		30.80	40,400	42,600
400	1,210	34.07	38,400	43,550
500	16,640	71,10	47,450	42,400
600	17,910	73.34	47,500	41,300
700	19,205	75.28	47,600	40,450
800	20,530	77.01	47,650	39,450
900	21,875	78.57	47,650	38,400
1,000	23,235	79.91	47,700	37,500
1,100	24,570	81.25	47,700	36,400
1,200	26,005	82.49	47,750	35,400
1,300	27,370	83.51	47,750	34,500
1,400	28,825	84.65	47,800	33,400
1,500	30,180	85.58	47,800	32,400
2,000	37,440	89.74	(47,750)	(27,150)

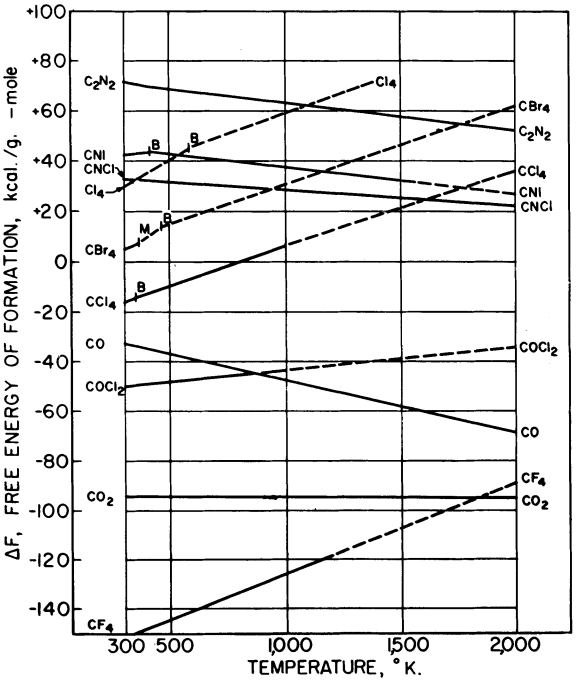

FIGURE 10.—Carbon.

CERIUM AND ITS COMPOUNDS

Element, Ce (c)

$S_{298}=13.64$ *e.u.* (*121*)
$M.P.=1{,}077°$ K. (*126*)
$\Delta H_M=2{,}120$ calories per atom (*112*)

Zone I (*c*) (298°–800° K.)

$C_p=4.40+6.00\times10^{-3}T$ (*82*)
$H_T-H_{298}=-1{,}575+4.40T+3.00\times10^{-3}T^2$
$F_T-H_{298}=-1{,}575-4.40T\ln T-3.00\times10^{-3}T^2+17.65T$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		13.64	13.64
400	670	15.57	13.87
500	1,380	17.15	14.38
600	2,140	18.54	14.97
700	2,970	19.82	15.57
800	3,860	21.00	16.16
900	(4,810)	(22.05)	(16.78)
1,000	(5,820)	(23.15)	(17.33)
1,500	(12,350)	(29.00)	(20.7)
2,000	(16,350)	(31.3)	(23.1)

Dicerium Trioxide, Ce_2O_3 (c)

$\Delta H_{298}^\circ=(-435{,}000)$ calories per mole (*24*)
$S_{298}=(21.81)$ *e.u.* (*24*)
$M.P.=1{,}960°$ K. (*42*)

Formation: $2Ce+3/2O_2\longrightarrow Ce_2O_3$ (estimated (*24*))

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		(−435, 000)	(−411, 500)
400	(2, 400)	(−435, 000)	(−403, 500)
500	(5, 500)	(−434, 500)	(−395, 500)
600	(8, 100)	(−434, 500)	(−387, 500)
700	(11, 400)	(−434, 000)	(−380, 000)
800	(14, 400)	(−434, 000)	(−372, 000)
900	(17, 500)	(−434, 000)	(−364, 500)
1,000	(21, 300)	(−433, 500)	(−356, 500)
1,100		(−438, 000)	(−348, 500)
1,200		(−438, 000)	(−340, 500)
1,300		(−438, 000)	(−332, 500)
1,400		(−437, 500)	(−324, 500)
1,500		(−437, 500)	(−316, 000)
1,600		(−437, 000)	(−308, 000)
1,700		(−437, 000)	(−300, 000)
1,800		(−437, 000)	(−292, 000)
1,900		(−436, 500)	(−284, 000)

Cerium Dioxide, CeO_2 (c)

$\Delta H_{298}^\circ=-260{,}180$ calories per mole (*58*)
$S_{298}^\circ=14.88$ *e.u.* (*24*)
$M.P.=>2{,}873°$ K. (*42*)

Zone I (*c*) (298°–2,500° K.)

$C_p=15.0+2.5\times10^{-3}T$ (*94*)
$H_T-H_{298}=-4{,}580+15.0T+1.25\times10^{-3}T^2$

Formation: $Ce+O_2\longrightarrow CeO_2$

Zone I (298°–800° K.)

$\Delta C_p=3.44-4.50\times10^{-3}T+0.40\times10^5T^{-2}$
$\Delta H_T=-259{,}500+3.44T-2.25\times10^{-3}T^2-0.40\times10^5T^{-1}$
$\Delta F_T=-259{,}500-3.44T\ln T+2.25\times10^{-3}T^2-0.20\times10^5T^{-1}+69.25T$

T, ° K.	H_T-H_{298}	S_T	$\Delta H°_T$	$\Delta F°_T$
298		14.88	−260, 180	−245, 940
400	1, 620	19.53	−259, 950	−241, 250
500	3, 230	23.28	−259, 780	−236, 480
600	4, 870	26.23	−259, 660	−231, 860
700	6, 530	28.68	−259, 610	−227, 110
800	8, 220	30.93	−259, 600	−222, 460
900	9, 930	32.98	(−259, 600)	(−217, 950)
1,000	11, 680	34.83	(−259, 550)	(−213, 200)
1,500	20, 730	42.28	(−261, 500)	(−189, 500)
2,000	30, 400	47.73	(261, 000)	(−161, 000)

Cerium Trifluoride, CeF_3 (c)

$\Delta H_{298}^\circ=-391{,}000$ calories per mole (*5*)
$S_{298}=(24)$ *e.u.* (*11*)
$M.P.=(1{,}703°)$ K. (*29*)
$\Delta H_M=(9{,}000)$ calories per mole
$B.P.=(2{,}600°)$ K. (*6*)
$\Delta H_V=(62{,}000)$ calories per mole

Formation: $Ce+3/2F_2\longrightarrow CeF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		−391,000	(−372,100)
500	(4,000)	(−391,000)	(−360,500)
1,000	(17,000)	(−388,500)	(−330,000)
1,500	(32,000)	(−386,500)	(−307,000)

Cerium Tetrafluoride, CeF_4 (*c*)

$\Delta H°_{298} = -442{,}000$ calories per mole (*11*)
$S_{298} = (37)$ *e.u.* (*11*)
$M.P. = (1{,}250°)$ K. (*6*)
$\Delta H_M = (10{,}000)$ calories per mole

Formation: $Ce + 2F_2 \longrightarrow CeF_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		−442,000	(−420,000)
500	(6,000)	(−440,500)	(−436,000)
1,000	(23,000)	(−436,500)	(−419,000)
1,500	(52,000)		(−390,000)

Cerium Trichloride, $CeCl_3$ (*c*)

$\Delta H°_{298} = -252{,}840$ calories per mole (*128*)
$S_{298} = 34.5$ *e.u.* (*128*)
$M.P. = 1{,}095°$ K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
$B.P. = (2{,}000°)$ K. (*6*)
$\Delta H_V = (46{,}000)$ calories per mole

Formation: $Ce + 3/2Cl_2 \longrightarrow CeCl_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		−252,840	−235,160
500	(5,000)	(−251,500)	(−225,300)
1,000	(19,000)	(−248,500)	(−198,800)
1,500	(43,000)	(−246,500)	(−179,300)

Cerium Tribromide, $CeBr_3$ (*c*)

$\Delta H°_{298} = -192{,}000$ calories per mole (*5*)
$S_{298} = (45)$ *e.u.* (*11*)
$M.P. = 1{,}005°$ K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
$B.P. = (1{,}830°)$ K. (*6*)
$\Delta H_V = (44{,}000)$ calories per mole

Formation: $Ce + 3/2Br_2 \longrightarrow CeBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		−192,000	(−185,000)
500	(5,000)	(−202,500)	(−174,000)
1,000	(18,000)	(−200,500)	(−148,000)
1,500	(43,000)	(−189,000)	(−127,000)

Cerium Triiodide, CeI_3 (*c*)

$\Delta H°_{298} = -163{,}000$ calories per mole (*5*)
$S_{298} = (50)$ *e.u.* (*11*)
$M.P. = 1{,}038°$ K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
$B.P. = (1{,}670°)$ K. (*6*)
$\Delta H_V = (40{,}000)$ calories per mole

Formation: $Ce + 3/2I_2 \longrightarrow CeI_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		−163,000	(−161,000)
500	(5,000)	(−184,500)	(−156,500)
1,000	(19,000)	(−181,500)	(−130,000)
1,500	(44,000)	(−169,700)	(−107,000)

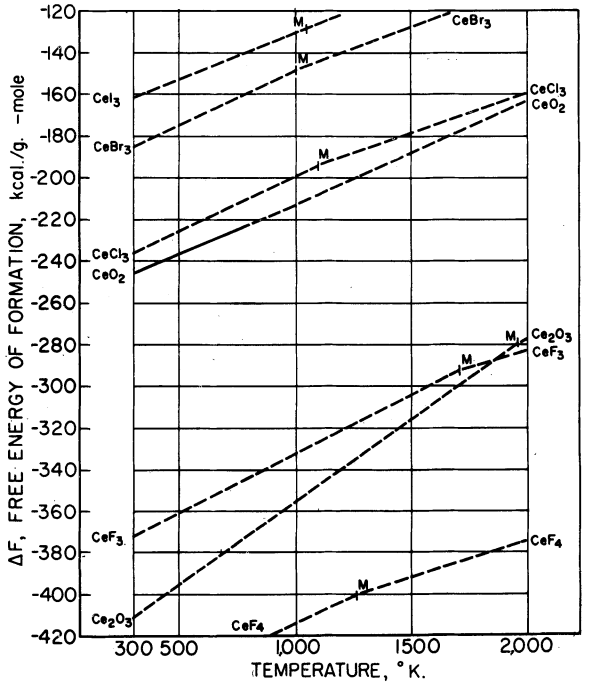

FIGURE 11.—Cerium.

CHLORINE

Element, Cl_2 (*g*)

$S_{298} = 53.31$ *e.u.* (*83*)
$M.P. = 172.16°$ K. (*112*)
$\Delta H_M = 1{,}531$ calories per atom
$B.P. = 239.1°$ K. (*112*)
$\Delta H_V = 4{,}878$ calories per atom

Zone I (*g*) (298°–3,000° K.)

$$C_p = 8.82 + 0.06\times10^{-3}T - 0.68\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -2{,}861 + 8.82T + 0.03\times10^{-3}T^2 + 0.68\times10^{5}T^{-1}$$
$$F_T - H_{298} = -2{,}861 - 8.82T\ln T - 0.03\times10^{-3}T^2 + 0.34\times10^{5}T^{-1} + 6.06T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		53.31	53.31
400	840	55.89	53.79
500	1,688	57.75	54.33
600	2,544	59.29	55.05
700	3,420	60.57	55.68
800	4,296	61.86	56.39
900	5,176	62.80	57.05
1,000	6,059	63.84	57.74
1,100	6,813	64.56	58.36
1,200	7,830	65.35	58.82
1,300	8,618	66.06	59.41
1,400	9,606	66.76	59.90
1,500	10,372	67.37	60.46
1,600	11,385	67.87	60.75
1,700	12,187	68.47	61.28
1,800	13,165	68.88	61.57
1,900	13,981	69.38	62.02
2,000	14,950	69.89	62.41

CHROMIUM AND ITS COMPOUNDS

Element, Cr (*c*)

$S_{298} = 5.68$ *e.u.* (*83*)
M.P. = 2,173° K. (*112*)
ΔH_M = 3,500 calories per atom
B.P. = 2.915° K. (*130*)
ΔH_V = 83,360 calories per atom

Zone I (*c*) (298°–1,800° K.)

$$C_p = 5.84 + 2.36\times10^{-3}T - 0.88\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -2{,}140 + 5.84T + 1.18\times10^{-3}T^2 + 0.88\times10^{5}T^{-1}$$
$$F_T - H_{298} = -2{,}140 - 5.84T\ln T - 1.18\times10^{-3}T^2 + 0.44\times10^{5}T^{-1} + 34.56T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		5.68	5.68
400	620	7.46	5.75
500	1,280	8.93	6.38
600	1,960	10.17	6.75
700	2,660	11.25	7.45
800	3,380	12.21	8.01
900	4,140	13.11	8.51
1,000	4,940	13.95	9.04
1,100	5,770	14.74	9.49
1,200	6,630	15.49	9.96
1,300	7,520	16.20	10.41
1,400	8,430	16.88	10.84
1,500	9,350	17.51	11.27
1,600	10,290	18.12	11.70
1,700	11,250	18.70	12.09
1,800	12,230	19.27	12.44
1,900	13,260	19.78	12.79
2,000	14,300	20.41	13.26

Dichromium Trioxide Cr_2O_3 (*c*)

$\Delta H^\circ_{298} = -272{,}650$ calories per mole (*98*)
$S_{298} = 19.4$ *e.u.* (*112*)
T.P. = 298.16° K. (*24*)
ΔH_T = 100 calories per mole
M.P. = 2,553° K. (*94*)
ΔH_M = 4,200 calories per mole
B.P. = 3,273° K. (*94*)

Zone I (c) (298°–1,800° K.)

$$C_p = 28.53 + 2.20\times10^{-3}T - 3.74\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -9{,}760 + 28.53T + 1.10\times10^{-3}T^2 + 3.74\times10^{5}T^{-1}$$

Formation: $2Cr + 3/2O_2 \longrightarrow Cr_2O_3$

Zone I (298°–1,800° K.)

$$\Delta C_p = 6.11 - 4.02\times10^{-3}T - 1.38\times10^{5}T^{-2}$$
$$\Delta H_T = -274{,}750 + 6.11T - 2.01\times10^{-3}T^2 + 1.38\times10^{5}T^{-1}$$
$$\Delta F_T = -274{,}750 - 6.11T\ln T + 2.01\times10^{-3}T^2 + 0.69\times10^{5}T^{-1} + 105.95T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		19.4	−272,650	−253,150
400	2,740	27.66	−272,650	−247,100
500	5,540	33.92	−271,850	−240,300
600	8,380	39.09	−271,500	−234,050
700	11,280	43.56	−271,150	−227,850
800	14,230	47.50	−270,850	−221,700
900	17,210	51.00	−270,600	−215,550
1,000	20,240	54.20	−270,450	−209,450
1,100	23,320	57.14	−270,200	−203,250
1,200	26,430	59.84	−270,050	−197,200
1,300	29,550	62.33	−269,950	−191,050
1,400	32,670	64.65	−269,900	−185,050
1,500	35,790	66.80	−269,950	−178,750
1,600	38,920	68.82	−270,000	−172,800
1,700	42,050	70.72	−270,100	−166,850
1,800	45,180	72.51	−270,250	−161,000

Chromium Dioxide, CrO_2 (*c*)

$\Delta H^\circ_{298} = -142{,}500$ calories per mole (*24*)
$S_{298} = (12.70)$ *e.u.* (*24*)
Disproportionates 700° K. (*8*)

Formation: $Cr + O_2 \longrightarrow CrO_2$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−142,500	(−130,000)
400	(1,300)	(−142,500)	(−125,500)
500	(2,700)	(−142,500)	(−121,500)
600	(4,200)	(−142,500)	(−117,500)
700	(5,600)	(−142,500)	(−113,000)

Chromium Trioxide, CrO_3 (*c*)

$\Delta H^\circ_{298} = (-140{,}000)$ calories per mole (*24*)
$S_{298} = (24)$ *e.u.* (*24*)
M.P. = 471° K. (*24*)
ΔH_M = 3,770 calories per mole

Formation: $Cr + 3/2O_2 \longrightarrow CrO_3$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−140,000)	(−121,000)
400	(2,700)	(−139,000)	(−114,500)
500	(9,500)	(−134,000)	(−108,500)
600	(12,300)	(−133,000)	(−103,500)

Chromium Difluoride, CrF_2 (*c*)

$\Delta H^\circ_{298} = -182{,}000$ calories per mole (*11*)
$S_{298} = (20)$ *e.u.* (*11*)
$M.P. = 1{,}375°$ K. (*6*)
$\Delta H_M = (5{,}500)$ calories per mole
$B.P. = (2{,}400°)$ K. (*6*)
$\Delta H_V = (60{,}000)$ calories per mole

Formation: $Cr + F_2 \longrightarrow CrF_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−182,000	(−172,000)
500	(3,000)	(−181,900)	(−165,500)
1,000	(13,000)	(−179,800)	(−148,000)
1,500	(32,000)	(−169,600)	(−137,000)

Chromium Trifluoride, CrF_3 (*c*)

$\Delta H^\circ_{298} = -266{,}000$ calories per mole (*112*)
$S_{298} = (25)$ *e.u.* (*11*)
$M.P. = 1{,}373°$ K. (*6*)
$\Delta H_M = (11{,}000)$ calories per mole
$B.P. = (1{,}700°)$ K. (*6*)
$\Delta H_V = (48{,}000)$ calories per mole

Formation: $Cr + 3/2F_2 \longrightarrow CrF_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−266,000	(−250,000)
500	(5,000)	(−264,700)	(−239,000)
1,000	(18,000)	(−261,100)	(−215,000)
1,500	(42,000)	(−248,700)	(−197,000)

Chromium Tetrafluoride, CrF_4 (*c*)

$\Delta H^\circ_{298} = (-286{,}500)$ calories per mole (*11*)
$S_{298} = (38)$ *e.u.* (*11*)
$M.P. = (550°)$ K. (*6*)
$\Delta H_M = (5{,}500)$ calories per mole
$B.P. = (570°)$ K. (*6*)
$\Delta H_V = (14{,}000)$ calories per mole

Formation: $Cr + 2F_2 \longrightarrow CrF_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−286,500)	(−267,100)
500	(6,000)	(−284,500)	(−254,000)
1,000			(−241,000)
1,500			(−220,000)

Chromium Dichloride, $CrCl_2$ (*c*)

$\Delta H^\circ_{298} = -94{,}560$ calories per mole (*112*)
$S_{298} = 27.8$ *e.u.* (*83*)
$M.P. = 1{,}088°$ K. (*112*)
$\Delta H_M = 7{,}700$ calories per mole
$B.P. = 1{,}573°$ K. (*94*)
$\Delta H_V = 47{,}500$ calories per mole

Zone I (*c*) (298°–1,088° K.)

$$C_p = 15.23 + 5.30\times10^{-3}T \quad (94)$$
$$H_T - H_{298} = -4{,}770 + 15.23T + 2.65\times10^{-3}T^2$$

Zone II (*l*) (1,088°–1,573° K.)

$$C_p = 24.0 \quad (94)$$
$$H_T - H_{298} = -3{,}400 + 24.T$$

Formation: $Cr + Cl_2 \longrightarrow CrCl_2$

Zone I (298°–1,088° K.)

$$\Delta C_p = 0.57 + 2.88\times10^{-3}T + 1.56\times10^{5}T^{-2}$$
$$\Delta H_T = -94{,}330 + 0.57T + 1.44\times10^{-3}T^2 - 1.56\times10^{5}T^{-1}$$
$$\Delta F_T = -94{,}330 - 0.57T\ln T - 1.44\times10^{-3}T^2 - 0.78\times10^{5}T^{-1} + 34.98T$$

Zone II (1,088°–1,573° K.)

$$\Delta C_p = 9.34 - 2.42\times10^{-3}T + 1.56\times10^{5}T^{-2}$$
$$\Delta H_T = -92{,}900 + 9.34T - 1.21\times10^{-3}T^2 - 1.56\times10^{5}T^{-1}$$
$$\Delta F_T = -92{,}900 - 9.34T\ln T + 1.21\times10^{-3}T^2 - 0.78\times10^{5}T^{-1} + 90.87T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		27.8	−94,560	−85,250
400	1,750	33.0	−94,270	−82,150
500	3,507	36.71	−94,020	−79,050
600	5,330	40.00	−93,730	−76,050
700	7,215	43.02	−93,430	−73,050
800	9,123	45.66	−93,110	−70,350
900	11,085	48.08	−92,780	−67,700
1,000	13,105	49.93	−92,450	−65,600
1,100	22,985	60.4	−84,160	−63,400
1,200	25,385	62.4	−83,635	−61,000
1,300	27,785	64.4	−82,910	−59,700
1,400	30,185	66.4	−82,410	−58,250
1,500	32,585	67.8	−81,700	−56,100

Chromium Trichloride, $CrCl_3$ (*c*)

$\Delta H^\circ_{298} = -132{,}500$ calories per mole (*94*)
$S_{298} = (30)$ *e.u.* (*83*)
$S.P. = 1{,}220°$ K. (*6*)
$\Delta H_{subl} = 56{,}800$ calories per mole

Zone I (*c*) (298°–1,200° K.)

$$C_p = 19.44 + 7.03\times10^{-3}T \quad (94)$$
$$H_T - H_{298} = -6{,}105 + 19.44T + 3.51\times10^{-3}T^2$$

Formation: $Cr + 3/2Cl_2 \longrightarrow CrCl_3$

Zone I (298°–1,220° K.)

$$\Delta C_p = 0.37 + 4.58\times10^{-3}T + 1.90\times10^{5}T^{-2}$$
$$\Delta H_T = -132{,}300 + 0.37T + 2.29\times10^{-3}T^2 - 1.90\times10^{5}T^{-1}$$
$$\Delta F_T = -132{,}300 - 0.37T\ln T - 2.29\times10^{-3}T^2 - 0.95\times10^{5}T^{-1} + 58.90T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		(30.0)	−132,500	(−115,900)
400	2,200	(36.23)	−132,180	(−110,200)
500	4,475	(41.44)	−131,840	(−104,800)
600	6,830	(45.74)	−131,450	(−99,450)
700	9,130	(49.24)	−131,160	(−94,150)
800	11,710	(52.75)	−130,610	(−88,800)
900	13,240	(55.55)	−130,160	(−83,650)
1,000	16,850	(58.35)	−129,680	(−78,300)
1,100	19,540	(60,95)	−128,950	(−73,200)
1,200	22,290	(63.45)	−128,580	(−68,550)

Chromium Tetrachloride, $CrCl_4$ (l)

$\Delta H^\circ_{298} = -110{,}000$ calories per mole (*11*)
$S_{298} = (61)$ *e.u.* (*11*)
$M.P. = (245°)$ K. (*6*)
$\Delta H_M = (2{,}000)$ calories per mole
$B.P. = (430°)$ K. (*6*)
$\Delta H_V = (9{,}000)$ calories per mole

Formation: $Cr + 2Cl_2 \longrightarrow CrCl_4$ (estimated (11))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−110,000	(−95,000)
500	(17,000)	(−97,500)	(−85,500)

Chromium Dibromide, $CrBr_2$ (c)

$\Delta H^\circ_{298} = (-74{,}000)$ calories per mole (*11*)
$S_{298} = (30)$ *e.u.* (*11*)
$M.P. = 1{,}115°$ K. (*6*)
$\Delta H_M = (6{,}500)$ calories per mole
$B.P. = (1{,}400°)$ K. (*6*)
$\Delta H_V = (35{,}000)$ calories per mole

Formation: $Cr + Br_2 \longrightarrow CrBr_2$ (estimated (11))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔH°_T
298		(−74,000)	(−70,000)
500	(4,000)	(−80,500)	(−63,500)
1,000	(14,000)	(−79,000)	(−48,000)
1,500	(69,000)	(−33,000)	(−36,000)

Chromium Tribromide, $CrBr_3$ (c)

$\Delta H^\circ_{298} = -91{,}000$ calories per mole (*11*)
$S_{298} = (44)$ *e.u.* (*11*)
$S.P. = (1{,}200°)$ K. (*6*)
$\Delta H_{subl} = (54{,}000)$ calories per mole

Formation: $Cr + 3/2Br_2 \longrightarrow CrBr_3$ (estimated (11))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−91,000	(−86,000)
500	(5,000)	(−101,600)	(−77,000)

Chromium Diiodide, CrI_2 (c)

$\Delta H^\circ_{298} = (-43{,}000)$ calories per mole (*11*)
$S_{298} = (34)$ *e.u.* (*11*)
$M.P. = 1{,}066°$ K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = (1{,}100°)$ K. (*6*)
$\Delta H_V = (24{,}000)$ calories per mole

Formation: $Cr + I_2 \longrightarrow CrI_2$ (estimated (11))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−43,000)	(−43,000)
500	(4,000)	(−57,000)	(−41,000)
1,000	(14,000)	(−55,100)	(−26,000)
1,500	(58,000)	(−20,000)	(−16,000)

Tetrachromium Carbide, Cr_4C (c)

$\Delta H^\circ_{298} = -16{,}400$ calories per mole (*112*)
$S_{298} = 25.3$ *e.u.* (*112*)
$M.P. = 1{,}793°$ K. (*94*)

Zone I (c) (298°–1700° K.)

$C_p = 29.35 + 7.40 \times 10^{-3}T - 5.02 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -10{,}764 + 29.35T + 3.70 \times 10^{-3}T^2 + 5.02 \times 10^5 T^{-1}$

Formation: $4Cr + C \longrightarrow Cr_4C$

Zone I (298°–1,700° K.)

$\Delta C_p = 1.89 - 3.06 \times 10^{-3}T + 0.60 \times 10^5 T^{-2}$
$\Delta H_T = -16{,}620 + 1.89T - 1.53 \times 10^{-3}T^2 - 0.60 \times 10^5 T^{-1}$
$\Delta F_T = -16{,}620 - 1.89T \ln T + 1.53 \times 10^{-3}T^2 - 0.30 \times 10^5 T^{-1} + 10.19T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		25.3	−16,400	−16,750
400	2,800	33.36	−16,350	−16,900
500	5,850	40.16	−16,250	−17,050
600	9,010	45.92	−16,200	−17,250
700	12,290	50.97	−16,100	−17,400
800	15,700	55.52	−16,050	−17,600
900	19,200	59.64	−16,050	−17,750
1,000	22,770	63.41	−16,200	−17,950
1,100	26,420	66.88	−16,400	−18,150
1,200	30,160	70.14	−16,600	−18,150
1,300	34,000	73.12	−16,850	−18,450
1,400	37,950	76.14	−17,100	−18,500
1,500	42,010	78.94	−17,250	−18,650
1,600	46,180	81.63	−17,550	−18,700
1,700	50,480	84.23	−17,850	−18,750

Heptachromium Tricarbide, Cr_7C_3 (c)

$\Delta H^\circ_{298} = -42{,}600$ calories per mole (*112*)
$S_{298} = 48.0$ *e.u.* (*112*)
Disproportionates 1,940° K. (*8*)

Zone I (c) (298°–1,500° K.)

$C_p = 56.96 + 14.54 \times 10^{-3}T - 10.12 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -21{,}010 + 56.96T + 7.27 \times 10^{-3}T^2 + 10.12 \times 10^5 T^{-1}$

Formation: $7Cr + 3C \longrightarrow Cr_7C_3$

Zone I (298°–1,500° K.)

$\Delta C_p = 3.78 - 5.04 \times 10^{-3}T + 2.34 \times 10^5 T^{-2}$
$\Delta H_T = -42{,}600 + 3.78T - 2.52 \times 10^{-3}T^2 - 2.34 \times 10^5 T^{-1}$
$\Delta F_T = -42{,}600 - 3.78T \ln T + 2.52 \times 10^{-3}T^2 - 1.17 \times 10^5 T^{-1} + 18.30T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	48.0	−42,600	−43,840
400	5,440	63.66	−42,250	−43,350
500	11,320	76.77	−41,950	−44,900
600	17,450	87.94	−41,720	−45,500
700	23,860	97.81	−41,470	−46,150
800	30,480	106.65	−41,270	−46,850
900	37,240	114.60	−41,270	−47,500
1,000	44,230	121.97	−41,380	−48,200
1,100	51,360	128.76	−41,590	−48,850
1,200	58,600	135.06	−41,960	−49,500
1,300	66,000	140.98	−42,410	−50,150
1,400	73,700	146.69	−42,700	−50,700
1,500	81,750	152.24	−42,840	−51,300

Trichromium Dicarbide, Cr_3C_2 (*c*)

$\Delta H^\circ_{298}=-21{,}000$ calories per mole (*112*)
$S_{298}=20.42$ *e.u.* (*31*)
M.P.=2,163° K. (*112*)

Zone I (*c*) (298°–1,700° K.)

$$C_p=26.19+9.48\times10^{-3}T-4.72\times10^{5}T^{-2}\ (84)$$
$$H_T-H_{298}=-9{,}790+26.19T+4.74\times10^{-3}T^2+4.72\times10^{5}T^{-1}$$

Formation: $3Cr+2C\longrightarrow Cr_3C_2$

Zone I (298°–1,700° K.)

$$\Delta C_p=0.47+0.36\times10^{-3}T+2.12\times10^{5}T^{-2}$$
$$\Delta H_T=-20{,}450+0.47T+0.18\times10^{-3}T^2-2.12\times10^{5}T^{-1}$$
$$\Delta F_T=-20{,}450-0.47T\ln T-0.18\times10^{-3}T^2-1.06\times10^{5}T^{-1}+1.40T$$

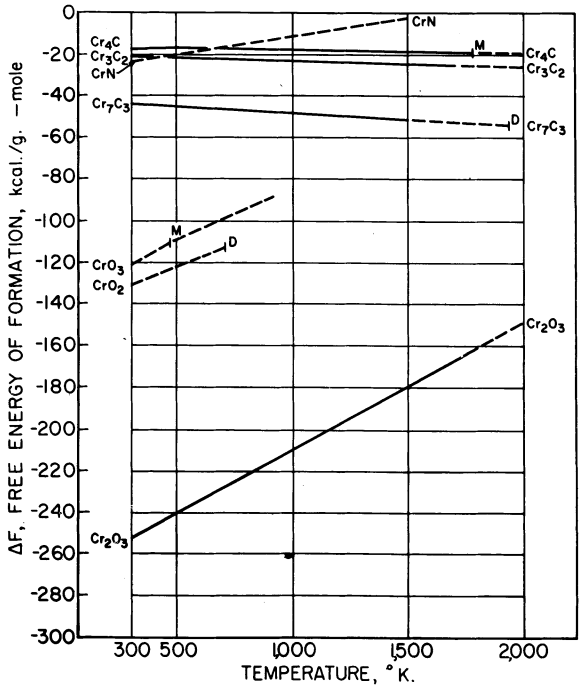

FIGURE 12.—Chromium (a).

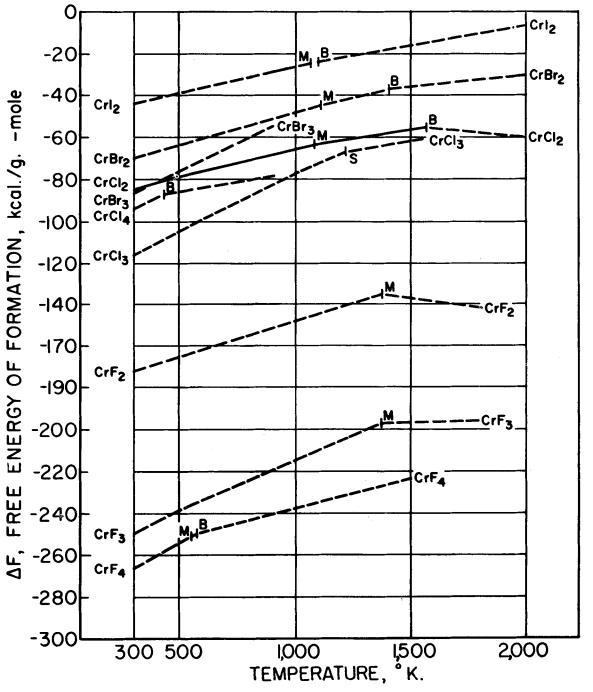

FIGURE 13.—Chromium (b).

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	20.4	−21,000	−21,200
400	2,610	28.09	−20,750	−21,350
500	5,420	34.37	−20,560	−21,550
600	8,350	39.78	−20,430	−21,800
700	11,510	44.40	−20,210	−21,900
800	14,780	48.89	−20,020	−22,250
900	18,130	52.71	−19,910	−22,400
1,000	21,580	56.36	−19,860	−22,700
1,100	25,140	59.71	−19,810	−22,950
1,200	28,790	63.08	−19,800	−23,450
1,300	32,540	66.16	−19,800	−23,900
1,400	36,400	69.04	−19,750	−24,200
1,500	40,340	71.62	−19,670	−24,350
1,600	44,400	74.32	−19,550	−24,650
1,700	48,600	76.72	−19,370	−24,850
1,800	(52,800)	(79.0)	(−19,250)	(−24,950)
1,900	(57,150)	(81.32)	(−19,200)	(−25,450)
2,000	(61,650)	(83.92)	(−19,050)	(−25,850)

Chromium Nitride, CrN (*c*)

$\Delta H^\circ_{298}=-29{,}500$ calories per mole (*81*)
$S_{298}=8.9$ *e.u.* (*81*)
Disproportionates (1,800° K.) (*94*)

Zone I (*c*) (298°–800° K.)

$$C_p=9.84+3.9\times10^{-3}T\ (82)$$
$$H_T-H_{298}=-3{,}110+9.84T+1.95\times10^{-3}T^2$$

Formation: $Cr+1/2N_2\longrightarrow CrN$

Zone I (298°–800° K.)

$$\Delta C_p=0.67+1.03\times10^{-3}T+0.88\times10^{5}T^{-2}$$
$$\Delta H_T=-29.450+0.67T+0.51\times10^{-3}T^2-0.88\times10^{5}T^{-1}$$
$$\Delta F_T=-29{,}450-0.67T\ln T-0.51\times10^{-3}T^2-0.44\times10^{5}T^{-1}+23.96T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		8.9	−29,500	−23,650
400	1,140	12.20	−29,330	−21,650
500	2,300	14.79	−29,180	−19,750
600	3,500	16.98	−29,020	−17,850
700	4,730	18,92	−28,850	−16,050
800	5,990	20.56	−28,690	−14,250

COBALT AND ITS COMPOUNDS

Element, Co (*c*)

$S_{298}=6.86$ *e.u.* (*83*)
$T.P.=718°$ K. (*82*)
$\Delta H_T=0$ calories per atom
$T.P.=1{,}400°$ K. (*82*)
$\Delta H_T=130$ calories per atom
$M.P.=1{,}763°$ K. (*82*)
$\Delta H_M=3{,}640$ calories per atom
$B.P.=3{,}373°$ K. (*112*)

Zone I (α) (298°–718° K.)

$$C_p=4.72+4.30\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-1{,}600+4.72T+2.15\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}600-4.72T\ln T-2.15\times10^{-3}T^2+25.94T$$

Zone II (β) (718°–1,400° K.)

$$C_p=3.30+5.86\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-979+3.30T+2.93\times10^{-3}T^2$$
$$F_T-H_{298}=-979-3.30T\ln T-2.93\times10^{-3}T^2+16.36T$$

Zone III (γ) (1,400°–1,763° K.)

$$C_p=9.60 \quad (82)$$
$$H_T-H_{298}=-3{,}920+9.60T$$
$$F_T-H_{298}=-3{,}920-9.60T\ln T+60.0T$$

Zone IV (*l*) (1,763°–1,900° K.)

$$C_p=8.30 \quad (82)$$
$$H_T-H_{298}=+2{,}010+8.30T$$
$$F_T-H_{298}=+2{,}010-8.30T\ln T+47.07T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		6.86	6.86
400	640	8.70	7.10
500	1,300	10.17	7.56
600	2,010	11.47	8.12
700	2,760	12.62	8.67
800	3,550	13.67	9.24
900	4,380	14.65	9.78
1,000	5,250	15.57	10.32
1,100	6,180	16.45	10.83
1,200	7,180	17.32	11.33
1,300	8,250	18.18	11.83
1,400	9,390	19.02	12.31
1,500	10,480	19.78	12.80
1,600	11,440	20.40	13.25
1,700	12,400	20.98	13.69
1,800	16,950	23.56	14.14
1,900	17,780	24.01	14.65
2,000	(18,610)		(14.60)

Cobalt Oxide, CoO (*c*)

$\Delta H_{298}^\circ=-57{,}300$ calories per mole (*4*)
$S_{298}=12.63$ *e.u.* (*88*)
$M.P.=2{,}078°$ K. (*112*)

Zone I (*c*) (298–1,800° K.)

$$C_p=11.54+2.04\times10^{-3}T+0.40\times10^5T^{-2} \quad (82)$$
$$H_T-H_{298}=-3{,}400+11.54T+1.02\times10^{-3}T^2-0.40\times10^5T^{-1}$$

Formation: $Co+1/2O_2\longrightarrow CoO$

Zone I (298°–718° K.)

$$\Delta C_p=3.24-2.76\times10^{-3}T+0.6\times10^5T^{-2}$$
$$\Delta H_T=-57{,}940+3.24T-1.38\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-57{,}940-3.24T\ln T+1.38\times10^{-3}T^2-0.30\times10^5T^{-1}+39.28T$$

Zone II (718°–1,400° K.)

$$\Delta C_p=4.66-4.32\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-58{,}590+4.66T-2.16\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-58{,}590-4.66T\ln T+2.16\times10^{-3}T^2-0.30\times10^5T^{-1}+48.9T$$

Zone III (1,400°–1,673° K.)

$$\Delta C_p=1.64+1.54\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-55{,}750-1.64T+0.77\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-55{,}750+1.64T\ln T-0.77\times10^{-3}T^2-0.30\times10^5T^{-1}+5.47T$$

Zone IV (1,673°–1,800° K.)

$$\Delta C_p=-0.34+1.54\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-61{,}480-0.34T+0.77\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-61{,}480+0.34T\ln T-0.77\times10^{-3}T^2-0.30\times10^5T^{-1}+18.27T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		12.63	−57,300	−51,700
400	1,290	16.35	−57,000	−49,850
500	2,570	19.21	−56,750	−48,100
600	3,860	21.56	−56,550	−46,400
700	5,160	23.56	−56,400	−44,700
800	6,470	25.31	−56,250	−43,050
900	7,790	26.87	−56,200	−41,100
1,000	9,120	28.27	−56,150	−39,750
1,100	10,460	29.55	−56,100	−38,100
1,200	11,820	30.73	−56,200	−36,450
1,300	13,210	31.84	−56,150	−34,650
1,400	14,640	32.90	−56,400	−33,150
1,500	16,100	33.81	−56,500	−31,300
1,600	17,600	34.88	−56,350	−29,750
1,700	19,140	35.81	−56,250	−28,150
1,800	20,750	36.72	−59,650	−26,500

Tricobalt Tetraoxide, Co_3O_4 (*c*)

$\Delta H_{298}^\circ=-207{,}000$ calories per mole (*24*)
$S_{298}=35.66$ *e.u.* (*24*)

Zone I (*c*) (298°–1,000° K.)

$$C_p=30.84+17.08\times10^{-3}T-5.72\times10^5T^{-2} \quad (91)$$
$$H_T-H_{298}=-11{,}870+30.84T+8.54\times10^{-3}T^2+5.72\times10^5T^{-1}$$

Formation: $3Co+2O_2\longrightarrow Co_3O_4$

Zone I (298°–718° K.)

$$\Delta C_p=2.36+2.18\times10^{-3}T-4.92\times10^5T^{-2}$$
$$\Delta H_T=-209{,}450+2.36T+1.09\times10^{-3}T^2+4.92\times10^5T^{-1}$$
$$\Delta F_T=-209{,}450-2.36T\ln T-1.09\times10^{-3}T^2+2.46\times10^5T^{-1}+102.16T$$

Zone II (718°–1,000° K.)

$\Delta C_p = 6.62 - 2.50\times10^{-3}T - 4.92\times10^{5}T^{-2}$
$\Delta H_T = -211{,}220 + 6.62T - 1.25\times10^{-3}T^2 - 4.92\times10^{5}T^{-1}$
$\Delta F_T = -211{,}220 - 6.62T\ln T + 1.25\times10^{-3}T^2 + 2.46\times10^{5}T^{-1} + 131.03T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		35.66	−207,000	−182,300
400	3,270	45.06	−207,100	−173,800
500	6,850	53.04	−206,950	−165,500
600	10,660	59.98	−206,800	−157,200
700	14,640	66.11	−206,600	−149,000
800	18,820	71.69	−206,400	−140,750
900	23,300	76.96	−206,050	−132,550
1,000	28,250	82.18	−205,350	−124,650
1,500				(−82,500)

Cobalt Difluoride, CoF_2 (*c*)

$\Delta H^\circ_{298} = -158{,}000$ calories per mole (*11*)
$S_{298} = (21)$ *e.u.* (*11*)
M.P. = 1,475° K. (*6*)
$\Delta H_M = (9{,}000)$ calories per mole
B.P. = (2,000°) K. (*6*)
$\Delta H_V = (48{,}000)$ calories per mole

Formation: $Co + F_2 \longrightarrow CoF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−158,000	(−147,900)
500	(3,500)	(−157,400)	(−141,000)
1,000	(13,000)	(−156,100)	(−125,000)
1,500	(34,000)	(−144,700)	(−108,500)

Cobalt Trifluoride, CoF_3 (*c*)

$\Delta H^\circ_{298} = (-190{,}000)$ calories per mole (*11*)
$S_{298} = (27)$ *e.u.* (*11*)
M.P. = (1,300°) K. (*6*)
$\Delta H_M = (12{,}000)$ calories per mole
B.P. = (1,600°) K. (*6*)
$\Delta H_V = (40{,}000)$ calories per mole

Formation: $Co + 3/2F_2 \longrightarrow CoF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−190,000)	(−174,000)
500	(5,000)	(−188,700)	(−163,500)
1,000	(19,000)	(−185,000)	(−140,000)

Cobalt Dichloride, $CoCl_2$ (*c*)

$\Delta H^\circ_{298} = -77{,}800$ calories per mole (*112*)
$S_{298} = 25.4$ *e.u.* (*83*)
M.P. = 997° K. (*112*)
$\Delta H_M = 7{,}400$ calories per mole
B.P. = 1,323° K. (*112*)
$\Delta H_V = 27{,}200$ calories per mole

Zone I (*c*) (298°–997° K.)

$C_p = 14.41 + 14.60\times10^{-3}T$ (*82*)
$H_T - H_{298} = -4.945 + 14.41T + 7.30\times10^{-3}T^2$

Formation: $Co + Cl_2 \longrightarrow CoCl_2$

Zone I (298°–718° K.)

$\Delta C_p = 0.87 + 10.24\times10^{-3}T + 0.68\times10^{5}T^{-2}$
$\Delta H_T = -78{,}300 + 0.87T + 5.12\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$
$\Delta F_T = -78{,}300 - 0.87T\ln T - 5.12\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 43.3T$

Zone II (718°–997° K.)

$\Delta C_p = 2.29 + 8.68\times10^{-3}T + 0.68\times10^{5}T^{-2}$
$\Delta H_T = -79{,}000 + 2.29T + 4.34\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$
$\Delta F_T = -79{,}000 - 2.29T\ln T - 4.34\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 53.02T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		25.4	−77,800	−67,430
400	2,020	31.22	−77,260	−63,900
500	4,120	35.9	−76,670	−60,650
600	6,340	39.94	−76,010	−57,500
700	8,720	43.61	−75,260	−54,550
800	11,260	47.0	−74,400	−51,600
900	13,920	50.12	−73,440	−48,850
1,000	24,100	60.45	−65,000	−46,000

Cobalt Dibromide, $CoBr_2$ (*c*)

$\Delta H^\circ_{298} = -50{,}600$ calories per mole (*11*)
$S_{298} = (33)$ *e.u.* (*11*)
M.P. = 951° K. (*6*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (1,200°) K. (*6*)
$\Delta H_V = (25{,}000)$ calories per mole

Formation: $Co + Br_2 \longrightarrow CoBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−50,600	(−47,500)
500	(4,000)	(−57,000)	(−42,000)
1,000	(24,000)	(−45,900)	(−29,000)
1,500	(61,000)	(−18,500)	(−20,500)

Cobalt Diiodide, CoI_2 (*c*)

$\Delta H^\circ_{298} = -21{,}000$ calories per mole (*11*)
$S_{298} = (37)$ *e.u.* (*11*)
M.P. = 790° K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (1,100°) K. (*6*)
$\Delta H_V = (24{,}000)$ calories per mole

Formation: $Co + I_2 \longrightarrow CoI_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−21,000	(−21,900)
500	(4,000)	(−35,000)	(−20,000)
1,000	(24,000)	(−23,400)	(−7,000)
1,500	(60,000)	(+3,000)	(+1,000)

Tricobalt Carbide, Co_3C (*c*)

$\Delta H^\circ_{298} = +9{,}330$ calories per mole (*81*)
$S_{298} = 22.9$ *e.u.* (*9*)
$\Delta F_{298} = 9{,}000$ calories per mole

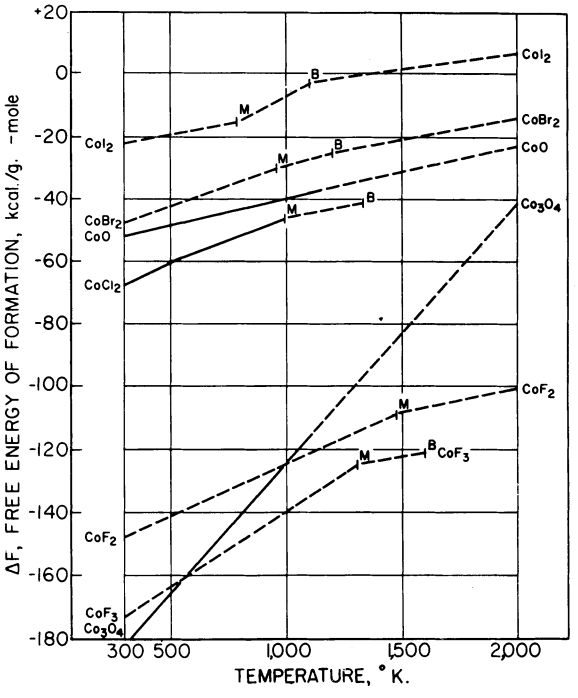

FIGURE 14.—Cobalt.

COLUMBIUM AND ITS COMPOUNDS

Element, Cb (*c*)

$S_{298} = 8.7$ *e.u.* (*7*)
M.P. = 2,770° K. (*7*)
$\Delta H_M = (6{,}500)$ calories per atom
B.P. = (5,400°) K. (*7*)
$\Delta H_V = (155{,}000)$ calories per atom

Zone I (*c*) (298°–1,900° K.)

$$C_p = 5.66 + 0.96\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -1{,}730 + 5.66T + 0.48\times10^{-3}T^2$$
$$F_T - H_{298} = -1{,}730 - 5.66T\ln T - 0.48\times10^{-3}T^2 + 29.45T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		8.7	8.7
400	610	10.46	8.91
500	1,215	11.81	9.36
600	1,835	12.94	9.86
700	2,470	13.92	10.40
800	3,110	14.77	10.86
900	3,750	15.53	11.39
1,000	4,400	16.21	11.81
1,100	5,070	16.85	12.23
1,200	5,760	17.45	12.67
1,300	6,450	18.00	13.04
1,400	7,160	18.53	13.44
1,500	7,870	19.02	13.78
1,600	8,580	19.48	14.11
1,700	9,300	19.91	14.44
1,800	10,020	20.34	14.77
1,900	10,760	20.72	15.05
(2,000)	(11,410)	(21.13)	(15.42)

Columbium Dioxide, CbO_2 (*c*)

$\Delta H^\circ_{298} = (-190{,}400)$ calories per mole (*24*)
$S_{298} = 13.03$ *e.u.* (*91*)

Formation: $Cb + O_2 \longrightarrow CbO_2$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(190,400)	(−177,200)
400	(1,500)	(−190,200)	(−172,800)
500	(3,100)	(−190,000)	(−168,500)
600	(4,700)	(−189,700)	(−164,200)
700	(6,400)	(−189,500)	(−160,000)
800	(8,000)	(−189,300)	(−155,700)
900	(9,600)	(−189,100)	(−151,600)
1,000	(10,300)	(−188,900)	(−147,400)
1,100	(13,000)	(−188,700)	(−143,300)
1,200	(14,700)	(−188,500)	(−139,100)
1,300	(16,400)	(−188,300)	(−135,000)
1,400	(18,200)	(−188,100)	(−130,900)
1,500	(20,100)	(−187,900)	(−126,900)
1,600	(21,700)	(−187,700)	(−122,800)
1,700	(23,500)	(−187,500)	(−118,800)
1,800	(25,300)	(−187,300)	(−114,700)
1,900	(27,200)	(−187,100)	(−110,700)
2,000	(29,200)	(−186,800)	(−106,700)

Dicolumbium Pentaoxide, Cb_2O_5 (*c*)

$\Delta H^\circ_{298} = -455{,}000$ calories per mole (*67*)
$S_{298} = 32.8$ *e.u.* (*90*)
M.P. = 1,785° K. (*107*)
$\Delta H_M = 24{,}200$ calories per mole
B.P. = >2,500° K. (*42*)

Zone I (*c*) (298°–1,785° K.)

$$C_p = 36.23 + 5.54\times10^{-3}T - 4.88\times10^5T^{-2} \quad (107)$$
$$H_T - H_{298} = -12{,}680 + 36.23T + 2.77\times10^{-3}T^2 + 4.88\times10^5T^{-1}$$

Zone II (*l*) (1,785°–1,810° K.)

$$C_p = 57.90 \quad (107)$$
$$H_T - H_{298} = -17{,}255 + 57.90T$$

Formation: $2Cb + 5/2O_2 \longrightarrow Cb_2O_5$

Zone I (298°–1,785° K.)

$$\Delta C_p = 7.01 + 1.12\times10^{-3}T - 3.88\times10^5T^{-2}$$
$$\Delta H_T = -458{,}440 + 7.01T + 0.56\times10^{-3}T^2 + 3.88\times10^5T^{-1}$$
$$\Delta F_T = -458{,}440 - 7.01T\ln T - 0.56\times10^{-3}T^2 + 1.94\times10^5T^{-1} + 156.52T$$

Zone II (1,785°–1,810° K.)

$$\Delta C_p = 28.68 - 4.42\times10^{-3}T + 1.0\times10^5T^{-2}$$
$$\Delta H_T = -463{,}750 + 28.68T - 2.21\times10^{-3}T^2 - 1.0\times10^5T^{-1}$$
$$\Delta F_T = -463{,}750 - 28.68T\ln T + 2.21\times10^{-3}T^2 - 0.50\times10^5T^{-1} + 317.0T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		32.8	−455,000	−423,050
400	3,500	42.91	−454,550	−412,250
500	7,100	51.00	−453,950	−401,750
600	10,880	57.85	−453,200	−391,200
700	14,500	63.82	−452,900	−381,300
800	18,700	69.08	−452,000	−370,900
900	23,000	73.82	−451,000	−360,500
1,000	26,800	78.14	−450,600	−350,800
1,100	30,940	82.11	−449,700	−340,600
1,200	35,260	85.78	−448,850	−330,850
1,300	39,470	89.20	−448,100	−321,100
1,400	43,890	92.42	−447,200	−311,100
1,500	48,070	95.56	−446,900	−301,900
1,600	52,720	98.34	−445,550	−291,650
1,700	57,150	100.68	−444,800	−281,800
1,800	86,430	117.35	−419,150	−273,150
1,900	(92,370)	(120.48)	(−416,950)	(−264,650)
2,000	(98,230)	(123.45)	(−415,000)	(−256,200)

Columbium Pentachloride, $CbCl_5$ (*c*)

$\Delta H°_{298} = -190{,}600$ calories per mole (*48*)
$S_{298} = (65)$ *e.u.* (*11*)
M.P. = 485° K. (*6*)
$\Delta H_M = 8{,}400$ calories per mole
B.P. = 516° K. (*6*)
$\Delta H_V = 11{,}500$ calories per mole

Formation: $Cb + 5/2Cl_2 \longrightarrow CbCl_5$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	$\Delta H°_T$	$\Delta F°_T$
298		−190,600	(−167,500)
500	(13,000)	(−183,000)	(−153,000)

Columbium Pentabromide, $CbBr_5$ (*c*)

$\Delta H°_{298} = -132{,}850$ calories per mole (*48*)
$S_{298} = (78)$ *e.u.* (*11*)
M.P. = 500° K. (*6*)
$\Delta H_M = (8{,}500)$ calories per mole
B.P. = 545° K. (*6*)
$\Delta H_V = (12{,}000)$ calories per mole

Formation: $Cb + 5/2Br_2 \longrightarrow CbBr_5$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	$\Delta H°_T$	$\Delta F°_T$
298		−132,850	(−126,200)
500	(12,000)	(−108,500)	(−114,500)

Columbium Nitride, CbN (*c*)

$\Delta H°_{298} = -56{,}800$ calories per mole (*100*)
$S_{298} = 10.5$ *e.u.* (*9*)
M.P. = 2,372° K. (*94*)
$\Delta H_M = (14{,}500)$ calories per mole

Zone I (*c*) (298°–600° K.)

$C_p = 8.69 + 5.40 \times 10^{-3} T$ (*94*)
$H_T - H_{298} = -2{,}831 + 8.69T + 2.70 \times 10^{-3} T^2$

Formation: $Cb + 1/2N_2 \longrightarrow CbN$

Zone I (298°–600° K.)

$\Delta C_p = -0.30 + 3.93 \times 10^{-3} T$
$\Delta H_T = -56{,}900 - 0.30T + 1.96 \times 10^{-3} T^2$
$\Delta F_T = -56{,}900 + 0.30 T \ln T - 1.96 \times 10^{-3} T^2 + 20.42T$

T, ° K.	$H_T - H_{298}$	S_T	$\Delta H°_T$	$\Delta F°_T$
298		10.5	−56,800	−50,550
400	1,080	13.61	−56,700	−48,400
500	2,190	16.09	−56,550	−46,300
600	3,355	18.21	−56,350	−44,300
700	(4,570)		(−56,150)	(−42,300)
800	(5,850)		(−55,900)	(−40,350)
900	(7,170)		(−55,600)	(−38,400)
1,000	(8,560)		(−55,250)	(−36,550)
1,100	(10,000)		(−54,850)	(−34,700)
1,200	(11,480)		(−54,450)	(−32,850)
1,300	(13,030)		(−54,000)	(−31,050)
1,400	(14,640)		(−53,500)	(−29,350)
1,500	(16,270)		(−52,950)	(−27,600)
1,600	(18,000)		(−52,350)	(−26,000)
1,700	(19,670)		(−51,750)	(−24,350)
1,800	(21,550)		(−51,100)	(−22,800)
1,900	(23,420)		(−50,400)	(−21,250)
2,000	(25,350)		(−49,600)	(−19,700)

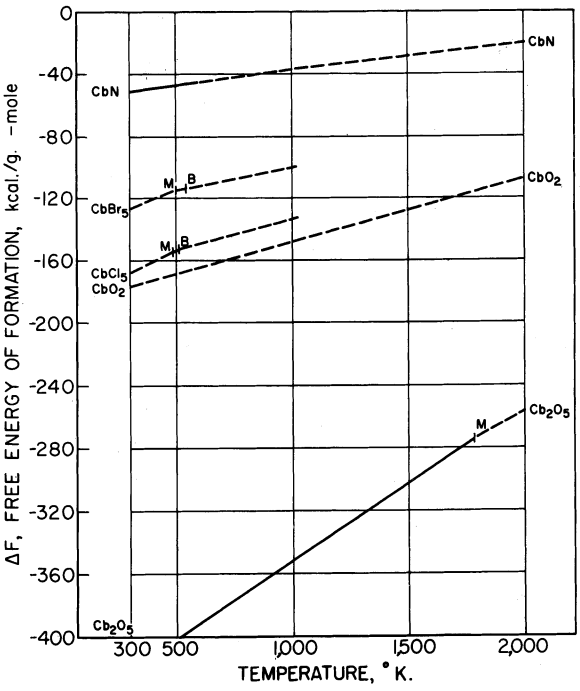

FIGURE 15.—Columbium.

COPPER AND ITS COMPOUNDS

Element, Cu (*c*)

$S_{298} = 7.97$ *e.u.* (*83*)
M.P. = 1,357° K. (*82*)
$\Delta H_M = 3{,}120$ calories per atom
B.P. = 2,855° K. (*112*)
$\Delta H_V = 72{,}800$ calories per atom

Zone I (*c*) (298°–1,357° K.)

$C_p = 5.41 + 1.50 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -1{,}680 + 5.41T + 0.75 \times 10^{-3} T^2$
$F_T - H_{298} = -1{,}680 - 5.41 T \ln T - 0.75 \times 10^{-3} T^2 + 28.7T$

Zone II (*l*) (1,357°–1,600° K.)

$C_p = 7.50$ (*82*)
$H_T - H_{298} = -20 + 7.50T$
$F_T - H_{298} = -20 - 7.50\ T \ln\ T + 41.54T$

T, ° K.	$H_T - H_{298}$	S_T	$\frac{(F_T - H_{298})}{T}$
298		7.97	7.97
400	600	9.70	8.20
500	1,215	11.07	8.64
600	1,845	12.22	9.14
700	2,480	13.20	9.66
800	3,130	14.07	10.16
900	3,800	14.86	10.64
1,000	4,490	15.58	11.09
1,100	5,190	16.25	11.53
1,200	5,895	16.87	11.96
1,300	6,615	17.44	12.35
1,400	10,480	20.29	12.80
1,500	11,230	20.81	13.32
1,600	11,980	21.29	13.80
1,700	(12,740)	(21.74)	(14.24)
1,800	(13,480)	(22.17)	(14.68)
1,900	(14,230)	(22.58)	(15.09)
2,000	(14,980)	(22.96)	(15.47)

Dicopper Oxide, Cu_2O (*c*)

$\Delta H^\circ_{298} = -40{,}800$ calories per mole (*2*)
$S_{298} = 22.44$ *e.u.* (*24*)
M.P. = 1,502° K. (*112*)
$\Delta H_M = 13{,}400$ calories per mole

Zone 1 (*c*) (298°–1,200° K.)

$C_p = 14.90 + 5.70\times10^{-3}T$ (*82*)
$H_T - H_{298} = -4{,}696 + 14.90T + 2.85\times10^{-3}T^2$

Formation: $2Cu + 1/2O_2 \longrightarrow Cu_2O$

Zone 1 (298°–1,200° K.)

$\Delta C_p = 0.50 + 2.2\times10^{-3}T + 0.20\times10^5T^{-2}$
$\Delta H_T = -40{,}980 + 0.50T + 1.1\times10^{-3}T^2 - 0.20\times10^5T^{-1}$
$\Delta F_T = -40{,}980 - 0.50T\ln T - 1.1\times10^{-3}T^2 - 0.10\times10^5T^{-1} + 21.98T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		22.44	−40,800	−35,450
400	1,720	27.40	−40,650	−33,650
500	3,470	31.31	−40,500	−31,900
600	5,280	34.70	−40,300	−30,250
700	7,150	37.58	−40,100	−28,550
800	9,050	40.12	−39,900	−26,950
900	11,000	42.42	−39,700	−25,350
1,000	13,020	44.54	−39,500	−23,750
1,100	15,120	46.54	−39,150	−22,150
1,200	17,320	48.46	−38,800	−20,650
1,300	(19,570)	(50.2)	(−38,400)	(−19,100)
1,400	(22,020)	(52.0)	(−44,100)	(−17,500)
1,500	(24,600)	(53.2)	(−43,500)	(−15,600)
1,600	(40,400)	(63.7)	(−29,600)	(−13,700)

Copper Oxide, CuO (*c*)

$\Delta H^\circ_{298} = -37{,}500$ calories per mole (*2*)
$S_{298} = 10.19$ *e.u.* (*56*)
M.P. = 1,720° K. (*24*)
$\Delta H_M = 2{,}820$ calories per mole

Zone I (*c*) (298°–1,250° K.)

$C_p = 9.27 + 4.80\times10^{-3}T$ (*82*)
$H_T - H_{298} = -2{,}977 + 9.27T + 2.40\times10^{-3}T^2$

Formation: $Cu + 1/2O_2 \longrightarrow CuO$

Zone I (298°–1,250° K.)

$\Delta C_p = 0.28 + 2.8\times10^{-3}T + 0.20\times10^5T^{-2}$
$\Delta H_T = -37{,}640 + 0.28T + 1.4\times10^{-3}T^2 - 0.20\times10^5T^{-1}$
$\Delta F_T = -37{,}640 - 0.28T\ln T - 1.4\times10^{-3}T^2 - 0.10\times10^5T^{-1} + 24.93T$

T, ° K.	$H_T - H_{298}$	S_T	$\Delta H°_T$	$\Delta F°_T$
298		10.19	−37,500	−30,850
400	1,110	13.40	−37,350	−28,600
500	2,260	15.95	−37,200	−26,450
600	3,460	18.14	−37,000	−24,300
700	4,710	20.07	−36,750	−22,200
800	6,000	21.79	−36,500	−20,150
900	7,320	23.34	−36,300	−18,100
1,000	8,680	24.77	−36,000	−16,050
1,100	10,120	26.15	−35,700	−14,100
1,200	11,600	27.43	−35,300	−12,150
1,300	(12,860)	(28.6)	(−35,000)	(−10,250)
1,400	(14,640)	(29.9)	(−37,700)	(−8,500)
1,500	(15,870)	(31.0)	(−37,300)	(−6,400)
1,600	(18,800)	(32.0)	(−36,900)	(−4,300)

Copper Fluoride, CuF (*c*)

$\Delta H^\circ_{298} = -60{,}000$ calories per mole (*11*)
$S_{298} = (16)$ *e.u.* (*11*)
M.P. = (1,020°) K. (*42*)
$\Delta H_M = (4{,}500)$ calories per mole
B.P. = (1,660°) K. (*42*)
$\Delta H_V = (36{,}000)$ calories per mole

Formation: $Cu + 1/2F_2 \longrightarrow CuF$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−60,000	(−55,200)
500	(3,000)	(−59,000)	(−52,000)
1,000	(10,000)	(−57,400)	(−46,000)
1,500	(22,000)	(−50,300)	(−39,000)

Copper Difluoride, CuF_2 (*c*)

$\Delta H^\circ_{298} = -128{,}000$ calories per mole (*11*)
$S_{298} = (22)$ *e.u.* (*11*)
M.P. = (1,200°) K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (1,800°) K. (*6*)

Formation: $Cu + F_2 \longrightarrow CuF_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−128,000	(−117,600)
500	(4,000)	(−126,800)	(−110,500)
1,000	(13,000)	(−125,300)	(−95,000)

Copper Chloride, CuCl (*c*)

$\Delta H^\circ_{298} = -32{,}600$ calories per mole (*11*)
$S_{298} = 20.8$ *e.u.* (*83*)
M.P. = 703° K. (*82*)
$\Delta H_M = 2{,}620$ calories per mole
B.P. = 1,963° K. (*6*)
$\Delta H_V = 39{,}600$ calories per mole

Zone I (*c*) (298°–703° K.)

$C_p = 5.87 + 19.20\times10^{-3}T$ (*82*)
$H_T - H_{298} = -2{,}605 + 5.87T + 9.60\times10^{-3}T^2$

Zone II (*l*) (703°–1,200° K.)

$C_p = 15.80$ (*79*)
$H_T - H_{298} = -2{,}220 + 15.80T$

Formation: $Cu + 1/2Cl_2 \longrightarrow CuCl$

Zone I (298°–703° K.)

$\Delta C_p = -3.95 + 17.67\times10^{-3}T + 0.34\times10^5T^{-2}$
$\Delta H_T = -31{,}066 - 3.95T + 8.83\times10^{-3}T^2 - 0.34\times10^5T^{-1}$
$\Delta F_T = -31{,}066 + 3.95T\ln T - 8.83\times10^{-3}T^2 - 0.17\times10^5T^{-1} - 7.56T$

Zone II (703°–1,200° K.)

$\Delta C_p = 6.0 - 1.53\times10^{-3}T + 0.34\times10^5T^{-2}$
$\Delta H_T = -31{,}800 + 6.0T - 0.765\times10^{-3}T^2 - 0.34\times10^5T^{-1}$
$\Delta F_T = -31{,}800 - 6.0T\ln T + 0.765\times10^{-3}T^2 - 0.17\times10^5T^{-1} + 50.5T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		20.8	−32,600	−28,500
400	1,280	24.48	−32,450	−27,200
500	2,720	27.68	−31,950	−25,800
600	4,385	30.71	−31,500	−24,850
700	6,210	33.52	−30,600	−23,600
800	10,420	39.37	−27,450	−22,950
900	12,000	41.23	−27,000	−22,500
1,000	13,580	42.9	−26,550	−21,950
1,100	15,160	44.41	−26,050	−21,400
1,200	16,740	45.78	−25,650	−21,150

Copper Dichloride, $CuCl_2$ (*c*)

$\Delta H_{298}^\circ = -53{,}400$ calories per mole (*11*)
$S_{298} = (27)$ *e.u.* (*11*)
Decomposes = 810° K., 1 atm Cl_2 (*6*)

Zone I (*c*) (298°–800° K.)

$$C_p = 15.42 + 12.00\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -5{,}131 + 15.42T + 6.00\times10^{-3}T^2$$

Formation: $Cu + Cl_2 \longrightarrow CuCl_2$

Zone I (298°–800° K.)

$$\Delta C_p = 1.19 + 10.44\times10^{-3}T + 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -53{,}990 + 1.19T + 5.22\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -53{,}990 - 1.19T\ln T - 5.22\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 45.0T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		(27.0)	−53,400	(−43,200)
400	2,000	(32.7)	−52,850	(−39,700)
500	4,080	(37.4)	−52,200	(−36,500)
600	6,290	(41.4)	−51,500	(−33,450)
700	8,620	(45.0)	−50,700	(−30,550)
800	11,030	(49.2)	−49,800	(−28,450)

Copper Bromide, CuBr (*c*)

$\Delta H_{298}^\circ = -25{,}450$ calories per mole (*11*)
$S_{298} = 22.97$ *e.u.* (*55*)
$M.P. = 761°$ K. (*6*)
$\Delta H_M = (2{,}300)$ calories per mole
$B.P. = 1{,}591°$ K. (*6*)
$\Delta H_V = (33{,}400)$ calories per mole

Formation: $Cu + 1/2Br_2 \longrightarrow CuBr$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−25,450	−24,400
500	(3,000)	(−28,400)	(−21,500)
1,000	(13,000)	(−24,000)	(−17,000)
1,500	(21,000)	(−24,900)	(−13,400)

Copper Dibromide, $CuBr_2$ (*c*)

$\Delta H_{298}^\circ = -33{,}200$ calories per mole (*112*)
$S_{298} = (33)$ *e.u.* (*11*)
Decomposes = 600° K., 1 atm Br_2 (*6*)

Formation: $Cu + Br_2 \longrightarrow CuBr_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−33,200	(−30,400)
500	(4,000)	(−40,000)	(−24,300)

Copper Iodide, CuI (*c*)

$\Delta H_{298}^\circ = -16{,}500$ calories per mole (*11*)
$S_{298} = 23.1$ *e.u.* (*112*)
$M.P. = 861°$ K. (*6*)
$\Delta H_M = (2{,}600)$ calories per mole
$B.P. = 1{,}480°$ K. (*6*)
$\Delta H_V = (31{,}100)$ calories per mole

Zone I (*c*) (298°–675° K.)

$$C_p = 12.1 + 2.86\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -3{,}733 + 12.1T + 1.43\times10^{-3}T^2$$

Formation: $Cu + 1/2I_2 \longrightarrow CuI$

Zone I (298°–386.1° K.)

$$\Delta C_p = 1.9 - 4.59\times10^{-3}T$$
$$\Delta H_T = -16{,}850 + 1.9T - 2.29\times10^{-3}T^2$$
$$\Delta F_T = -16{,}850 - 1.9T\ln T + 2.29\times10^{-3}T^2 + 9.47T$$

Zone II (386.1°–456° K.)

$$\Delta C_p = -2.91 + 1.36\times10^{-3}T$$
$$\Delta H_T = -17{,}350 - 2.91T + 0.68\times10^{-3}T^2$$
$$\Delta F_T = -17{,}350 + 2.91T\ln T - 0.68\times10^{-3}T^2 - 16.1T$$

Zone III (456°–675° K.)

$$\Delta C_p = 2.21 + 1.36\times10^{-3}T$$
$$\Delta H_T = -24{,}700 - 2.21T + 0.68\times10^{-3}T^2$$
$$\Delta F_T = -24{,}700 - 2.21T\ln T - 0.68\times10^{-3}T^2 + 31.3T$$

(estimated (*11*))

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		23.1	−16,500	−17,000
400	1,335	26.95	−18,400	−16,900
500	2,670	29.95	−23,400	−16,100
600	4,040	32.44	−23,100	−14,700
1,000	(13,000)		(−18,500)	(−9,500)
1,500	(52,000)		(+11,500)	(−5,800)

Tricopper Nitride, Cu_3N(*c*)

$\Delta H_{298}^\circ = 17{,}800$ calories per mole (*9*)
Metastable, decomposes > 740° K.

Copper Nitride, CuN (*c*)

$\Delta H_{298}^\circ = -60{,}230$ calories per mole (*131*)
$S_{298} = 39.68$ *e.u.*
$\Delta F_{298}^\circ = -62{,}850$ calories per mole

Copper Trinitride, CuN_3 (*c*)

$\Delta H_{298}^\circ = 67{,}230$ calories per mole (*43*)

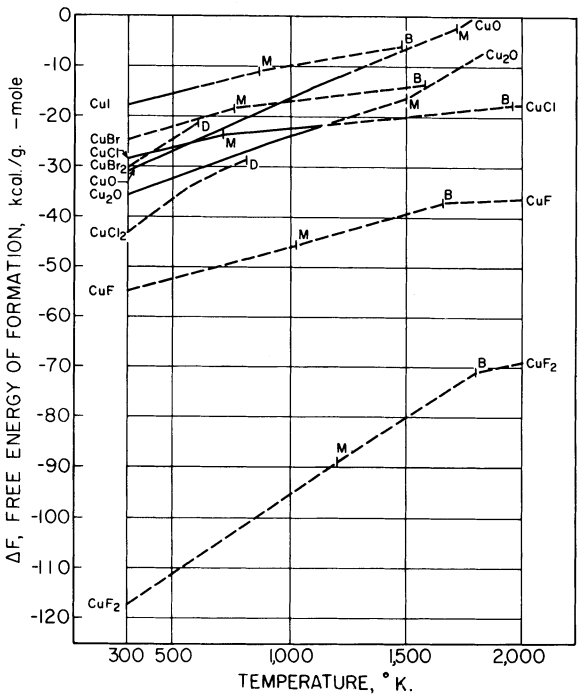

FIGURE 16.—Copper.

DYSPROSIUM AND ITS COMPOUNDS

Element, Dy (*c*)

S_{298}=17.87 *e.u.* (*127*)
$M.P.$=1,673° K. (*125*)
ΔH_M=4,100 calories per atom
$B.P.$=2,600° K. (*125*)
ΔH_V=67,000 calories per atom

Data above 298° K. estimated by (*130*)

T, ° K.	H_T-H_{298}	S_T	$\frac{(F_T-H_{298})}{T}$
298		17.87	17.87
400	(670)	(19.81)	(18.14)
500	(1,350)	(21.31)	(18.61)
600	(2,040)	(22.58)	(19.18)
700	(2,750)	(23.67)	(19.75)
800	(3,480)	(24.64)	(20.29)
900	(4,220)	(25.52)	(20.84)
1,000	(4,990)	(26.32)	(21.33)
1,100	(5,760)	(27.06)	(21.83)
1,200	(6,560)	(27.76)	(22.30)
1,300	(7,370)	(28.41)	(22.75)
1,400	(8,200)	(29.02)	(23.17)
1,500	(9,050)	(29.61)	(23.58)
1,600	(9,911)	(30.16)	(23.97)
1,700	(10,790)	(30.70)	(24.36)
1,800	(15,760)	(33.51)	(24.76)
1,900	(16,560)	(33.94)	(25.23)
2,000	(17,360)	(34.36)	(25.68)

Dysprosium Trifluoride, DyF_3 (*c*)

ΔH°_{298}=(−373,000) calories per mole (*5*)
S_{298}=(25) *e.u.* (*11*)
$M.P.$=(1,427°) K. (*29*)
ΔH_M=(8,000) calories per mole
$B.P.$=(2,500°) K. (*6*)
ΔH_V=(60,000) calories per mole

Formation: $Dy+3/2F_2 \longrightarrow DyF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−373,000)	(−355,000)
500	(4,000)	(−372,500)	(−343,000)
1,000	(17,000)	(−370,000)	(−313,000)
1,500	(32,000)	(−365,500)	(−287,500)

Dysprosium Trichloride, $DyCl_3$ (*c*)

ΔH°_{298}=(−211,000) calories per mole (*5*)
S_{298}=(40) *e.u.* (*11*)
$M.P.$=920° K. (*29*)
ΔH_M=(7,000) calories per mole
$B.P.$=(1,800°) K. (*6*)
ΔH_V=(45,000) calories per mole

Formation: $Dy+3/2Cl_2 \longrightarrow DyCl_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−211,000)	(−195,000)
500	(5,000)	(−210,000)	(−185,000)
1,000	(19,000)	(−206,000)	(−161,000)
1,500	(43,000)	(−202,500)	(−142,000)

Dysprosium Tribromide, $DyBr_3$ (*c*)

ΔH°_{298}=(−173,000) calories per mole (*5*)
S_{298}=(45) *e.u.* (*11*)
$M.P.$=1,152° K. (*29*)
ΔH_M=(9,000) calories per mole
$B.P.$=(1,750°) K. (*6*)
ΔH_V=(44,000) calories per mole

Formation: $Dy+3/2Br_2 \longrightarrow DyBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−173,000)	(−166,500)
500	(5,000)	(−183,500)	(−156,000)
1,000	(18,000)	(−181,000)	(−131,000)
1,500	(43,000)	(−167,000)	(−112,000)

Dysprosium Triiodide, DyI_3 (*c*)

ΔH°_{298}=−143,700 calories per mole (*5*)
S_{298}=(47) *e.u.* (*11*)
$M.P.$=1,243° K. (*29*)
ΔH_M=(10,000) calories per mole
$B.P.$=(1,590°) K. (*6*)
ΔH_V=(41,000) calories per mole

Formation: $Dy+3/2I_2 \longrightarrow DyI_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−143,700	(−141,000)
500	(5,000)	(−165,000)	(−143,600)
1,000	(19,000)	(−161,500)	(−108,000)
1,500	(46,000)	(−145,000)	(−84,000)

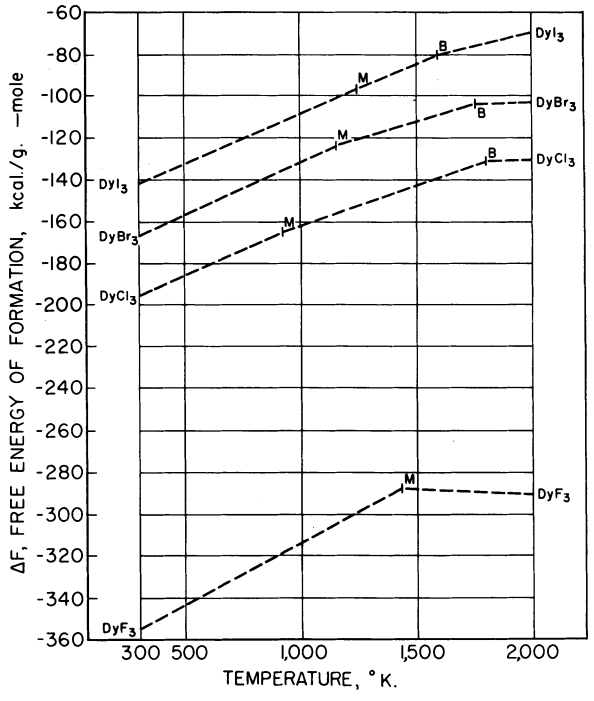

FIGURE 17.—Dysprosium.

ERBIUM AND ITS COMPOUNDS

Element, Er (*c*)

S_{298}=17.48 *e.u.* (*122*)
M.P.=1,800° K. (*125*)
ΔH_M=4,100 calories per atom
B.P.=2,900° K. (*125*)
ΔH_V=70,000 calories per atom

(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		17.48	17.48
400	(690)	(19.47)	(17.75)
500	(1,390)	(21.02)	(18.24)
600	(2,095)	(22.32)	(18.83)
700	(2,820)	(23.43)	(19.41)
800	(3,560)	(24.42)	(19.97)
900	(4,310)	(25.31)	(20.53)
1,000	(5,080)	(26.12)	(21.04)
1,100	(5,870)	(26.87)	(21.54)
1,200	(6,670)	(27.56)	(22.01)
1,300	(7,480)	(28.21)	(22.46)
1,400	(8,310)	(28.83)	(22.90)
1,500	(9,160)	(29.41)	(23.31)
1,600	(10,020)	(29.97)	(23.71)
1,700	(10,890)	(30.50)	(24.10)
1,800	(15,880)	(33.29)	(24.47)
1,900	(16,680)	(33.72)	(24.95)
2,000	(17,480)	(34.13)	(25.39)

Erbium Trifluoride, ErF_3 (*c*)

ΔH°_{298}=(−367,000) calories per mole (*5*)
S_{298}=(25) *e.u.* (*11*)
M.P.=(1,413°) K. (*29*)
ΔH_M=(8,000) calories per mole
B.P.=(2,500°) K. (*6*)
ΔH_V=(60,000) calories per mole

Formation: $Er+3/2F_2 \longrightarrow ErF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−367,000)	(−349,000)
500	(4,000)	(−367,000)	(−337,000)
1,000	(17,000)	(−364,000)	(−308,000)
1,500	(32,000)	(−359,500)	(−281,500)

Erbium Trichloride, $ErCl_3$ (*c*)

ΔH°_{298}=−229,070 calories per mole (*127*)
S_{298}=35.1 *e.u.* (*127*)
M.P.=(1,049°) K. (*29*)
ΔH_M=(8,000) calories per mole
B.P.=(1,770°) K. (*6*)
ΔH_V=(44,000) calories per mole

Formation: $Er+3/2Cl_2 \longrightarrow ErCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−229,000	−211,400
500	(5,000)	(−228,000)	(−201,900)
1,000	(19,000)	(−224,000)	(−177,100)
1,500	(43,000)	(−210,500)	(−158,600)

Erbium Tribromide, $ErBr_3$ (*c*)

ΔH°_{298}=(−169,000) calories per mole (*5*)
S_{298}=(44) *e.u.* (*11*)
M.P.=1,196° K. (*29*)
ΔH_M=(10,000) calories per mole
B.P.=(1,730°) K. (*6*)
ΔH_V=(43,000) calories per mole

Formation: $Er+3/2Br_2 \longrightarrow ErBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−169,000)	(−162,000)
500	(5,000)	(−179,500)	(−153,000)
1,000	(18,000)	(−177,000)	(−126,000)
1,500	(43,000)	(−163,000)	(−106,500)

Erbium Triiodide, ErI_3 (*c*)

ΔH°_{298}=−140,000 calories per mole (*5*)
S_{298}=(47) *e.u.* (*11*)
M.P.=1,273° K. (*29*)
ΔH_M=(10,000) calories per mole
B.P.=(1,550°) K. (*6*)
ΔH_V=(40,000) calories per mole

Formation: $Er+3/2I_2 \longrightarrow ErI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−140,000	(−137,000)
500	(5,000)	(−161,500)	(−132,000)
1,000	(19,000)	(−157,500)	(−104,000)
1,500	(44,000)	(−143,000)	(−79,500)

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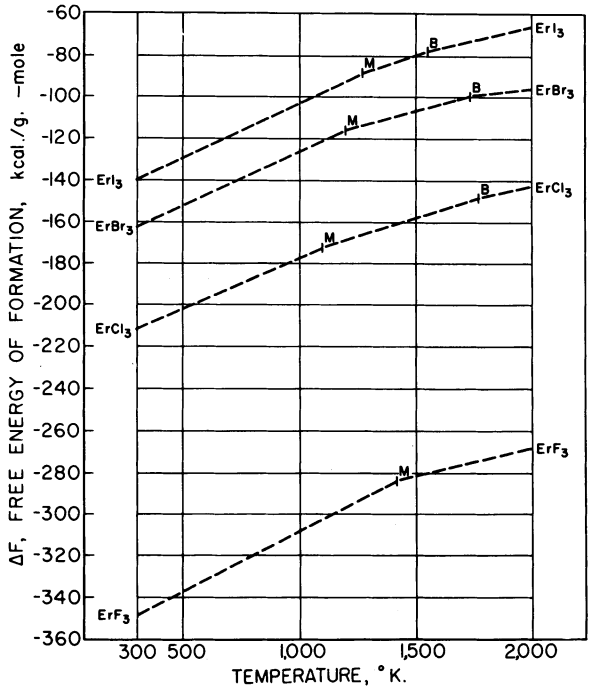

FIGURE 18.—Erbium.

EUROPIUM AND ITS COMPOUNDS

Element, Eu (*c*)

S_{298}=(17.0) *e.u.* (*130*)
M.P.=(1,173°) K. (*125*)
ΔH_M=2,500 calories per atom
B.P.=(1,700°) K. (*125*)
ΔH_V=40,000 calories per atom

(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		(17.0)	(17.0)
400	(660)	(18.91)	(17.26)
500	(1,330)	(20.40)	(17.74)
600	(2,020)	(21.66)	(18.30)
700	(2,730)	(22.76)	(18.86)
800	(3,460)	(23.73)	(19.41)
900	(4,210)	(24.62)	(19.95)
1,000	(4,980)	(25.43)	(20.45)
1,100	(8,270)	(28.45)	(20.94)
1,200	(9,070)	(29.15)	(21.60)
1,300	(9,870)	(29.79)	(22.20)
1,400	(10,670)	(30.38)	(22.76)
1,500	(11,470)	(30.93)	(23.29)
1,600	(12,270)	(31.45)	(23.79)
1,700	(13,070)	(31.94)	(24.26)
1,800	(48,670)	(53.49)	(25.89)
1,900	(49,170)	(53.26)	(27.38)
2,000	(49,680)	(53.57)	(28.73)

Europium Difluoride, EuF_2 (*c*)

ΔH°_{298}=(−282,000) calories per mole (*5*)
S_{298}=(20) *e.u.* (*11*)
M.P.=(1,571°) K. (*29*)
ΔH_M=(5,000) calories per mole
B.P.=(2,700°) K. (*6*)
ΔH_V=(78,000) calories per mole

Formation: $Eu+F_2 \longrightarrow EuF_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−282,000)	(−270,000)
500	(4,000)	(−281,000)	(−261,000)
1,000	(13,000)	(−280,000)	(−243,000)
1,500	(24,000)	(−279,500)	(−223,500)

Europium Trifluoride, EuF_3 (*c*)

ΔH°_{298}=(−366,000) calories per mole (*5*)
S_{298}=(25) *e.u.* (*11*)
M.P.=(1,560°) K. (*29*)
ΔH_M=(8,000) calories per mole
B.P.=(2,550°) K. (*6*)
ΔH_V=(60,000) calories per mole

Formation: $Eu+3/2F_2 \longrightarrow EuF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−366,000)	(−347,800)
500	(4,000)	(−366,000)	(−336,000)
1,000	(17,000)	(−363,000)	(−306,000)
1,500	(32,000)	(−361,000)	(−279,000)

Europium Dichloride, $EuCl_2$ (*c*)

ΔH°_{298}=(−192,000) calories per mole (*5*)
S_{298}=(30) *e.u.* (*11*)
M.P.=(1,000°) K. (*29*)
ΔH_M=(6,000) calories per mole
B.P.=(2,300°) K. (*6*)
ΔH_V=(55,000) calories per mole

Formation: $Eu+Cl_2 \longrightarrow EuCl_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−192,000)	(−181,000)
500	(4,000)	(−191,000)	(−173,500)
1,000	(13,000)	(−190,000)	(−158,000)
1,500	(31,000)	(−183,000)	(−145,500)

Europium Trichloride, $EuCl_3$ (*c*)

ΔH°_{298}=(−208,000) calories per mole (*5*)
S_{298}=(40) *e.u.* (*11*)
M.P.=896° K. (*29*)
ΔH_M=(7,000) calories per mole
Decomposes (*6*)

Formation: $Eu+3/2Cl_2 \longrightarrow EuCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−208,000)	(−192,000)
500	(5,000)	(−207,000)	(−181,500)
1,000	(19,000)	(−203,000)	(−158,000)
1,500	(43,000)	(−192,000)	(−139,000)

Europium Dibromide, $EuBr_2$ (*c*)

$\Delta H^{\circ}_{298}=(-162{,}000)$ calories per mole (*5*)
$S_{298}=(40)$ *e.u.* (*11*)
M.P.$=(950°)$ K. (*29*)
$\Delta H_M=(6{,}000)$ calories per mole
B.P.$=(2{,}150°)$ K. (*6*)
$\Delta H_V=(50{,}000)$ calories per mole

Formation: $Eu+Br_2 \longrightarrow EuBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−162,000)	(−158,000)
500	(4,000)	(−169,000)	(−151,000)
1,000	(20,000)	(−161,000)	(−133,000)
1,500	(32,000)	(−160,000)	(−122,500)

Europium Tribromide, $EuBr_3$ (*c*)

$\Delta H^{\circ}_{298}=(-166{,}000)$ calories per mole (*5*)
$S_{298}=(46)$ *e.u.* (*11*)
M.P.$=(975°)$ K. (*6*)
$\Delta H_M=(8{,}000)$ calories per mole
Decomposes (*6*)

Formation: $Eu+3/2Br_2 \longrightarrow EuBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−166,000)	(−159,000)
500	(5,000)	(−176,500)	(−149,500)
1,000	(18,000)	(−174,000)	(−125,000)
1,500	(43,000)	(−162,000)	(−106,500)

Europium Diiodide, EuI_2 (*c*)

$\Delta H^{\circ}_{298}=(-127{,}000)$ calories per mole (*5*)
$S_{298}=(40)$ *e.u.* (*11*)
M.P.$=(800°)$ K. (*29*)
$\Delta H_M=(5{,}000)$ calories per mole
B.P.$=(1{,}850°)$ K. (*6*)
$\Delta H_V=(40{,}000)$ calories per mole

Formation: $Eu+I_2 \longrightarrow EuI_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−127,000)	(−127,000)
500	(4,000)	(−141,000)	(−124,000)
1,000	(19,000)	(−134,000)	(−110,000)
1,500	(31,000)	(−133,000)	(−99,000)

Europium Triiodide, EuI_3 (*c*)

$\Delta H^{\circ}_{298}=(-112{,}000)$ calories per mole (*5*)
$S_{298}=(48)$ *e.u.* (*11*)
M.P.$=(1{,}150°)$ K. (*29*)
$\Delta H_M=(9{,}000)$ calories per mole
Decomposes (*6*)

Formation: $Eu+3/2I_2 \longrightarrow EuI_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−112,000)	(−110,000)
500	(5,000)	(−133,000)	(−104,000)
1,000	(19,000)	(−129,500)	(−77,000)
1,500	(44,000)	(−118,000)	(−53,000)

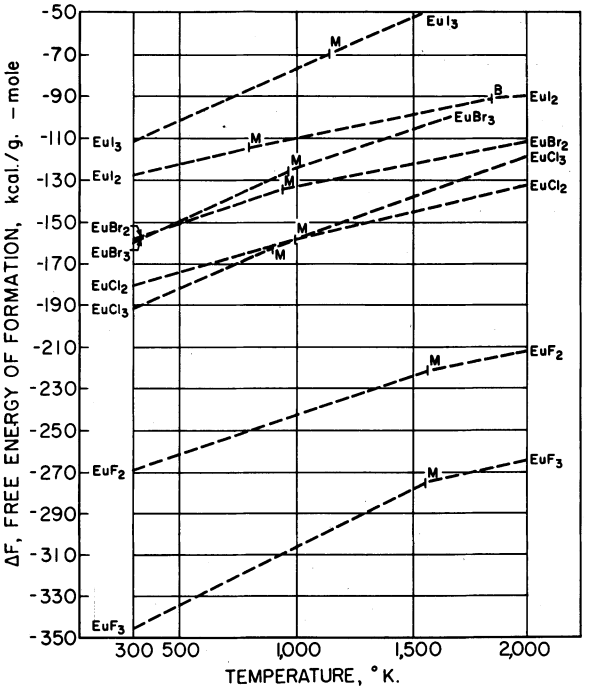

FIGURE 19.—Europium.

FLUORINE

Element, F_2 (*g*)

$S_{298}=48.56$ *e.u.* (*83*)
M.P.$=53.54°$ K. (*112*)
$\Delta H_M=122$ calories per atom
B.P.$=85.0°$ K. (*112*)
$\Delta H_V=1{,}562$ calories per atom

Zone I (*g*) (298°–2,000° K.)

$$C_p=8.29+0.44\times10^{-3}T-0.80\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-2{,}760+8.29T+0.22\times10^{-3}T^{2}+0.80\times10^{5}T^{-1}$$
$$F_T-H_{298}=-2{,}760-8.29T\ln T-0.22\times10^{-3}T^{2}+0.40\times10^{5}T^{-1}+7.3T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		48.56	48.56
400	786	50.83	48.86
500	1,590	52.62	49.44
600	2,420	54.14	50.11
700	3,265	55.44	50.77
800	4,120	56.58	51.43
900	4,980	57.59	52.06
1,000	5,850	58.51	52.66
1,100	6,725	59.34	53.14
1,200	7,600	60.11	53.77
1,300	8,480	60.81	54.29
1,400	9,360	61.46	54.77
1,500	10,240	62.07	55.24
1,600	11,125	62.64	55.69
1,700	12,010	63.18	56.11
1,800	12,895	63.68	56.52
1,900	13,785	64.16	56.90
2,000	14,670	64.62	57.29

GADOLINIUM AND ITS COMPOUNDS

Element, Gd (*c*)

$S_{298}=15.83$ *e.u.* (*121*)
$M.P.=1,523°$ K. (*127*)
$\Delta H_M=3,700$ calories per atom
$B.P.=3,000°$ K. (*127*)
$\Delta H_V=72,000$ calories per atom

(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		15.83	15.83
400	(780)	(18.12)	(15.93)
500	(1,480)	(19.66)	(16.70)
600	(2,200)	(20.98)	(17.31)
700	(2,940)	(22.13)	(17.93)
800	(3,700)	(23.14)	(18.51)
900	(4,480)	(24.05)	(19.07)
1,000	(5,270)	(24.89)	(19.62)
1,100	(6,080)	(25.66)	(20.13)
1,200	(6,900)	(26.37)	(20.62)
1,300	(7,740)	(27.05)	(21.09)
1,400	(8,600)	(27.68)	(21.53)
1,500	(9,480)	(28.29)	(21.97)
1,600	(14,070)	(31.17)	(22.37)
1,700	(14,870)	(31.66)	(22.91)
1,800	(15,670)	(32.12)	(23.41)
1,900	(16,470)	(32.55)	(23.88)
2,000	(17,270)	(32.96)	(24.32)

Digadolinium Trioxide, Gd_2O_3 (*c*)

$\Delta H^\circ_{298}=-433,940\pm 860$ calories per mole (*59*)

Gadolinium Trifluoride, GdF_3 (*c*)

$\Delta H^\circ_{298}=(-379,000)$ calories per mole (*5*)
$S_{298}=(25)$ *e.u.* (*11*)
$T.P.=1,280°$ K. (*29*)
$M.P.=1,650°$ K. (*29*)
$\Delta H_M=(8,000)$ calories per mole
$B.P.=(2,550°)$ K. (*6*)
$\Delta H_V=(60,000)$ calories per mole

Formation: $Gd+3/2F_2\longrightarrow GdF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−379,000)	(−361,000)
500	(4,000)	(−379,000)	(−349,000)
1,000	(17,000)	(−376,000)	(−319,000)
1,500	(32,000)	(−372,000)	(−290,500)

Gadolinium Trichloride, $GdCl_3$ (*c*)

$\Delta H^\circ_{298}=-240,080$ calories per mole (*127*)
$S_{298}=34.9$ *e.u.* (*127*)
$M.P.=882°$ K. (*29*)
$\Delta H_M=(7,000)$ calories per mole
$B.P.=(1,850°)$ K. (*6*)
$\Delta H_V=(45,000)$ calories per mole

Formation: $Gd+3/2Cl_2\longrightarrow GdCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−240,100	−222,000
500	(5,000)	(−239,000)	(−211,000)
1,000	(19,000)	(−235,500)	(−188,000)
1,500	(43,000)	(−222,000)	(−170,000)

Gadolinium Tribromide, $GdBr_3$ (*c*)

$\Delta H^\circ_{298}=-178,000$ calories per mole (*11*)
$S_{298}=(46)$ *e.u.* (*11*)
$M.P.=1,043°$ K. (*29*)
$\Delta H_M=(8,000)$ calories per mole
$B.P.=(1,760°)$ K. (*6*)
$\Delta H_V=(44,000)$ calories per mole

Formation: $Gd+3/2Br_3\longrightarrow GdBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−178,000	(−171,500)
500	(5,000)	(−189,000)	(−161,500)
1,000	(18,000)	(−186,000)	(−137,000)
1,500	(43,000)	(−172,000)	(−118,500)

Gadolinium Triiodide, GdI_3 (*c*)

$\Delta H^\circ_{298}=-147,000$ calories per mole (*11*)
$S_{298}=(48)$ *e.u.*
$M.P.=1,199°$ K. (*29*)
$\Delta H_M=(10,000)$ calories per mole
$B.P.=(1,610°)$ K. (*6*)
$\Delta H_V=(40,000)$ calories per mole

Formation: $Gd+3/2I_2\longrightarrow GdI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−147,000	(−144,000)
500	(5,000)	(−168,000)	(−140,500)
1,000	(19,000)	(−165,000)	(−113,000)
1,500	(44,000)	(−151,000)	(−89,000)

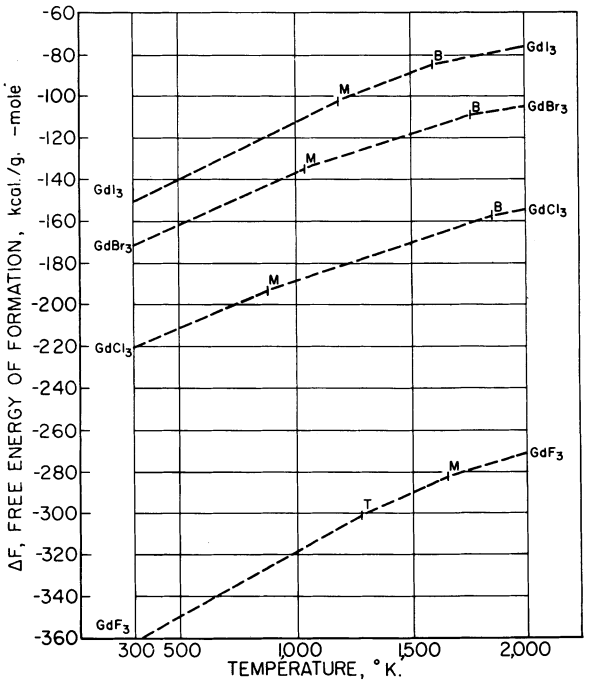

FIGURE 20.—Gadolinium.

GOLD AND ITS COMPOUNDS

Element, Au (*c*)

$S_{298}=11.32$ *e.u.* (*37*)
M.P.=1,336° K. (*82*)
$\Delta H_M=2{,}955$ calories per atom
B.P.=2,980° K. (*130*)
$\Delta H_V=77{,}540$ calories per atom

Zone I (*c*) (298°–1,336° K.)

$$C_p=5.66+1.24\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-1{,}743+5.66T+0.62\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}743-5.66T\ln T-0.62\times10^{-3}T^2+26.95T$$

Zone II (*l*) (1,336°–1,600° K.)

$$C_p=7.00 \text{ (82)}$$
$$H_T-H_{298}=530+7.00T$$
$$F_T-H_{298}=530-7.00T\ln T+34.1T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		11.32	11.32
400	625	13.12	11.56
500	1,245	14.51	12.02
600	1,880	15.66	12.53
700	2,530	16.67	13.06
800	3,180	17.53	13.56
900	3,850	18.32	14.04
1,000	4,530	19.04	14.51
1,100	5,220	19.70	14.95
1,200	5,930	20.32	15.37
1,300	6,660	20.90	15.78
1,400	10,330	23.64	16.26
1,500	11,030	24.12	16.77
1,600	11,730	24.57	17.24
1,700	(12,430)	(24.99)	(17.68)
1,800	(13,130)	(25.39)	(18.10)
1,900	(13,830)	(25.77)	(18.50)
2,000	(14,530)	(26.13)	(18.87)

Digold Trioxide, Au_2O_3 (*c*)

$\Delta H^\circ_{298}=(-800)$ calories per mole (*24*)
$S_{298}=(31)$ *e.u.* (*24*)

Formation: $2Au+3/2O_2\longrightarrow Au_2O_3$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−800)	(18,550)
400	(2,800)	(−350)	(25,100)
500	(6,000)	(+100)	(31,450)

Gold Fluoride, AuF (*g*)

$\Delta H^\circ_{298}=-18{,}000$ calories per mole (*11*)
$S_{298}=(23)$ *e.u.* (*11*)

Formation: $Au+1/2F_2\longrightarrow AuF$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−18,000	(−14,100)
500	(3,000)	(−17,000)	(−11,500)
1,000	(12,000)	(−13,500)	(−9,000)

Gold Difluoride, AuF_2 (*c*)

$\Delta H^\circ_{298}=(-57{,}000)$ calories per mole (*11*)
$S_{298}=(28)$ *e.u.* (*11*)

Formation: $Au+F_2\longrightarrow AuF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−57,000)	(−47,400)
500	(4,000)	(−55,800)	(−40,500)

Gold Trifluoride, AuF_3 (*c*)

$\Delta H^\circ_{298}=(-100{,}000)$ calories per mole (*11*)
$S_{298}=(38)$ *e.u.* (*11*)
M.P.=(1,000°) K. (*6*)

Formation: $Au+3/2F_2\longrightarrow AuF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−100,000)	(−86,200)
500	(4,000)	(−99,600)	(−77,500)

Gold Chloride, AuCl (*c*)

$\Delta H^\circ_{298}=-8{,}400$ calories per mole (*112*)
$S_{298}=(24)$ *e.u.* (*11*)
B.P.=(1,600°) K. (*6*)

Formation: $Au+1/2Cl_2\longrightarrow AuCl$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−8,400	(−4,200)
500	(3,000)	(−7,500)	(−1,400)
1,000	(13,000)	(−2,900)	(+2,600)

Gold Dichloride, $AuCl_2$ (*c*)

$\Delta H^\circ_{298} = -18{,}100$ calories per mole (*112*)
$S_{298} = (36)$ *e.u.* (*11*)
Decomposes = >460° K. (*6*)

Formation: $Au + Cl_2 \longrightarrow AuCl_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−18,100	(−9,500)
500	(4,000)	(−17,000)	(−3,600)

Gold Trichloride, $AuCl_3$ (*c*)

$\Delta H^\circ_{298} = -28{,}300$ calories per mole (*112*)
$S_{298} = (45)$ *e.u.* (*6*)
M.P. = 561° K. (*6*)
B.P. = (700°) K.

Formation: $Au + 3/2Cl_2 \longrightarrow AuCl_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−28,300	(−14,600)
500	(5,000)	(−27,100)	(−5,300)

Gold Bromide, AuBr (*c*)

$\Delta H^\circ_{298} = -3{,}300$ calories per mole (*112*)
$S_{298} = (27)$ *e.u.* (*11*)
M.P. = (1,600°) K. (*6*)

Formation: $Au + 1/2Br_2 \longrightarrow AuBr$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−3,300	(−2,550)
500	(3,000)	(−300)	(0)

Gold Dibromide, $AuBr_2$ (*c*)

$\Delta H^\circ_{298} = -5{,}550$ calories per mole (*11*)
$S_{298} = (39)$ *e.u.* (*11*)
Decomposes (*6*)

Formation: $Au + Br_2 \longrightarrow AuBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−5,550	(−2,900)
500	(4,000)	(12,300)	(+3,100)

Gold Tribromide, $AuBr_3$ (*c*)

$\Delta H^\circ_{298} = -11{,}000$ calories per mole (*11*)
$S_{298} = (54)$ *e.u.* (*11*)
Decomposes (*6*)

Formation: $Au + 3/2Br_2 \longrightarrow AuBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−11,000	(−7,600)
500	(5,000)	(−16,800)	(+2,000)

Gold Iodide, AuI (*c*)

$\Delta H^\circ_{298} = +240$ calories per mole (*11*)
$S_{298} = (28)$ *e.u.* (*11*)
M.P. = (1,600°) K. (*6*)

Formation: $Au + 1/2\ I_2 \longrightarrow AuI$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		240	(−400)
500	(3,000)	(−9,000)	(+300)

Gold Diiodide, AuI_2 (*c*)

$\Delta H^\circ_{298} = (+6{,}900)$ calories per mole (*11*)
$S_{298} = (39)$ *e.u.* (*11*)
Decomposes (*6*)

Formation: $Au + I_2 \longrightarrow AuI_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(+6,900)	(+6,900)
500	(4,000)	(−7,000)	(+8,000

Gold Triiodide, AuI_3 (*c*)

$\Delta H^\circ_{298} = (+8{,}300)$ calories per mole (*11*)
$S_{298} = (50)$ *e.u.* (*11*)
Decomposes (*6*)

Formation: $Au + 3/2I_2 \longrightarrow AuI_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(8,300)	(+9,200)
500	(5,000)	(−13,000)	(+9,500)

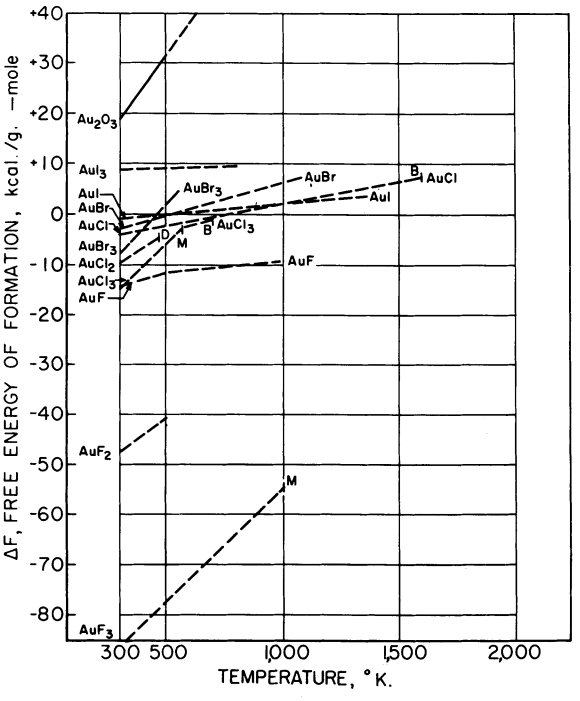

FIGURE 21.—Gold.

HAFNIUM AND ITS COMPOUNDS

Element, Hf (*c*)

$S_{298}=13.1$ *e.u.* (*83*)
$M.P.=2{,}488°$ K. (*85*)
$\Delta H_M=(6{,}000)$ calories per atom
$B.P.=5{,}500°$ K. (*7*)
$\Delta H_V=155{,}000$ calories per atom

Zone I (*c*) (298°–2,488° K.)

$$C_p=6.00+0.52\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-1{,}810+6.00T+0.26\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}810-6.00T\ln T-0.26\times10^{-3}T^2+27.16T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		13.1	13.1
400	670	14.95	13.30
500	1,320	16.40	13.70
600	1,980	17.55	14.27
700	2,645	18.45	14.61
800	3,320	19.26	15.26
900	4,010	20.10	15.68
1,000	4,710	20.81	16.10
1,100	5,420	21.44	16.54
1,200	6,140	21.96	16.84
1,300	6,870	22.51	17.31
1,400	7,610	23.07	17.58
1,500	8,360	23.52	17.91
1,600	9,120	23.92	18.22
1,700	9,890	24.32	18.59
1,800	10,595	24.77	18.78
1,900	11,470	25.03	19.11
2,000	12,270	25.43	19.31
2,500	(16,440)	(28.14)	(21.56)

Hafnium Dioxide, HfO_2 (*c*)

$\Delta H^\circ_{298}=-266{,}050$ calories per mole (*66*)
$S_{298}=14.18$ *e.u.* (*132*)
$M.P.=3{,}063°$ K. (*8*)

Zone I (*c*) (298°–1,800° K.)

$$C_p=17.39+2.08\times10^{-3}T-3.48\times10^5T^{-2} \text{ (105)}$$
$$H_T-H_{298}=-6{,}440+17.39T+1.04\times10^{-3}T^2+3.48\times10^5T^{-1}$$

Formation: $Hf+O_2\longrightarrow HfO_2$

Zone I (298°–1,800° K.)

$$\Delta C_p=4.23+0.56\times10^{-3}T-3.08\times10^5T^{-2}$$
$$\Delta H_T=-268{,}400+4.23T+0.28\times10^{-3}T^2+3.08\times10^5T^{-1}$$
$$\Delta F_T=-268{,}400-4.23T\ln T-0.28\times10^{-3}T^2+1.54\times10^5T^{-1}+78.16T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		14.81	−266,050	−251,750
400	1,550	19.61	−265,900	−246,900
500	3,150	22.24	−265,650	−242,150
600	4,900	25.40	−265,350	−237,550
700	6,700	28.19	−264,950	−232,950
800	8,550	30.67	−264,600	−228,650
900	10,450	32.88	−264,200	−224,100
1,000	12,350	34.88	−263,850	−219,700
1,100	14,300	36.72	−263,400	−215,300
1,200	16,250	38.42	−263,100	−211,200
1,300	18,200	40.00	−262,600	−206,900
1,400	20,200	41.48	−262,200	−202,500
1,500	22,200	42.87	−261,850	−198,350
1,600	24,250	44.19	−261,350	−194,350
1,700	26,300	45.44	−260,950	−190,250
1,800	28,400	46.63	−260,350	−186,050
1,900	(30,500)	(47.76)	(−259,100)	(−181,400)
2,000	(32,600)	(48.85)	(−258,550)	(−177,600)
2,500			(−255,850)	(−159,600)

Hafnium Tetrafluoride, HfF_4 (*c*)

$\Delta H^\circ_{298}=(-435{,}000)$ calories per mole (*11*)
$S_{298}=(35)$ *e.u.* (*11*)
$S.P.=(1{,}200°)$ K. (*6*)
$\Delta H_{sub\,l}=(63{,}000)$ calories per mole

Formation: $Hf+2F_2\longrightarrow HfF_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−435,000)	(−412,500)
500	(6,000)	(−433,500)	(−398,500)
1,000	(22,000)	(−429,500)	(−363,000)

Hafnium Tetrachloride, $HfCl_4$ (*c*)

$\Delta H^\circ_{298}=(-255{,}000)$ calories per mole (*11*)
$S_{298}=45.6$ *e.u.* (*132*)
$S.P.=590°$ K. (*6*)
$\Delta H_{sub\,l}=(24{,}000)$ calories per mole

Zone I (*c*) (298°–485° K.)

$$C_p=31.47-2.38\times10^5T^{-2} \text{ (105)}$$
$$H_T-H_{298}=-10{,}180+31.47T+2.38\times10^5T^{-1}$$

Formation: $Hf+2Cl_2 \longrightarrow HfCl_4$

Zone I (298°–485° K.)

$\Delta C_p = 7.83 - 0.64\times10^{-3}T - 1.02\times10^{5}T^{-2}$
$\Delta H_T = -257{,}650 + 7.83T - 0.32\times10^{-3}T^2 + 1.02\times10^{5}T^{-1}$
$\Delta F_T = -257{,}650 - 7.83T\ln T + 0.32\times10^{-3}T^2 + 0.51\times10^{5}T^{-1} + 126.78T$

Zone II (500°–2,000° K.)
(estimated (*42*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−255,000)	(−232,900)
400	3,000	(−254,350)	(−225,350)
500	6,000	(−253,700)	(−218,200
1,000			(−209,000)
1,500			(−199,000)
2,000			(−180,000)

Hafnium Tetrabromide, $HfBr_4$ (*c*)

$\Delta H_{298}^\circ = (-210{,}000)$ calories per mole (*11*)
$S_{298} = (57)$ *e.u.* (*11*)
S.P. = 595° K. (*6*)
$\Delta H_{subl} = (24{,}000)$ calories per mole

Formation: $Hf+2Br_2 \longrightarrow HfBr_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−210,000)	(−201,750)
500	(6,000)	(−223,750)	(−187,500)

Hafnium Tetraiodide, HfI_4 (*c*)

$\Delta H_{298}^\circ = (-145{,}000)$ calories per mole (*11*)
$S_{298} = (62)$ *e.u.* (*11*)
S.P. = (700°) K. (*6*)
$\Delta H_{subl} = (28{,}000)$ calories per mole

Formation: $Hf+2I_2 \longrightarrow HfI_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−145,000)	(−142,000)
500	(6,000)	(−177,700)	(−137,500)

Hafnium Nitride, HfN (*c*)

$\Delta H_{298}^\circ = -88{,}240$ calories per mole (*66*)
$S_{298} = 13.1$ *e.u.* (*66*)
$\Delta F_{298} = 81{,}400$ calories per mole
M.P. = 3,580° K. (*9*)

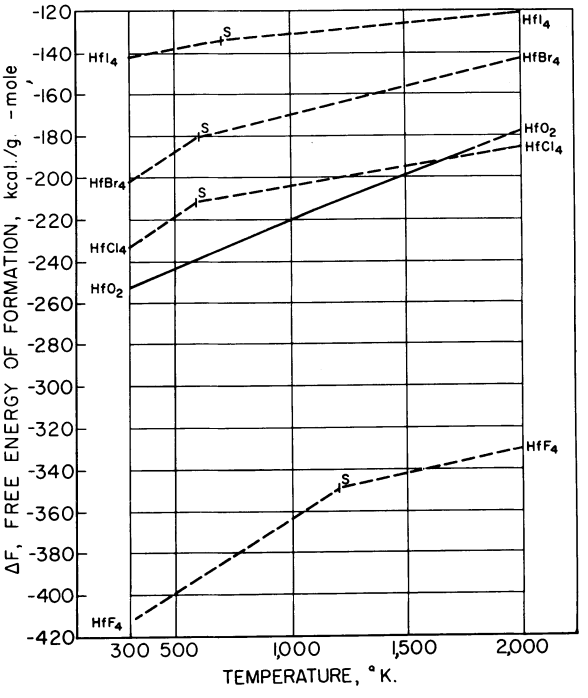

FIGURE 22.—Hafnium.

HOLMIUM AND ITS COMPOUNDS

Element, Ho (*c*)

$S_{298} = (17.77)$ *e.u.* (*121*)
M.P. = 1,773° K. (*125*)
$\Delta H_M = 4{,}100$ calories per atom
B.P. = 2,600° K. (*125*)
$\Delta H_V = 67{,}000$ calories per atom
(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		(17.77)	(17.77)
400	(670)	(19.71)	(18.04)
500	(1,350)	(21.21)	(18.51)
600	(2,040)	(22.48)	(19.08)
700	(2,750)	(23.57)	(19.65)
800	(3,480)	(24.54)	(20.19)
900	(4,220)	(25.42)	(20.74)
1,000	(4,985)	(26.22)	(21.24)
1,100	(5,760)	(26.96)	(21.73)
1,200	(6,560)	(27.66)	(22.20)
1,300	(7,370)	(28.31)	(22.65)
1,400	(8,200)	(28.92)	(23.07)
1,500	(9,050)	(29.51)	(23.48)
1,600	(9,910)	(30.06)	(23.87)
1,700	(10,790)	(30.60)	(24.26)
1,800	(15,760)	(33.41)	(24.66)
1,900	(16,560)	(33.84)	(25.13)
2,000	(17,360)	(34.26)	(25.58)
2,500	(21,360)	(36.04)	(27.50)

Holmium Trifluoride, HoF_3 (*c*)

$\Delta H^\circ_{298} = -370{,}000$ calories per mole (*5*)
$S_{298} = (25)$ *e.u.* (*11*)
M.P. = 1,416° K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (2,500°) K. (*6*)
$\Delta H_V = (60{,}000)$ calories per mole

Formation: $Ho + 3/2F_2 \longrightarrow HoF_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−370,000	(−352,000)
500	(4,000)	(−370,000)	(−340,000)
1,000	(17,000)	(−367,000)	(−311,000)
1,500	(32,000)	(−362,500)	(−285,000)

Holmium Trichloride, $HoCl_3$ (*c*)

$\Delta H^\circ_{298} = -233{,}000$ calories per mole (*5*)
$S_{298} = (39)$ *e.u.* (*11*)
M.P. = 991° K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (1,780°) K. (*6*)
$\Delta H_V = (44{,}000)$ calories per mole

Formation: $Ho + 3/2Cl_2 \longrightarrow HoCl_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−233,000	(−217,000)
500	(5,000)	(−232,000)	(−206,000)
1,000	(19,000)	(−228,000)	(−181,000)
1,500	(43,000)	(−224,500)	(−162,500)

Holmium Tribromide, $HoBr_3$ (*c*)

$\Delta H^\circ_{298} = (-171{,}000)$ calories per mole (*5*)
$S_{298} = (45)$ *e.u.* (*11*)
M.P. = 1,192° K. (*29*)
$\Delta H_M = (10{,}000)$ calories per mole
B.P. = (1,740°) K. (*6*)
$\Delta H_V = (43{,}000)$ calories per mole

Formation: $Ho + 3/2Br_2 \longrightarrow HoBr_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−171,000)	(−164,500)
500	(5,000)	(−181,500)	(−154,000)
1,000	(18,000)	(−179,000)	(−129,000)
1,500	(43,000)	(−165,000)	(−110,000)

Holmium Triiodide, HoI_3 (*c*)

$\Delta H^\circ_{298} = (-142{,}000)$ calories per mole (*5*)
$S_{298} = (47)$ *e.u.* (*11*)
M.P. = 1,262° K. (*29*)
$\Delta H_M = (10{,}000)$ calories per mole
B.P. = (1,570°) K. (*6*)
$\Delta H_V = (41{,}000)$ calories per mole

Formation: $Ho + 3/2I_2 \longrightarrow HoI_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−142,000)	(−139,000)
500	(5,000)	(−163,000)	(−134,500)
1,000	(19,000)	(−159,500)	(−106,000)
1,500	(44,000)	(−145,500)	(−81,500)

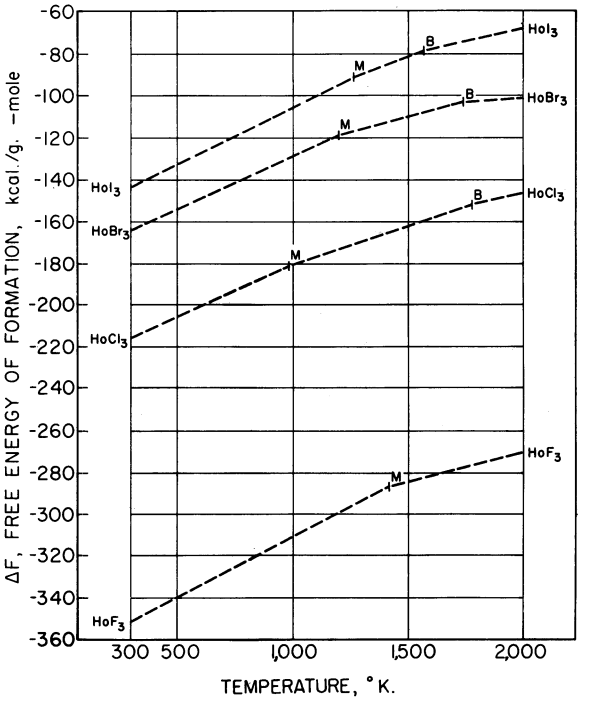

FIGURE 23.—Holmium.

HYDROGEN AND ITS COMPOUNDS

Element, H_2 (*g*)

$S_{298} = 31.22$ *e.u.* (*83*)
M.P. = 13.96° K. (*130*)
$\Delta H_M = 28$ calories per atom
B.P. = 20.39° K. (*130*)
$\Delta H_V = 216$ calories per atom

Zone I (*g*) (298°–3,000° K.)

$$C_p = 6.52 + 0.78\times10^{-3}T + 0.12\times10^{5}T^{-2} \text{ (82)}$$
$$H_T - H_{298} = -1{,}939 + 6.52T + 0.39\times10^{-3}T^2 - 0.12\times10^{5}T^{-1}$$
$$F_T - H_{298} = -1{,}939 - 6.52T\ ln\ T - 0.39\times10^{-3}T^2 - 0.06\times10^{5}T^{-1} + 12.7T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		31.22	31.22
400	707	33.26	31.50
500	1,406	34.82	32.01
600	2,105	36.09	32.58
700	2,808	37.18	33.17
800	3,514	38.12	33.73
900	4,224	38.96	34.27
1,000	4,942	39.71	34.77
1,100	5,681	40.32	35.15
1,200	6,422	40.99	35.64
1,300	7,180	41.67	36.15
1,400	7,937	42.15	36.49
1,500	8,670	42.73	36.95
1,600	9,571	43.21	37.23
1,700	10,271	43.68	37.63
1,800	10,935	44.06	37.98
1,900	11,851	44.54	38.32
2,000	12,648	45.01	38.68
2,500	16,827	46.88	40.15

Water, H_2O (l)

$\Delta H^\circ_{298}=-68{,}317$ calories per mole (*24*)
$S_{298}=16.75$ *e.u.* (*83*)
$M.P.=273.16°$ K. (*24*)
$\Delta H_M=1{,}436$ calories per mole
$B.P.=373.16°$ K. (*24*)
$\Delta H_V=9{,}770$ calories per mole

Zone I (l) (298°–373° K.)

$$C_p=18.03 \quad (82)$$
$$H_T-H_{298}=-5{,}376+18.03T$$

Zone II (g) (373°——→3,000° K.)

$$C_p=7.17+2.56\times10^{-3}T+0.08\times10^{5}T^{-2} \quad (82)$$
$$H_T-H_{298}=+8{,}280+7.17T+1.28\times10^{-3}T^{2}-0.08\times10^{5}T^{-1}$$

Formation: $H_2+1/2O_2$——→H_2O

Zone I (298°–373° K.)

$$\Delta C_p=7.95-1.28\times10^{-3}T+0.08\times10^{5}T^{-2}$$
$$\Delta H_T=-70{,}600+7.95T-0.64\times10^{-3}T^{2}-0.08\times10^{5}T^{-1}$$
$$\Delta F_T=-70{,}600-7.95T\ln T+0.64\times10^{-3}T^{2}+0.04\times10^{5}T^{-1}+91.75T$$

Zone II (373°–2,500° K.)

$$\Delta C_p=-2.91+1.28\times10^{-3}T+0.16\times10^{5}T^{-2}$$
$$\Delta H_T=-56{,}940-2.91T+0.64\times10^{-3}T^{2}-0.16\times10^{5}T^{-1}$$
$$\Delta F_T=-56{,}940+2.91T\ln T-0.64\times10^{-3}T^{2}-0.08\times10^{5}T^{-1}-8.11T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		16.75	−68,320	−56,720
400	11,345	47.01	−58,050	−53,350
500	12,174	48.86	−58,300	−52,150
600	13,026	50.41	−58,500	−50,900
700	13,910	51.77	−58,700	−49,600
800	14,821	52.99	−58,900	−48,300
900	15,762	54.10	−59,100	−46,800
1,000	16,735	55.12	−59,250	−45,800
1,100	17,735	56.07	−59,350	−44,300
1,200	18,768	56.97	−59,500	−42,900
1,300	19,830	57.82	−59,600	−41,400
1,400	20,917	58.63	−59,700	−40,000
1,500	22,031	59.40	−59,800	−38,650
1,600	23,040	60.06	−60,050	−37,350
1,700	24,180	60.71	−60,200	−35,950
1,800	25,335	61.42	−60,050	−34,400
1,900	26,510	62.02	−60,200	−33,050
2,000	27,915	62.78	−60,250	−31,650
2,500	34,205	65.59	−60,300	−24,400

Hydrogen Peroxide, H_2O_2 (l)

$\Delta H^\circ_{298}=-44{,}750$ calories per mole (*36*)
$S_{298}=22.35$ *e.u.* (*24*)
$M.P.=272.5°$ K. (*94*)
$\Delta H_M=2{,}920$ calories per mole
$B.P.=425°$ K. (*94*)
$\Delta H_V=10{,}530$ calories per mole

Zone I (g) (425°–1, 500° K.)

$$C_p=10.43+5.00\times10^{-3}T-1.68\times10^{5}T^{-2} \quad (82)$$
$$H_T-H_{298}=8{,}300+10.43T+2.50\times10^{-3}T^{2}+1.68\times10^{5}T^{-1}$$

Formation: H_2+O_2——→H_2O_2

Zone I (425°–1, 500° K.)

$$\Delta C_p=-3.25+3.22\times10^{-3}T-1.4\times10^{5}T^{-2}$$
$$\Delta H_T=-32{,}200-3.25T+1.61\times10^{-3}T^{2}+1.4\times10^{5}T^{-1}$$
$$\Delta F_T=-32{,}200+3.25T\ln T-1.61\times10^{-3}T^{2}+0.7\times10^{5}T^{-1}+4.38T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		22.35	−44,750	−28,100
400	2,130	28.92	−44,750	−22,600
500	14,460	61.55	−33,150	−20,200
600	15,690	63.84	−33,400	−17,600
700	17,020	65.89	−33,450	−14,900
800	18,440	67.78	−33,600	−12,300
900	19,850	69.83	−33,650	−9,900
1,000	21,400	71.08	−33,700	−6,900
1,100	22,900	72.47	−33,700	−4,200
1,200	24,510	73.92	−33,700	−1,600
1,300	26,170	75.22	−33,650	+1,200
1,400	27,870	76.48	−33,650	3,600
1,500	29,420	77.57	−33,700	6,500
2,000	(39,150)	(83.18)	(−32,400)	(19,600)
2,500	(50,000)	(88.00)	(−30,350)	(32,350)

Hydrogen Fluoride, HF (g)

$\Delta H^\circ_{298}=-64{,}200$ calories per mole (*112*)
$S_{298}=41.49$ *e.u.* (*83*)
$M.P.=190.1°$ K. (*112*)
$\Delta H_M=1{,}094$ calories per mole
$B.P.=293.1°$ K. (*112*)
$\Delta H_V=1{,}800$ calories per mole

Zone I (g) (298°–2,000° K.)

$$C_p=6.43+0.82\times10^{-3}T+0.26\times10^{5}T^{-2} \quad (82)$$
$$H_T-H_{298}=-1{,}866+6.43T+0.41\times10^{-3}T^{2}-0.26\times10^{5}T^{-1}$$

Formation: $1/2H_2+1/2F_2$——→HF

Zone I (298°–2,000° K.)

$$\Delta C_p=-0.98+0.21\times10^{-3}T+0.60\times10^{5}T^{-2}$$
$$\Delta H_T=-63{,}695-0.98T+0.10\times10^{-3}T^{2}-0.60\times10^{5}T^{-1}$$
$$\Delta F_T=-63{,}695+0.98T\ln T-0.10\times10^{-3}T^{2}-0.30\times10^{5}T^{-1}-8.45T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		41.49	−64,200	−64,520
400	710	43.54	−64,250	−64,650
500	1,405	45.09	−64,300	−65,000
600	2,105	46.36	−64,350	−65,150
700	2,800	47.43	−64,450	−65,250
800	3,505	48.38	−64,500	−65,350
900	4,215	49.21	−64,600	−65,450
1,000	4,935	49.97	−64,650	−65,550
1,100	5,681	50.68	−64,700	−65,700
1,200	6,395	51.31	−64,800	−65,750
1,300	7,160	51.99	−64,900	−65,850
1,400	7,895	52.46	−64,950	−65,900
1,500	8,684	53.01	−65,000	−65,950
1,600	9,440	53.49	−65,100	−66,050
1,700	10,235	54.02	−65,100	−66,150
1,800	11,020	54.42	−65,100	−66,150
1,900	11,817	54.89	−65,200	−66,200
2,000	12,635	55.28	−65,200	−66,200
2,500	(16,761)	(55.13)	(−65,400)	(−66,450)

Hydrogen Chloride, HCl (*g*)

$\Delta H^\circ_{298} = -22{,}063$ calories per mole (*112*)
$S_{298} = 44.61$ *e.u.* (*83*)
$M.P. = 158.9°$ K. (*112*)
$\Delta H_M = 476$ calories per mole
$B.P. = 188.1°$ K. (*112*)
$\Delta H_V = 3{,}860$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 6.34 + 1.10\times10^{-3}T + 0.26\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -1{,}860 + 6.34T + 0.55\times10^{-3}T^2 - 0.26\times10^{5}T^{-1}$$

Formation: $1/2H_2 + 1/2Cl_2 \longrightarrow HCl$

Zone I (298°–2,000° K.)

$$\Delta C_p = -1.33 + 0.68\times10^{-3}T + 0.54\times10^{5}T^{-2}$$
$$\Delta H_T = -21{,}500 - 1.33T + 0.34\times10^{-3}T^2 - 0.54\times10^{5}T^{-1}$$
$$\Delta F_T = -21{,}500 + 1.33T\ln T - 0.34\times10^{-3}T^2 - 0.27\times10^{5}T^{-1} - 11.39T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		44.61	−22,060	−22,750
400	710	46.66	−22,100	−22,950
500	1,405	48.21	−22,200	−23,200
600	2,105	49.49	−22,300	−23,400
700	2,815	50.58	−22,350	−23,600
800	3,535	51.54	−22,450	−23,750
900	4,265	52.40	−22,500	−23,900
1,000	5,005	53.18	−22,550	−24,000
1,100	5,765	53.84	−22,600	−24,150
1,200	6,530	54.57	−22,650	−24,400
1,300	7,315	55.16	−22,650	−24,400
1,400	8,095	55.78	−22,750	−24,650
1,500	8,800	56.28	−22,800	−24,700
1,600	9,700	56.85	−22,850	−24,900
1,700	10,520	57.30	(−22,800)	(−25,000)
1,800	11,335	57.81	(−22,800)	(−25,250)
1,900	12,170	58.32	(−22,800)	(−25,450)
2,000	12,995	58.69	(−22,850)	(−25,550)

Hydrogen Bromide, HBr (*g*)

$\Delta H^\circ_{298} = -8{,}660$ calories per mole (*112*)
$S_{298} = 47.63$ *e.u.* (*83*)
$M.P. = 186.24°$ K. (*112*)
$\Delta H_M = 575$ calories per mole
$B.P. = 206.4°$ K. (*112*)
$\Delta H_V = 4{,}210$ calories per mole

Zone I (*g*) (298°–1,600° K)

$$C_p = 6.25 + 1.40\times10^{-3}T + 0.26\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -1{,}838 + 6.25T + 0.70\times10^{-3}T^2 - 0.26\times10^{5}T^{-1}$$

Formation: $1/2H_2 + 1/2Br_2 \longrightarrow HBr$

Zone I (298°–331° K.)

$$\Delta C_p = -5.56 + 1.01\times10^{-3}T + 0.20\times10^{5}T^{-2}$$
$$\Delta H_T = -6{,}980 - 5.56T + 0.51\times10^{-3}T^2 - 0.20\times10^{5}T^{-1}$$
$$\Delta F_T = -6{,}980 + 5.56T\ln T - 0.51\times10^{-3}T^2 - 0.10\times10^{5}T^{-1} - 50.87T$$

Zone II (331°–1,600° K.)

$$\Delta C_p = -1.53 + 1.01\times10^{-3}T + 0.38\times10^{5}T^{-2}$$
$$\Delta H_T = -12{,}000 - 1.53T + 0.51\times10^{-3}T^2 - 0.38\times10^{5}T^{-1}$$
$$\Delta F_T = -12{,}000 + 1.53T\ln T - 0.51\times10^{-3}T^2 - 0.19\times10^{5}T^{-1} - 12.12T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		47.63	−8,660	−12,800
400	709	49.68	−12,650	−13,300
500	1,410	51.24	−12,700	−13,450
600	2,120	52,54	−12,800	−13,600
700	2,840	53.64	−12,900	−13,750
800	3,575	54.63	−12,950	−13,850
900	4,325	55.51	−13,000	−14,000
1,000	5,090	56.31	−13,050	−14,200
1,100	5,908	57.06	−13,050	−14,150
1,200	6,665	57.75	−13,100	−14,300
1,300	7,470	58.34	−13,150	−14,400
1,400	8,285	59.00	−13,150	−14,550
1,500	9,129	59.52	−13,150	−14,600
1,600	9,945	60.11	−13,250	−14,750
2,000	(13,475)	(62.02)	(−13,100)	(−14,950)

Hydrogen Iodide, HI (*g*)

$\Delta H^\circ_{298} = 6{,}200$ calories per mole (*112*)
$S_{298} = 49.33$ *e.u.* (*83*)
$M.P. = 222.36°$ K. (*112*)
$\Delta H_M = 686$ calories per mole
$B.P. = 237.8°$ K. (*112*)
$\Delta H_V = 4{,}724$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 6.29 + 1.42\times10^{-3}T + 0.22\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -1{,}865 + 6.29T + 0.71\times10^{-3}T^2 - 0.22\times10^{5}T^{-1}$$

Formation: $1/2H_2 + 1/2I_2 \longrightarrow HI$

Zone I (298°–386.8° K.)

$$\Delta C_p = -1.76 - 4.92\times10^{-3}T - 0.06\times10^{5}T^{-2}$$
$$\Delta H_T = 6{,}920 + 1.76T - 2.46\times10^{-3}T^2 + 0.06 + 10^{5}T^{-1}$$
$$\Delta F_T = 6{,}920 + 1.76T\ln T + 2.46\times10^{-3}T^2 + 0.03\times10^{5}T^{-1} - 32.9T$$

Zone II (386.8°–456° K.)

$$\Delta C_p = -6.57 + 1.03\times10^{-3}T + 0.16\times10^{5}T^{-2}$$
$$\Delta H_T = 6{,}530 - 6.57T + 0.51\times10^{-3}T^2 - 0.16\times10^{5}T^{-1}$$
$$\Delta F_T = 6{,}530 + 6.57T\ln T - 0.51\times10^{-3}T^2 - 0.08\times10^{5}T^{-1} - 58.47T$$

Zone III (456°–1,500° K.)

$$\Delta C_p = -1.41 + 1.03\times10^{-3}T + 0.16\times10^{5}T^{-2}$$
$$\Delta H_T = -800 - 1.41T + 0.52\times10^{-3}T^2 - 0.16\times10^{5}T^{-1}$$
$$\Delta F_T = -800 + 1.41T\ln T - 0.52\times10^{-3}T^2 - 0.08\times10^{5}T^{-1} - 11.76T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		49.33	+6,200	+300
400	710	51.38	+3,950	−1,750
500	1,410	52.94	−1,450	−2,450
600	2,125	54.25	−1,500	−2,650
700	2,855	55.37	−1,550	−2,800
800	3,595	56.36	−1,650	−3,000
900	4,355	57.25	−1,700	−3,150
1,000	5,180	58.07	−1,700	−3,350
1,100	5,894	58.84	−1,750	−3,550
1,200	6,715	59.51	−1,750	−3,700
1,300	7,495	60.18	−1,800	−3,850
1,400	8,345	60.77	−1,800	−4,050
1,500	9,152	61.36	−1,750	−4,150
1,600	10,000	61.87	(−1,750)	(−4,300)
1,700	10,867	62.45	(−1,750)	(−4,450)
1,800	11,685	62.87	(−1,750)	(−4,600)
1,900	12,639	63.43	(−1,750)	(−4,700)
2,000	13,385	63.76	(−1,750)	(−4,800)

Hydrogen Cyanide, HCN (*g*)

ΔH°_{298}=31,200 calories per mole (*112*)
S_{298}=48.23 *e.u.* (*83*)
M.P.=170.4° K. (*112*)
ΔH_M=40 calories per mole
B.P.=298.8° K. (*112*)
ΔH_V=6,027 calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 8.92 + 3.10\times10^{-3}T - 1.12\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -3{,}173 + 8.92T + 1.55\times10^{-3}T^2 + 1.12\times10^{5}T^{-1}$$

Formation: $1/2H_2 + C + 1/2N_2 \longrightarrow HCN$

Zone I (298°–2,000° K.)

$$\Delta C_p = -1.77 + 1.18\times10^{-3}T + 0.92\times10^{5}T^{-2}$$
$$\Delta H_T = 31{,}980 - 1.77T + 0.59\times10^{-3}T^2 - 0.92\times10^{5}T^{-1}$$
$$\Delta F_T = 31{,}980 + 1.77T\ln T - 0.59\times10^{-3}T^2 - 0.46\times10^{5}T^{-1} - 20.43T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	48.23	+31,200	28,700
400	917	50.87	31,150	27,850
500	1,890	53.04	31,100	27,050
600	2,915	54.91	31,150	26,300
700	3.990	56.56	31,000	25,400
800	5,105	58.05	30,900	24,600
900	6,260	59.41	30,850	23,850
1,000	7,450	60.67	30,800	23,050
1,100	8,610	61.74	30,800	22,350
1,200	9,910	62.91	30,700	21,450
1,300	11,130	63.86	30,600	20,800
1,400	12,480	64.89	30,600	20,000
1,500	13,770	65.51	30,550	19,600
1,600	15,130	66.65	30,550	18,350
1,700	16,540	67.51	30,550	17,550
1,800	17,850	68.26	30,600	16,750
1,900	19,430	69.19	30,700	16,000
2,000	20,610	69.71	30,600	15,450
2,500	(28,860)	(73.46)	(31,200)	(11,200)

Hydroden Trinitride (Azoimide), HN_3 (*g*)

ΔH°_{298}=70,300 calories per mole (*112*)
S_{298}=56.8 *e.u.* (*83*)
M.P.=193° K. (*112*)
B.P.=309° K. (*112*)
ΔH_V=7,100 calories per mole

Zone I (*g*) (309°–1,800° K.)

$$C_p = 11.33 + 4.62\times10^{-3}T - 2.38\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}382 + 11.33T + 2.31\times10^{-3}T^2 + 2.38\ 10^{5}T^{-1}$$

Formation: $1/2H_2 + 3/2N_2 \longrightarrow HN_3$

Zone I (309°–1,800° K.)

$$\Delta C_p = -1.92 + 2.7\times10^{-3}T - 2.44\times10^{5}T^{-2}$$
$$\Delta H_T = 69{,}940 - 1.92T + 1.35\times10^{-3}T^2 + 2.44\times10^{5}T^{-1}$$
$$\Delta F_T = 69{,}940 + 1.92T\ln T - 1.35\times10^{-3}T^2 + 1.22\times10^{5}T^{-1} + 15.67T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	56.8	70,300	78,480
400	1,095	59.95	70,000	81,350
500	2,295	62.62	69,800	84,250
600	3,600	65.00	69,650	87,100
700	4,990	67.14	69,600	90,000
800	6,460	69.10	69,600	92,950
900	7,985	70.90	69.650	95,850
1,000	9,565	72.56	69,700	98,750
1,100	10,996	74.00	69,800	101,750
1,200	12,870	75.58	69,900	104,500
1,300	14,440	76.75	69,900	107,650
1,400	16,280	78.20	70,100	110,350
1,500	17,970	79.36	70,200	113,250
1,600	19,810	80.56	70,400	115,950
1,700	21,659	81.62	70,700	118,900
1,800	23,420	82.68	70,850	121,950
1,900	(25,510)	(83.79)	(71,200)	(124,650)
2,000	(27,090)	(84.61)	(70,900)	(127,400)

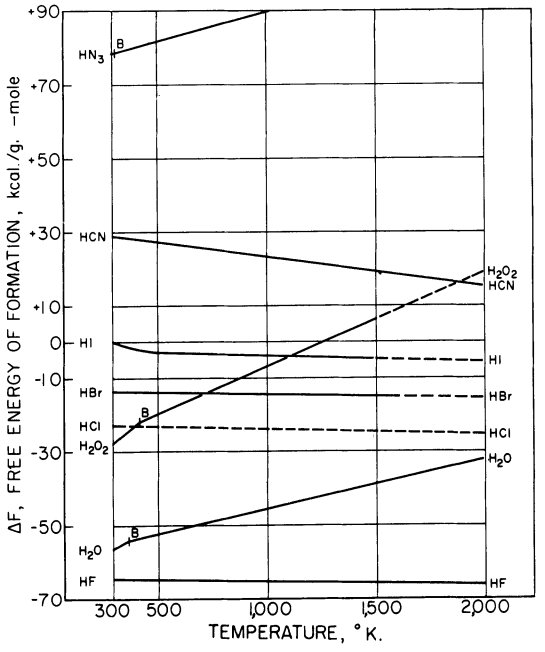

FIGURE 24.—Hydrogen.

IODINE

Element, I_2 (*c*)

S_{298}=27.90 *e.u.* (*112*)
M.P.=386.1° K. (*112*)
B.P.=456° K. (*82*)
ΔH_V=9,970 calories per atom

Zone I (*c*) (298°–386.1° K.)

$$C_p = 9.59 + 11.90\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -3{,}388 + 9.59T + 5.95\times10^{-3}T^2$$
$$F_T - H_{298} = -3{,}388 - 9.59T\ln T - 5.95\times10^{-3}T^2 + 39.73T$$

Zone II (l) (386.1°–456° K.)

$$C_p = 19.20 \text{ (82)}$$
$$H_T - H_{298} = -2{,}445 + 19.20T$$
$$F_T - H_{298} = -2{,}445 - 19.20T\ln T + 92.2T$$

Zone III (g) (456°–1,500° K.)

$$C_p = 8.89 \text{ (82)}$$
$$H_T - H_{298} = 12{,}226 + 8.89T$$
$$F_T - H_{298} = 12{,}226 - 8.89T\ln T - 3.04T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		27.90	27.90
400	5,235	41.85	28.76
500	16,670	67.05	33.71
600	17,560	68.67	39.40
700	18,450	70.04	43.68
800	19,340	71.23	47.06
900	20,240	72.29	49.06
1,000	21,130	73.23	52.10
1,100	22,020	74.08	54.05
1,200	22,910	74.85	55.76
1,300	23,810	75.57	57.25
1,400	24,700	76.23	58.59
1,500	25,590	76.84	59.78
2,000	(30,000)		(64.42)

IRON AND ITS COMPOUNDS

Element, Fe (c)

$$S_{298} = 6.49 \text{ e.u. (83)}$$
$$T.P. = 1{,}033° \text{ K. (82)}$$
$$\Delta H_T = 410 \text{ calories per atom}$$
$$T.P. = 1{,}179° \text{ K. (82)}$$
$$\Delta H_T = 210 \text{ calories per atom}$$
$$T.P. = 1{,}674° \text{ K. (82)}$$
$$\Delta H_T = 110 \text{ calories per atom}$$
$$M.P. = 1{,}803° \text{ K. (82)}$$
$$\Delta H_M = 3{,}700 \text{ calories per atom}$$
$$B.P. = 3{,}008° \text{ K. (8)}$$
$$\Delta H_V = 84{,}620 \text{ calories per atom}$$

Zone I (α) (298°–1,033° K.)

$$C_p = 3.37 + 7.10\times10^{-3}T + 0.43\times10^{5}T^{-2} \text{ (82)}$$
$$H_T - H_{298} = -1{,}176 + 3.37T + 3.55\times10^{-3}T^2 - 0.43\times10^{5}T^{-1}$$
$$F_T - H_{298} = -1{,}176 - 3.37T\ln T - 3.55\times10^{-3}T^2 - 0.21\times10^{5}T^{-1} + 17.96T$$

Zone II (β) (1,033°–1,179° K.)

$$C_p = 10.40 \text{ (82)}$$
$$H_T - H_{298} = -4{,}280 + 10.40T$$
$$F_T - H_{298} = -4{,}280 - 10.40T\ln T + 66.07T$$

Zone III (γ) (1,179°–1,674° K.)

$$C_p = 4.85 + 3.00\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = 390 + 4.85T + 1.50\times10^{-3}T^2$$
$$F_T - H_{298} = 390 - 4.85T\ln T - 1.50\times10^{-3}T^2 + 24.60T$$

Zone IV (δ) (1,674°–1,803° K.)

$$C_p = 10.30 \text{ (82)}$$
$$H_T - H_{298} = -4{,}420 + 10.30T$$
$$F_T - H_{298} = -4{,}420 - 10.30T\ln T + 65.31T$$

Zone V (l) (1,803°–1,900° K.)

$$C_p = 10.0 \text{ (82)}$$
$$H_T - H_{298} = -180 + 10.0T$$
$$F_T - H_{298} = -180 - 10.0T\ln T + 54.4T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		6.49	6.49
400	640	8.34	6.75
500	1,310	9.83	7.20
600	2,050	11.17	7.75
700	2,860	12.42	8.34
800	3,720	13.57	8.92
900	4,680	14.70	9.47
1,000	5,830	15.91	10.08
1,100	7,160	17.18	10.65
1,200	8,370	18.23	11.28
1,300	9,230	18.91	11.83
1,400	10,120	19.57	12.32
1,500	11,040	20.21	12.87
1,600	11,990	20.82	13.32
1,700	13,090	21.49	13.83
1,800	14,120	22.08	14.18
1,900	18,820	24.66	14.78
2,000	(19,760)	(25.08)	(15.20)

Iron Oxide, $Fe_{0.95}O$ (c)

$$\Delta H^{\circ}_{298} = -63{,}800 \text{ calories per mole (70)}$$
$$S_{298} = 13.74 \text{ e.u. (70)}$$
$$M.P. = 1{,}650° \text{ K. (24)}$$
$$\Delta H_M = 7{,}490 \text{ calories per mole}$$

Zone I (c) (298°–1,650° K.)

$$C_p = 11.66 + 2.00\times10^{-3}T - 0.67\times10^{5}T^{-2} \text{ (84)}$$
$$H_T - H_{298} = -3{,}790 + 11.66T + 1.00\times10^{-3}T^2 + 0.67\times10^{5}T^{-1}$$

Zone II (l) (1,650°–1,800° K.)

$$C_p = 16.30 \text{ (84)}$$
$$H_T - H_{298} = -1{,}200 + 16.30T$$

Formation: $0.95Fe + 1/2O_2 \longrightarrow Fe_{0.95}O$

Zone I (298°–1,033° K.)

$$\Delta C_p = 4.71 - 5.60\times10^{-3}T - 0.90\times10^{5}T^{-2}$$
$$\Delta H_T = -65{,}250 + 4.71T - 2.80\times10^{-3}T^2 + 0.90\times10^{5}T^{-1}$$
$$\Delta F_T = -65{,}250 - 4.71T\ln T + 2.80\times10^{-3}T^2 + 0.45\times10^{5}T^{-1} + 47.61T$$

Zone II (1,033°–1,179° K.)

$$\Delta C_p = -2.32 + 1.50\times10^{-3}T - 0.47\times10^{5}T^{-2}$$
$$\Delta H_T = -62{,}200 - 2.32T + 0.75\times10^{-3}T^2 + 0.47\times10^{5}T^{-1}$$
$$\Delta F_T = -62{,}200 + 2.32T\ln T - 0.75\times10^{-3}T^2 + 0.23\times10^{5}T^{-1} - 0.43T$$

Zone III (1,179°–1,650° K.)

$$\Delta C_p = 3.23 - 1.50\times10^{-3}T - 0.47\times10^{5}T^{-2}$$
$$\Delta H_T = -66{,}720 + 3.23T - 0.75\times10^{-3}T^2 + 0.47\times10^{5}T^{-1}$$
$$\Delta F_T = -66{,}720 - 3.23T\ln T + 0.75\times10^{-3}T^2 + 0.23\times10^{5}T^{-1} + 41.0T$$

Zone IV (1,674°–1,800° K.)

$$\Delta C_p = 2.42 - 0.50\times10^{-3}T + 0.20\times10^{5}T^{-2}$$
$$\Delta H_T = -59{,}430 + 2.42T - 0.25\times10^{-3}T^2 - 0.20\times10^{5}T^{-1}$$
$$\Delta F_T = -59{,}430 - 2.42T\ln T + 0.25\times10^{-3}T^2 - 0.10\times10^{5}T^{-1} + 31.35T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		13.74	−63,800	−58,670
400	1,210	17.22	−63,700	−57,000
500	2,440	19.97	−63,400	−55,300
600	3,700	22.07	−63,250	−53,550
700	4,980	24.24	−63,150	−51,100
800	6,280	25.97	−63,150	−50,500
900	7,590	27.52	−63,200	−48,950
1,000	8,920	28.92	−63,400	−47,350
1,100	10,280	30.21	−63,800	−45,700
1,200	11,670	31.42	−63,900	−43,950
1,300	13,080	32.55	−63,900	−42,350
1,400	14,520	33.62	−63,750	−40,750
1,500	15,980	34.62	−63,700	−39,050
1,600	17,460	35.58	−63,550	−37,400
1,700	26,510	41.06	−56,050	−36,000
1,800	28,140	42.00	−55,900	−34,750

Triiron Tetraoxide, Fe_3O_4 (*c*)

$\Delta H^\circ_{298}=-267{,}800$ calories per mole (*24*)
$S_{298}=35.0$ *e.u.* (*83*)
T.P.$=900°$ K. (*24*)
$\Delta H_T=0$ calories per mole
M.P.$=1{,}870°$ K. (*30*)
$\Delta H_M=33{,}000$ calories per mole

Zone I (α) (298°–900° K.)

$$C_p=21.88+48.20\times10^{-3}T \text{ (27)}$$
$$H_T-H_{298}=-8{,}640+21.88T+24.10\times10^{-3}T^2$$

Zone II (β) (900°–1,800° K.)

$$C_p=48.0 \text{ (27)}$$
$$H_T-H_{298}=-12{,}650+48.00T$$

Formation: $3Fe+2O_2\longrightarrow Fe_3O_4$

Zone I (298°–900° K.)

$$\Delta C_p=-2.55+24.90\times24.90\times10^{-3}T-0.49\times10^5T^{-2}$$
$$\Delta H_T=-268{,}300-2.55T+12.45\times10^{-3}T^2+0.49\times10^5T^{-1}$$
$$\Delta F_T=-268{,}300+2.55T\ln T-12.45\times10^{-3}T^2+0.24\times10^5T^{-1}+73.07T$$

Zone II (900°–1,033° K.)

$$\Delta C_p=23.57-23.30\times10^{-3}T-0.49\times10^5T^{-2}$$
$$\Delta H_T=-272{,}760+23.57T-11.65\times10^{-3}T^2+0.49\times10^5T^{-1}$$
$$\Delta F_T=-272{,}760-23.57T\ln T+11.65\times10^{-3}T^2+0.24\times10^5T^{-1}+234.0T$$

Zone III (1,033°–1,179° K.)

$$\Delta C_p=2.48-2.00\times10^{-3}T+0.80\times10^5T^{-2}$$
$$\Delta H_T=-262{,}950+2.48T-1.00\times10^{-3}T^2-0.80\times10^5T^{-1}$$
$$\Delta F_T=-262{,}950-2.48T\ln T+1.00\times10^{-3}T^2-0.40\times10^5T^{-1}+89.38T$$

Zone IV (1,179°–1,674° K.)

$$\Delta C_p=19.13-11.00\times10^{-3}T+0.80\times10^5T^{-2}$$
$$\Delta H_T=-277{,}000+19.13T-5.50\times10^{-3}T^2-0.80\times10^5T^{-1}$$
$$\Delta F_T=-277{,}000-19.13T\ln T+5.50\times10^{-3}T^2-0.40\times10^5T^{-1}+162.62T$$

Zone V (1,674°–1,800° K.)

$$\Delta C_p=2.78-2.00\times10^{-3}T+0.80\times10^5T^{-2}$$
$$\Delta H_T=-262{,}500+2.78T-1.00\times10^{-3}T^2-0.80\times10^5T^{-1}$$
$$\Delta F_T=-262{,}500-2.78T\ln T+1.00\times10^{-3}T^2-0.40\times10^5T^{-1}+91.0T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		35.0	−267,800	−243,200
400	3,990	46.48	−267,200	−234,900
500	8,320	56.12	−266,300	−226,900
600	13,060	64.75	−265,300	−219,100
700	18,340	72.88	−264,000	−211,500
800	24,260	80.77	−262,300	−204,200
900	30,550	88.18	−260,500	−197,000
1,000	35,350	93.24	−260,800	−189,900
1,100	40,350	97.81	−261,500	−182,600
1,200	44,950	101.99	−262,000	−175,500
1,300	49,750	105.83	−261,500	−168,300
1,400	54,550	109.39	−261,000	−161,100
1,500	59,350	112.70	−260,900	−154,000
1,600	64,150	115.80	−260,500	−146,800
1,700	68,950	118.71	−260,800	−139,800
1,800	73,750	121.45	−260,800	−133,000

Diiron Trioxide, Fe_2O_3 (*c*)

$\Delta H^\circ_{298}=-196{,}800$ calories per mole (*112*)
$S_{298}=21.5$ *e.u.* (*112*)
T.P.$=950°$ K. (*24*)
$\Delta H_T=160$ calories per mole
T.P.$=1{,}050°$ K. (*24*)
$\Delta H_T=0$ calories per mole
Decomposes$=1{,}730°$ K. (*24*)

Zone I (α) (298°–950° K.)

$$C_p=23.49+18.60\times10^{-3}T-3.55\times10^5T^{-2} \text{ (84)}$$
$$H_T-H_{298}=-9{,}020+23.49T+9.30\times10^{-3}T^2+3.55\times10^5T^{-1}$$

Zone II (β) (950°–1,050° K.)

$$C_p=36.0 \text{ (84)}$$
$$H_T-H_{298}=-11{,}980+36.0T$$

Zone III (γ) (1,050°–1,730° K.)

$$C_p=31.71+1.76\times10^{-3}T \text{ (84)}$$
$$H_T-H_{298}=-8{,}450+31.71T+0.88\times10^{-3}T^2$$

Formation: $2Fe+3/2O_2\longrightarrow Fe_2O_3$

Zone I (298°–950° K.)

$$\Delta C_p=6.01+2.90\times10^{-3}T-3.81\times10^5T^{-2}$$
$$\Delta H_T=-200{,}000+6.01T+1.45\times10^{-3}T^2+3.81\times10^5T^{-1}$$
$$\Delta F_T=-200{,}000-6.01T\ln T-1.45\times10^{-3}T^2+1.90\times10^5T^{-1}+108.4T$$

Zone II (950°–1,033° K.)

$$\Delta C_p=18.52-15.7\times10^{-3}T-0.26\times10^5T^{-2}$$
$$\Delta H_T=-203{,}300+18.52T-7.85\times10^{-3}T^2+0.26\times10^5T^{-1}$$
$$\Delta F_T=-203{,}300-18.52T\ln T+7.85\times10^{-3}T^2+0.13\times10^5T^{-1}+189.0T$$

Zone III (1,050°–1,179° K.)

$$\Delta C_p=0.17+0.26\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-193{,}100+0.17T+0.13\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-193{,}100-0.17T\ln T-0.13\times10^{-3}T^2-0.30\times10^5T^{-1}+60.07T$$

Zone IV (1,179°–1,674° K.)

$$\Delta C_p=11.27-5.74\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-202{,}600+11.27T-2.87\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-202{,}600-11.27T\ln T+2.87\times10^{-3}T^2-0.30\times10^5T^{-1}+142.29T$$

Zone V (1,674°–1,730° K.)

$\Delta C_p = 0.37 + 0.26\times10^{-3}T + 0.60\times10^{5}T^{-2}$
$\Delta H_T = -192{,}400 + 0.37T + 0.13\times10^{-3}T^2 - 0.60\times10^{5}T^{-1}$
$\Delta F_T = -192{,}400 - 0.37T\ln T - 0.13\times10^{-3}T^2 - 0.30\times10^{5}T^{-1} + 61.3T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		21.5	−196,800	−177,400
400	2,750	29.41	−196,400	−170,800
500	5,770	36.14	−195,800	−164,500
600	9,010	42.04	−195,200	−158,300
700	12,460	47.35	−194,500	−152,200
800	16,130	52,25	−193,800	−146,200
900	20,020	55.84	−193,000	−139,500
1,000	24,020	61.05	−192,600	−134,500
1,100	27,500	64.37	−192,900	−128,500
1,200	30,870	67.30	−193,200	−122,800
1,300	34,250	70.01	−192,800	−116,900
1,400	37,650	72.53	−192,500	−111,100
1,500	41,070	74.89	−192,300	−105,300
1,600	44,540	77.13	−191,900	−99,400
1,700	48,100	79.29	−191,400	−93,700

Iron Difluoride, FeF_2 (*c*)

$\Delta H_{298}^\circ = -168{,}000$ calories per mole (*112*)
$S_{298} = 20.8$ *e.u.* (*18*)
M.P. = 1,375° K. (*6*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (2,100°) K. (*6*)
$\Delta H_V = (50{,}000)$ calories per mole

Formation: $Fe + F_2 \longrightarrow FeF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−168,000	(−157,300)
500	(3,500)	(−167,400)	(−150,500)
1,000	(13,000)	(−166,700)	(−133,000)
1,500	(33,000)	(−156,300)	(−118,500)

Iron Trifluoride, FeF_3 (*c*)

$\Delta H_{298}^\circ = (-235{,}000)$ calories per mole (*11*)
$S_{298} = (25)$ *e.u.* (*11*)
M.P. = 1,300° K. (*6*)
$\Delta H_M = (12{,}000)$ calories per mole
B.P. = (1,600°) K. (*6*)
$\Delta H_V = (40{,}000)$ calories per mole

Formation: $Fe + 3/2F_2 \longrightarrow FeF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−235,000)	(−219,000)
500	(5,000)	(−232,900)	(−207,500)
1,000	(19,000)	(−230,600)	(−183,000)
1,500	(46,000)	(−215,400)	(−160,000)

Iron Dichloride, $FeCl_2$ (*c*)

$\Delta H_{298}^\circ = -81{,}900$ calories per mole (*112*)
$S_{298} = 28.7$ *e.u.* (*83*)
M.P. = 950° K. (*82*)
$\Delta H_M = 10{,}280$ calories per mole
B.P. = 1,299° K. (*112*)
$\Delta H_V = 30{,}210$ calories per mole

Zone I (*c*) 298°–950° K.)

$C_p = 18.94 + 2.08\times10^{-3}T - 1.17\times10^{5}T^{-2}$ (*82*)
$H_T - H_{298} = -6{,}090 + 18.94T + 1.04\times10^{-3}T^2 + 1.17\times10^{5}T^{-1}$

Zone II (*l*) (950°–1,110° K.)

$C_p = 24.40$ (*82*)
$H_T - H_{298} = 81{,}100 + 24.40T$

Formation: $Fe + Cl_2 \longrightarrow FeCl_2$

Zone I (298°–950° K.)

$\Delta C_p = 6.75 - 5.08\times10^{-3}T - 0.92\times10^{5}T^{-2}$
$\Delta H_T = -84{,}000 + 6.75T + 2.54\times10^{-3}T^2 + 0.92\times10^{5}T^{-1}$
$\Delta F_T = -84{,}000 - 6.75T\ln T + 2.54\times10^{-3}T^2 + 0.46\times10^{5}T^{-1} + 75.2T$

Zone II (950°–1,033° K.)

$\Delta C_p = 12.2 - 7.16\times10^{-3}T + 0.25\times10^{5}T^{-2}$
$\Delta H_T = -77{,}980 + 12.2T - 3.58\times10^{-3}T^2 - 0.25\times10^{5}T^{-1}$
$\Delta F_T = -77{,}980 - 12.2T\ln T + 3.58\times10^{-3}T^2 - 0.12\times10^{5}T^{-1} + 105.57T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		28.7	−81,900	−72,600
400	1,930	34.27	−81,450	−69,500
500	3,870	38.59	−81,030	−66,500
600	5,820	42.15	−80,670	−63,700
700	7,800	45.20	−80,400	−61,000
800	9,830	47.91	−80,090	−58,100
900	11,880	50.32	−79,880	−55,400
1,000	24,410	63.51	−69,380	−53,100
1,100	26,860	65.85	−69,010	−51,500

Iron Trichloride, $FeCl_3$ (*c*)

$\Delta H_{298}^\circ = -95{,}700$ calories per mole (*92*)
$S_{298} = (32.2)$ *e.u.* (*136*)
M.P. = 577° K. (*136*)
$\Delta H_M = 10{,}300$ calories per mole
B.P. = 592° K. (*136*)
$\Delta H_V = 6{,}020$ calories per mole

Zone I (*c*) (298°–577° K.)

$C_p = 29.56 - 6.11\times10^{5}T^{-2}$ (*136*)
$H_T - H_{298} = -10{,}860 + 29.56T + 6.11\times10^{5}T^{-1}$

Formation: $Fe + 3/2Cl_2 \longrightarrow FeCl_3$

Zone I (298°–577° K.)

$\Delta C_p = 12.96 - 7.19\times10^{-3}T - 5.52\times10^{5}T^{-2}$
$\Delta H_T = -101{,}100 + 12.96T - 3.59\times10^{-3}T^2 + 5.52\times10^{5}T^{-1}$
$\Delta F_T = -101{,}100 - 12.96T\ln T + 3.59\times10^{-3}T^2 + 2.76\times10^{5}T^{-1} + 142.0T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		32.2	−95,700	−79,500
400	2,500	39.38	−95,100	−74,000
500	5,140	45.27	−94,400	−68,800

Iron Dibromide, $FeBr_2$ (*c*)

$\Delta H_{298}^\circ = (-60{,}000)$ calories per mole (*112*)
$S_{298} = (32)$ *e.u.* (*11*)
$M.P. = 957°$ K. (*6*)
$\Delta H_M = (9{,}000)$ calories per mole
$B.P. = (1{,}200°)$ K. (*6*)
$\Delta H_V = (26{,}000)$ calories per mole

Formation: $Fe + Br_2 \longrightarrow FeBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−60,000	(−57,700)
500	(4,000)	(−66,800)	(−52,000)
1,000	(24,000)	(−55,800)	(−38,000)
1,500	(62,000)	(−27,500)	(−29,500)

Iron Tribromide, $FeBr_3$ (*c*)

$\Delta H_{298}^\circ = (-65{,}000)$ calories per mole (*11*)
$S_{298} = (46)$ *e.u.* (*11*)
$M.P. = (500°)$ K. (*6*)
$\Delta H_M = (5{,}000)$ calories per mole
$B.P. = (900°)$ K. (*6*)
$\Delta H_V = (20{,}000)$ calories per mole

Formation: $Fe + 3/2Br_2 \longrightarrow FeBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−65,000)	(−60,400)
500	(5,000)	(−54,500)	(−37,000)

Iron Diiodide, FeI_2 (*c*)

$\Delta H_{298}^\circ = -30{,}000$ calories per mole (*11*)
$S_{298} = (36)$ *e.u.* (*11*)
$M.P. = 860°$ K. (*6*)
$\Delta H_M = (7{,}000)$ calories per mole
$B.P. = (1{,}100°)$ K. (*6*)
$\Delta H_V = (25{,}000)$ calories per mole

Formation: $Fe + I_2 \longrightarrow Fe\,I_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−30,000	(−30,200)
500	(4,000)	(−44,000)	(−28,500)
1,000	(24,000)	(−33,000)	(−15,000)
1,500	(61,000)	(−5,500)	(−6,000)

Triiron Carbide, Fe_3C (*c*)

$\Delta H_{298}^\circ = 5{,}780$ calories per mole (*81*)
$S_{298} = 24.2$ *e.u.* (*83*)
$T.P. = 463°$ K. (*82*)
$\Delta H_T = 180$ calories per mole
$M.P. = 1{,}500°$ K. (*82*)
$\Delta H_M = 12{,}330$ calories per mole
Metastable above 2,000° K.

Zone I (α) (298°–463° K.)

$$C_p = 19.64 + 20.00\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -6{,}745 + 19.64T + 10.00\times10^{-3}T^2$$

Zone II (β) (463°–1,500° K.)

$$C_p = 25.62 + 3.00\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -7{,}515 + 25.62T + 1.50\times10^{-3}T^2$$

Zone III (*l*) (1,500°–1,900° K.)

$$C_p = 30.60 \text{ (82)}$$
$$H_T - H_{298} = +740 + 30.60T$$

Formation: $3Fe + C \longrightarrow Fe_3C$

Zone I (298°–463° K.)

$$\Delta C_p = 5.43 - 2.32\times10^{-3}T + 0.81\times10^{5}T^{-2}$$
$$\Delta H_T = +4{,}530 + 5.43T - 1.16\times10^{-3}T^2 - 0.81\times10^{5}T^{-1}$$
$$\Delta F_T = +4{,}530 - 5.43T\ln T + 1.16\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 31.98T$$

Zone II (463°–1,033° K.)

$$\Delta C_p = 11.41 - 19.32\times10^{-3}T + 0.81\times10^{5}T^{-2}$$
$$\Delta H_T = +3{,}850 + 11.41T - 9.66\times10^{-3}T^2 - 0.81\times10^{5}T^{-1}$$
$$\Delta F_T = +3{,}850 - 11.41T\ln T + 9.66\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 66.2T$$

Zone III (1,033°–1,179° K.)

$$\Delta C_p = -9.68 + 1.98\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = 13{,}130 - 9.68T + 0.99\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = 13{,}130 + 9.68T\ln T - 0.99\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} - 78.14T$$

Zone IV (1,179°–1,500° K.)

$$\Delta C_p = 7.00 - 7.0\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = -1{,}000 + 7.00T - 3.5\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = -1{,}000 - 7.00T\ln T + 3.5\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} + 46.45T$$

Zone II (1,500°–1,674° K.)

$$\Delta C_p = 11.95 - 10.02\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = 7{,}340 + 11.95T - 5.01\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = 7{,}340 - 11.95T\ln T + 5.01\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} + 74.62T$$

Zone III (1,674°–1,803° K.)

$$\Delta C_p = -4.4 - 1.02\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = 21{,}700 - 4.4T - 0.51\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = 21{,}700 + 4.4T\ln T + 0.51\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} - 47.48T$$

Zone IV (1,803°–1,900° K.)

$$\Delta C_p = -3.50 - 1.02\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = 8{,}980 - 3.50T - 0.51\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = 8{,}980 + 3.50T\ln T + 0.51\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} - 33.8T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		24.2	+5,780	4,800
400	2,690	31.96	6,300	4,400
500	5,670	38.61	6,950	3,800
600	8,390	43.57	7,050	3,100
700	11,150	47.82	7,000	2,500
800	13,940	51.55	6,750	1,850
900	16,760	54.86	6,200	1,300
1,000	19,610	57.87	5,100	750
1,100	22,490	60.61	3,450	450
1,200	25,400	63.15	2,200	200
1,300	28,340	65.50	2,050	10
1,400	31,310	67.70	1,800	−400
1,500	46,640	77.99	13,800	−650
1,600	49,700	79.96	13,450	−1,150
1,700	52,760	81.82	12,650	−2,050
1,800	55,820	83.57	12,050	−2,900
1,900	58,880	85.23	400	−3,200

Tetrairon Nitride, Fe_4N (c)

$\Delta H_{298}^\circ = -2{,}550$ calories per mole (*112*)
$S_{298} = 37.3$ *e.u.* (*112*)

Zone I (c) (298°–1,000° K.)

$C_p = 26.84 + 8.16\times10^{-3}T$ (*82*)
$H_T - H_{298} = -8{,}350 + 26.84T + 4.08\times10^{-3}T^2$

Formation: $4Fe + 1/2N_2 \longrightarrow Fe_4N$

Zone I (298°–1,000° K.)

$\Delta C_p = 10.03 - 20.75\times10^{-3}T - 1.72\times10^{5}T^{-2}$
$\Delta H_T = -5{,}200 + 10.03T - 10.37\times10^{-3}T^2 + 1.72\times10^{5}T^{-1}$
$\Delta F_T = -5{,}200 - 10.03T\ln T + 10.37\times10^{-3}T^2 + 0.86\times10^{5}T^{-1} + 73.47T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		37.3	−2,550	+900
400	3,030	46.4	−2,435	+1,900
500	6,090	53.0	−2,400	+3,100
600	9,230	58.8	−2,580	+4,150
700	12,450	63.8	−2,970	+5,300
800	15,650	67.8	−3,580	+6,700
900	19,120	72.2	−4,330	+7,800
1,000	22,570	75.3	−5,070	+9,500

Diiron Nitride, Fe_2N (c)

$\Delta H_{298}^\circ = -900$ calories per mole (*112*)
$S_{298} = 24.2$ *e.u.* (*112*)

Zone I (c) (298°–1,000° K.)

$C_p = 14.91 + 6.09\times10^{-3}T$ (*82*)
$H_T - H_{298} = -4{,}713 + 14.91T + 3.04\times10^{-3}T^2$

Formation: $2Fe + 1/2N_2 \longrightarrow Fe_2N$

Zone I (298°–1,000° K.)

$\Delta C_p = 4.84 - 8.62\times10^{-3}T - 0.86\times10^{5}T^{-2}$
$\Delta H_T = -2{,}250 + 4.84T - 4.31\times10^{-3}T^2 + 0.86\times10^{5}T^{-1}$
$\Delta F_T = -2{,}250 - 4.84T\ln T + 4.31\times10^{-3}T^2 + 0.43\times10^{5}T^{-1} + 41.7T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		24.2	−900	2,500
400	1,730	29.3	−800	3,600
500	3,500	33.3	−740	4,750
600	5,320	36.7	−740	5,850
700	7,200	39.5	−830	7,000
800	9,100	42.2	−1,040	8,000
900	11,170	44.4	−1,270	9,350
1,000	13,240	46.6	−1,600	10,600

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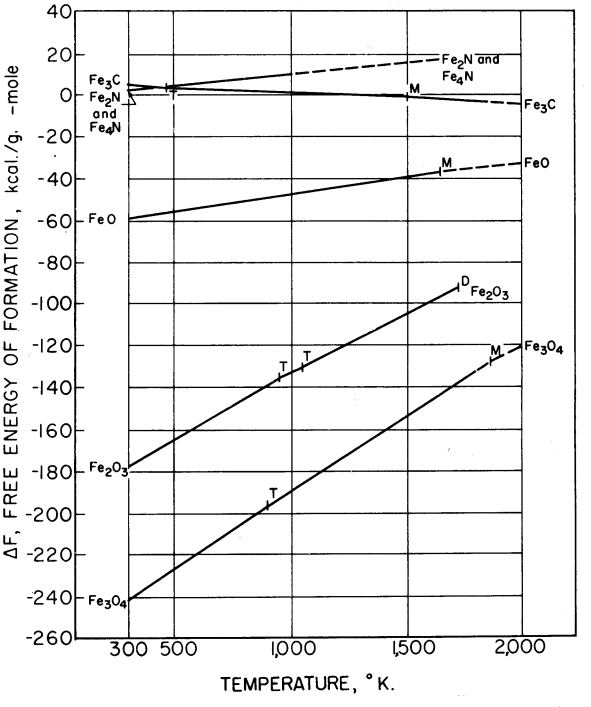
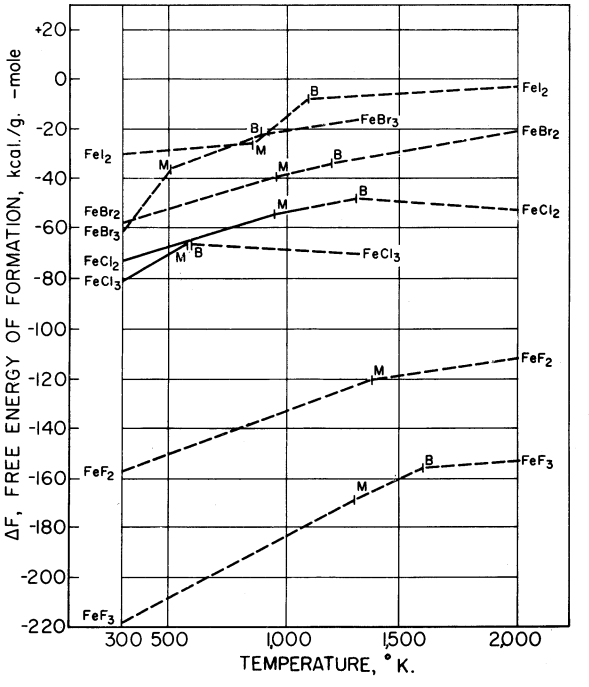


FIGURES 25.—Iron (a).



FIGURES 26.—Iron (b).

LANTHANUM AND ITS COMPOUNDS

Element, La (*c*)

$S_{298}=13.64$ *e.u.* (*121*)
$T.P.=1{,}141°$ K. (*125*)
$M.P.=1{,}193°$ K. (*84*)
$\Delta H_M=2{,}790$ calories per atom
$B.P.=4{,}515°$ K. (*112*)
$\Delta H_V=81{,}000$ calories per atom

Zone I (*c*) (298°–800° K.)

$$C_p=6.17+1.60\times10^{-3}T \text{ (84)}$$
$$H_T-H_{298}=-1{,}910+6.17T+0.80\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}910-6.17T\ln T-0.80\times10^{-3}T^2+28.11T$$

Zone II above 1,193° K.
(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		13.64	13.64
400	680	15.60	13.90
500	1,380	17.16	14.40
600	2,080	18.44	15.00
700	2,805	19.56	15.57
800	3,530	20.52	16.09
900	(4,290)	(21.50)	(16.73)
1,000	(5,060)	(22.26)	(17.20)
1,100	(5,850)	(23.02)	(17.68)
1,200	(9,380)	(25.94)	(18.13)
1,300	(10,180)	(26.58)	(18.75)
1,400	(10,980)	(27.17)	(19.33)
1,500	(11,780)	(27.73)	(19.88)
1,600	(12,580)	(28.24)	(20.38)
1,700	(13,380)	(28.73)	(20.86)
1,800	(14,180)	(29.18)	(21.31)
1,900	(14,980)	(29.62)	(21.74)
2,000	(15,780)	(30.03)	(22.14)

Dilanthanum Trioxide, La_2O_3 (*c*)

$\Delta H^\circ_{298}=-428{,}570$ calories per mole (*60*)
$S_{298}=13.6$ *e.u.* (*109*)
$M.P.=2{,}600°$ K. (*94*)

Zone I (*c*) (298°–1,173° K.)

$$C_p=28.86+3.076\times10^{-3}T-3.275\times10^5T^{-2} \text{ (3)}$$
$$H_T-H_{298}=-9{,}835+28.86T+1.538\times10^{-3}T^2+3.275\times10^5T^{-1}$$

Formation: $2La+3/2O_2\longrightarrow La_2O_3$

Zone I (298°–1,173° K.)

$$\Delta C_p=5.78-1.62\times10^{-3}T-2.675\times10^5T^{-2}$$
$$\Delta H_T=-431{,}120+5.78T-0.81\times10^{-3}T^2+2.675\times10^5T^{-1}$$
$$\Delta F_T=-431{,}120-5.78T\ln T+0.81\times10^{-3}T^2+1.337\times10^5T^{-1}+126.88T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		13.6	−428,570	−402,600
400	2,670	19.7	−428,350	−393,100
500	5,470	26.5	−428,050	−384,500
600	8,270	32.6	−427,800	−376,600
700	11,370	37.5	−427,300	−368,100
800	14,170	41.7	−427,050	−360,000
900	17,570	45.7	(−426,400)	(−351,300)
1,000	20,870	48.7	(−425,950)	(−342,400)
1,100	23,870	51.9	(−425,700)	(−334,900)
1,200	(27,070)	(55.0)	(−430,150)	(−326,900)

Lanthanum Trifluoride, LaF_3 (*c*)

$\Delta H^\circ_{298}=(-396{,}000)$ calories per mole (*5*)
$S_{298}=(24)$ *e.u.* (*11*)
$M.P.=1{,}766°$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
$B.P.=(2{,}600°)$ K. (*6*)
$\Delta H_V=(62{,}000)$ calories per mole

Formation: $La+3/2F_2\longrightarrow LaF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−396,000)	(−377,000)
500	(4,000)	(−395,800)	(−365,000)
1,000	(17,000)	(−392,800)	(−336,000)
1,500	(32,000)	(−391,250)	(−307,000)

Lanthanum Trichloride, $LaCl_3$ (*c*)

$\Delta H^\circ_{298}=-255{,}910$ calories per mole (*127*)
$S_{298}=34.5$ *e.u.* (*127*)
$M.P.=1{,}135°$ K. (*29*)
$\Delta H_M=(9{,}000)$ calories per mole
$B.P.=(2{,}020°)$ K. (*6*)
$\Delta H_V=(44{,}000)$ calories per mole

Formation: $La+3/2Cl_2\longrightarrow LaCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−255,900	−238,300
500	(5,000)	(−254,700)	(−227,400)
1,000	(19,000)	(−250,900)	(−200,900)
1,500	(43,000)	(−237,800)	(−180,900)

Lanthanum Tribromide, $LaBr_3$ (*c*)

$\Delta H^\circ_{298}=(-197{,}000)$ calories per mole (*5*)
$S_{298}=(45)$ *e.u.* (*11*)
$M.P.=1{,}062°$ K. (29)
$\Delta H_M=(8{,}000)$ calories per mole
$B.P.=(1{,}850°)$ K. (*6*)
$\Delta H_V=(45{,}000)$ calories per mole

Formation: $La+3/2Br_2\longrightarrow LaBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−197,000)	(−191,000)
500	(5,000)	(−213,500)	(−180,000)
1,000	(18,000)	(−217,200)	(−154,000)
1,500	(43,000)	(−209,900)	(−133,000)

Lanthanum Triiodide, LaI_3 (*c*)

$\Delta H^\circ_{298}=(-166{,}700)$ calories per mole (*5*)
$S_{298}=(49)$ *e.u.* (*11*)
$M.P.=1{,}045°$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
$B.P.=(1{,}675°)$ K. (*6*)
$\Delta H_V=(40{,}000)$ calories per mole

Formation: $La+3/2I_2\longrightarrow LaI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−166,700)	(−164,800)
500	(5,000)	(−188,100)	(−160,000)
1,000	(19,000)	(−184,400)	(−133,000)
1,500	(44,000)	(−173,500)	(−109,500)

Lanthanum Nitride, LaN (*c*)

$\Delta H^\circ_{298} = -72{,}100$ calories per mole (*112*)
$S_{298} = 11.5$ *e.u.* (*9*)
$\Delta F^\circ_{298} = -64{,}700$ calories per mole

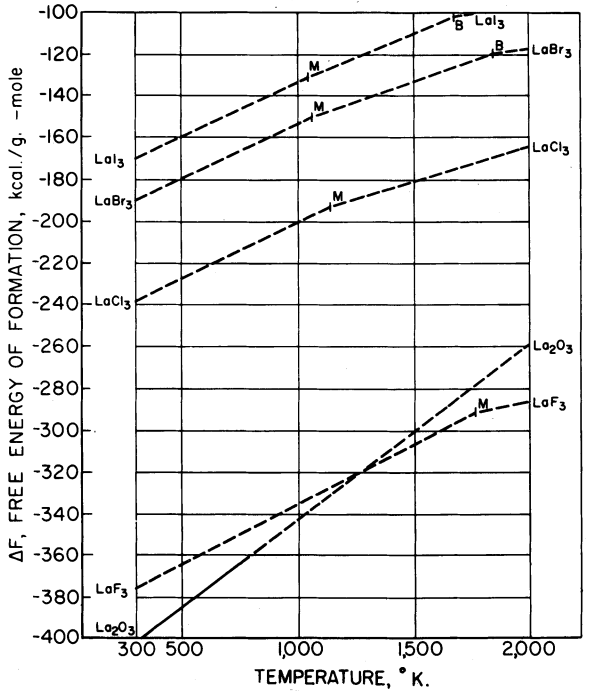


FIGURE 27.—Lanthanum.

LEAD AND ITS COMPOUNDS

Element, Pb (*c*)

$S_{298} = 15.49$ *e.u.* (*83*)
$M.P. = 600.5°$ K. (*82*)
$\Delta H_M = 1{,}225$ calories per atom
$B.P. = 2{,}024°$ K. (*130*)
$\Delta H_V = 42{,}880$ calories per atom

Zone I (*c*) (298°–600.5° K.)

$$C_p = 5.82 + 1.90\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -1{,}820 + 5.82T + 0.95\times10^{-3}T^2$$
$$F_T - H_{298} = -1{,}820 - 5.82T\ln T - 0.95\times10^{-3}T^2 + 24.04T$$

Zone II (*l*) (600.5°–1,300° K.)

$$C_p = 6.80 \text{ (82)}$$
$$H_T - H_{298} = -838 + 6.80T$$
$$F_T - H_{298} = -838 - 6.80T\ln T + 28.15T$$

Zone III (1,300°–2,000° K.)

(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		15.49	15.49
400	655	17.38	15.75
500	1,335	18.90	15.83
600	2,015	20.14	16.78
700	3,920	23.23	17.63
800	4,600	24.14	18.39
900	5,280	24.94	19.08
1,000	5,960	25.65	19.69
1,100	6,640	26.30	20.26
1,200	7,320	26.89	20.79
1,300	8,000	27.44	21.28
1,400	(8,780)	(28.02)	(21.75)
1,500	(9,450)	(28.48)	(22.18)
1,600	(10,110)	(28.91)	(22.60)
1,700	(10,760)	(29.30)	(22.98)
1,800	(11,410)	(29.67)	(23.34)
1,900	(12,050)	(30.02)	(23.68)
2,000	(12,680)	(30.34)	(24.00)

Lead Oxide (Yellow), PbO (*c*)

$\Delta H^\circ_{298} = -52{,}070$ calories per mole (*112*)
$S_{298} = 16.1$ *e.u.* (*89*)
$M.P. = 1{,}159°$ K. (*112*)
$\Delta H_M = 2{,}800$ calories per mole
$B.P. = 1{,}745°$ K. (*112*)
$\Delta H_V = 51{,}000$ calories per mole

Zone I (*c*) (298°–1,000° K.)

$$C_p = 9.05 + 6.40\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -2{,}983 + 9.05T + 3.20\times10^{-3}T^2$$

Formation: $Pb + 1/2O_2 \longrightarrow PbO$

Zone I (298°–600.5° K.)

$$\Delta C_p = -0.35 + 4.0\times10^{-3}T + 0.20\times10^5T^{-2}$$
$$\Delta H_T = -52{,}070 - 0.35T + 2.0\times10^{-3}T^2 - 0.20\times10^5T^{-1}$$
$$\Delta F_T = -52{,}070 + 0.35T\ ln\ T - 2.0\times10^{-3}T^2 - 0.10\times10^5T^{-1} + 23.35T$$

Zone II (600.5°–1,000° K.)

$$\Delta C_p = -1.33 + 5.90\times10^{-3}T + 0.20\times10^5T^{-2}$$
$$\Delta H_T = -53{,}070 - 1.33T + 2.95\times10^{-3}T^2 - 0.20\times10^5T^{-1}$$
$$\Delta F_T = -53{,}070 + 1.33T\ ln\ T - 2.95\times10^{-3}T^2 - 0.10\times10^5T^{-1} + 18.57T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		16.1	−52,070	−44,950
400	1,150	19.42	−51,950	−42,750
500	2,340	22.07	−51,800	−40,200
600	3,600	24.36	−51,600	−37,900
700	4,920	26.4	−52,600	−35,450
800	6,310	28.25	−52,250	−32,900
900	7,760	29.96	−51,450	−30,600
1,000	9,260	31.54	−51,450	−28,250
1,100	(10,800)		(−51,000)	(−26,450)
1,200	(15,200)		(−47,700)	(−24,400)
1,300	(16,750)		(−47,250)	(−22,450)
1,400	(18,450)		(−46,750)	(−20,550)
1,500	(20,100)		(−46,250)	(−18,700)
1,600	(21,650)		(−45,750)	(−16,850)
1,700	(23,200)		(−45,300)	(−15,100)

Lead Oxide (Red), PbO (*c*)

$\Delta H^\circ_{298} = -52{,}400$ calories per mole (*112*)
$S_{298} = 15.6$ *e.u.* (*89*)
$T.P. = 762°$ K. (red $\longrightarrow$ yellow) (*24*)
$\Delta H_T = 250$ calories per mole

Zone I (β) (298°–762° K.)

$$C_p = 10.60 + 4.00\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -3{,}338 + 10.60T + 2.00\times10^{-3}T^2$$

Formation: $Pb + 1/2O_2 \longrightarrow PbO$

Zone I (298°–600.5° K.)

$$\Delta C_p = 1.20 + 1.60\times10^{-3}T + 0.20\times10^{5}T^{-2}$$
$$\Delta H_T = -52{,}770 + 1.20T + 0.80\times10^{-3}T^2 - 0.20\times10^{5}T^{-1}$$
$$\Delta F_T = -52{,}770 - 1.20T\ ln\ T - 0.80\times10^{-3}T^2 - 0.10\times10^{5}T^{-1} + 32.77T$$

Zone II (600.5°–762° K.)

$$\Delta C_p = 0.22 + 3.50\times10^{-3}T + 0.20\times10^{5}T^{-2}$$
$$\Delta H_T = -53.730 + 0.22T + 1.75\times10^{-3}T^2 - 0.20\times10^{5}T^{-1}$$
$$\Delta F_T = -53{,}730 - 0.22T\ ln\ T - 1.75\times10^{-3}T^2 - 0.10\times10^{5}T^{-1} + 28.72T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		15.6	−52,400	−45,130
400	1,220	19.12	−52,200	−42,700
500	2,460	21.88	−52,000	−40,300
600	3,740	24.22	−51,900	−38,100
700	5,060	26.25	−52,750	−35,500
762				−34,250

Trilead Tetraoxide, Pb_3O_4 (c)

$\Delta H_{298}^\circ = -175{,}500$ calories per mole (*112*)
$S_{298} = 50.5$ *e.u.* (*83*)

Formation: $3Pb + 2O_2 \longrightarrow Pb_3O_4$ (estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF°
298		−175,500	−147,500
400	(3,390)	(−175,500)	(−138,000)
500	(7,410)	(−175,000)	(−129,000)
600	(11,470)	(−174,500)	(−119,500)
700	(15,740)	(−177,500)	(−110,000)
800	(20,370)	(−176,500)	(−100,500)
900	(25,370)	(−175,000)	(−91,000)
1,000	(31,180)	(−173,000)	(−81,500)

Lead Dioxide, PbO_2 (c)

$\Delta H_{298}^\circ = -66{,}120$ calories per mole (*112*)
$S_{298} = 18.3$ *e.u.* (*83*)

Formation: $Pb + O_2 \longrightarrow PbO_2$ (estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−66,100	−52,300
400	(1,580)	(−65,900)	(−47,700)
500	(3,190)	(−65,700)	(−43,100)
600	(4,825)	(−65,500)	(−38,600)
700	(6,610)	(−66,400)	(−34,000)
800	(8,490)	(−66,000)	(−29,400)
900	(10,480)	(−65,500)	(−24,800)
1,000	(12,460)	(−65,000)	(−20,300)
1,100	(14,550)	(−64,400)	(−15,900)

Lead Difluoride, PbF_2 (c)

$\Delta H_{298}^\circ = -158{,}500$ calories per mole (*112*)
$S_{298} = (29)$ *e.u.* (*112*)
$M.P. = 1{,}097°$ K. (*6*)
$\Delta H_M = 1{,}860$ calories per mole
$B.P. = 1{,}566°$ K. (*6*)
$\Delta H_V = 38{,}340$ calories per mole

Zone I (298°–1, 097° K.)

$$C_p = 16.50 + 4.10\times10^{-3}T \quad (15)$$
$$H_T - H_{298} = -5{,}100 + 16.50T + 2.05\times10^{-3}T^2$$

Formation: $Pb + F_2 \longrightarrow PbF_2$

Zone I (298°–600.5° K.)

$$\Delta C_p = 2.39 + 1.76\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -159{,}000 + 2.39T + 0.88\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -159{,}000 - 2.39T ln T - 0.88\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 51.13T$$

Zone II (600.5°–1, 097° K.)

$$\Delta C_p = 1.41 + 3.66\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -160{,}010 + 1.41T + 1.83\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -160{,}010 - 1.41T ln T - 1.83\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 47.48T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		29.0	−158,500	−148,060
400	1,830	34.32	−158,100	−144,550
500	3,160	38.43	−158,250	−141,700
600	5,540	41.74	−157,400	−137,900
700	7,450	44.75	−158,250	−134,500
800	9,410	47.26	−157,800	−131,000
900	11,410	49.57	−157,350	−127,700
1,000	13,450	51.88	−156,850	−124,550
1,100	17,390	53.89	−154,500	−119,600
1,500	(27,000)	(64.0)	(−151,200)	(−112,100)

Lead Tetrafluoride, PbF_4 (c)

$\Delta H_{298}^\circ = -222{,}300$ calories per mole (*112*)
$S_{298} = (45)$ *e.u.* (*11*)
$S.P. = 773°$ K. (*6*)

Formation: $Pb + 2F_2 \longrightarrow PbF_4$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−222,300	(−202,000)
500	(6,000)	(−220,800)	(−189,300)

Lead Dichloride, $PbCl_2$ (c)

$\Delta H_{298}^\circ = -85{,}850$ calories per mole (*112*)
$S_{298} = 32.6$ *e.u.* (*83*)
$M.P. = 771°$ K. (*82*)
$\Delta H_M = 5{,}800$ calories per mole
$B.P. = 1{,}227°$ K. (*6*)
$\Delta H_V = 29{,}604$ calories per mole

Zone I (c) (298°–771° K.)

$$C_p = 15.96 + 8.00\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -5{,}115 + 15.96T + 4.00\times10^{-3}T^2$$

Zone II (l) (771°–900° K.)

$$C_p = 27.20 \quad (82)$$
$$H_T - H_{298} = -5{,}600 + 27.20T$$

Formation: $Pb+Cl_2 \longrightarrow PbCl_2$

Zone I (298°–600.5° K.)

$\Delta C_p = 1.32 + 6.04\times10^{-3}T + 0.68\times10^{5}T^{-2}$
$\Delta H_T = -86{,}280 + 1.32T + 3.02\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$
$\Delta F_T = -86{,}280 - 1.32T\ln T - 3.02\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 46.26T$

Zone II (600.5°–771° K.)

$\Delta C_p = 0.34 + 7.94\times10^{-3}T + 0.68\times10^{5}T^{-2}$
$\Delta H_T = -87{,}240 + 0.34T + 3.97\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$
$\Delta F_T = -87{,}240 - 0.34T\ln T - 3.97\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 42.4T$

Zone III (771°–900° K.)

$\Delta C_p = 11.58 - 0.06\times10^{-3}T + 0.68\times10^{5}T^{-2}$
$\Delta H_T = -87{,}750 + 11.58T - 0.03\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$
$\Delta F_T = -87{,}750 - 11.58T\ln T + 0.03\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 113.74T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		32.6	−85,850	−75,060
400	1,920	38.14	−85,450	−71,400
500	3,830	42.40	−85,050	−67,900
600	5,890	46.15	−84,500	−64,550
700	8,040	49.46	−85,150	−61,100
800	16,160	60.07	−78,590	−57,850
900	18,880	63.27	−77,430	−55,550
1,000	(21,400)	(66.1)	(−76,450)	(−53,000)

Lead Dibromide, $PbBr_2$ (*c*)

$\Delta H^\circ_{298} = -66{,}210$ calories per mole (*112*)
$S_{298} = 38.6$ *e.u.* (*83*)
$M.P. = 761°$ K. (*82*)
$\Delta H_M = 4{,}430$ calories per mole
$B.P. = 1{,}187°$ K. (*6*)
$\Delta H_V = 27{,}694$ calories per mole

Zone I (*c*) (298°–761° K.)

$C_p = 18.59 + 2.20\times10^{-3}T$ (*82*)
$H_T - H_{298} = -5{,}640 + 18.59T + 1.10\times10^{-3}T^{-2}$

Zone II (*l*) (761°–900° K.)

$C_p = 27.60$ (*82*)
$H_T - H_{298} = -7{,}435 + 27.60T$

Formation: $Pb+Br_2 \longrightarrow PbBr_2$

Zone I (298°–331° K.)

$\Delta C_p = -4.33 + 0.30\times10^{-3}T$
$\Delta H_T = -64{,}930 - 4.33T + 0.15\times10^{-3}T^2$
$\Delta F_T = -64{,}930 + 4.33T\ln T - 0.15\times10^{-3}T^2 - 15.62T$

Zone II (331°–600.5° K.)

$\Delta C_p = 3.73 + 0.30\times10^{-3}T + 0.37\times10^{5}T^{-2}$
$\Delta H_T = -74{,}975 + 3.73T + 0.15\times10^{-3}T^2 - 0.37\times10^{5}T^{-1}$
$\Delta F_T = -74{,}975 - 3.73T\ln T - 0.15\times10^{-3}T^2 - 0.18\times10^{5}T^{-1} + 61.94T$

Zone III (600.5°–761° K.)

$\Delta C_p = 2.75 + 2.20\times10^{-3}T + 0.37\times10^{5}T^{-2}$
$\Delta H_T = -75{,}940 + 2.75T + 1.10\times10^{-3}T^2 - 0.37\times10^{5}T^{-1}$
$\Delta F_T = -75{,}940 - 2.75T\ln T - 1.10\times10^{-3}T^2 - 0.18\times10^{5}T^{-1} + 57.85T$

Zone IV (761°- 900° K.)

$\Delta C_p = 11.74 + 0.37\times10^{5}T^{-2}$
$\Delta H_T = -77{,}730 + 11.74T - 0.37\times10^{5}T^{-1}$
$\Delta F_T = -77{,}730 - 11.74T\ln T - 0.18\times10^{5}T^{-1} + 118.0T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		38.6	−66,210	−62,250
400	1,970	44.29	−73,500	−59,150
500	3,930	48.66	−73,150	−55,650
600	5,900	52.25	−72,750	−52,200
700	7,910	55.35	−73,550	−48,600
800	14,640	64.22	−68,400	−45,300
900	17,400	67.47	−67,200	−42,500
1,000	(19,800)	(69.80)	−66,400	(−39,650)

Lead Diiodide, PbI_2 (*c*)

$\Delta H^\circ_{298} = -41{,}850$ calories per mole (*112*)
$S_{298} = 42.3$ *e.u.* (*112*)
$M.P. = 685°$ K. (*82*)
$\Delta H_M = 6{,}010$ calories per mole
$B.P. = 1{,}145°$ K. (*6*)
$\Delta H_V = 24{,}846$ calories per mole

Zone I (*c*) (298°–685° K.)

$C_p = 18.00 + 4.70\times10^{-3}T$ (*82*)
$H_T - H_{298} = -5{,}576 + 18.00T + 2.35\times10^{-3}T^2$

Zone II (*l*) (685°–800° K.)

$C_p = 32.40$ (*82*)
$H_T - H_{298} = -8{,}325 + 32.40T$

Formation: $Pb+I_2 \longrightarrow PbI_2$

Zone I (298°- 386.1° K.)

$\Delta C_p = 2.59 - 9.10\times10^{-3}T$
$\Delta H_T = -42{,}220 + 2.59T - 4.55\times10^{-3}T^2$
$\Delta F_T = -42{,}220 - 2.59T\ln T + 4.55\times10^{-3}T^2 + 15.72T$

Zone II (386.1°–456° K.)

$\Delta C_p = -7.02 + 2.80\times10^{-3}T$
$\Delta H_T = -43{,}150 - 7.02T + 1.40\times10^{-3}T^2$
$\Delta F_T = -43{,}150 + 7.02T\ln T - 1.40\times10^{-3}T^2 - 36.83T$

Zone III (456°–600° K.)

$\Delta C_p = 3.29 + 2.80\times10^{-3}T$
$\Delta H_T = -57{,}850 + 3.29T + 1.40\times10^{-3}T^2$
$\Delta F_T = -57{,}850 - 3.29T\ln T - 1.40\times10^{-3}T^2 + 58.55T$

Zone IV (685°–800° K.)

$\Delta C_p = 16.71$
$\Delta H_T = -61{,}550 + 16.71T$
$\Delta F_T = -61{,}550 - 16.71T\ln T + 150.87T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		42.3	−41,850	−41,550
400	2,010	48.1	−45,730	−41,280
500	4,000	52.54	−55,850	−39,150
600	6,070	56.31	−55,350	−36,850
700	14,360	68.58	−49,850	−32,570
800	17,600	72.9	−48,200	−30,200

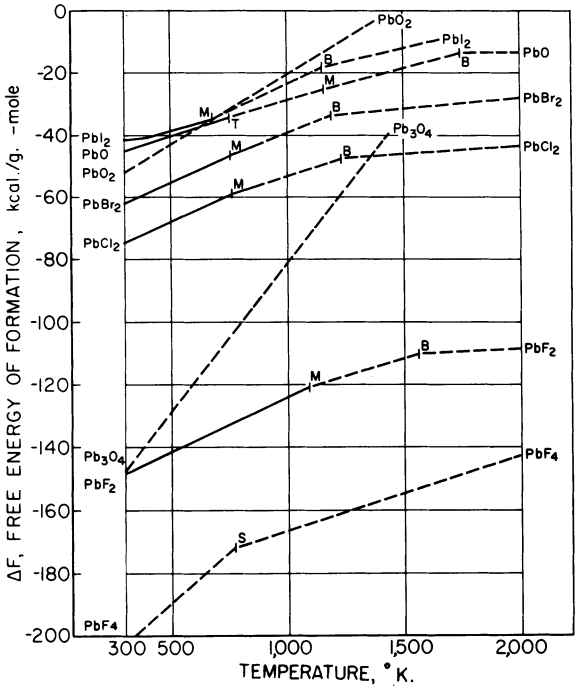


FIGURE 28.—Lead.

LITHIUM AND ITS COMPOUNDS

Element, Li (*c*)

$S_{298}=6.75$ *e.u.* (*34*)
$M.P.=453.7°$ K. (*34*)
$\Delta H_M=723$ calories per atom
$B.P.=1{,}604°$ K. (*130*)
$\Delta H_V=32{,}190$ calories per atom

Zone I (*c*) (298°–452° K.)

$$C_p=3.15+8.40\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-1{,}313+3.15T+4.20\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}313-3.15T\ln T-4.20\times10^{-3}T^2+16.84T$$

Zone II (*l*) (452°–1,604° K.)

$$C_p=6.935-0.078\times10^{-3}T+0.36\times10^{5}T^{-2} \text{ (34)}$$
$$H_T-H_{298}=-1{,}324+6.935T-0.039\times10^{-3}T^2-0.36\times10^{5}T^{-1}$$
$$F_T-H_{298}=-1{,}324-6.935T\ln T+0.039\times10^{-3}T^2-0.18\times10^{5}T^{-1}+38.19T$$

Zone III (*g*) (1,640°–2,500° K.)

$$C_p=3.93+0.364\times10^{-3}T+12.94\times10^{5}T^{-2} \text{ (34)}$$
$$H_T-H_{298}=+38{,}956+3.93T+0.182\times10^{-3}T^2-12.94\times10^{5}T^{-1}$$
$$F_T-H_{298}=+38{,}956-3.93T\ln T-0.182\times10^{-3}T^2-6.47\times10^{5}T^{-1}-8.23T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		6.75	6.75
400	630	8.57	7.0
500	2,049	11.71	7.62
600	2,763	13.01	8.4
700	3,462	14.09	9.14
800	4,155	15.01	9.82
900	4,846	15.83	10.44
1,000	5,536	16.55	11.01
1,100	6,224	17.21	11.55
1,200	6,912	17.81	12.05
1,300	7,598	18.36	12.51
1,400	8,284	18.86	12.94
1,500	8,967	19.34	13.36
1,600	9,648	19.78	13.75
1,700	45,404	41.79	15.08
1,800	45,901	42.08	16.58
1,900	46,399	42.35	17.93
2,000	46,897	42.60	19.15

Dilithium Oxide, Li_2O (*c*)

$\Delta H^\circ_{298}=-142{,}570$ calories per mole (*75*)
$S_{298}=9.06$ *e.u.* (*75*)
$M.P.=(2{,}000)°$ K. (*42*)

Zone I (*c*) (298°–1500° K.)

$$C_p=14{,}939+6.08\times10^{-3}T-3.38\times10^{5}T^{-2} \text{ (116)}$$
$$H_T=H_{298}=5{,}858+14.939T+3.04\times10^{-3}T^2+3.38\times10^{5}T^{-1}$$

Formation: $2Li+1/2O_2\longrightarrow Li_2O$

Zone I (298°–452° K.)

$$\Delta C_p=5.06-11.22\times10^{-3}T-3.18\times10^{5}T^{-2}$$
$$\Delta H_T=144{,}648+5.06T-5.61\times10^{-3}T^2+3.18\times10^{5}T^{-1}$$
$$\Delta F_T=144{,}648-5.06T\ln T+5.61\times10^{-3}T^2+1.59\times10^{5}T^{-1}+61.28T$$

Zone II (452°–1,500° K.)

$$\Delta C_p=2.51+5.74\times10^{-3}T-3.90\times10^{5}T^{-2}$$
$$\Delta H_T=138{,}800-2.51T+2.87\times10^{-3}T^2+3.90\times10^{5}T^{-1}$$
$$\Delta F_T=138{,}800+2.51T\ln T-2.87\times10^{-3}T^2+1.95\times10^{5}T^{-1}+18.6T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		9.06	−142,570	−133,950
400	7,306	13.22	−136,900	−125,100
500	8,905	16.79	−138,500	−122,000
600	10,620	19.91	−138,600	−118,700
700	12,430	22.70	−138,550	−115,350
800	14,320	25.22	−138,450	−112,050
900	16,270	27.53	−138,300	−108,800
1,000	18,317	29.68	−138,050	−105,500
1,100	20,418	31.68	−137,700	−102,200
1,200	22,586	33.56	−137,350	−99,050
1,300	24,818	35.35	−136,900	−95,850
1,400	27,050	37.05	−136,550	−92,900
1,500	30,233	38.67	−136,100	−89,550

Lithium Fluoride, LiF (*c*)

$\Delta H^\circ_{298}=-146{,}300$ calories per mole (*112*)
$S_{298}=8.57$ *e.u.* (*112*)
$M.P.=1{,}120°$ K. (*6*)
$\Delta H_M=2{,}360$ calories per mole
$B.P.=1{,}954°$ K. (*6*)
$\Delta H_V=50{,}970$ calories per mole

Zone I (*c*) (298°–1,120° K.)

$$C_p = 9.14 + 5.19\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -2{,}954 + 9.14T + 2.59\times10^{-3}T^2$$

Formation: $Li + 1/2F_2 \longrightarrow LiF$

Zone I (298°–452° K.)

$$\Delta C_p = 1.84 - 3.43\times10^{-3}T + 0.40\times10^5T^{-2}$$
$$\Delta H_T = -146{,}550 + 1.84T - 1.71\times10^{-3}T^2 - 0.40\times10^5T^{-1}$$
$$\Delta F_T = -146{,}550 - 1.84T\ln T + 1.71\times10^{-3}T^2 - 0.20\times10^5T^{-1} + 33.53T$$

Zone II (452°–1,120° K.)

$$\Delta C_p = -1.94 + 5.05\times10^{-3}T + 0.04\times10^5T^{-2}$$
$$\Delta H_T = -146{,}400 - 1.94T + 2.52\times10^{-3}T^2 - 0.04\times10^5T^{-1}$$
$$\Delta F_T = -146{,}400 + 1.94T\ln T - 2.52\times10^{-3}T^2 - 0.02\times10^5T^{-1} + 12.23T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		8.57	−146,300	−139,650
400	1,116	11.79	−146,150	−137,250
500	2,263	14.34	−146,800	−134,950
600	3,462	16.53	−146,700	−132,550
700	4,713	18.46	−146,550	−130,200
800	6,016	20.20	−146,350	−127,850
900	7,370	21.79	−146,100	−125,550
1,000	8,776	23.28	−145,800	−123,300
1,100	10,234	24.66	−145,400	−120,950
1,500	(18,200)	(30.57)	(−141,900)	(−112,200)

Lithium Chloride, LiCl (*c*)

$\Delta H_{298}^\circ = -97{,}700$ calories per mole (*112*)
$S_{298} = 13.9$ *e.u.* (*83*)
M.P. = 887° K. (*6*)
$\Delta H_M = 3{,}200$ calories per mole
B.P. = 1,653° K. (*6*)
$\Delta H_V = 35{,}960$ calories per mole

Zone I (*c*) (298°–887° K.)

$$C_p = 11.0 + 3.40\times10^{-3}T \text{ (74)}$$
$$H_T - H_{298} = -3{,}429 + 11.0T + 1.70\times10^{-3}T^2$$

Formation: $Li + 1/2Cl_2 \longrightarrow LiCl$

Zone I (298°–452° K.)

$$\Delta C_p = 3.44 - 5.03\times10^{-3}T + 0.34\times10^5T^{-2}$$
$$\Delta H_T = -98{,}400 + 3.44T - 2.51\times10^{-3}T^2 - 0.34\times10^5T^{-1}$$
$$\Delta F_T = -98{,}400 - 3.44T\ln T + 2.51\times10^{-3}T^2 - 0.17\times10^5T^{-1} + 38.76T$$

Zone II (452°–887° K.)

$$\Delta C_p = -0.345 + 3.45\times10^{-3}T - 0.02\times10^5T^{-2}$$
$$\Delta H_T = -98{,}360 - 0.345T + 1.72\times10^{-3}T^2 - 0.02\times10^5T^{-1}$$
$$\Delta F_T = -98{,}360 + 0.345T\ln T - 1.72\times10^{-3}T^2 - 0.01\times10^5T^{-1} + 17.02T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		13.9	−97,700	−92,500
400	1,243	17.48	−97,500	−90,850
500	2,496	20.28	−98,100	−89,200
600	3,783	22.63	−97,450	−87,000
700	5,104	24.66	−97,750	−85,600
800	6,459	26.47	−97,850	−84,450
900	11,050	31.71	−94,100	−82,600
1,000	(12,700)	(33.6)	(−93,550)	(−81,500)
1,500	(20,700)	(40.1)	(−90,800)	(−75,800)

Lithium Bromide, LiBr (*c*)

$\Delta H_{298}^\circ = -83{,}720$ calories per mole (*11*)
$S_{298} = 19$ *e.u.* (*11*)
M.P. = 825° K. (*6*)
$\Delta H_M = 2{,}900$ calories per mole
B.P. = 1,583° K. (*6*)
$\Delta H_V = 35{,}420$ calories per mole

Zone I (*c*) (298°–825° K.)

$$C_p = 11.5 + 3.02\times10^{-3}T \text{ (74)}$$
$$H_T - H_{298} = -3{,}560 + 11.5T + 1.51\times10^{-3}T^2$$

Formation: $Li + 1/2Br_2 \longrightarrow LiBr$

Zone I (298°–331° K.)

$$\Delta C_p = -0.2 - 5.38\times10^{-3}T$$
$$\Delta H_T = -83{,}420 - 0.2T - 2.69\times10^{-3}T^2$$
$$\Delta F_T = -83{,}420 + 0.2T\ln T + 2.69\times10^{-3}T^2 + 3.01T$$

Zone II (331°–452° K.)

$$\Delta C_p = 3.83 - 5.38\times10^{-3}T + 0.19\times10^5T^{-2}$$
$$\Delta H_T = -88{,}650 + 3.83T - 2.69\times10^{-3}T^2 - 0.19\times10^5T^{-1}$$
$$\Delta F_T = -88{,}650 - 3.83T\ln T + 2.69\times10^{-3}T^2 - 0.09\times10^5T^{-1} + 42.83T$$

Zone III (452°–825° K.)

$$\Delta C_p = 0.05 + 3.1\times10^{-3}T + 0.17\times10^5T^{-2}$$
$$\Delta H_T = -88{,}400 + 0.05T + 1.55\times10^{-3}T^2 + 0.17\times10^5T^{-1}$$
$$\Delta F_T = -88{,}400 - 0.05T\ln T - 1.55\times10^{-3}T^2 + 0.08\times10^5T^{-1} + 20.45T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		19.0	−83,720	−81,950
400	1,281	22.69	−87,400	−80,500
500	2,567	25.56	−87,950	−78,700
600	3,884	27.95	−87,800	−76,850
700	5,240	30.03	−87,600	−75,050
800	7,606	31.87	−87,400	−73,300
1,000	(12,700)	(38.9)	(−83,550)	(−70,450)
1,500	(20,700)	(45.4)	(−81,250)	(−64,600)

Lithium Iodide, LiI (*c*)

$\Delta H_{298}^\circ = -64{,}790$ calories per mole (*112*)
$S_{298} = (21)$ *e.u.* (*11*)
M.P. = 713° K. (*6*)
$\Delta H_M = 1{,}420$ calories per mole
B.P. = 1,440° K. (*6*)
$\Delta H_V = 40{,}772$ calories per mole

Zone I (*c*) (298°–713° K.)

$$C_p = 12.3 + 2.44\times10^{-3}T \text{ (74)}$$
$$H_T - H_{298} = -3{,}773 + 12.3T + 1.22\times10^{-3}T^2$$

Formation $Li + 1/2I_2 \longrightarrow LiI$

Zone I (298°–386.8° K.)

$$\Delta C_p = 4.36 - 11.91\times10^{-3}T$$
$$\Delta H_T = -65{,}550 + 4.36T - 5.95\times10^{-3}T^2$$
$$\Delta F_T = -65{,}550 - 4.36T\ln T + 5.95\times10^{-3}T^2 + 34.3T$$

Zone II (386.8°–452° K.)

$$\Delta C_p = -0.45 - 5.96\times10^{-3}T$$
$$\Delta H_T = -63{,}750 - 0.45T - 2.98\times10^{-3}T^2$$
$$\Delta F_T = -63{,}750 + 0.45T\ln T + 2.98\times10^{-3}T^2 + 2.0T$$

Zone II (456°–713° K.)

$\Delta C_p = -0.93 + 2.52\times10^{-3}T - 0.36\times10^{5}T^{-2}$
$\Delta H_T = -65{,}600 + 0.93T + 1.26\times10^{-3}T^2 + 0.36\times10^{5}T^{-1}$
$\Delta F_T = -65{,}600 - 0.93T\ln T - 1.26\times10^{-3}T^2 + 0.18\times10^{5}T^{-1} + 15.54T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		(21.0)	−64,790	(−62,200)
400	1,342	(24.9)	−64,400	(−61,350)
500	2,682	(27.9)	−64,750	(−61,000)
600	4,046	(30.3)	−66,000	(−60,800)
700	5,435	(32.5)	−65,450	(−60,200)

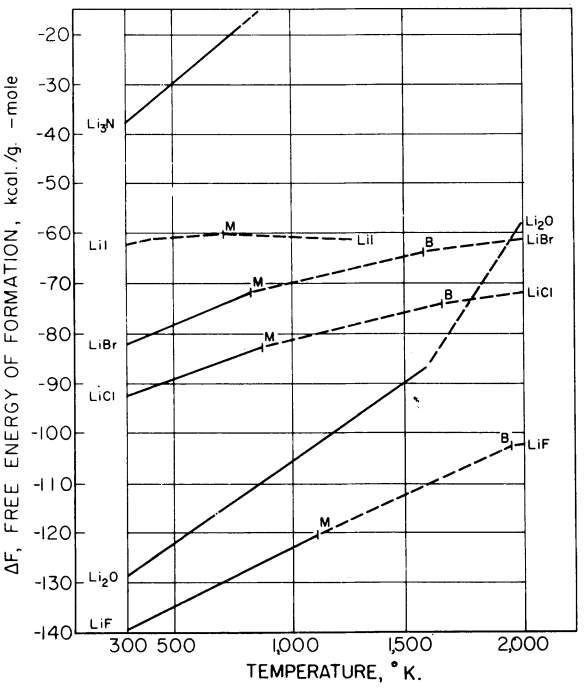


FIGURE 29.—Lithium.

Trilithium Nitride, Li_3N (c)

$\Delta H_{298}^\circ = -47{,}500$ calories per mole (9)
$S_{298} = 9$ e.u. (9)
Decomposes (9)

Zone I (c) (298°–800° K.)

$C_p = 11.73 + 23.00\times10^{-3}T$ (82)
$H_T - H_{298} = -4{,}520 + 11.73T + 11.5\times10^{-3}T^2$

Formation: $3Li + 1/2N_2 \longrightarrow Li_3N$

Zone I (298°–452° K.)

$\Delta C_p = -1.05 - 2.71\times10^{-3}T$
$\Delta H_T = -47{,}050 - 1.05T - 1.35\times10^{-3}T^2$
$\Delta F_T = -47{,}050 + 1.05T\ln T + 1.35\times10^{-3}T^2 + 26.35T$

Zone II (452°–800° K.)

$\Delta C_p = -12.40 + 22.72\times10^{-3}T - 1.08\times10^{5}T^{-2}$
$\Delta H_T = -47{,}000 - 12.40T + 11.36\times10^{-3}T^2 + 1.08\times10^{5}T^{-1}$
$\Delta F_T = -47{,}000 + 12.40T\ln T - 11.36\times10^{-3}T^2 + 0.54\times10^{5}T^{-1} - 37.8T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		9.0	−47,500	−37,300
400	2,000	14.7	−48,100	−34,150
500	4,200	19.7	−50,150	−30,100
600	6,680	24.2	−50,170	−26,050
700	9,360	28.3	−49,950	−22,000
800	12,190	32.1	−49,570	−18,100

LUTETIUM AND ITS COMPOUNDS

Element, Lu (c)

$S_{298} = (11.79)$ e.u. (121)
M.P. = (2,000°) K. (125)
$\Delta H_M = (4{,}600)$ calories per atom
B.P. = (2,200°) K. (125)
$\Delta H_V = 59{,}000$ calories per atom (estimated (130))

T, ° K.	H_T-H_{298}	S_T	$\frac{(F_T-H_{298})}{T}$
298		(11.79)	(11.79)
400	(665)	(13.66)	(12.00)
500	(1,330)	(15.15)	(12.49)
600	(2,015)	(16.40)	(13.05)
700	(2,710)	(17.47)	(13.60)
800	(3,425)	(18.42)	(14.14)
900	(4,150)	(19.28)	(14.67)
1,000	(4,890)	(20.06)	(15.17)
1,100	(5,650)	(20.78)	(15.65)
1,200	(6,420)	(21.46)	(16.11)
1,300	(7,210)	(22.09)	(16.55)
1,400	(8,010)	(22.68)	(16.96)
1,500	(8,830)	(23.25)	(17.37)
1,600	(9,660)	(23.78)	(17.75)
1,700	(10,510)	(24.30)	(18.12)
1,800	(11,370)	(24.79)	(18.48)
1,900	(12,250)	(25.26)	(18.82)
2,000	(17,740)	(28.04)	(19.17)

Lutetium Trifluoride, LuF_3 (c)

$\Delta H_{298}^\circ = (-367{,}000)$ calories per mole (5)
$S_{298} = (26)$ e.u. (11)
T.P. = 927° K. (29)
M.P. = (1,455°) K. (29)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (2,500°) K. (6)
$\Delta H_V = (60{,}000)$ calories per mole

Formation: $Lu + 3/2F_2 \longrightarrow LuF_3$ (estimated (11))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−367,000)	(−349,000)
500	(4,000)	(−366,700)	(−338,000)
1,000	(17,000)	(−363,700)	(−309,000)
1,500	(32,000)	(−359,200)	(−283,000)

Lutetium Trichloride, $LuCl_3$ (c)

$\Delta H_{298}^\circ = -228{,}000$ calories per mole (5)
$S_{298} = (37)$ e.u. (11)
M.P. = 1,178° K. (29)
$\Delta H_M = (9{,}000)$ calories per mole
B.P. = (1,750°) K. (6)
$\Delta H_V = (43{,}000)$ calories per mole

Formation: $Lu + 3/2Cl_2 \longrightarrow LuCl_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−228,000	(−211,500)
500	(5,000)	(−226,100)	(−200,000)
1,000	(19,000)	(−223,000)	(−174,000)
1,500	(43,000)	(−219,400)	(−154,500)

Lutetium Tribromide, $LuBr_3$ (*c*)

$\Delta H_{298}^\circ = (-164{,}000)$ calories per mole (*5*)
$S_{298} = (44)$ *e.u.* (*11*)
M.P. = (1,298°) K. (*29*)
$\Delta H_M = (10{,}000)$ calories per mole
B.P. = (1,680°) K. (*6*)
$\Delta H_V = (42{,}000)$ calories per mole

Formation: $Lu + 3/2Br_2 \longrightarrow LuBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		(−164,000)	(−157,000)
500	(5,000)	(−174,600)	(−146,000)
1,000	(18,000)	(−171,900)	(−121,000)
1,500	(43,000)	(−157,600)	(−104,500)

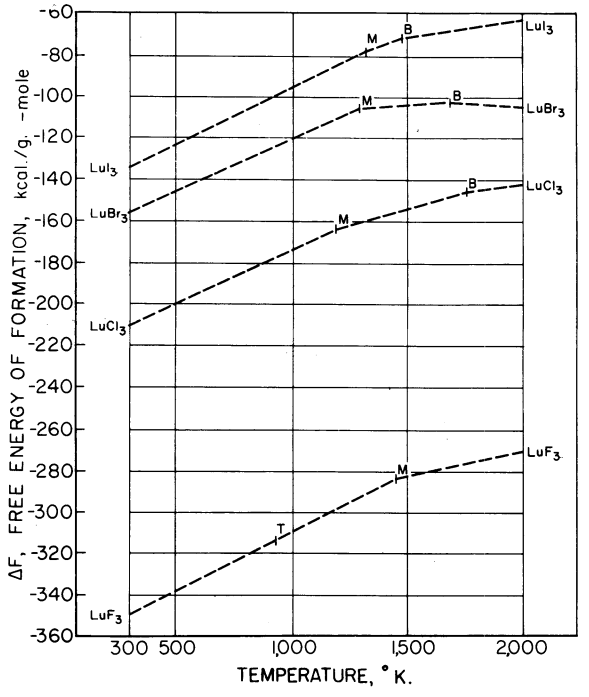


FIGURE 30.—Lutetium.

Lutetium Triiodide, LuI_3 (*c*)

$\Delta H_{298}^\circ = -133{,}000$ calories per mole (*5*)
$S_{298} = (46)$ *e.u.* (*11*)
M.P. = 1,323° K. (*29*)
$\Delta H_M = (11{,}000)$ calories per mole
B.P. = (1,480°) K. (*6*)
$\Delta H_V = (38{,}000)$ calories per mole

Formation: $Lu + 3/2I_2 \longrightarrow LuI_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−133,000	(−131,000)
500	(5,000)	(−154,000)	(−125,000)
1,000	(19,000)	(−150,500)	(−96,000)
1,500	(82,000)	(−98,000)	(−71,000)

MAGNESIUM AND ITS COMPOUNDS

Element, Mg (*c*)

$S_{298} = 7.77$ *e.u.* (*83*)
M.P. = 923° K. (*82*)
$\Delta H_M = 2{,}160$ calories per atom
B.P. = 1,393° K. (*112*)
$\Delta H_V = 31{,}500$ calories per atom

Zone I (*c*) (298°–923° K.)

$$C_p = 6.14 + 1.50\times10^{-3}T - 0.78\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -2{,}160 + 6.14T + 0.75\times10^{-3}T^2 + 0.78\times10^{5}T^{-1}$$
$$F_T - H_{298} = -2{,}160 - 6.14T\ln T - 0.75\times10^{-3}T^2 + 0.39\times10^{5}T^{-1} + 33.08T$$

Zone II (*l*) (923°–1,393° K.)

$$C_p = 7.4 \quad (82)$$
$$H_T - H_{298} = -440 + 7.40T$$
$$F_T - H_{298} = -440 - 7.40T\ln T + 40.2T$$

Zone III (*g*) (1,393–1,800° K.)

$$C_p = 4.97 \quad (84)$$
$$H_T - H_{298} = 34{,}440 + 4.97T$$
$$F_T - H_{298} = 34{,}440 - 4.97T\ln T - 2.4T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		7.77	7.77
400	615	9.52	7.97
500	1,255	10.95	8.44
600	1,920	12.16	8.97
700	2,615	13.23	9.49
800	3,330	14.19	10.01
900	4,060	15.04	10.52
1,000	6,960	18.16	11.20
1,100	7,700	18.87	11.68
1,200	8,430	19.47	12.43
1,300	8,980	20.07	13.09
1,400	41,400	43.27	13.53
1,500	41,900	43.67	15.73
1,600	42,390	43.99	17.58
1,700	42,890	44.37	19.12
1,800	43,390	44.67	20.62
1,900	(43,890)	(44.87)	(21.79)
2,000	(44,390)	(45.17)	(22.92)

Magnesium Oxide, MgO (*c*)

$\Delta H_{298}^\circ = -143{,}700$ calories per mole (*117*)
$S_{298} = 6.40$ *e.u.* (*83*)
M.P. = 3,173° K. (*112*)
$\Delta H_M = 18{,}500$ calories per mole

Zone I (298°–2,100° K.)

$$C_p = 10.18 + 1.74\times10^{-3}T - 1.48\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -3{,}609 + 10.18T + 0.87\times10^{-3}T^2 + 1.48\times10^{5}T^{-1}$$

Formation: $Mg + 1/2O_2 \longrightarrow MgO$

Zone I (298°–923° K.)

$$\Delta C_p = 0.46 - 0.26\times10^{-3}T - 0.50\times10^{5}T^{-2}$$
$$\Delta H_T = -144{,}000 + 0.46T - 0.13\times10^{-3}T^2 + 0.50\times10^{5}T^{-1}$$
$$\Delta F_T = -144{,}000 - 0.46T\ln T + 0.13\times10^{-3}T^2 + 0.25\times10^{5}T^{-1} + 28.73T$$

Zone II (923°–1,393° K.)

$$\Delta C_p = -0.80 + 1.24\times10^{3}T - 1.28\times10^{5}T^{-2}$$
$$\Delta H_T = -145{,}750 - 0.80T + 0.62\times10^{-3}T^2 + 1.28\times10^{5}T^{-1}$$
$$\Delta F_T = -145{,}750 + 0.80T\ln T - 0.62\times10^{-3}T^2 + 0.64\times10^{5}T^{-1} + 22.71T$$

Zone III (1,393°–1,800° K.)

$$\Delta C_p = 1.63 + 1.24\times10^{-3}T - 1.28\times10^{5}T^{-2}$$
$$\Delta H_T = -180{,}500 + 1.63T + 0.62\times10^{-3}T^2 + 1.28\times10^{5}T^{-1}$$
$$\Delta F_T = -180{,}500 - 1.63T\ln T - 0.62\times10^{-3}T^2 + 0.64\times10^{5}T^{-1} + 65.4T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		6.40	−143,700	−136,100
400	965	9.18	−143,700	−133,500
500	1,975	11.43	−143,700	−131,000
600	3,020	13.34	−143,700	−128,400
700	4,100	15.0	−143,700	−125,900
800	5,225	16.5	−143,700	−123,300
900	6,390	17.87	−143,650	−120,750
1,000	7,580	19.13	−145,800	−118,050
1,100	8,800	20.29	−145,700	−115,200
1,200	10,050	21.38	−145,600	−112,600
1,300	11,310	22.38	−145,300	−109,500
1,400	12,570	23.32	−176,850	−106,850
1,500	13,830	24.19	−176,600	−101,700
1,600	15,090	25.0	−176,200	−96,700
1,700	16,350	25.76	−175,900	−91,600
1,800	17,610	26.48	−175,600	−86,600
1,900	(18,870)	(27.16)	(−175,200)	(−81,800)
2,000	(20,130)	(27.81)	(−175,050)	(−76,950)

Magnesium Difluoride, MgF_2 (*c*)

$\Delta H^\circ_{298} = -263{,}500$ calories per mole (*112*)
$S_{298} = 13.68$ *e.u.* (*112*)
M.P. = 1,536° K. (*82*)
$\Delta H_M = 13{,}900$ calories per mole
B.P. = 2,500° K. (*112*)
$\Delta H_V = 65{,}000$ calories per mole

Zone I (*c*) (298°–1,536° K.)

$$C_p = 16.93 + 2.52\times10^{-3}T - 2.20\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -5{,}898 + 16.93T + 1.26\times10^{-3}T^2 + 2.20\times10^{5}T^{-1}$$

Zone II (*l*) (1,536°–1,800° K.)

$$C_p = 22.60 \quad (82)$$
$$H_T - H_{298} = 2{,}400 + 22.60T$$

Formation: $Mg + F_2 \longrightarrow MgF_2$

Zone I (298°–923° K.)

$$\Delta C_p = 2.50 + 0.58\times10^{-3}T - 0.62\times10^{5}T^{-2}$$
$$\Delta H_T = -264{,}500 + 2.50T + 0.29\times10^{-3}T^2 + 0.62\times10^{5}T^{-1}$$
$$\Delta F_T = -264{,}500 - 2.50T\ln T - 0.29\times10^{-3}T^2 + 0.31\times10^{5}T^{-1} + 59.87T$$

Zone II (923°–1,393° K.)

$$\Delta C_p = 1.24 + 2.08\times10^{-3}T - 1.4\times10^{5}T^{-2}$$
$$\Delta H_T = -266{,}220 + 1.24T + 1.04\times10^{-3}T^2 + 1.4\times10^{5}T^{-1}$$
$$\Delta F_T = -266{,}220 - 1.24T\ln T - 1.04\times10^{-3}T^2 + 0.7\times10^{5}T^{-1} + 53.81T$$

Zone III (1,393°–1,536° K.)

$$\Delta C_p = 3.67 + 2.08\times10^{-3}T - 1.40\times10^{5}T^{-2}$$
$$\Delta H_T = -301{,}050 + 3.67T + 1.04\times10^{-3}T^2 + 1.40\times10^{5}T^{-1}$$
$$\Delta F_T = -301{,}050 - 3.67T\ln T - 1.04\times10^{-3}T^2 + 0.70\times10^{5}T^{-1} + 96.44T$$

Zone IV (1,536°–1,800° K.)

$$\Delta C_p = 9.34 - 0.44\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -292{,}760 + 9.34T - 0.22\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -292{,}760 - 9.34T\ln T + 0.22\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 130.8T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		13.68	−263,500	−250,800
400	1,645	18.42	−263,250	−246,500
500	3,320	22.15	−263,000	−242,300
600	5,080	25.36	−262,750	−238,200
700	6,890	28.15	−262,600	−234,200
800	8,720	30.60	−262,250	−230,150
900	10,590	32.80	−261,950	−226,150
1,000	12,510	34.82	−263,800	−221,950
1,100	14,450	36.67	−263,450	−216,750
1,200	16,430	38.39	−263,100	−213,700
1,300	18,440	40.00	−262,500	−209,500
1,400	20,460	41.50	−293,800	−205,300
1,500	22,490	42.90	−293,150	−198,950
1,600	38,560	53.35	−278,450	−193,250
1,700	40,820	54.72	−277,600	−187,800
1,800	43,080	56.01	−276,700	−182,600

Magnesium Dichloride, $MgCl_2$ (*c*)

$\Delta H^\circ_{298} = -153{,}200$ calories per mole (*112*)
$S_{298} = 21.4$ *e.u.* (*112*)
M.P. = 987° K. (*82*)
$\Delta H_M = 10{,}300$ calories per mole
B.P. = 1,691° K. (*112*)
$\Delta H_V = 32{,}700$ calories per mole

Zone I (*c*) (298°–987° K.)

$$C_p = 18.90 + 1.42\times10^{-3}T - 2.06\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -6{,}389 + 18.90T + 0.71\times10^{-3}T^2 + 2.06\times10^{5}T^{-1}$$

Zone II (*l*) (987°–1,500° K.)

$$C_p = 22.10 \quad (82)$$
$$H_T - H_{298} = +1{,}650 + 22.10T$$

Formation: $Mg + Cl_2 \longrightarrow MgCl_2$

Zone I (298°–923° K.)

$$\Delta C_p = 3.94 - 0.14\times10^{-3}T - 0.6\times10^{5}T^{-2}$$
$$\Delta H_T = -154{,}600 + 3.94T - 0.07\times10^{-3}T^2 + 0.6\times10^{5}T^{-1}$$
$$\Delta F_T = -154{,}600 - 3.94T\ln T + 0.07\times10^{-3}T^2 - 0.3\times10^{5}T^{-1} + 66.56T$$

Zone II (923°–987° K.)

$$\Delta C_p = 2.68 + 1.36\times10^{-3}T - 1.38\times10^{5}T^{-2}$$
$$\Delta H_T = -154{,}200 + 2.68T + 0.68\times10^{-3}T^2 + 1.38\times10^{5}T^{-1}$$
$$\Delta F_T = -154{,}200 - 2.68T\ln T - 0.68\times10^{-3}T^2 - 0.69\times10^{5}T^{-1} + 55.47T$$

Zone III (987°–1,393° K.)

$$\Delta C_p = 5.88 - 0.06\times10^{-3}T + 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -148{,}150 + 5.88T - 0.03\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -148{,}150 - 5.88T\ln T + 0.03\times10^{-3}T^2 + 0.34\times10^{5}T^{-1} + 73.54T$$

Zone IV (1,393°–1,500° K.)

$$\Delta C_p = 8.31 - 0.06\times10^{-3}T + 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -183{,}100 + 8.31T - 0.03\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -183{,}100 - 8.31T\ln T + 0.03\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 116.34T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	21.40	−153,200	−141,400
400	1,800	26.59	−152,850	−137,300
500	3,650	30.71	−152,500	−133,500
600	5,555	34.19	−152,100	−129,700
700	7,480	37.15	−151,750	−126,100
800	9,420	39.74	−151,400	−122,400
900	11,380	42.05	−151,050	−118,850
1,000	23,750	54.67	−142,450	−115,150
1,100	25,960	56.78	−141,750	−112,450
1,200	28,170	58.70	−141,300	−110,000
1,300	30,380	60.47	−141,450	−107,050
1,400	32,590	62.10	−171,600	−104,600
1,500	34,800	63.67	−170,650	−99,650

Magnesium Dibromide, $MgBr_2$ (*c*)

$\Delta H^\circ_{298} = (-123{,}900)$ calories per mole (*11*)
$S_{298} = (30)$ *e.u.* (*11*)
$M.P. = 984°$ K. (*6*)
$\Delta H_M = 8{,}300$ calories per mole
$B.P. = (1{,}500°)$ K. (*6*)
$\Delta H_V = (35{,}000)$ calories per mole

Formation: $Mg + Br_2 \longrightarrow MgBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298	----------	(−123,900)	(−120,000)
500	(4,000)	(−130,700)	(−111,000)
1,000	(22,700)	(−122,200)	(−92,450)
1,500	(34,800)	(−149,500)	(−69,600)

Magnesium Diiodide, MgI_2 (*c*)

$\Delta H^\circ_{298} = -86{,}800$ calories per mole (*11*)
$S_{298} = (33)$ *e.u.* (*11*)
$M.P. = 923°$ K. (*6*)
$\Delta H_M = (5{,}300)$ calories per mole
$B.P. = (1{,}200°)$ K. (*6*)
$\Delta H_V = (25{,}000)$ calories per mole

Formation: $Mg + I_2 \longrightarrow MgI_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298	----------	−86,800	(−86,000)
500	(4,000)	(−100,700)	(−83,000)
1,000	(19,900)	(−95,000)	(−69,500)
1,500	(57,000)	(−97,500)	(−58,000)

Trimagnesium Dinitride, Mg_3N_2 (*c*)

$\Delta H^\circ_{298} = -110{,}200$ calories per mole (*102*)
$S_{298} = 21.8$ *e.u.* (*102*)
$T.P. = 823°$ K. (*82*)
$\Delta H_T = 110$ calories per mole
$T.P. = 1{,}061°$ K. (*82*)
$\Delta H_T = 220$ calories per mole
Decomposes = 1,300° K. (*9*)

Zone I (α) (298°–823° K.)

$$C_p = 20.77 + 11.20\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -6{,}691 + 20.77T + 5.60\times10^{-3}T^2$$

Zone II (β) (823°–1,061° K.)

$$C_p = 20.07 + 10.66\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -5{,}830 + 20.07T + 5.33\times10^{-3}T^2$$

Zone III (γ) (1,061°–1,300)° K.)

$$C_p = 28.50 \text{ (79)}$$
$$H_T - H_{298} = -8{,}560 + 28.50T$$

Formation: $3Mg + N_2 \longrightarrow Mg_3N_2$

Zone I (298°–823° K.)

$$\Delta C_p = -4.31 + 5.68\times10^{-3}T + 2.34\times10^{5}T^{-2}$$
$$\Delta H_T = -108{,}400 - 4.31T + 2.84\times10^{-3}T^2 - 2.34\times10^{5}T^{-1}$$
$$\Delta F_T = -108{,}400 + 4.31T\ln T - 2.84\times10^{-3}T^2 - 1.17\times10^{5}T^{-1} + 18.05T$$

Zone II (823°–923° K.)

$$\Delta C_p = -5.01 + 5.14\times10^{-3}T + 2.34\times10^{5}T^{-2}$$
$$\Delta H_T = -107{,}500 - 5.01T + 2.57\times10^{-3}T^2 - 2.34\times10^{5}T^{-1}$$
$$\Delta F_T = -107{,}500 + 5.01T\ln T - 2.57\times10^{-3}T^2 - 1.17\times10^{5}T^{-1} + 12.70T$$

Zone III (923°–1,061° K.)

$$\Delta C_p = -8{,}79 + 9.64\times10^{-3}T$$
$$\Delta H_T = -112\ 700 - 8.79T + 4.82\times10^{-3}T^2$$
$$\Delta F_T = -112{,}700 + 8.79T\ln T - 4.82\times10^{-3}T^2 - 5.38T$$

Zone IV (1,061°–1,300° K.)

$$\Delta C_p = 0.32 - 1.02\times10^{-3}T$$
$$\Delta H_T = -115{,}430 - 0.32T - 0.51\times10^{-3}T^2$$
$$\Delta F_T = -115{,}430 + 0.32T\ln T + 0.51\times10^{-3}T^2 + 50.4T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298	----------	21.8	−110,200	−96,100
400	2,510	29.04	−110,250	−91,300
500	5,100	34.81	−110,300	−86,600
600	7,790	39.72	−110,300	−81,900
700	10,590	44.03	−110,300	−77,100
800	13,510	47.93	−110,250	−72,400
900	16,550	51.50	−110,200	−67,700
1,000	19,570	54.69	−116,650	−62,350
1,100	22,790	57.76	−116,400	−56,900
1,200	25,640	60.24	−116,350	−51,350
1,300	28,490	62.52	−116,150	−45,650

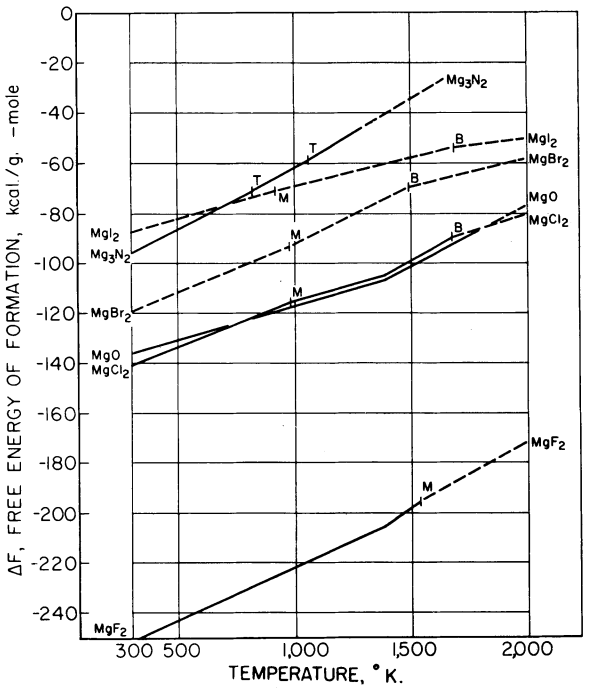


FIGURE 31.—Magnesium.

MANGANESE AND ITS COMPOUNDS

Element, Mn (*c*)

$S_{298}=7.59$ *e.u.* (*83*)
$T.P.=1{,}000°$ K. (*82*)
$\Delta H_T=535$ calories per atom
$T.P.=1{,}374°$ K. (*82*)
$\Delta H_T=545$ calories per atom
$T.P.=1{,}410°$ K. (*82*)
$\Delta H_T=430$ calories per atom
$M.P.=1{,}517°$ K. (*82*)
$\Delta H_M=3{,}500$ calories per atom
$B.P.=2{,}368°$ K. (*82*)
$\Delta H_V=53{,}700$ calories per atom

Zone I (α) (298°–1,000° K.)

$$C_p=5.70+3.38\times10^{-3}T-0.37\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-1{,}974+5.70T+1.69\times10^{-3}T^2+0.37\times10^{5}T^{-1}$$
$$F_T-H_{298}=-1{,}974-5.70T\ln T-1.69\times10^{-3}T^2+0.18\times10^{5}T^{-1}+31.74T$$

Zone II (β) (1,000°–1,374° K.)

$$C_p=8.33+0.66\times10^{-3}T$$
$$H_T-H_{298}=-2{,}675+8.33T+0.33\times10^{-3}T^2$$
$$F_T-H_{298}=-2{,}675-8.33T\ln T-0.33\times10^{-3}T^2+49.27T$$

Zone III (γ) (1,374°–1,410° K.)

$$C_p=10.70$$
$$H_T-H_{298}=-4{,}760+10.70T$$
$$F_T-H_{298}=-4{,}760-10.70T\ln T+67.5T$$

Zone IV (δ) (1,410°–1,517° K.)

$$C_p=11.30\ (82)$$
$$H_T-H_{298}=-1{,}517+11.30T$$
$$F_T-H_{298}=-1{,}517-11.30T\ln T+69.7T$$

Zone V (*l*) (1,517°–2,368° K.)

$$C_p=11.0$$
$$H_T-H_{298}=-1{,}220+11.0T$$
$$F_T-H_{298}=-1{,}220-11.0T\ln T+67.2T$$

Zone VI (*g*) (2,368°–5,000° K.)

$$C_p=6.26\ (82)$$
$$H_T-H_{298}=63{,}710+6.26T$$
$$F_T-H_{298}=63{,}710-6.26T\ln T+4.26T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		7.59	7.59
400	690	9.58	7.85
500	1,385	11.13	8.36
600	2,210	12.47	8.78
700	2,895	13.66	9.53
800	3,715	14.75	10.12
900	4,570	15.76	10.67
1,000	5,450	16.69	11.24
1,100	6,890	18.09	11.82
1,200	7,795	18.87	12.37
1,300	8,715	19.61	12.91
1,400	10,220	20.72	13.56
1,500	11,780	21.80	13.95
1,600	16,380	24.82	14.58
1,700	17,480	25.49	15.21
1,800	18,580	26.12	15.80
1,900	19,680	26.71	16.35
2,000	20.780	27.28	16.89
2,500	79,190	52.09	20.41

Manganese Oxide, MnO (*c*)

$\Delta H^{\circ}_{298}=-92{,}050$ calories per mole (*124*)
$S_{298}=14.27$ *e.u.* (*135*)
$M.P.=2{,}058°$ K. (*94*)
$\Delta H_M=13{,}000$ calories per mole
$B.P.=3{,}400°$ K. (*8*)

Zone I (*c*) (298°–1,800° K.)

$$C_p=11.11+1.94\times10^{-3}T-0.88\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-3{,}690+11.11T+0.97\times10^{-3}T^2+0.88\times10^{5}T^{-1}$$

Formation: $Mn+1/2O_2\longrightarrow MnO$

Zone I (298°–1,000° K.)

$$\Delta C_p=1.83-1.94\times10^{-3}T-0.31\times10^{5}T^{-2}$$
$$\Delta H_T=-92{,}600+1.83T-0.97\times10^{-3}T^2+0.31\times10^{5}T^{-1}$$
$$\Delta F_T=-92{,}600-1.83T\ln T+0.97\times10^{-3}T^2+0.15\times10^{5}T^{-1}+29.6T$$

Zone II (1,000°–1,374° K.)

$$\Delta C_p=-0.80+0.78\times10^{-3}T-0.68\times10^{5}T^{-2}$$
$$\Delta H_T=-92{,}950-0.80T+0.39\times10^{-3}T^2+0.68\times10^{5}T^{-1}$$
$$\Delta F_T=-92{,}950+0.80T\ln T-0.39\times10^{-3}T^2+0.34\times10^{5}T^{-1}+13.15T$$

Zone III (1,374°–1,410° K.)

$$\Delta C_p=-3.17+1.44\times10^{-3}T-0.68\times10^{5}T^{-2}$$
$$\Delta H_T=-89{,}800-3.17T+0.72\times10^{-3}T^2+0.68\times10^{5}T^{-1}$$
$$\Delta F_T=-89{,}800+3.17T\ln T-0.72\times10^{-3}T^2+0.34\times10^{5}T^{-1}-5.97T$$

Zone IV (1,410°–1,517° K.)

$$\Delta C_p=-3.77+1.44\times10^{-3}T-0.68\times10^{5}T^{-2}$$
$$\Delta H_T=-89{,}480-3.77T+0.72\times10^{-3}T^2+0.68\times10^{5}T^{-1}$$
$$\Delta F_T=-89{,}480+3.77T\ln T-0.72\times10^{-3}T^2+0.34\times10^{5}T^{-1}-10.63T$$

Zone V (1,517°–1,800° K.)

$$\Delta C_p = -3.47 + 1.44\times10^{-3}T - 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -93{,}400 - 3.47T + 0.72\times10^{-3}T^2 + 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -93{,}400 + 3.47T\ln T - 0.72\times10^{-3}T^2 + 0.34\times10^{5}T^{-1} - 5.79T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		14.27	−92,050	−86,750
400	1,130	17.53	−92,000	−84,950
500	2,280	20.09	−91,900	−83,200
600	3,470	22.26	−91,900	−81,550
700	4,680	24.13	−91,750	−79,700
800	5,900	25.76	−91,750	−78,000
900	7,150	27.23	−91,750	−76,300
1,000	8,430	28.54	−91,800	−74,550
1,100	8,750	29.83	−93,300	−72,750
1,200	11,100	31.01	−92,250	−71,000
1,300	12,470	32.01	−92,250	−69,100
1,400	13,840	33.12	−92,800	−67,450
1,500	15,210	34.07	−93,450	−65,600
1,600	16,590	34.96	−97,050	−63,500
1,700	17,970	35.79	−97,250	−61,450
1,800	19,350	36.58	−97,400	−59,450

Trimanganese Tetraoxide, Mn_3O_4 (*c*)

$\Delta H_{298}^\circ = -331{,}400$ calories per mole (*115*)
$S_{298} = 35.5$ *e.u.* (*83*)
$T.P. = 1{,}445°$ K. (*82*)
$\Delta H_T = 4{,}970$ calories per mole
$M.P. = 1{,}863°$ K. (*8*)
$\Delta H_M = (39{,}000)$ calories per mole (*42*)

Zone I (α) (298°–1,445° K.)

$$C_p = 34.64 + 10.82\times10^{-3}T - 2.20\times10^{5}T^{-2}\ (82)$$
$$H_T - H_{298} = -11{,}550 + 34.64T + 5.41\times10^{-3}T^2 + 2.20\times10^{5}T^{-1}$$

Zone II (β) (1,445°–1,800° K.)

$$C_p = 50.20\ (82)$$
$$H_T - H_{298} = -17{,}600 + 50.20T$$

Formation: $3Mn + 2O_2 \longrightarrow Mn_3O_4$

Zone I (298°–1,000° K.)

$$\Delta C_p = 3.22 - 1.32\times10^{-3}T - 0.29\times10^{5}T^{-2}$$
$$\Delta H_T = -332{,}400 + 3.22T - 0.66\times10^{-3}T^2 + 0.29\times10^{5}T^{-1}$$
$$\Delta F_T = -332{,}400 - 3.22T\ln T + 0.66\times10^{-3}T^2 + 0.15\times10^{5}T^{-1} + 106.75T$$

Zone II (1,000°–1,374° K.)

$$\Delta C_p = -4.67 + 6.84\times10^{-3}T - 1.40\times10^{5}T^{-2}$$
$$\Delta H_T = -330{,}600 - 4.67T + 3.42\times10^{-3}T^2 + 1.40\times10^{5}T^{-1}$$
$$\Delta F_T = -330{,}600 + 4.67T\ln T - 3.42\times10^{-3}T^2 + 0.70\times10^{5}T^{-1} + 54.40T$$

Zone III (1,374°–1,410° K.)

$$\Delta C_p = -11.78 + 8.82\times10^{-3}T - 1.40\times10^{5}T^{-2}$$
$$\Delta H_T = -324{,}130 - 11.78T + 4.41\times10^{-3}T^2 + 1.40\times10^{5}T^{-1}$$
$$\Delta F_T = -324{,}130 + 11.78T\ln T - 4.41\times10^{-3}T^2 + 0.70\times10^{5}T^{-1} - 0.14T$$

Zone IV (1,410°–1,445° K.)

$$\Delta C_p = -13.58 + 8.82\times10^{-3}T - 1.40\times10^{5}T^{-2}$$
$$\Delta H_T = -321{,}600 - 13.58T + 4.41\times10^{-3}T^2 + 1.40\times10^{5}T^{-1}$$
$$\Delta F_T = -321{,}600 + 13.58T\ln T - 4.41\times10^{-3}T^2 + 0.70\times10^{5}T^{-1} - 15.43T$$

Zone V (1,445°–1,517° K.)

$$\Delta C_p = 2.0 - 2.00\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -329{,}100 + 2.0T - 1.00\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -329{,}100 - 2.0T\ln T + 1.00\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 95.46T$$

Zone VI (1,517°–1,800° K.)

$$\Delta C_p = 2.88 - 2.00\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -340{,}700 + 2.88T - 1.00\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -340{,}700 - 2.88T\ln T + 1.00\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 109.88T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		35.5	−331,400	−308,100
400	3,730	46.25	−331,200	−297,300
500	7,590	54.86	−330,900	−288,850
600	11,590	62.15	−330,850	−280,800
700	15,740	68.54	−330,300	−272,200
800	19,980	74.20	−330,150	−263,900
900	24,250	79.23	−330,050	−255,600
1,000	28,570	83.78	−330,050	−247,350
1,100	33,020	88.02	−331,450	−238,750
1,200	37,650	92.05	−331,200	−230,400
1,300	42,510	95.93	−330,800	−221,950
1,400	47,620	99.72	−331,900	−213,650
1,500	57,690	106.68	−328,400	−205,300
1,600	62,710	109.92	−338,600	−196,250
1,700	67,730	112.96	−338,800	−187,600
1,800	72,750	115.84	−338,850	−179,100

Dimanganese Trioxide, Mn_2O_3 (*c*)

$\Delta H_{298}^\circ = -229{,}200$ calories per mole (*8*)
$S_{298} = 26.4$ *e.u.* (*91*)
Decomposes = 1,620° K. (*42*)

Zone I (*c*) (298°–1,350° K.)

$$C_p = 24.73 + 8.38\times10^{-3}T - 3.23\times10^{5}T^{-2}\ (106)$$
$$H_T - H_{298} = -8{,}830 + 24.73T + 4.19\times10^{-3}T^2 + 3.23\times10^{5}T^{-1}$$

Formation: $2Mn + 3/2O_2 \longrightarrow Mn_2O_3$

Zone I (298°–1,000° K.)

$$\Delta C_p = 2.59 + 0.12\times10^{-3}T - 1.89\times10^{5}T^{-2}$$
$$\Delta H_T = -230{,}600 + 2.59T + 0.06\times10^{-3}T^2 + 1.89\times10^{5}T^{-1}$$
$$\Delta F_T = -230{,}600 - 2.59T\ln T - 0.06\times10^{-3}T^2 + 0.94\times10^{5}T^{-1} + 80.7T$$

Zone II (1,000°–1,350° K.)

$$\Delta C_p = -2.67 + 5.56\times10^{-3}T - 2.63\times10^{5}T^{-2}$$
$$\Delta H_T = -229{,}210 - 2.67T + 2.78\times10^{-3}T^2 + 2.63\times10^{5}T^{-1}$$
$$\Delta F_T = -229{,}210 + 2.67T\ln T - 2.78\times10^{-3}T^2 + 1.31\times10^{5}T^{-1} + 50.84T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		26.4	−229,200	−210,650
300	2,550	33.73	−229,200	−204,350
400	5,220	39.68	−228,900	−198,050
500	8,040	44.82	−228,900	−192,150
600	10,990	49,37	−228,500	−185,850
700	14,040	53.44	−228,300	−179,800
800	17,190	57.15	−228,050	−173,900
900	20,420	60.55	−227,800	−167,650
1,000	23,740	63.71	−228,550	−161,450
1,100	27,150	66.68	−228,200	−155,450
1,200	30,650	69.48	−227,900	−149,450
1,300			(−228,700)	(−143,400)
1,400			(−229,500)	(−137,300)
1,500			(−236,300)	(−130,700)

Manganese Dioxide, MnO_2 (*c*)

$\Delta H_{298}^\circ = -124{,}450$ calories per mole (*24*)
$S_{298} = 12.68$ *e.u.* (*83*)
Decomposes = 1,120° K. (*8*)

Zone I (*c*) (298°–800° K.)

$$C_p = 16.60 + 2.44\times10^{-3}T - 3.88\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -6{,}360 + 16.60T + 1.22\times10^{-3}T^2 + 3.88\times10^{5}T^{-1}$$

Formation: $Mn + O_2 \longrightarrow MnO_2$

Zone I (298°–800° K.)

$$\Delta C_p = 3.74 - 1.94\times10^{-3}T - 3.11\times10^{5}T^{-2}$$
$$\Delta H_T = -126{,}620 + 3.74T - 0.97\times10^{-3}T^2 + 3.11\times10^{5}T^{-1}$$
$$\Delta F_T = -126{,}620 - 3.74T\ln T + 0.97\times10^{-3}T^2 + 1.55\times10^{5}T^{-1} + 70.21T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		12.68	−124,450	−111,350
400	1,450	16.84	−124,400	−106,900
500	3,020	20.35	−124,350	−102,600
600	4,690	23.38	−124,200	−98,250
700	6,410	26.04	−124,000	−93,900
800	8,190	28.41	−123,850	−89,650
900	(10,000)		(−123,700)	(−85,350)
1,000	(11,850)		(−123,550)	(−81,150)
1,100	(13,730)		(−123,200)	(−77,000)

Manganese Difluoride, MnF_2 (*c*)

$\Delta H_{298}^\circ = -190{,}000$ calories per mole (*11*)
$S_{298} = 22.3$ *e.u.* (*11*)
$M.P.$ = 1,129° K. (*6*)
ΔH_M = (5,500) calories per mole
$B.P.$ = (2,300°) K. (*6*)
ΔH_V = (57,000) calories per mole

Formation: $Mn + F_2 \longrightarrow MnF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−190,000	−180,000
500	(3,500)	(−189,500)	(−173,000)
1,000	(13,000)	(−188,300)	(−157,000)
1,500	(30,000)	(−182,000)	(−146,500)

Manganese Trifluoride, MnF_3 (*c*)

$\Delta H_{298}^\circ = -238{,}000$ calories per mole (*11*)
$S_{298} = (28)$ *e.u.* (*11*)
$M.P.$ = (1,350°) K. (*6*)
ΔH_M = (11,000) calories per mole
$B.P.$ = (1,600°) K. (*6*)
ΔH_V = (42,000) calories per mole

Formation: $Mn + 3/2F_2 \longrightarrow MnF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−238,000	(−222,200)
500	(5,000)	(−236,800)	(−210,500)
1,000			(−191,000)

Manganese Dichloride, $MnCl_2$ (*c*)

$\Delta H_{298}^\circ = -115{,}190$ calories per mole (*92*)
$S_{298} = 28$ *e.u.* (*83*)
$M.P.$ = 923° K. (*82*)
ΔH_M = 8,970 calories per mole
$B.P.$ = 1,463° K. (*6*)
ΔH_V = 29,600 calories per mole

Zone I (*c*) (298°–923° K.)

$$C_p = 18.04 + 3.16\times10^{-3}T - 1.37\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -6{,}000 + 18.04T + 1.58\times10^{-3}T^2 + 1.37\times10^{5}T^{-1}$$

Zone II (*l*) (923°–1,200° K.)

$$C_p = 22.60 \quad (82)$$
$$H_T - H_{298} = +280 + 22.60T$$

Formation: $Mn + Cl_2 \longrightarrow MnCl_2$

Zone I (298°–923° K.)

$$\Delta C_p = 3.52 - 0.28\times10^{-3}T - 0.32\times10^{5}T^{-2}$$
$$\Delta H_T = -116{,}350 + 3.52T - 0.14\times10^{-3}T^2 + 0.32\times10^{5}T^{-1}$$
$$\Delta F_T = -116{,}350 - 3.52T\ln T + 0.14\times10^{-3}T^2 + 0.16\times10^{5}T^{-1} + 58.5T$$

Zone II (923°–1,000° K.)

$$\Delta C_p = 8.08 - 3.44\times10^{-3}T + 1.05\times10^{5}T^{-2}$$
$$\Delta H_T = -110{,}100 + 8.08T - 1.72\times10^{-3}T^2 - 1.05\times10^{5}T^{-1}$$
$$\Delta F_T = -110{,}100 - 8.08T\ln T + 1.72\times10^{-3}T^2 - 0.52\times10^{5}T^{-1} + 79.81T$$

Zone III (1,000°–1,200° K.)

$$\Delta C_p = 5.45 - 0.72\times10^{-3}T + 0.68\times10^{5}T^{-2}$$
$$\Delta H_T = -109{,}280 + 5.45T - 0.36\times10^{-3}T^2 - 0.68\times10^{5}T^{-1}$$
$$\Delta F_T = -109{,}280 - 5.45T\ln T + 0.36\times10^{-3}T^2 - 0.34\times10^{5}T^{-1} + 62.33T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		28.0	−115,190	−105,100
400	1,850	33.33	−114,900	−102,050
500	3,730	37.52	−114,550	−98,850
600	5,640	41.0	−114,300	−95,850
700	7,590	44.01	−113,900	−92,750
800	9,600	46.69	−113,600	−89,650
900	11,680	49.14	−113,250	−86,800
1,000	22,880	61.21	−103,850	−84,500
1,100	25,140	63.36	−103,750	−82,550
1,200	27,400	65.33	−103,400	−80,750
1,300	(29,400)	(67.2)	(−103,150)	(−79,150)
1,400	(31,650)	(68.8)	(−102,400)	(−76,250)

Manganese Trichloride, $MnCl_3$ (*c*)

$\Delta H^\circ_{298} = -110{,}000$ calories per mole (*11*)
$S_{298} = (39)$ *e.u.* (*11*)
B.P. = (900°) K. (*6*)
$\Delta H_V = (21{,}000)$ calories per mole

Formation: $Mn + 3/2Cl_2 \longrightarrow MnCl_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−110, 000	(−95, 400)
500	(5, 000)	(−108, 900)	(−85, 500)

Manganese Dibromide, $MnBr_2$ (*c*)

$\Delta H^\circ_{298} = -88{,}700$ calories per mole (*11*)
$S_{298} = (32)$ *e.u.* (*11*)
M.P. = 971° K. (*6*)
$\Delta H_M = (7{,}000)$ calories per mole
B.P. = (1,300°) K. (*6*)
$\Delta H_V = (27{,}000)$ calories per mole

Formation: $Mn + Br_2 \longrightarrow MnBr_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−88, 700	(−85, 100)
500	(4, 000)	(−95, 600)	(−79, 000)
1,000	(23, 000)	(−85, 100)	(−64, 000)
1,500	(62, 000)	(−57, 000)	(−54, 000)

Manganese Diiodide, MnI_2 (*c*)

$\Delta H^\circ_{298} = -57{,}100$ calories per mole (*11*)
$S_{298} = (35)$ *e.u.* (*11*)
M.P. = 911° K. (*6*)
$\Delta H_M = (6{,}500)$ calories per mole
B.P. = (1,100°) K. (*6*)
$\Delta H_V = (23{,}000)$ calories per mole

Formation: $Mn + I_2 \longrightarrow MnI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−57, 100	(−57, 000)
500	(4, 000)	(−69, 100)	(−54, 500)
1,000	(23, 000)	(−60, 700)	(−40, 000)
1,500	(58, 000)	(−36, 500)	(−30, 000)

Trimanganese Carbide, Mn_3C (*c*)

$\Delta H^\circ_{298} = -3{,}600$ calories per mole (*89*)
$S_{298} = 23.7$ *e.u.* (*81*)
T.P. = 1,310° K. (*82*)
$\Delta H_T = 3{,}570$ calories per mole
M.P. = 1,480° K. (*9*)

Zone I (α) (298°-1,310° K.)

$$C_p = 25.26 + 5.60\times10^{-3}T - 4.07\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -9{,}145 + 25.26T + 2.80\times10^{-3}T^2 + 4.07\times10^{5}T^{-1}$$

Zone II (β) (1,310°–1,480° K.)

$$C_p = 38.00 \quad (82)$$
$$H_T - H_{298} = -17{,}150 + 38.00T$$

Formation: $3Mn + C \longrightarrow Mn_3C$

Zone I (298°-1,000° K.)

$$\Delta C_p = 4.06 - 5.56\times10^{-3}T - 0.86\times10^{5}T^{-2}$$
$$\Delta H_T = -4{,}840 + 4.06T - 2.78\times10^{-3}T^2 + 0.86\times10^{5}T^{-1}$$
$$\Delta F_T = -4{,}840 - 4.06T\ lnT + 2.78\times10^{-3}T^2 + 0.43\times10^{5}T^{-1} + 26.42T$$

Zone II (1,000-1,310° K.)

$$\Delta C_p = -3.83 + 2.60\times10^{-3}T - 2.0\times10^{5}T^{-2}$$
$$\Delta H_T = -2{,}740 - 3.83T + 1.30\times10^{-3}T^2 + 2.0\times10^{5}T^{-1}$$
$$\Delta F_T = -2{,}740 + 3.83T\ lnT - 1.30\times10^{-3}T^2 + 1.0\times10^{5}T^{-1} - 26.15T$$

Zone III (1,310–1,374° K.)

$$\Delta C_p = 9.0 - 3.00\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = -12{,}600 + 9.0T - 1.50\times10^{-3}T^2 + 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = -12{,}600 - 9.0T\ lnT + 1.50\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} + 69.4T$$

Zone IV (1,374°–1,410° K.)

$$\Delta C_p = 1.8 - 1.02\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = -4{,}550 + 1.8T - 0.51\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = -4{,}550 - 1.8T\ lnT + 0.51\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} + 13.4T$$

Zone V (1,410°–1,480° K.)

$$\Delta C_p = -1.02\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = -3{,}300 - 0.51\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = -3{,}300 + 0.51\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} - 0.65T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		23. 7	−3, 600	−3, 500
400	2, 450	30. 75	−3, 450	−3, 450
500	5, 020	36. 48	−3, 300	−3, 450
600	7, 700	41. 37	−3, 500	−3, 600
700	10, 490	45. 66	−3, 150	−3, 600
800	13, 350	49. 48	−3, 200	−3, 600
900	16, 300	52. 95	−3, 300	−3, 600
1, 000	19, 320	56. 14	−3, 450	−3, 600
1, 100	22, 400	59. 07	−5, 200	−3, 600
1, 200	25, 540	61. 8	−5, 300	−3, 400
1, 300	28, 740	64. 36	−5, 400	−3, 250
1, 400	36, 050	69. 86	−3, 150	−3, 200
1, 500	39, 850	72. 48	−4, 600	−3, 200

Tetramanganese Nitride, Mn_4N (*c*)

$\Delta H^\circ_{298} = -30{,}300$ calories per mole (*97*)

Zone I (*c*) (298°–800° K.)

$$C_p = 21.15 + 30.50\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -7{,}661 + 21.15T + 15.25\times10^{-3}T^2$$

Formation: $4Mn + 1/2N_2 \longrightarrow Mn_4N$

T, ° K.	H_T-H_{298}	$S_T=S_{298}$	ΔH_T°
298			−30,300
400	3,250	9.36	−30,150
500	6,720	17.10	−29,800
600	10,520	24.02	−29,700
700	14,640	30.35	−28,700
800	19,000	36.17	−27,950

Pentamanganese Dinitride, Mn_5N_2 (*c*)

$\Delta H_{298}^\circ=-48{,}200$ calories per mole (*97*)
$S_{298}=47.3$ *e.u.* (*9*)

Zone I (*c*) (298°-800° K.)

$C_p=30.55+38.40\times10^{-3}T$ (*82*)
$H_T-H_{298}=-10{,}800+30.55T+19.20\times10^{-3}T^2$

Formation: $5Mn+N_2\longrightarrow Mn_5N_2$

Zone I (298°–800° K.)

$\Delta C_p=-4.61+20.48\times10^{-3}T+1.85\times10^5T^{-2}$
$\Delta H_T=-56{,}800-4.61T+10.24\times10^{-3}T^2-1.85\times10^5T^{-1}$
$\Delta F_T=-56{,}800+4.61T\ln T-10.24\times10^{-3}T^2-0.92\times10^5T^{-1}+10.67T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		47.3	−48,200	−37,350
400	4,480	60.2	−47,900	−33,700
500	9,240	70.81	−47,300	−30,200
600	14,460	80.32	−46,900	−27,250
700	20,040	88.91	−45,500	−23,650
800	25,840	97.65	−44,100	−20,600

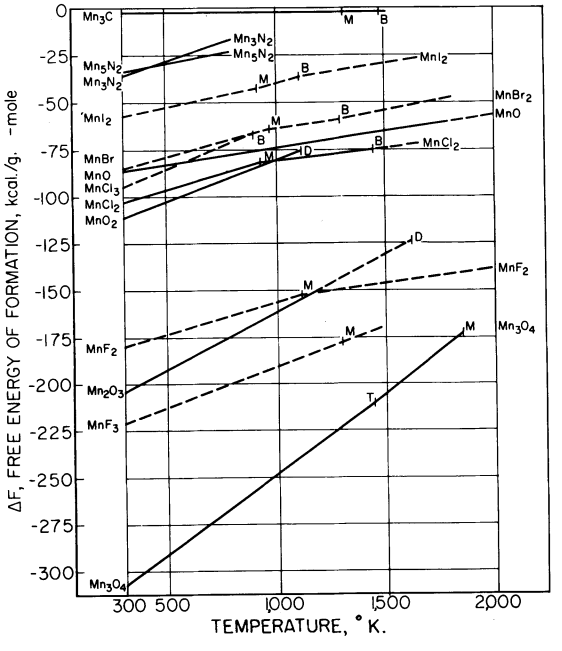


FIGURE 32.—Manganese.

Trimanganese Dinitride, Mn_3N_2 (*c*)

$\Delta H_{298}^\circ=-45{,}800$ calories per mole (*9*)
$S_{298}=32.7$ *e.u.* (*9*)

Zone I (*c*) (298°–800° K.)

$C_p=22.32+22.40\times10^{-3}T$ (*82*)
$H_T-H_{298}=-7{,}650+22.32T+11.20\times10^{-3}T^2$

Formation: $3Mn+N_2\longrightarrow Mn_3N_2$

Zone I (298°–800° K.)

$\Delta C_p=-1.44+11.24\times10^{-3}T+1.11\times10^5T^{-2}$
$\Delta H_T=-45{,}500+1.44T+5.62\times10^{-3}T^2-1.11\times10^5T^{-1}$
$\Delta F_T=-45{,}500+1.44T\ln T-5.62\times10^{-3}T^2-0.55\times10^5T^{-1}+28.86T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		32.7	−45,800	−35,150
400	3,070	41.55	−45,500	−31,500
500	6,300	48.75	−45,050	−28,050
600	9,750	55.03	−44,800	−24,950
700	13,470	60.76	−43,900	−21,500
800	17,350	65.94	−43,200	−18,300

MERCURY AND ITS COMPOUNDS

Element, Hg (*l*)

$S_{298}=18.19$ *e.u.* (*130*)
$M.P.=234.29°$ K. (*130*)
$\Delta H_M=549$ calories per atom
$B.P.=629.88°$ K. (*130*)
$\Delta H_V=14{,}137$ calories per atom

Zone I (*l*) (298°–630° K.)

$C_p=6.61$ (*82*)
$H_T-H_{298}=-1{,}971+6.61T$
$F_T-H_{298}=-1{,}971-6.61T\ln T+26.08T$

Zone II (*g*) (630°–3,000° K.)

$C_p=4.969$ (*82*)
$H_T-H_{298}=13{,}055+4.969T$
$F_T-H_{298}=13{,}055-4.969T\ln T-8.21T$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		18.19	18.19
400	673	20.13	18.45
500	1,335	21.61	18.94
600	1,995	22.81	19.48
700	16,535	45.73	22.10
800	17,030	46.39	25.10
900	17,525	46.97	27.50
1,000	18,025	47.50	29.47
1,100	18,521	47.97	31.13
1,200	19,020	48.41	32.56
1,300	19,515	48.81	34.57
1,400	20,010	49.18	35.19
1,500	20,509	49.52	35.85
1,600	21,005	49.84	36.71
1,700	21,502	50.14	37.49
1,800	22,000	50.43	38.21
1,900	22,496	50.70	38.86
2,000	22,995	50.95	39.45

Dimercury Oxide, Hg_2O (*c*)

$\Delta H_{298}^\circ=-21{,}800$ calories per mole (*112*)
$S_{298}=(31.4)$ *e.u.* (*24*)

Formation: $2Hg+1/2O_2\longrightarrow Hg_2O$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−21, 800	(−13, 000)
400	(2, 000)	(−21, 500)	(−10, 000)
500	(3, 700)	(−21, 500)	(−7, 000)
600	(5, 900)	(−21, 000)	(−4, 000)
700	(7, 350)	(−49, 000)	(2, 000)
800	(9. 750)	(−48, 000)	(9, 000)
900	(11, 650)	(−47, 500)	(16, 000)
1,000	(13, 550)	(−47, 000)	(23, 000)

Mercury Oxide, HgO (*c*)

$\Delta H^\circ_{298}=-21{,}680$ calories per mole (*112*)
$S_{298}=17.2$ *e.u.* (*112*)

Formation: $Hg+1/2O_2\longrightarrow HgO$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−21, 680	−14, 000
400	(1, 150)	(−21, 550)	(−11, 350)
500	(2, 380)	(−21, 350)	(−8, 850)
600	(3, 660)	(−21, 100)	(−6, 350)
700	(4, 870)	(−34, 850)	(−2, 400)
800	(6, 250)	(−34, 350)	(+2, 250)
900	(7, 700)	(−33, 800)	(+6, 800)
1,000	(9, 200)	(−33, 200)	(+11, 250)
1,100	(10, 700)	(−32, 600)	(+15, 650)
1,200	(12, 300)	(−31, 900)	(+20, 050)
1,300	(14, 050)	(−31, 150)	(+24, 350)
1,400	(15, 680)	(−30, 350)	(+28, 600)
1,500	(17, 490)	(−29, 550)	(+32, 750)

Mercury Fluoride, HgF (*c*)

$\Delta H^\circ_{298}=-46{,}000$ calories per mole (*11*)
$S_{298}=22$ *e.u.* (*11*)
M.P.=843° K. (*6*)
Decomposes to $Hg+HgF_2$ (*6*)

Formation: $Hg+1/2F_2\longrightarrow HgF$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−46, 000	−40, 000
500	(3, 000)	(−45, 000)	(−35, 000)

Mercury Difluoride, HgF_2 (*c*)

$\Delta H^\circ_{298}=-95{,}000$ calories per mole (*11*)
$S_{298}=(28)$ *e.u.* (*11*)
M.P.=918° K. (*6*)
$\Delta H_M=(5{,}500)$ calories per mole
B.P.=920° K. (*6*)
$\Delta H_V=(22{,}000)$ calories per mole

Formation: $Hg+F\longrightarrow HgF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−95, 000	(−83, 000)
500	(4, 000)	(−94, 000)	(−75, 000)

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Mercury Chloride, HgCl (*c*)

$\Delta H^\circ_{298}=-31{,}600$ calories per mole (*11*)
$S_{298}=23.5$ *e.u.* (*83*)
M.P.=816° K. (*6*)
Decomposes to $Hg+HgCl_2$

Zone I (*c*) (298°–800° K.)

$$C_p=11.05+3.70\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-3{,}457+11.05T+1.85\times10^{-3}T^2$$

Formation: $Hg+1/2Cl_2\longrightarrow HgCl$

Zone I (298°–630° K.)

$$\Delta C_p=+0.03+3.67\times10^{-3}T+0.34\times10^5T^{-2}$$
$$\Delta H_T=-31{,}650+0.03T+1.83\times10^{-3}T^2-0.34\times10^5T^{-1}$$
$$\Delta F_T=-31{,}650-0.03T\ln T-1.83\times10^{-3}T^2-0.17\times10^5T^{-1}+22.44T$$

Zone II (630°–800° K.)

$$\Delta C_p=1.67+3.67\times10^{-3}T+0.34\times10^5T^{-2}$$
$$\Delta H_T=-46{,}670+1.67T+1.83\times10^{-3}T^2-0.34\times10^5T^{-1}$$
$$\Delta F_T=-46{,}670-1.67T\ln T-1.83\times10^{-3}T^2-0.17\times10^5T^{-1}+56.73T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		23. 5	−31, 600	−25, 250
400	1, 260	27. 13	−31, 350	−22, 950
500	2, 530	29. 97	−31, 250	−21, 000
600	3, 840	32. 36	−31, 000	−19, 009
700	5, 185	34. 43	−45, 650	−16, 550
800	6, 565	36. 27	−44, 200	−11, 350

Mercury Dichloride, $HgCl_2$ (*c*)

$\Delta H^\circ_{298}=-53{,}400$ calories per mole (*11*)
$S_{298}=34.5$ *e.u* (*83*)
M.P.=550° K. (*6*)
$\Delta H_M=4{,}150$ calories per mole
B.P.=557° K. (*6*)
$\Delta H_V=14{,}080$ calories per mole

Zone I (*c*) (298°–550° K.)

$$C_p=15.28+10.4\times10^{-3}T \text{ (110)}$$
$$H_T-H_{298}=-5{,}015+15.28T+5.2\times10^{-3}T^2$$

Zone II (*g*) (557°–1,000° K.)

$$C_p=14.66+0.26\times10^3T-0.75\times10^5T^{-2} \text{ (110)}$$
$$H_T-H_{298}\leqq15{,}220+14.66T+0.13\times10^{-3}T^2+0.75\times10^5T^{-1}$$

Formation: $Hg+Cl_2\longrightarrow HgCl_2$

Zone I (298°–550° K.)

$$\Delta C_p=-0.15+10.34\times10^{-3}T+0.68\times10^5T^{-2}$$
$$H_T=-53{,}600-0.15T+5.17\times10^{-3}T^2-0.68\times10^5T^{-1}$$
$$\Delta F_T=-53{,}600+0.15T\ln T-5.17\times10^{-3}T^2-0.34\times10^5T^{-1}+38.70T$$

Zone II (557°–630° K.)

$$\Delta C_p=-0.77+0.2\times10^{-3}T-0.07\times10^5T^{-2}$$
$$\Delta H_T=-33{,}335-0.77T+0.10\times10^{-3}T^2+0.07\times10^5T^{-1}$$
$$\Delta F_T=-33{,}335+0.77T\ln T-0.10\times10^{-3}T^2+0.035\times10^5T^{-1}-4.88T$$

Zone III (630°–1,000° K.).

$$\Delta C_p=+0.87+0.20\times10^{-3}T-0.07\times10^5T^{-2}$$
$$\Delta H_T=-48{,}350+0.87T+0.10\times10^{-3}T^2+0.07\times10^5T^{-1}$$
$$\Delta F_T=-48{,}350-0.87T\ln T-0.10\times10^{-3}T^2+0.035\times10^5T^{-1}+29.45T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		34.5	−53,400	−42,370
400	1,825	40.05	−53,100	−38,700
500	3,825	44.51	−52,600	−35,200
600	24,190	81.41	−33,750	−33,350
700	25,650	83.67	−47,500	−31,650
800	27,125	85.64	−47,600	−29,500
900	28,600	87.37	−47,500	−27,350
1,000	30,085	88.94	−47,400	−25,000

Mercury Bromide, HgBr (*c*)

$\Delta H^\circ_{298}=-24{,}470$ calories per mole (*83*)
$S_{298}=26.7$ *e.u.* (*83*)
$M.P.=680°$ K. (*6*)
Decomposes to $Hg+HgBr_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−24,470	−21,200
500	(3,000)	(−27,450)	(−16,600)

Mercury Dibromide, $HgBr_2$ (*c*)

$\Delta H^\circ_{298}=-40{,}500$ calories per mole (*106*)
$S_{298}=38.9$ *e.u.* (*80*)
$M.P.=514°$ K. (*6*)
$\Delta H_M=3{,}960$ calories per mole
$B.P.=592°$ K. (*6*)
$\Delta H_V=14{,}080$ calories per mole

Formation: $Hg+Br_2\longrightarrow HgBr_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−40,500	−35,900
500	(4,000)	(−47,350)	(−34,000)

Mercury Iodide, HgI (*c*)

$\Delta H^\circ_{298}=-14{,}455$ calories per mole (*112*)
$S_{298}=28.6$ *e.u.* (*112*)
$M.P.=563°$ K. (*6*)
Decomposes to $Hg+HgI_2$

Zone I (*c*) (298°–563° K.)

$$C_p=11.40+4.61\times10^{-3}T \text{ (110)}$$
$$H_T-H_{298}=-3{,}600+11.40T+2.30\times10^{-3}T^2$$

Formation: $Hg+1/2I_2\longrightarrow HgI$

Zone I (298°–386.8° K.)

$$\Delta C_p=-1.34\times10^{-3}T$$
$$\Delta H_T=-14{,}400-0.67\times10^{-3}T^2$$
$$\Delta F_T=-14{,}400+0.67\times10^{-3}T^2+8.14T$$

Zone II (386.8°–456° K.)

$$\Delta C_p=-4.81+4.61\times10^{-3}T$$
$$\Delta H_T=-14{,}910-4.81T+2.30\times10^{-3}T^2$$
$$\Delta F_T=-14{,}910+4.81T\ln T-2.30\times10^{-3}T^2-23.16T$$

Zone III (456°–563° K.)

$$\Delta C_p=0.35+4.61\times10^{-3}T$$
$$\Delta H_T=-22{,}200+0.35T+2.30\times10^{-3}T^2$$
$$\Delta F_T=-22{,}200-0.35T\ln T-2.30\times10^{-3}T^2+13.52T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		28.6	−14,450	−11,900
400	1,328	32.42	−16,450	−13,000
500	2,675	35.43	−21,450	−17,100

Mercury Diiodide, HgI_2 (*c*)

$\Delta H^\circ_{298}=-25{,}200$ calories per mole (*112*)
$S_{298}=40.8$ *e.u.* (*83*)
$T.P.=403°$ K. (*82*)
$\Delta H_T=650$ calories per mole
$M.P.=523°$ K. (*82*)
$\Delta H_M=4{,}500$ calories per mole
$B.P.=627°$ K. (*82*)
$\Delta H_V=14{,}263$ calories per mole

Zone I (α) (298°–403° K.)

$$C_p=18.50 \text{ (82)}$$
$$H_T-H_{298}=-5{,}516+18.50T$$

Zone II (β) (403°–523° K.)

$$C_p=20.20 \text{ (82)}$$
$$H_T-H_{298}=5{,}550+20.20T$$

Zone III (l) (523°–627° K.)

$$C_p=25.0 \text{ (82)}$$
$$H_T-H_{298}=3{,}560+25.0T$$

Zone IV (g) (627°–1,000° K.)

$$C_p=14.90-0.27\times10^5T^{-2} \text{ (82)}$$
$$H_T-H_{298}=+16{,}993+14.90T+0.27\times10^5T^{-1}$$

Formation: $Hg+I_2\longrightarrow HgI_2$

Zone I (298°–386° K.)

$$\Delta C_p=2.30-11.90\times10^{-3}T$$
$$\Delta H_T=-25{,}357+2.30T-5.95\times10^{-3}T^2$$
$$\Delta F_T=-25{,}357-2.30T\ln T+5.95\times10^{-3}T^2+17.14T$$

Zone II (386.1°–403° K.)

$$\Delta C_p=-7.31$$
$$\Delta H_T=-26{,}300-7.31T$$
$$\Delta F_T=-26{,}300+7.31T\ln T-35.41T$$

Zone III (456°–523° K.)

$$\Delta C_p=4.7$$
$$\Delta H_T=-41{,}000+4.7T$$
$$\Delta F_T=-41{,}000-4.7T\ln T+70.22T$$

Zone IV (523°–627° K.)

$$\Delta C_p=9.5$$
$$\Delta H_T=-39.015+9.5T$$
$$\Delta F_T=-39{,}015-9.5T\ln T+96.45T$$

Zone V (630°–1,000° K.)

$$\Delta C_p=1.04-0.27\times10^5T^{-2}$$
$$\Delta H_T=-33{,}500+1.04T+0.27\times10^5T^{-1}$$
$$\Delta F_T=-33{,}500-1.04T\ln T+0.135\times10^5T^{-1}+32.88T$$

T, ° K.	H_T-H_{298}	S_T	$\Delta H°_T$	ΔF°_T
298		40.8	−25,200	−23,600
400	1,885	46.28	−29,200	−22,950
500	4,550	52.35	−38,650	−20,500
600	11,440	65.3	−33,300	−17,600
700	27,460	90.78	−32,700	−15,200
800	28,950	92.76	−32,600	−12,750
900	30,430	94.50	−32,500	−10,250
1,000	31,920	96.08	−32,400	−7,800

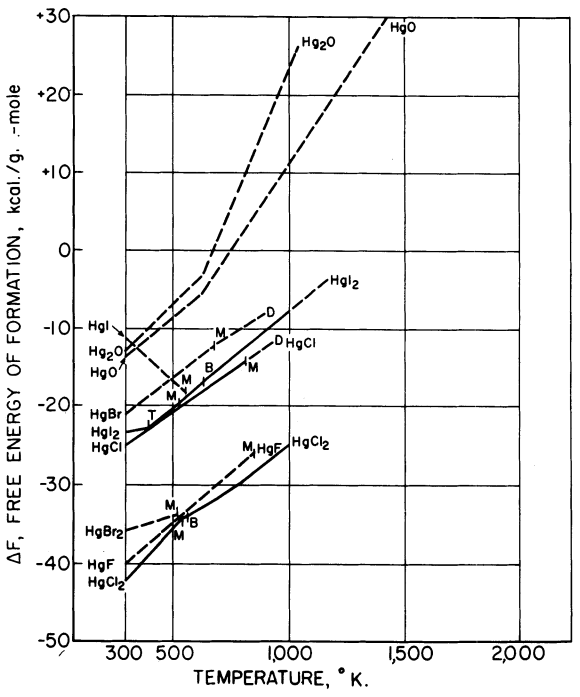

FIGURE 33.—Mercury.

MOLYBDENUM AND ITS COMPOUNDS

Element, Mo (*c*)

$S_{298}=6.83$ *e.u.* (*83*)
M.P.$=2,883°$ K. (*112*)

Zone I (*c*) (298°–1,800° K.)

$$C_p=5.48+1.30\times10^{-3}T$$
$$H_T-H_{298}=-1,690+5.48T+0.65\times10^{-3}T^2$$
$$F_T-H_{298}=-1,690-5.48T\ln T-0.65\times10^{-3}T^2+30.24T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		6.83	6.83
400	610	8.59	7.06
500	1,215	9.95	7.52
600	1,830	11.07	8.02
700	2,460	12.04	8.53
800	3,105	12.90	9.00
900	3,765	13.68	9.48
1,000	4,440	14.39	9.95
1,100	5,125	15.04	10.36
1,200	5,825	15.65	10.80
1,300	6,530	16.21	11.19
1,400	7,250	16.74	11.53
1,500	7,985	17.25	11.91
1,600	8,740	17.74	12.29
1,700	9,510	18.21	12.64
1,800	10,300	18.66	12.96
1,900	(11,075)		(13.27)
2,000	(11,890)		(13.65)
2,500	(16,070)		(14.86)

Molybdenum Dioxide, MoO_2 (*c*)

$\Delta H^\circ_{298}=(-131,000)$ calories per mole (*8*)
$S_{298}=11.06$ *e.u.* (*24*)
M.P.$=>2,500°$ K. (*42*)

Formation: $Mo+O_2\longrightarrow MoO_2$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−131,000)	(−118,300)
400	(4,000)	(−130,500)	(−115,000)
500	(5,800)	(−130,500)	(−111,500)
600	(7,900)	(−130,500)	(−108,000)
700	(10,200)	(−130,000)	(−104,500)
800	(12,400)	(−130,000)	(−101,000)
900	(14,600)	(−130,000)	(−97,500)
1,000	(16,900)	(−129,500)	(−94,000)
1,100	(19,100)	(−129,500)	(−91,000)
1,200	(21,300)	(−129,500)	(−87,500)
1,300	(24,000)	(−129,000)	(−84,000)
1,400	(26,800)	(−129,000)	(−80,500)
1,500	(29,500)	(−129,000)	(−77,000)
1,600	(32,500)	(−128,500)	(−73,500)
1,700	(35,300)	(−128,500)	(−70,000)
1,800	(38,100)	(−128,500)	(−67,000)
1,900	(41,200)	(−128,000)	(−63,500)
2,000	(44,400)	(−128,000)	(−60,000)

Molybdenum Trioxide, MoO_3 (*c*)

$\Delta H^\circ_{298}=-180,330$ calories per mole (*112*)
$S_{298}=18.68$ *e.u.* (*112*)
M.P.$=1,068°$ K. (*112*)
$\Delta H_M=12,540$ calories per mole
B.P.$=1,428°$ K. (*112*)
$\Delta H_V=33,000$ calories per mole

Zone I (*c*) (298°–1,068° K.)

$$C_p=20.07+5.90\times10^{-3}T-3.68\times10^5T^{-2}\ (23)$$
$$H_T-H_{298}=-7,480+20.07T+2.95\times10^{-3}T^2+3.68\times10^5T^{-1}$$

Formation: $Mo+3/2O_2\longrightarrow MoO_3$

Zone I (298°–1,068° K.)

$$\Delta C_p=3.85+3.10\times10^{-3}T-3.08\times10^5T^{-2}$$
$$\Delta H_T=-182,600+3.85T+1.55\times10^{-3}T^2+3.08\times10^5T^{-1}$$
$$\Delta F_T=-182,600-3.85T\ln T-1.55\times10^{-3}T^2+1.54\times10^5T^{-1}+89.7T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		18.68	−180,330	−162,030
400	1,970	24.77	−180,050	−155,500
500	4,020	28.95	−179,700	−149,700
600	6,270	33.30	−179,200	−143,900
700	8,680	36.76	−178,700	−137,900
800	10,960	41.06	−178,150	−132,250
900	13,430	43.00	−177,550	−126,550
1,000	16,550	45.73	−176,850	−120,900
1,100	(31,070)		(−163,700)	(−115,300)
1,200	(33,770)		(−162,950)	(−109,500)
1,300	(36,430)		(−162,250)	(−105,200)
1,400	(39,310)		(−161,350)	(−101,000)
1,500	(75,040)		(−127,650)	(−98,000)
2,000	(90,800)		(−122,600)	(−90,000)

Molybdenum Hexafluoride, MoF_6 (*l*)

$\Delta H^\circ_{298} = -405{,}000$ calories per mole (*112*)
$S_{298} = (77)$ *e.u.* (*42*)
$M.P. = 290°$ K. (*6*)
$\Delta H_M = 2{,}500$ calories per mole
$B.P. = 309°$ K. (*6*)
$\Delta H_V = 6{,}000$ calories per mole

Formation: $Mo + 3F_2 \longrightarrow MoF_6$
(estimated (*42*))

T, ° K.	ΔF°_T
298	(−383,000)
500	(−368,000)
1,000	(−332,000)
1,500	(−297,000)
2,000	(−264,000)

Molybdenum Dichloride, $MoCl_2$ (*c*)

$\Delta H^\circ_{298} = (-44{,}000)$ calories per mole (*12*)
$S_{298} = (29)$ *e.u.* (*12*)
$M.P. = 1{,}000°$ K. (*12*)
$\Delta H_M = 6{,}000$ calories per mole
$B.P. = 1{,}700°$ K. (*12*)
$\Delta H_V = 36{,}000$ calories per mole

Formation: $Mo + Cl_2 \longrightarrow MoCl_2$
(estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−44,000)	(−35,000)
500	(4,000)	(−43,000)	(−29,000)
1,000	(15,000)	(−39,000)	(−16,000)
1,500	(34,000)	(−28,000)	(−8,000)

Molybdenum Trichloride, $MoCl_3$ (*c*)

$\Delta H^\circ_{298} = (-65{,}000)$ calories per mole (*12*)
$S_{298} = 37.8$ *e.u.* (*12*)
$S.P. = 1{,}300°$ K. (*12*)
$\Delta H_{subl} = 52{,}000$ calories per mole

Formation: $Mo + 3/2Cl_2 \longrightarrow MoCl_3$
(estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−65,000)	(−50,000)
500	(5,000)	(−64,000)	(−40,000)
1,000	(20,000)	(−58,000)	(−20,000)
1,500	(83,500)	(−5,000)	(−6,000)

Molybdenum Tetrachloride, $MoCl_4$ (*c*)

$\Delta H^\circ_{298} = (-79{,}000)$ calories per mole (*112*)
$S_{298} = 47.4$ *e.u.* (*12*)
$S.P. = 595°$ K. (*12*)
$\Delta H_{subl} = 25{,}000$ calories per mole

Formation: $Mo + 2Cl_2 \longrightarrow MoCl_4$
(estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−79,000)	(−60,000)
500	(6,600)	(−77,000)	(−47,000)
1,000	(44,500)	(−51,000)	(−36,000)
1,500	(56,700)	(−51,000)	(−28,000)

Molybdenum Pentachloride, $MoCl_5$ (*c*)

$\Delta H^\circ_{298} = (-90{,}800)$ calories per mole (*112*)
$S_{298} = (65)$ *e.u.* (*94*)
$M.P. = 467°$ K. (6)
$\Delta H_M = (8{,}000)$ calories per mole
$B.P. = 540°$ K. (*6*)
$\Delta H_V = (12{,}000)$ calories per mole

Formation: $Mo + 5/2Cl_2 \longrightarrow MoCl_5$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−90,800)	(−68,500)
500	(12,000)	(−84,000)	(−56,000)
1,000	(35,000)	(−75,000)	(−31,000)
1,500	(50,000)	(−75,000)	(−10,000)

Molybdenum Hexachloride, $MoCl_6$ (*c*)

$\Delta H^\circ_{298} = (-90{,}000)$ calories per mole (*112*)
$S_{298} = 72.3$ *e.u.* (*11*)
$S.P. = 630°$ K. (*6*)
$\Delta H_{subl} = (19{,}000)$ calories per mole

Formation: $Mo + 3Cl_2 \longrightarrow MoCl_6$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−90,000)	(−62,000)
500	(9,300)	(−87,000)	(−43,000)
1,000	(45,600)	(−67,000)	(−13,000)
1,500	(62,100)	(−67,000)	(+14,000)

Molybdenum Dibromide, $MoBr_2$ (*c*)

$\Delta H^\circ_{298} = (-28{,}500)$ calories per mole (*12*)
$S_{298} = 34.5$ *e.u.* (*12*)
$M.P. = (1{,}000°)$ K. (*12*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = (1{,}500°)$ K. (*12*)
$\Delta H_V = (31{,}000)$ calories per mole

Formation: $Mo + Br_2 \longrightarrow MoBr_2$
(estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−28,500)	(−26,000)
500	(4,000)	(−35,000)	(−21,000)
1,000	(16,500)	(−30,000)	(−8,000)
1,500	(36,000)	(−19,000)	(+1,000)
2,000	(75,000)	(+12,000)	(+4,000)

Molybdenum Tribromide, $MoBr_3$ (*c*)

$\Delta H^\circ_{298} = (-40{,}000)$ calories per mole (*12*)
$S_{298} = 43.8$ *e.u.* (*12*)
S.P. = (1,250°) K. (*12*)
$\Delta H_{subl} = (50{,}000)$ calories per mole

Formation: $Mo + 3/2Br_2 \longrightarrow MoBr_3$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−40,000)	(−35,000)
500	(5,000)	(−50,000)	(−25,500)
1,000	(19,000)	(−46,000)	(−3,000)
1,500	(81,000)	(+6,000)	(+7,000)

Molybdenum Tetrabromide, $MoBr_4$ (*c*)

$\Delta H^\circ_{298} = (-45{,}300)$ calories per mole (*12*)
$S_{298} = (59)$ *e.u.* (*12*)
S.P. = 620° K. (*12*)
$\Delta H_{subl} = (26{,}000)$ calories per mole

Formation: $Mo + 2Br_2 \longrightarrow MoBr_4$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−45,300)	(−39,500)
500	(7,300)	(−58,400)	(−28,000)
1,000	(46,300)	(−31,500)	(−17,000)
1,500	(58,800)	(−31,500)	(−4,000)

Molybdenum Pentabromide, $MoBr_5$ (*c*)

$\Delta H^\circ_{298} = (-50{,}000)$ calories per mole (*12*)
$S_{298} = (77)$ *e.u.* (*12*)
M.P. = < 500° K. (*12*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (600°) K. (*12*)
$\Delta H_V = (14{,}000)$ calories per mole

Formation: $Mo + 5/2Br_2 \longrightarrow MoBr_5$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−50,000)	(−43,000)
500	(13,700)	(−61,400)	(−31,000)
1,000	(44,000)	(−45,500)	(−12,000)
1,500	(59,000)	(−45,500)	(+4,000)

Molybdenum Diiodide, MoI_2 (*c*))

$\Delta H^\circ_{298} = (-12{,}000)$ calories per mole (*112*)
$S_{298} = (36)$ *e.u.* (*12*)
M.P. = (1,000°) K. (*12*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (1,200°) K. (*12*)
$\Delta H_V = (25{,}000)$ calories per mole

Formation: $Mo + I_2 \longrightarrow MoI_2$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−12,000)	(−12,500)
500	(4,000)	(−26,000)	(−11,000)
1,000	(16,500)	(−21,500)	(+3,000)
1,500	(57,500)	(+12,000)	(+6,000)

Molybdenum Triiodide, MoI_3 (*c*)

$\Delta H^\circ_{298} = (-15{,}000)$ calories per mole (*112*)
$S_{298} = (48)$ *e.u.* (*12*)
S.P. = (1,200°) K. (*12*)
$\Delta H_{subl} = (48{,}000)$ calories per mole

Formation: $Mo + 3/2I_2 \longrightarrow MoI_3$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−15,000)	(−15,000)
500	(5,000)	(−36,000)	(−11,000)
1,000	(19,000)	(−32,000)	(+12,000)
1,500	(67,000)	(+18,000)	(+21,000)

Molybdenum Tetraiodide, MoI_4 (*c*)

$\Delta H^\circ_{298} = (-18{,}000)$ calories per mole (*112*)
$S_{298} = (64)$ *e.u.* (*12*)
S.P. = 695° K. (12)
$\Delta H_{subl} = (29{,}000)$ calories per mole

Formation: $Mo + 2I_2 \longrightarrow MoI_4$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−18,000)	(−18,500)
500	(6,000)	(−46,000)	(−15,000)
1,000	(50,000)	(−15,000)	(+4,000)
1,500	(59,000)	(−15,000)	(+13,000)

Molybdenum Pentaiodide, MoI_5 (*c*)

$\Delta H^\circ_{298} = (-18{,}000)$ calories per mole (*112*)
$S_{298} = 81.5$ *e.u.* (*12*)
S.P. = 650° K. (*12*)
$\Delta H_{subl} = (26{,}000)$ calories per mole

Formation: $Mo + 5/2I_2 \longrightarrow MoI_5$ (estimated (*12*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−18,000)	(−19,500)
500	(8,000)	(−52,000)	(−15,000)
1,000	(51,000)	(−24,000)	(+10,000)
1,500	(62,000)	(−24,000)	(+25,000)

Dimolybdenum Carbide, Mo_2C (*c*)

$\Delta H^\circ_{298} = 4{,}200$ calories per mole (*9*)
$S_{298} = 19.1$ *e.u* (*9*)
M.P. = 2,965° K. (*9*)

Formation: $2Mo + C \longrightarrow Mo_2C$

Zone I (300°–3,000° K.)

$$\Delta F_T = 4{,}200 - 4.8T \ (81)$$

T, ° K.	ΔF_T°	T, ° K.	ΔF_T°
298	2,970	1,200	(−1,550)
400	(2,300)	1,300	(−2,050)
500	(1,800)	1,400	(−2,500)
600	(1,300)	1,500	(−3,000)
700	(800)	1,600	(−3,500)
800	(350)	1,700	(−3,950)
900	(−100)	1,800	(−4,450)
1,000	(−600)	1,900	(−4,900)
1,100	(−1,100)	2,000	(−5,400)

Dimolybdenum Nitride, Mo_2N (c)

$\Delta H_{298}^\circ = -16{,}600$ calories per mole (81)
$S_{298} = 21$ e. u. (81)

Zone I (c) (298°–800° K.)

$$C_p = 11.19 + 13.80 \times 10^{-3}T \ (82)$$
$$H_T - H_{298} = -3{,}950 + 11.19T + 6.90 \times 10^{-3}T^2$$

Formation: $2Mo + 1/2N_2 \longrightarrow Mo_2N$

Zone I (298°–800° K.)

$$\Delta C_p = -3.10 + 10.69 \times 10^{-3}T$$
$$\Delta H_T = -16{,}150 - 3.10T + 5.34 \times 10^{-3}T^2$$
$$\Delta F_T = -16{,}150 + 3.10T \ln T - 5.34 \times 10^{-3}T^2 - 1.98T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		21.0	−16,600	−11,970
400	1,610	25.64	−16,550	−10,400
500	3,360	29.54	−16,400	−8,850
600	5,280	33.03	−16,050	−7,400
700	7,290	36.13	−15,650	−5,950
800	9,370	38.90	−15,050	−4,400

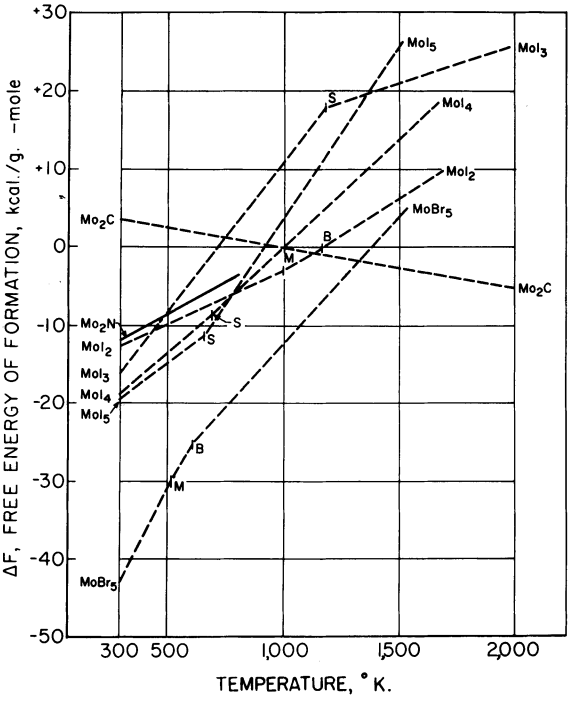

FIGURE 35.—Molybdenum (b).

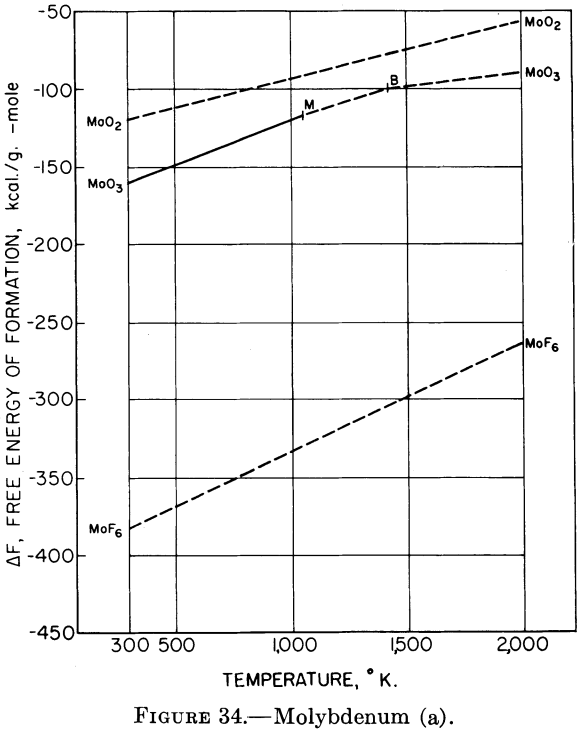

FIGURE 34.—Molybdenum (a).

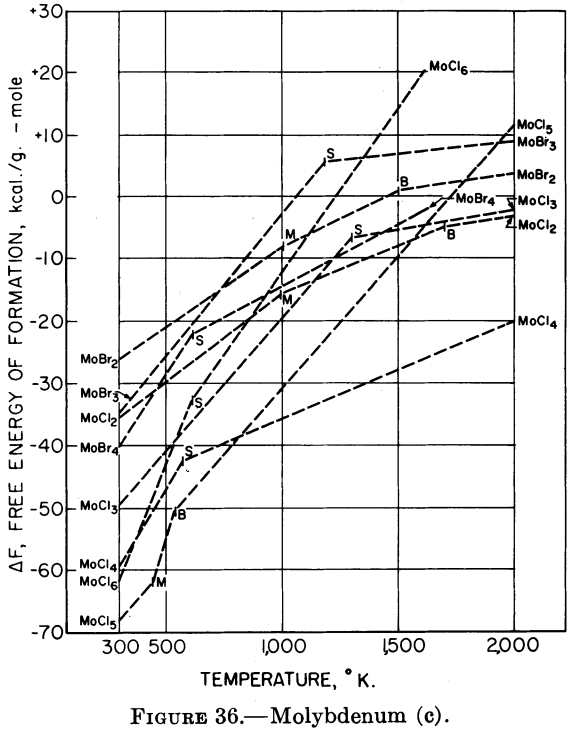

FIGURE 36.—Molybdenum (c).

NEODYMIUM AND ITS COMPOUNDS

Element, Nd (*c*)

$S_{298}=17.54$ *e.u.* (*121*)
M.P.$=1{,}297°$ K. (*125*)
$\Delta H_M=2{,}600$ calories per atom
B.P.$=3{,}450°$ K. (*125*)
$\Delta H_V=69{,}000$ calories per atom

Zone I (*c*) (298°–900° K.)

$C_p=5.61+5.34\times10^{-3}T$ (*82*)
$H_T-H_{298}=-1{,}910+5.61T+2.67\times10^{-3}T^2$
$F_T-H_{298}=-1{,}910-5.51T\ln T-2.67\times10^{-3}T^2+21.61T$

T, ° K	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		17.54	17.54
400	755	19.72	17.85
500	1,560	21.51	18.38
600	2,420	23.08	19.05
700	3,330	24.48	19.70
800	4,290	25.76	20.40
900	5,300	26.95	21.07
1,000	(6,370)	(28.1)	(21.83)
1,100	(7,490)	(29.2)	(22.39)
1,200	(8,670)	(30.2)	(22.97)
1,300	(12,280)		(23.56)
1,400	(13,080)		(24.25)
1,500	(13,880)		(24.90)
1,600	(14,680)		(25.47)
1,700	(15,480)		(26.04)
1,800	(16,300)		(26.55)
1,900	(17,100)		(27.03)
2,000	(17,900)		(27.48)

Dineodymium Trioxide, Nd_2O_3 (*c*)

$\Delta H^\circ_{298}=-432{,}150$ calories per mole (*61*)
$S_{298}=(41.6)$ *e.u.* (*24*)

Zone I (*c*) (298°–1,175° K.)

$C_p=28.99+5.76\times10^{-3}T-4.159\times10^5T^{-2}$ (*3*)
$H_T-H_{298}=-10{,}290+28.99T+2.88\times10^{-3}T^2+4.159\times10^5T^{-1}$

Formation: $2Nd+3/2O_2\longrightarrow Nd_2O_3$

Zone I (298°–900° K.)

$\Delta C_p=7.03-6.42\times10^{-3}T-3.559\times10^5T^{-2}$
$\Delta H_T=-435{,}150+7.03T-3.21\times10^{-3}T^2+3.559\times10^5T^{-1}$
$\Delta F_T=-435{,}150-7.03T\ln T+3.21\times10^{-3}T^2+1.78\times10^5T^{-1}+115.1T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(41.6)	−432,150	(−412,500)
400	3,100	(48.8)	−432,000	(−405,000)
500	6,050	(55.3)	−431,700	(−398,300)
600	9,150	(61.1)	−431,500	(−391,700)
700	12,350	(66.0)	−431,250	(−385,100)
800	15,600	(70.4)	−431,000	(−378,600)
900	18,950	(74.0)	−431,000	(−372,100)
1,000	22,300	(77.7)	(−431,000)	(−365,200)
1,100	25,750	(81.0)	(−431,000)	(−359,000)
1,200	29,300	(84.3)	(−436,900)	(−352,250)

Neodymium Trifluoride, NdF_3 (*c*)

$\Delta H^\circ_{298}=(-385{,}000)$ calories per mole (*5*)
$S_{298}=(24)$ *e.u.* (*11*)
M.P.$=1{,}647°$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
B.P.$=(2{,}600°)$ K. (*6*)
$\Delta H_V=(62{,}000)$ calories per mole

Formation: $Nd+3/2F_2\longrightarrow NdF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−385,000)	(−366,000)
500	(4,000)	(−385,000)	(−354,500)
1,000	(17,000)	(−383,100)	(−324,000)
1,500	(32,000)	(−382,200)	(−296,500)

Neodymium Trichloride, $NdCl_3$ (*c*)

$\Delta H^\circ_{298}=-245{,}600$ calories per mole (*128*)
$S_{298}=34.6$ *e.u.* (*128*)
M.P.$=1{,}031°$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
B.P.$=(1{,}940°)$ K. (*6*)
$\Delta H_V=(46{,}000)$ calories per mole

Formation: $Nd+3/2Cl_2\longrightarrow NdCl_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−245,600	−227,930
500	(5,000)	(−244,000)	(−217,600)
1,000	(19,000)	(−241,100)	(−192,600)
1,500	(43,000)	(−232,000)	(−173,600)

Neodymium Tribromide, $NdBr_3$ (*c*)

$\Delta H^\circ_{298}=(-187{,}000)$ calories per mole (*5*)
$S_{298}=(47)$ *e.u.* (*11*)
M.P.$=955°$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
B.P.$=(1{,}810°)$ K. (*6*)
$\Delta H_V=(45{,}000)$ calories per mole

Formation: $Nd+3/2Br_2\longrightarrow NdBr_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−187,000)	(−180,600)
500	(5,000)	(−197,800)	(−170,000)
1,000	(18,000)	(−196,400)	(−145,000)
1,500	(43,000)	(−185,700)	(−126,500)

Neodymium Triiodide, NdI_3 (*c*)

$\Delta H^\circ_{298}=-158{,}000$ calories per mole (*5*)
$S_{298}=(49)$ *e.u.* (*11*)
T.P.$=827°$ K. (*29*)
M.P.$=1{,}048°$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
B.P.$=(1{,}640°)$ K. (*6*)
$\Delta H_V=(41{,}000)$ calories per mole

Formation: $Nd+3/2I_2\longrightarrow NdI_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−158,000	(−156,000)
500	(5,000)	(−179,500)	(−151,000)
1,000	(19,000)	(−177,000)	(−124,000)
1,500	(44,000)	(−166,000)	(−100,000)

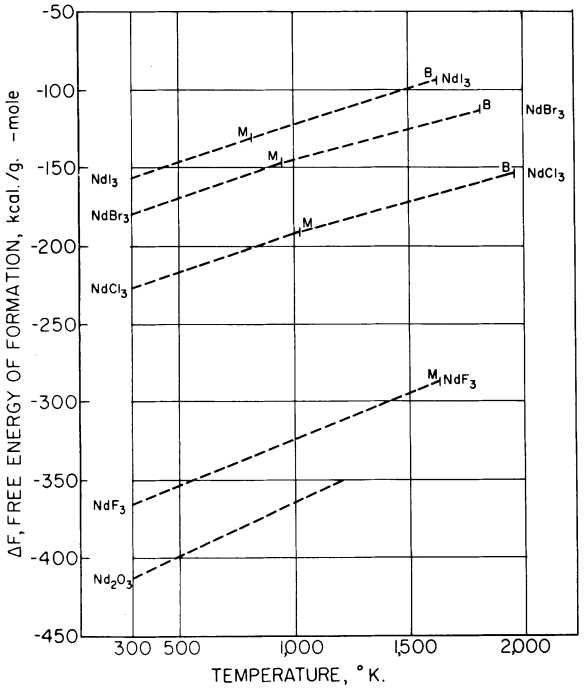

FIGURE 37.—Neodymium.

NICKEL AND ITS COMPOUNDS

Element, Ni (*c*)

$S_{298}=7.12$ *e.u.* (*83*)
$T.P.=633°$ K. (*82*)
$\Delta H_T=0$ calories per atom
$M.P.=1{,}725°$ K. (*82*)
$\Delta H_M=4{,}210$ calories per atom
$B.P.=3{,}073°$ K. (*112*)
$\Delta H_V=91{,}000$ calories per atom

Zone I (α) (298°–633° K.)

$$C_p=4.06+7.04\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-1{,}525+4.06T+3.52\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}525-4.06T\ln T-3.52\times10^{-3}T^2+22.16T$$

Zone II (β) (633°–1,725° K.)

$$C_p=6.00+1.80\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-1{,}700+6.00T+0.90\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}700-6.00T\ln T-0.90\times10^{-3}T^2+33.3T$$

Zone III (*l*) (1,725°–1,900° K.)

$$C_p=9.20 \quad (82)$$
$$H_T-H_{298}=-330+9.20T$$
$$F_T-H_{298}=-330-9.20T\ln T+54.85T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		7.12	7.12
400	665	9.03	7.37
500	1,380	10.63	7.87
600	2,180	12.08	8.44
700	2,940	13.26	9.06
800	3,690	14.26	9.65
900	4,445	15.15	10.21
1,000	5,210	15.96	10.75
1,100	5,985	16.70	11.26
1,200	6,780	17.39	11.74
1,300	7,600	18.05	12.20
1,400	8,450	18.68	12.64
1,500	9,320	19.28	13.07
1,600	10,210	19.85	13.47
1,700	11,110	20.40	13.86
1,800	16,230	23.35	14.33
1,900	17,150	23.85	14.82
2,000	(18,070)	(24.32)	(15.30)

Nickel Oxide, NiO (*c*)

$\Delta H^\circ_{298}=-57{,}300$ calories per mole (*4*)
$S_{298}=9.08$ *e.u.* (*88*)
$T.P.=525°$ K. (*82*)
$\Delta H_T=0$ calories per mole
$T.P.=565°$ K. (*82*)
$\Delta H_T=0$ calories per mole
$M.P.=2{,}233°$ K. (*42*)

Zone I (α) (298°–525° K.)

$$C_p=-4.99+37.58\times10^{-3}T+3.89\times10^5T^{-2} \quad (82)$$
$$H_T-H_{298}=+1{,}122-4.99T+18.79\times10^{-3}T^2-3.89\times10^5T^{-1}$$

Zone II (β) (525°–565° K.)

$$C_p=13.88 \quad (82)$$
$$H_T-H_{298}=-4{,}347+13.88T$$

Zone III (γ) (565°–1,800° K.)

$$C_p=11.18+2.02\times10^{-3}T \quad (82)$$
$$H_T-H_{298}=-3{,}140+11.18T+1.01\times10^{-3}T^2$$

Formation: $Ni+1/2O_2\longrightarrow NiO$

Zone I (298°–525° K.)

$$\Delta C_p=-12.63+30.04\times10^{-3}T+4.09\times10^5T^{-2}$$
$$\Delta H_T=-53{,}500-12.63T+15.02\times10^{-3}T^2-4.09\times10^5T^{-1}$$
$$\Delta F_T=-53{,}500+12.63T\ln T-15.02\times10^{-3}T^2-2.04\times10^5T^{-1}-55.39T$$

Zone II (525°–565° K.)

$$\Delta C_p=6.24-7.54\times10^{-3}T+0.20\times10^5T^{-2}$$
$$\Delta H_T=-58{,}970+6.24T-3.77\times10^{-3}T^2-0.20\times10^5T^{-1}$$
$$\Delta F_T=-58{,}970-6.24T\ln T+3.77\times10^{-3}T^2-0.10\times10^5T^{-1}+63.65T$$

Zone III (565°–633° K.)

$$\Delta C_p=3.54-5.52\times10^{-3}T+0.20\times10^5T^{-2}$$
$$\Delta H_T=-57{,}808+3.54T-2.76\times10^{-3}T^2-0.20\times10^5T^{-1}$$
$$\Delta F_T=-57{,}808-3.54T\ln T+2.76\times10^{-3}T^2-0.10\times10^5T^{-1}+43.98T$$

Zone IV (633°–1,725° K.)

$\Delta C_p = 1.6 - 0.28\times10^{-3}T + 0.20\times10^{5}T^{-2}$
$\Delta H_T = -57{,}600 + 1.6T - 0.14\times10^{-3}T^2 - 0.20\times10^{5}T^{-1}$
$\Delta F_T = -57{,}600 - 1.6T\ln T + 0.14\times10^{-3}T^2 - 0.10\times10^{5}T^{-1} + 32.82T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		9.08	−57,300	−50,600
400	1,165	12.43	−57,150	−48,300
500	2,535	15.47	−56,850	−46,100
600	3,940	18.05	−56,650	−44,000
700	5,220	20.02	−56,500	−41,900
800	6,500	21.73	−56,400	−39,800
900	7,780	23.24	−56,250	−37,750
1,000	9,070	24.60	−56,150	−35,700
1,100	10,370	25.84	−56,000	−33,600
1,200	11,700	26.97	−55,900	−31,600
1,300	13,060	28.08	−55,800	−29,550
1,400	14,450	29.11	−55,650	−27,550
1,500	15,860	30.08	−55,600	−25,550
1,600	17,300	31.01	−55,450	−23,500
1,700	18,770	31.90	−55,300	−21,550
1,800	20,260	32.76	−59,400	−19,550

Nickel Difluoride, NiF_2 (*c*)

$\Delta H_{298}^\circ = -158{,}000$ calories per mole (*11*)
$S_{298} = 17.69$ *e.u.* (*18*)
M.P. = (1,300°) K. (*6*)
ΔH_M = (8,000) calories per mole
B.P. = (1,900°) K. (*6*)
ΔH_V = (48,000) calories per mole

Formation: $Ni + F_2 \longrightarrow NiF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−158,000	−146,700
500	(4,000)	(−156,900)	(−140,000)
1,000	(13,000)	(−156,000)	(−124,000)
1,500	(34,000)	(−143,600)	(−108,500)

Nickel Dichloride, $NiCl_2$ (*c*)

$\Delta H_{298}^\circ = -73{,}000$ calories per mole (*11*)
$S_{298} = 23.3$ *e.u.* (*16*)
M.P. = 1,303° K. (*25*)
ΔH_M = 18,470 calories per mole

Zone I (*c*) (298°–1,303° K.)

$C_p = 17.50 + 3.16\times10^{-3}T - 1.19\times10^{5}T^{-2}$ (*25*)
$H_T - H_{298} = -5{,}750 + 17.50T + 1.58\times10^{-3}T^2 + 1.19\times10^{5}T^{-1}$

Formation: $Ni + Cl_2 \longrightarrow NiCl_2$

Zone I (298°–633° K.)

$\Delta C_p = 4.62 - 3.94\times10^{-3}T - 0.51\times10^{5}T^{-2}$
$\Delta H_T = -74{,}375 + 4.62T - 1.97\times10^{-3}T^2 + 0.51\times10^{5}T^{-1}$
$\Delta F_T = -74{,}375 - 4.62T\ln T + 1.97\times10^{-3}T^2 + 0.25\times10^{5}T^{-1} + 67.13T$

Zone II (633°–1,303° K.)

$\Delta C_p = 2.68 + 1.30\times10^{-3}T - 0.51\times10^{5}T^{-2}$
$\Delta H_T = -74{,}200 + 2.68T + 0.65\times10^{-3}T^2 + 0.51\times10^{5}T^{-1}$
$\Delta F_T = -74{,}200 - 2.68T\ln T - 0.65\times10^{-3}T^2 + 0.25\times10^{5}T^{-1} + 56.05T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		23.3	−73,000	−61,900
400	1,800	28.46	−72,700	−58,100
500	3,650	32.61	−72,400	−54,500
600	5,550	36.06	−72,150	−51,000
700	7,465	39.02	−71,900	−47,500
800	9,400	41.60	−71,600	−44,000
900	11,360	43.91	−71,250	−40,600
1,000	13,350	46.01	−70,900	−37,100
1,100	15,390	47.95	−70,400	−33,800
1,200	17,510	49.80	−70,100	−30,600
1,300	19,750	51.59	−69,450	−25,900

Nickel Dibromide, $NiBr_2$ (*c*)

$\Delta H_{298}^\circ = -51{,}700$ calories per mole (*11*)
$S_{298} = (30)$ *e.u.* (*11*)
S.P. = (1,150°) K. (*6*)
ΔH_{subl} = (36,000) calories per mole

Formation: $Ni + Br_2 \longrightarrow NiBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−51,700	(−47,000)
500	(4,000)	(−58,600)	(−41,500)
1,000	(14,000)	(−56,900)	(−24,000)
1,500	(72,000)	(−7,500)	(−17,000)

Nickel Diiodide, NiI_2 (*c*)

$\Delta H_{298}^\circ = -23{,}100$ calories per mole (*11*)
$S_{298} = (34)$ *e.u.* (*11*)
S.P. = (1,020°) K. (*6*)
ΔH_{subl} = (32,000) calories per mole

Formation: $Ni + I_2 \longrightarrow NiI_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−23,100	(−23,000)
500	(4,000)	(−37,000)	(−20,500)
1,000	(14,000)	(−35,300)	(−2,000)
1,500	(68,000)	(+10,000)	(+4,000)

Trinickel Carbide, Ni_3C (*c*)

$\Delta H_{298}^\circ = 9{,}200$ calories per mole (*81*)
$S_{298} = (23.8)$ *e.u.* (*78*)

Formation: $3Ni + C \longrightarrow Ni_3C$ (estimated (*81*))

T, ° K.	ΔF_T°
298	(+8,900)
400	(4,800)
500	(3,700)
600	(2,600)
700	(1,500)

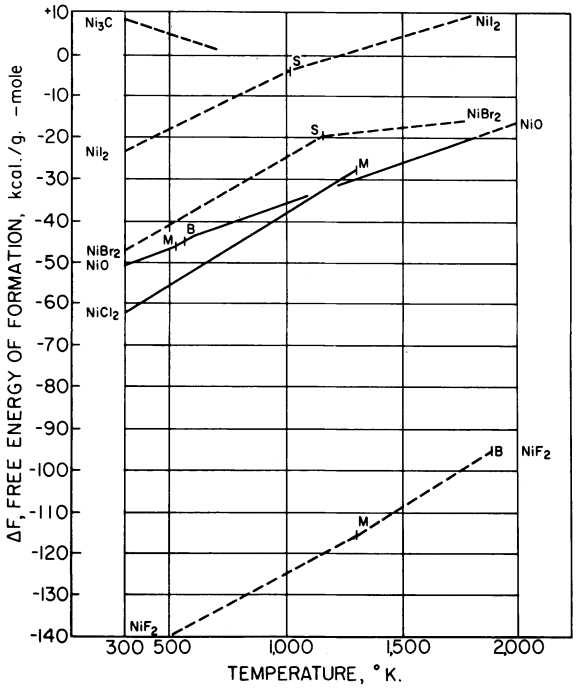

FIGURE 38.—Nickel.

NITROGEN AND ITS COMPOUNDS

Element, N_2 (*g*)

$S_{298}=45.77$ *e.u.* (*83*)
$M.P.=63.18°$ K. (*112*)
$\Delta H_M=172$ calories per atom
$B.P.=77.36°$ K. (*112*)
$\Delta H_V=1,335$ calories per atom

Zone I (*g*) (298°–2,500° K.)

$C_p=6.66+1.02\times10^{-3}T$ (*82*)
$H_T-H_{298}=-2,031+6.66T+0.51\times10^{-3}T^2$
$F_T-H_{298}=-2,031-6.66T\ln T-0.51\times10^{-3}T^2-0.87T$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		45.77	45.77
400	710	47.82	46.05
500	1,413	49.39	46.48
600	2,126	50.69	47.19
700	2,854	51.81	47.70
800	3,598	52.80	48.25
900	4,358	53.70	48.86
1,000	5,132	54.51	49.38
1,100	5,916	55.25	49.87
1,200	6,723	55.96	50.31
1,300	7,500	56.65	50.72
1,400	8,288	57.26	51.25
1,500	9,186	57.79	51.60
1,600	9,943	58.26	52.08
1,700	10,750	58.76	52.40
1,800	11,620	59.37	52.78
1,900	12,470	59.77	53.14
2,000	13,433	60.23	53.51

Dinitrogen Oxide, N_2O (*g*)

$\Delta H^\circ_{298}=19,490$ calories per mole (*112*)
$S_{298}=52.8$ *e.u.* (*112*)
$M.P.=182.30°$ K. (*112*)
$\Delta H_M=1,563$ calories per mole
$B.P.=184.68°$ K. (*112*)
$\Delta H_V=3,956$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$C_p=10.92+2.06\times10^{-3}T-2.04\times10^5T^{-2}$ (*82*)
$H_T-H_{298}=-4,032+10.92T+1.03\times10^{-3}T^2+2.04\times10^5T^{-1}$

Formation: $N_2+1/2O_2\longrightarrow N_2O$

Zone I (298°–2,000° K.)

$\Delta C_p=0.68+0.54\times10^{-3}T-1.84\times10^5T^{-2}$
$\Delta H_T=18,650+0.68T+0.27\times10^{-3}T^2+1.84\times10^5T^{-1}$
$\Delta F_T=18,650-0.68T\ln T-0.27\times10^{-3}T^2+0.92\times10^5T^{-1}+23.2T$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		52.8	+19,500	24,700
400	990	55.65	19,400	26,100
500	2,055	58.02	19,400	28,250
600	3,175	60.07	19,450	30,050
700	4,360	61.89	19,500	31,800
800	5,585	63.53	19,600	33,550
900	6,855	65.02	19,700	35,300
1,000	8,145	66.38	19,800	37,050
1,100	9,318	67.66	19,900	38,700
1,200	10,815	68.88	20,000	40,450
1,300	12,062	69.87	20,100	42,150
1,400	13,555	70.92	20,300	43,900
1,500	14,801	71.82	20,500	45,700
1,600	16,345	72.78	20,600	47,200
1,700	17,629	73.58	20,700	48,800
1,800	19,170	74.45	20,800	50,450
1,900	20,541	75.22	20,900	52,000
2,000	22,030	75.59	21,000	54,500

Nitrogen Oxide, NO (*g*)

$\Delta H^\circ_{298}=21,600$ calories per mole (*112*)
$S_{298}=50.34$ *e.u.* (*83*)
$M.P.=109.5°$ K. (*112*)
$\Delta H_M=550$ calories per mole
$B.P.=121.4°$ K. (*112*)
$\Delta H_V=3,293$ calories per mole

Zone I (*g*) (298°–2,500° K.)

$C_p=7.03+0.92\times10^{-3}T-0.14\times10^5T^{-2}$ (*82*)
$H_T-H_{298}=-2,184+7.03T+0.46\times10^{-3}T^2+0.14\times10^5T^{-1}$

Formation: $1/2N_2+1/2O_2\longrightarrow NO$

Zone I (298°–2,500° K.)

$\Delta C_p=0.12-0.08\times10^{-3}T+0.06\times10^5T^{-2}$
$\Delta H_T=21,590+0.12T-0.04\times10^{-3}T^2-0.06\times10^5T^{-1}$
$\Delta F_T=21,590-0.12T\ln T+0.04\times10^{-3}T^2-0.03\times10^5T^{-1}-2.2T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		50.34	+21,600	20,700
400	727	52.44	21,600	20,400
500	1,450	54.05	21,600	20,100
600	2,189	55.40	21,600	19,800
700	2,946	56.57	21,600	19,500
800	3,718	57.60	21,600	19,200
900	4,532	58.55	21,600	18,850
1,000	5,318	59.38	21,600	18,650
1,100	6,119	60.13	21,600	18,300
1,200	6,926	60.84	21,650	18,050
1,300	7,743	61.5	21,650	17,800
1,400	8,570	62.11	21,650	17,500
1,500	9,508	62.77	21,650	17,100
1,600	10,251	63.24	21,700	16,900
1,700	11,104	63.75	21,700	16,550
1,800	11,968	64.26	21,700	16,250
1,900	12,841	64.73	21,700	15,950
2,000	13,844	65.26	21,700	15,650

Dinitrogen Trioxide, N_2O_3 (*g*)

$\Delta H_{298}^\circ = 17{,}500$ calories per mole (*24*)
$S_{298} = (63.9)$ *e.u.* (*24*)
M.P. = 162° K. (*112*)
B.P. = 275° K. (*112*)
$\Delta H_V = 9{,}400$ calories per mole

Formation: $N_2 + 3/2O_2 \longrightarrow N_2O_3$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		17,500	(33,500)
400	(1,800)	(17,500)	(39,000)
500	(3,600)	(17,500)	(44,000)

Nitrogen Dioxide, NO_2 (*g*)

$\Delta H_{298}^\circ = 8{,}091$ calories per mole (*112*)
$S_{298} = 57.46$ *e.u.* (*83*)

Zone I (*g*) (298°–2,000° K.)

$$C_p = 10.26 + 2.04\times10^{-3}T - 1.61\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -3{,}690 + 10.26T + 1.02\times10^{-3}T^2 + 1.61\times10^{5}T^{-1}$$

Formation: $1/2N_2 + O_2 \longrightarrow NO_2$

Zone I (298°–2,000° K.)

$$\Delta C_p = -0.23 - 0.54\times10^{-3}T - 1.21\times10^{5}T^{-2}$$
$$\Delta H_T = 7{,}780 - 0.23T - 0.27\times10^{-3}T^2 + 1.21\times10^{5}T^{-1}$$
$$\Delta F_T = 7{,}780 + 0.23T\ ln\ T + 0.27\times10^{-3}T^2 + 0.60\times10^{5}T^{-1} + 13.41T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		57.46	8,100	12,400
400	960	60.23	8,000	13,900
500	1,975	62.49	7,900	15,350
600	3,055	64.46	7,800	16,750
700	4,190	66.2	7,750	18,250
800	5,370	67.78	7,750	19,750
900	6,585	69.21	7,900	21,350
1,000	7,830	70.52	7,900	22,850
1,100	8,976	71.65	7,900	24,400
1,200	10,375	72.84	8,050	25,900
1,300	11,500	73.77	8,000	27,400
1,400	12,975	74.84	8,000	28,700
1,500	14,092	75.64	7,900	30,300
1,600	15,625	76.61	8,200	31,750
1,700	16,795	77.33	8,200	33,300
1,800	18,300	78.19	8,300	34,600
1,900	19,571	78.88	8,300	36,150
2,000	20,990	79.60	8,200	37,700

Dinitrogen Tetraoxide, N_2O_4 (*g*)

$\Delta H_{298}^\circ = 2{,}309$ calories per mole (*112*)
$S_{298} = 72.73$ *e.u.* (*112*)
M.P. = 261.96° K. (*112*)
$\Delta H_M = 3{,}502$ calories per mole
B.P. = 294° K. (*112*)
$\Delta H_V = 9{,}101$ calories per mole

Zone I (*g*) (298°–1,000° K.)

$$C_p = 20.05 + 9.50\times10^{-3}T - 3.56\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -7{,}594 + 20.05T + 4.75\times10^{-3}T^2 + 3.56\times10^{5}T^{-1}$$

Formation: $N_2 + 2O_2 \longrightarrow N_2O_4$

Zone I (298°–1,000° K.)

$$\Delta C_p = -0.93 + 6.48\times10^{-3}T - 2.76\times10^{5}T^{-2}$$
$$\Delta H_T = 1{,}372 - 0.93T + 3.24\times10^{-3}T^2 + 2.76\times10^{5}T^{-1}$$
$$\Delta F_T = 1{,}372 + 0.93T\ ln\ T - 3.24\times10^{-3}T^2 + 1.38\times10^{5}T^{-1} + 68.31T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		72.73	2,300	+23,500
400	2,060	78.66	2,200	30,750
500	4,310	83.67	2,300	37,600
600	6,740	88.09	2,500	44,000
700	9,300	92.03	2,850	52,100
800	11,980	95.61	3,100	59,050
900	14,730	98.85	3,450	66,000
1,000	17,560	101.83	3,900	73,000

Nitrosyl Chloride, NOCl (*g*)

$\Delta H_{298}^\circ = 12{,}570$ calories per mole (*112*)
$S_{298} = 63$ *e.u.* (*112*)
M.P. = 211.7° K. (*112*)
B.P. = 267.4° K. (*112*)
$\Delta H_V = 6{,}000$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 10.73 + 1.84\times10^{-3}T - 1.66\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -3{,}838 + 10.73T + 0.92\times10^{-3}T^2 + 1.66\times10^{5}T^{-1}$$

Formation: $1/2N_2 + 1/2O_2 + 1/2Cl_2 \longrightarrow NOCl$

Zone I (298°–2,000° K.)

$$\Delta C_p = -0.59 + 0.81\times10^{-3}T - 1.12\times10^{5}T^{-2}$$
$$\Delta H_T = 12{,}335 - 0.59T + 0.40\times10^{-3}T^2 + 1.12\times10^{5}T^{-1}$$
$$\Delta F_T = 12{,}335 + 0.59T\ ln\ T - 0.40\times10^{-3}T^2 + 0.56\times10^{5}T^{-1} + 7.96T$$

T, ° K.	H_T-H_{298}	$\Delta H°_T$	$\Delta F°_T$
298		12,550	15,850
400	1,000	12,450	17,050
500	2,055	12,350	18,200
600	3,175	12,300	19,350
700	4,340	12,300	20,500
800	5,540	12,250	21,750
900	6,770	12,250	22,900
1,000	8,030	12,300	24,100
1,100	9,229	12,350	25,300
1,200	10,600	12,350	26,350
1,300	11,794	12,350	27,700
1,400	13,215	12,400	28,900
1,500	14,434	12,400	30,000
1,600	15,875	12,550	31,100
1,700	17,160	12,600	32,300
1,800	18,555	12,600	33,350
1,900	19,957	12,700	34,600
2,000	21,255	12,600	35,600

Ammonia, NH_3 (g)

$\Delta H^\circ_{298} = -11{,}040$ calories per mole (*112*)
$S_{298} = 45.96$ *e.u.* (*83*)
$M.P. = 195.40°$ K. (*112*)
$\Delta H_M = 1{,}350$ calories per mole
$B.P. = 239.73°$ K. (*112*)
$\Delta H_V = 5{,}580$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 7.11 + 6.00\times10^{-3}T - 0.37\times10^{5}T^{-2} \quad (83)$$
$$H_T - H_{298} = -2{,}510 + 7.11T + 3.00\times10^{-3}T^2 + 0.37\times10^{5}T^{-1}$$

Formation: $1/2N_2 + 3/2H_2 \longrightarrow NH_3$

Zone I (298°–2,000° K.)

$$\Delta C_p = -6.0 + 4.32\times10^{-3}T - 0.55\times10^{5}T^{-2}$$
$$\Delta H_T = -9{,}630 - 6.0T + 2.16\times10^{-3}T^2 + 0.55\times10^{5}T^{-1}$$
$$\Delta F_T = -9{,}630 + 6.0T\ln T - 2.16\times10^{-3}T^2 + 0.27\times10^{5}T^{-1} - 14.93T$$

T, ° K.	$H_T - H_{298}$	S_T	$\Delta H°_T$	$\Delta F°_T$
298		45.96	−11,050	−4,000
400	895	48.54	−11,650	−1,600
500	1,845	50.66	−12,000	+1,200
600	2,885	52.55	−12,400	+3,700
700	3,975	54.23	−12,800	+6,350
800	5,145	55.79	−12,950	9,200
900	6,380	57.28	−13,150	12,000
1,000	7,680	58.61	−13,350	14,800
1,100	8,975	59.88	−13,500	16,400
1,200	10,450	61.14	−13,600	20,300
1,300	11,830	62.28	−13,700	23,200
1,400	13,420	63.42	−13,700	26,000
1,500	14,930	64.47	−13,700	28,900
1,600	16,565	65.52	−13,800	31,500
1,700	18,269	66.58	−13,550	34,400
1,800	19,820	67.44	−13,400	37,400
1,900	21,848	68.58	−13,200	40,050
2,000	23,195	69.21	−13,500	43,150

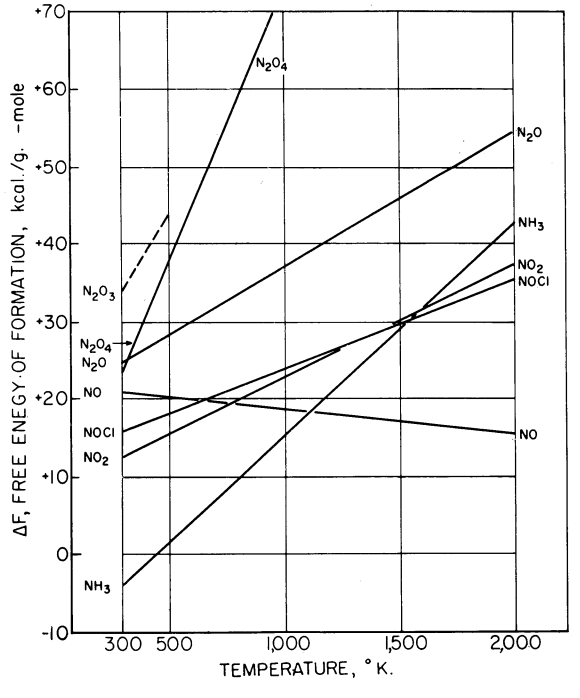

FIGURE 39.—Nitrogen.

OXYGEN

Element, O_2 (g)

$S_{298} = 49.01$ *e.u.* (*83*)
$M.P. = 54.36°$ K. (*112*)
$\Delta H_M = 106$ calories per atom
$B.P. = 90.19°$ K. (*112*)
$\Delta H_V = 1{,}630$ calories per atom

Zone I (*g*) (298°–3,000° K.)

$$C_p = 7.16 + 1.00\times10^{-3}T - 0.40\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -2{,}313 + 7.16T + 0.50\times10^{-3}T^2 + 0.40\times10^{5}T^{-1}$$
$$F_T - H_{298} = -2{,}313 - 7.16T\ln T - 0{,}50\times10^{-3}T^2 + 0.20\times10^{5}T^{-1} - 0.55T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		49.01	49.01
400	723	51.1	49.29
500	1,455	52.73	49.82
600	2,210	54.10	50.42
700	2,989	55.30	51.03
800	3,786	56.37	51.64
900	4,602	57.33	52.21
1,000	5,430	58.20	52.77
1,100	6,208	59.01	53.27
1,200	7,040	59.72	53.83
1,300	7,873	60.41	54.35
1,400	8,716	61.01	54.78
1,500	9,711	61.67	55.21
1,600	10,442	62.21	55.68
1,700	11,334	62.71	56.04
1,800	12,219	63.11	56.32
1,900	13,113	63.66	56.77
2,000	14,155	64.22	57.14

PHOSPHORUS AND ITS COMPOUNDS

Element (White), P_4 (c)

$S_{298} = 42.4$ *e.u.* (*83*)
$M.P. = 317.4°$ K. (*82*)
$\Delta H_M = 601$ calories per atom
$B.P. = 553°$ K. (*112*)
$\Delta H_V = 11{,}880$ calories per atom

Zone I (*c*) (298°–317.4° K.)

$$C_p = 22.50 \quad (82)$$
$$H_T - H_{298} = -6{,}709 + 22.50T$$
$$F_T - H_{298} = -6{,}709 - 22.50T\ln T + 108.28T$$

Zone II (*l*) (317.4°–553° K.)

$$C_p = 23.50 \quad (82)$$
$$H_T - H_{298} = -6{,}435 + 23.50T$$
$$F_T - H_{298} = -6{,}435 - 23.50T\ln T + 113.15T$$

Zone III (*g*) (553°–1,500° K.)

$$C_p = 18.93 + 0.86\times10^{-3}T - 2.81\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = 7{,}343 + 18.93T + 0.43\times10^{-3}T^2 + 2.81\times10^{5}T^{-1}$$
$$F_T - H_{298} = 7{,}343 - 18.93T\ln T - 0.43\times10^{-3}T^2 + 1.40\times10^{5}T^{-1} + 59.17T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		42.4	42.4
400	2,975	51.14	43.7
500	5,325	56.40	45.75
600	19,324	81.76	49.55
700	21,206	84.66	54.36
800	23,110	87.21	58.32
900	25,040	89.48	61.66
1,000	26,980	91.52	64.5
1,100	28,940	93.39	67.08
1,200	30,900	95.10	69.35
1,300	32,860	96.66	71.39
1,400	34,820	98.12	73.25
1,500	36,790	99.48	74.95

Element (Red), P_4 (*c*)

$S_{298}=21.84$ *e.u.* (*130*)
S.P.$=870°$ K. (*112*)
$\Delta H_{subl}=7{,}350$ calories per atom

Zone I (*c*) (298°–870° K.)

$$C_p=18.96+15.60\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-6{,}348+18.96T+7.80\times10^{-3}T^2$$
$$F_T-H_{298}=-6{,}348-18.96T\ln T-7.80\times10^{-3}T^2+109.78T$$

Zone II (*g*) (870°–1,500° K.)

$$C_p=18.93+0.86\times10^{-3}T-2.81\times10^{5}T^{-2} \text{ (82)}$$
$$H_T-H_{298}=6{,}293+18.93T+0.43\times10^{-3}T^2+2.81\times10^{5}T^{-1}$$
$$F_T-H_{298}=6{,}293-18.93T\ln T-0.43\times10^{-3}T^2+1.40\times10^{5}T^{-1}+89.47T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		21.84	21.84
400	2,480	29.00	22.80
500	5,080	34.80	24.64
600	7,880	39.88	26.75
700	10,760	44.32	28.95
800	13,760	48.32	31.12
900	23,990	59.19	32.53
1,000	25,934	61.23	35.29
1,100	27,890	63.10	37.75
1,200	29,850	64.81	39.94
1,300	31,810	66.37	41.90
1,400	33,770	67.83	43.71
1,500	35,740	69.19	45.36

Phosphorus Oxide, PO (*g*)

$\Delta H^{\circ}_{298}=-9{,}500$ calories per mole (*112*)
$S_{298}=(53.6)$ *e.u.* (*24*)

Formation: $1/4P_4+1/2O_2\longrightarrow PO$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−9,500	(−15,000)
400	(600)	(−10,000)	(−17,000)
500	(1,550)	(−10,000)	(−18,500)
600	(2,450)	(−13,000)	(−20,000)
700	(3,000)	(−13,500)	(−21,000)
800	(3,650)	(−13,500)	(−22,000)
900	(4,550)	(−13,500)	(−23,500)
1,000	(5,450)	(−13,500)	(−24,500)
1,100	(6,350)	(−13,500)	(−25,500)
1,200	(7,000)	(−14,000)	(−26,500)
1,300	(7,650)	(−14,000)	(−27,500)
1,400	(8,550)	(−14,000)	(−28,500)
1,500	(9,550)	(−14,000)	(−29,500)

Tetraphosphorus Decaoxide, P_4O_{10} (*c*)

$\Delta H^{\circ}_{298}=-720{,}000$ calories per mole (*112*)
$S_{298}=(67.4)$ *e.u.* (*24*)
S.P.$=631°$ K. (*82*)
$\Delta H_{subl}=17{,}600$ calories per mole

Zone I (*c*) (298°-631° K.)

$$C_p=16.75+108.0\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-9{,}795+16.75T+54.0\times10^{-3}T^2$$

Zone II (*g*) (631°–1,400° K.)

$$C_p=73.60 \text{ (82)}$$
$$H_T-H_{298}=-6{,}570+73.60T$$

Formation: $P_4+5O_2\longrightarrow P_4O_{10}$

Zone I (298°–317.4° *K.*)

$$\Delta C_p=-41.55+103.00\times10^{-3}T+2.0\times10^{5}T^{-2}$$
$$\Delta H_T=-711{,}525-41.55T+51.5\times10^{-3}T^2-2.0\times10^{5}T^{-1}$$
$$\Delta F_T=-711{,}525+41.55T\ln T-51.5\times10^{-3}T^2-1.0\times10^{5}T^{-1}-28.68T$$

Zone II (317.4°–553° *K.*)

$$\Delta C_p=-42.55+103.0\times10^{-3}T+2.0\times10^{5}T^{-2}$$
$$\Delta H_T=-711{,}720-42.55T+51.5\times10^{-3}T^2-2.0\times10^{5}T^{-1}$$
$$\Delta F_T=-711{,}720+42.55T\ln T-51.5\times10^{-3}T^2-1.0\times10^{5}T^{-1}-33.72T$$

Zone III (553°-631° K.)

$$\Delta C_p=-38.0+102.14\times10^{-3}T+4.81\times10^{5}T^{-2}$$
$$\Delta H_T=-725{,}450-38.0T+51.07\times10^{-3}T^2-4.81\times10^{5}T^{-1}$$
$$\Delta F_T=-725{,}450+38.0T\ln T-51.07\times10^{-3}T^2-2.40\times10^{5}T^{-1}+1.05T$$

Zone IV (631°-1,400° K.)

$$\Delta C_p=18.87-5.86\times10^{-3}T+4.81\times10^{5}T^{-2}$$
$$\Delta H_T=-722{,}540+18.87T-2.93\times10^{-3}T^2-4.81\times10^{5}T^{-1}$$
$$\Delta F_T=-722{,}540-18.87T\ln T+2.93\times10^{-3}T^2-2.40\times10^{5}T^{-1}+347.93T$$

(estimated (*24*))

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(67.4)	−720,000	(−654,400)
400	5,550	(83.37)	−721,100	(−631,800)
500	12,080	(97.87)	−720,500	(−609,400)
600	19,700	(110.74)	−730,700	(−597,800)
700	44,950	(151.45)	−711,200	(−564,400)
800	52,300	(161.26)	−709,700	(−543,700)
900	59,650	(169.91)	−708,400	(−522,800)
1,000	67,050	(177.71)	−707,100	(−502,300)
1,100	74,400	(184.72)	−705,600	(−481,500)
1,200	81,750	(191.12)	−704,300	(−461,300)
1,300	89,100	(196.99)	−703,100	(−440,900)
1,400	96,450	(202.44)	−702,000	(−420,900)

Phosphorus Trifluoride, PF_3 (*g*)

$\Delta H^{\circ}_{298}=(-170{,}000)$ calories per mole (*42*)
$S_{298}=64.1$ *e.u.* (*83*)
M.P.$=122°$ K. (*112*)
B.P.$=172°$ K. (*112*)
$\Delta H_V=3{,}700$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p=17.18+1.92\times10^{-3}T-3.88\times10^{5}T^{-2} \text{ (82)}$$
$$H_T-H_{298}=-6{,}509+17.18T+0.96\times10^{-3}T^2+3.88\times10^{5}T^{-1}$$

Formation: $1/4P_4+3/2F_2\longrightarrow PF_3$

Zone I (298°-317.4° K.)

$$\Delta C_p=-0.88+1.26\times10^{-3}T-2.68\times10^{5}T^{-2}$$
$$\Delta H_T=-170{,}700-0.88T+0.63\times10^{-3}T^2+2.68\times10^{5}T^{-1}$$
$$\Delta F_T=-170{,}700+0.88T\ln T-0.63\times10^{-3}T^2+1.34\times10^{5}T^{-1}+15.33T$$

Zone II (317.4°–553° K.)

$$\Delta C_p=-1.13+1.26\times10^{-3}T-2.68\times10^{5}T^{-2}$$
$$\Delta H_T=-170{,}770-1.13T+0.63\times10^{-3}T^2+2.68\times10^{5}T^{-1}$$
$$\Delta F_T=-170{,}770+1.13T\ln T-0.63\times10^{-3}T^2+1.34\times10^{5}T^{-1}+14.13T$$

Zone III (553°–1,500° K.)

$\Delta C_p = 0.01 + 1.05 \times 10^{-3} T - 1.98 \times 10^5 T^{-2}$
$\Delta H_T = -174{,}100 + 0.01T + 0.525 \times 10^{-3} T^2 + 1.98 \times 10^5 T^{-1}$
$\Delta F_T = -174{,}100 - 0.01 T \ln T - 0.52 \times 10^{-3} T^2 + 0.99 \times 10^5 T^{-1} + 27.5T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		64.1	(−170,000)	(−164,250)
400	1,470	68.33	(−170,500)	(−162,200)
500	3,075	71.91	(−170,600)	(−160,000)
600	4,790	75.03	(−173,600)	(−157,600)
700	6,565	77.77	(−173,600)	(−155,000)
800	8,390	80.2	(−173,500)	(−152,400)
900	10,245	82.38	(−173,500)	(−149,800)
1,000	12,125	84.37	(−173,400)	(−147,100)
1,100	13,804	86.06	(−173,500)	(−144,600)
1,200	15,940	87.84	(−173,200)	(−141,900)
1,300	17,745	89.28	(−173,200)	(−139,200)
1,400	19,795	90.81	(−173,000)	(−136,700)
1,500	21,680	92.11	(−172,900)	(−134,100)

Phosphorus Trichloride, PCl_3 (l)

$\Delta H_{298}^\circ = -76{,}900$ calories per mole (*11*)
$S_{298} = 52.2$ *e.u.* (*11*)
$\Delta F_{298}^\circ = -74{,}500$ calories per mole
$M.P. = 182°$ K. (*6*)
$B.P. = 348°$ K. (*6*)
$\Delta H_V = 7{,}278$ calories per atom

Phosphorus Pentachloride, PCl_5 (c)

$\Delta H_{298}^\circ = -106{,}500$ calories per mole (*11*)
$S_{298} = 40.8$ *e.u.* (*11*)
$\Delta F_{298}^\circ = -75{,}800$ calories per mole
$S.P. = 439°$ K. (*6*)
$\Delta H_{subl} = 14{,}000$ calories per mole

Phosphoryl Chloride, $POCl_3$ (l)

$\Delta H_{298}^\circ = -151{,}000$ calories per mole (*112*)
$M.P. = 274.3°$ K. (*112*)
$B.P. = 378.5°$ K. (*112*)
$\Delta H_V = 8{,}211$ calories per mole

Phosphorus Tribromide, PBr_3 (l)

$\Delta H_{298}^\circ = (-47{,}500)$ calories per mole (*112*)
$S_{298} = (59)$ *e.u.* (*11*)
$M.P. = 233°$ K. (*6*)
$B.P. = 447°$ K. (*6*)
$\Delta H_V = 9{,}500$ calories per mole

Formation: $1/4P_4 + 3/2Br_2 \longrightarrow PBr_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		(−47,500)	(−45,500)
500	(15,500)	(−44,500)	(−40,000)

Phosphorus Pentabromide, PBr_5 (c)

$\Delta H_{298}^\circ = -66{,}000$ calories per mole (*112*)
$S_{298} = (53)$ *e.u.* (*11*)
$\Delta F_{298}^\circ = (-41{,}500)$ calories per mole
$S.P. = 379°$ K. (*6*)
$H_{subl} = 13{,}000$ calories per mole

Phosphoryl Bromide, $POBr_3$ (c)

$\Delta H_{298}^\circ = -114{,}600$ calories per mole (*112*)
$M.P. = 328°$ K. (*112*)
$B.P. = 464.9°$ K. (*112*)
$\Delta H_V = 9{,}080$ calories per mole

Phosphorus Triiodide, PI_3 (c)

$\Delta H_{298}^\circ = -10{,}900$ calories per mole (*11*)
$S_{298} = (57)$ *e.u.* (*11*)
$M.P. = 334°$ K. (*6*)
$B.P. = (500°)$ K. (*6*)
$\Delta H_V = 10{,}500$ calories per mole

Formation: $1/4P_4 + 3/2I_2 \longrightarrow PI_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−10,900	(−12,000)
500	(7,000)	(−19,300)	(−9,600)

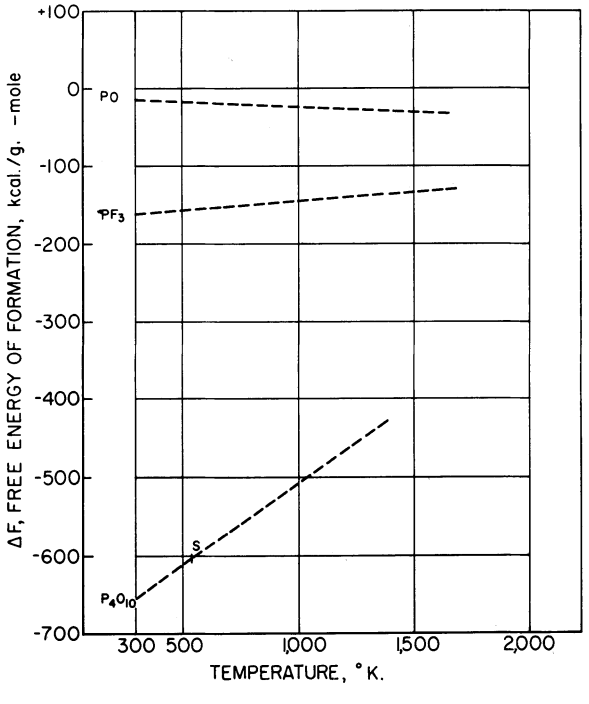

FIGURE 40.—Phosphorus.

PLATINUM AND ITS COMPOUNDS

Element, Pt (*c*)

$S_{298}=10.00$ *e.u.* (*83*)
$M.P.=2{,}042.5°$ K. (*112*)
$\Delta H_M=5{,}200$ calories per atom
$B.P.=4{,}100°$ K. (*112*)
$\Delta H_V=(122{,}000)$ calories per atom

Zone I (*c*) (298°–1, 900° K.)

$$C_p=5.74+1.34\times10^{-3}T+0.10\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-1{,}737+5.74T+0.67\times10^{-3}T^{2}-0.10\times10^{5}T^{-1}$$
$$F_T-H_{298}=-1{,}737-5.74T\ln T-0.67\times10^{-3}T^{2}-0.05\times10^{5}T^{-1}+28.79T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		10.0	10.0
400	645	11.86	10.25
500	1,280	13.28	10.72
600	1,920	14.44	11.24
700	2,580	15.46	11.77
800	3,260	16.37	12.29
900	3,950	17.18	12.79
1,000	4,660	17.93	13.27
1,100	5,380	18.61	13.71
1,200	6,110	19.25	14.16
1,300	6,850	19.84	14.57
1,400	7,600	20.39	14.96
1,500	8,370	20.93	15.35
1,600	9,150	21.43	15.71
1,700	9,940	21.93	16.08
1,800	10,740	22.37	16.40
1,900	11,550	22.81	16.73
2,000	(12,370)	(23.52)	(19.34)

Platinum Chloride, PtCl (*c*)

$\Delta H^\circ_{298}=-13{,}000$ calories per mole (*11*)
$S_{298}=(22)$ *e.u.* (*11*)
Decomposes = 856° K., 1 atm Cl_2 (*6*)

Formation: $Pt+1/2Cl_2\longrightarrow PtCl$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−13,000	(−8,500)
500	(2,000)	(−13,100)	(−6,000)
1,000	(11,000)	(−9,700)	(+3,000)

Platinum Dichloride, $PtCl_2$ (*c*)

$\Delta H^\circ_{298}=-29{,}000$ calories per mole (*11*)
$S_{298}=(31)$ *e.u.* (*11*)
Decomposes = 854° K., 1 atm Cl_2 (*6*)

Formation: $Pt+Cl_2\longrightarrow PtCl_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−29,000	(−19,500)
500	(4,000)	(−28,000)	(−12,500)
1,000	(15,000)	(−24,700)	(+4,000)

Platinum Trichloride, $PtCl_3$ (*c*)

$\Delta H^\circ_{298}=-43{,}000$ calories per mole (*11*)
$S_{298}=(35)$ *e.u.* (*11*)
Decomposes = 708° K., 1 atm Cl_2 (*6*)

Formation: $Pt+2/3Cl_2\longrightarrow PtCl_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔH°_T
298		−43,000	(−26,600)
500	(5,000)	(−41,800)	(−15,500)
1,000	(20,000)	(−36,800)	(+9,000)

Platinum Tetrachloride, $PtCl_4$ (*c*)

$\Delta H^\circ_{298}=-53{,}000$ calories per mole (*11*)
$S_{298}=(50)$ *e.u.* (*11*)
$M.P.=>600°$ K. (*6*)

Formation: $Pt+2Cl_2\longrightarrow PtCl_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−53,000	(−33,000)
500	(6,000)	(−51,700)	(−20,500)
1,000	(24,000)	(−45,000)	(+10,000)

Platinum Bromide, PtBr (*c*)

$\Delta H^\circ_{298}=-6{,}350$ calories per mole (*11*)
$S_{298}=(25)$ *e.u.* (*11*)
Disproportionates (*6*)

Formation: $Pt+1/2Br_2\longrightarrow PtBr$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−6,350	(−5,400)
500	(2,000)	(−10,400)	(−3,000)

Platinum Dibromide, $PtBr_2$ (*c*)

$\Delta H^\circ_{298}=-15{,}650$ calories per mole (*11*)
$S_{298}=(36)$ *e.u.* (*11*)
Decomposes = 683° K., 1 atm Br_2 (*6*)

Formation: $Pt+Br_2\longrightarrow PtBr_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−15,650	(−12,400)
500	(4,000)	(−22,450)	(−7,000)

Platinum Tribromide, $PtBr_3$ (*c*)

$\Delta H^\circ_{298} = -24{,}000$ calories per mole (*11*)
$S_{298} = (47)$ *e.u.* (*11*)
Decomposes = 678° K., 1 atm Br_2 (*6*)

Formation: $Pt + 3/2Br_2 \longrightarrow PtBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−24,000	(−18,700)
500	(5,000)	(−34,500)	(−9,500)

Platinum Tetrabromide, $PtBr_4$ (*c*)

$\Delta H^\circ_{298} = -32{,}300$ calories per mole (*11*)
$S_{298} = (60)$ *e.u.* (*11*)
Decomposes = 600° K., 1 atm Br_2 (*6*)

Formation: $Pt + 2Br_2 \longrightarrow PtBr_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−32,300	(−25,500)
500	(6,000)	(−46,600)	(−14,000)

Platinum Iodide, PtI (*c*)

$\Delta H^\circ_{298} = 440$ calories per mole (*11*)
$S_{298} = (26)$ *e.u.* (*11*)
Disproportionates (*6*)

Formation: $Pt + 1/2I_2 \longrightarrow PtI$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		+440	(−200)
500	(2,000)	(−7,200)	(0)

Platinum Diiodide, PtI_2 (*c*)

$\Delta H^\circ_{298} = -4{,}100$ calories per mole (*11*)
$S_{298} = (38)$ *e.u.* (*11*)
Decomposes = 600° K., 1 atm I_2 (*6*)

Formation: $Pt + I_2 \longrightarrow PtI_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−4,100	(−4,300)
500	(4,000)	(−18,000)	(−1,500)

Platinum Triiodide, PtI_3 (*c*)

$\Delta H^\circ_{298} = -8{,}700$ calories per mole (*11*)
$S_{298} = (50)$ *e.u.* (*11*)
Decomposes = 550° K., 1 atm I_2 (*6*)

Formation: $Pt + 3/2I_2 \longrightarrow PtI_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	$H\Delta^\circ_T$	ΔF°_T
298		−8,700	(−8,200)
500	(5,000)	(−30,000)	(−4,000)

Platinum Tetraiodide, PtI_4 (*c*)

$\Delta H^\circ_{298} = -11{,}250$ calories per mole (*11*)
$S_{298} = (64)$ *e.u.* (*11*)
Decomposes = 550° K., 1 atm (*6*)

Formation: $Pt + 2I_2 \longrightarrow PtI_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−11,250	(−13,900)
500		(−39,900)	(−5,500)

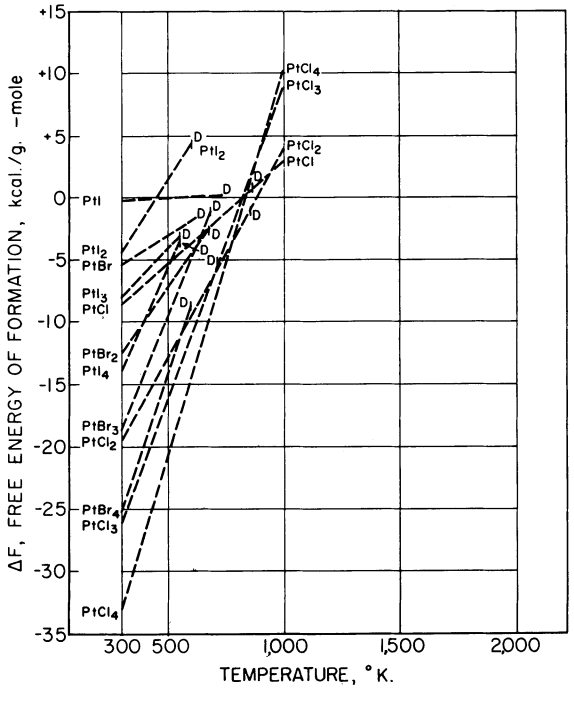

FIGURE 41.—Platinum.

POTASSIUM AND ITS COMPOUNDS

Element, K (*c*)

$S_{298}=15.3$ *e.u.* (*83*)
$M.P.=336.7°$ K. (*32*)
$\Delta H_M=554$ calories per atom
$B.P.=1{,}030°$ K. (*130*)
$\Delta H_V=18{,}530$ calories per atom

Zone I (*c*) (298°–336.7° K.)

$$C_p=6.04+3.12\times10^{-3}T \text{ } 34$$
$$H_T-H_{298}=-1{,}940+6.04T+1.56\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}940-6.04T\ln T-1.56\times10^{-3}T^2+26.08T$$

Zone II (*l*) (336.7°–1,030° K.)

$$C_p=6.03+0.992\times10^{-3}T+1.96\times10^5T^{-2} \text{ } (34)$$
$$H_T-H_{298}=-676+6.03T+0.49\times10^{-3}T^2-1.96\times10^5T^{-1}$$
$$F_T-H_{298}=-676-6.03T\ln T-0.496\times10^{-3}T^2-0.98\times10^5T^{-1}+22.79T$$

Zone III (*g*) (1,030°–2,500° K.)

$$C_p=4.90+0.054\times10^{-3}T+0.033\times10^5T^{-2} \text{ } (34)$$
$$H_T-H_{298}=+20{,}016+4.90T+0.027\times10^{-3}T^2-0.033\times10^5T^{-1}$$
$$F_T-H_{298}=+20{,}016-4.90T\ln T-0.027\times10^{-3}T^2-0.016\times10^5T^{-1}-5.47T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		15.3	15.3
400	1,324	19.17	15.86
500	2,067	20.83	16.70
600	2,793	22.15	17.50
700	3,509	23.26	18.24
800	4,220	24.21	18.94
900	4,934	25.05	19.57
1,000	5,654	25.81	20.16
1,100	25,404	44.69	21.60
1,200	25,900	45.12	23.54
1,300	26,397	45.52	25.22
1,400	26,894	45.89	26.68
1,500	27,391	46.23	27.97
1,600	27,889	46.56	29.13
1,700	28,386	46.86	30.16
1,800	28,885	47.14	31.09
1,900	29,384	47.41	31.94
2,000	29,884	47.67	32.73

Dipotassium Oxide, K_2O (*c*)

$\Delta H^\circ_{298}=-86{,}400$ calories per mole (*112*)
$S_{298}=(20.3)$ *e.u.* (*24*)

Formation: $2K+1/2O_2\longrightarrow K_2O$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−86,400	(−76,300)
400	(1,800)	(−87,600)	(−72,600)
500	(3,650)	(−87,600)	(−68,900)
600	(5,400)	(−87,700)	(−65,100)
700	(7,200)	(−87,700)	(−61,400)
800	(8,950)	(−87,800)	(−57,600)
900	(10,700)	(−87,800)	(−53,800)
1,000	(12,500)	(−87,900)	(−50,000)
1,100	(14,900)	(−125,400)	(−44,400)
1,200	(17,000)	(−124,700)	(−37,100)
1,300	(19,100)	(−124,000)	(−29,800)
1,400	(21,250)	(−123,300)	(−22,600)
1,500	(23,400)	(−122,600)	(−15,400)

Dipotassium Dioxide, K_2O_2 (*c*)

$\Delta H^\circ_{298}=-118{,}000$ calories per mole (*112*)
$S_{298}=(26.3)$ *e.u.* (*24*)
$M.P.=763°$ K. (*106*)
$\Delta H_M=6{,}100$ calories per mole (*24*)

Formation: $2K+O_2\longrightarrow K_2O_2$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−118,000	(−102,000)
400	(2,350)	(−119,000)	(−96,500)
500	(4,600)	(−119,000)	(−91,000)
600	(7,300)	(−118,500)	(−85,500)
700	(9,500)	(−118,500)	(−80,000)
800	(18,200)	(−112,000)	(−75,000)
900	(21,450)	(−111,000)	(−70,500)
1,000	(24,750)	(−110,000)	(−66,000)
1,100	(28,000)	(−147,000)	(−59,500)
1,200	(31,350)	(−145,500)	(−51,500)
1,300	(34,150)	(−144,500)	(−44,000)
1,400	(37,500)	(−143,000)	(−36,500)
1,500	(41,950)	(−141,500)	(−28,500)

Dipotassium Trioxide, K_2O_3 (*c*)

$\Delta H^\circ_{298}=-125{,}000$ calories per mole (*112*)
$S_{298}=(28.6)$ *e.u.* (*24*)
$M.P.=703°$ K. (*112*)
$\Delta H_M=7{,}030$ calories per mole

Formation: $2K+3/2O_2\longrightarrow K_2O_3$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−125,000	−102,500
400	(3,250)	(−125,500)	(−95,000)
500	(6,300)	(−125,000)	(−87,500)
600	(9,400)	(−124,500)	(−80,000)
700	(12,500)	(−124,000)	(−72,500)
800	(23,600)	(−115,500)	(−66,000)
900	(27,250)	(−114,500)	(−60,000)
1,000	(30,950)	(−113,500)	(−54,000)

Potassium Dioxide, KO_2 (*c*)

$\Delta H^\circ_{298}=-67{,}600$ calories per mole (*40*)
$S_{298}=27.9$ *e.u.* (*133*)
$M.P.=653°$ K. (*8*)
$\Delta H_M=3.920$ calories per mole

Formation: $K+O_2\longrightarrow KO_2$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−67,600	−56,800
400	(1,950)	(−67,700)	(−53,000)
500	(3,800)	(−67,300)	(−49,400)
600	(5,800)	(−66,800)	(−45,900)
700	(11,800)	(−62,300)	(−42,700)
800	(14,100)	(−61,500)	(−40,000)
900	(16,450)	(−60,700)	(−37,400)
1,000	(18,750)	(−59,900)	(−34,800)

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Potassium Trioxide, KO_3 (*c*)

$\Delta H^\circ_{298} = -62{,}000$ calories per mole (*104*)
$S_{298} = (33.5)$ *e.u.* (*24*)

Formation: $K + 3/2O_2 \longrightarrow KO_3$ (estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−62,000	(−45,500)
400	(2,400)	(−62,000)	(−39,500)
500	(4,750)	(−61,500)	(−34,000)

Potassium Fluoride, KF (*c*)

$\Delta H^\circ_{298} = -134{,}500$ calories per mole (*112*)
$S_{298} = 15.91$ *e.u.* (*112*)
$M.P. = 1{,}130°$ K. (*82*)
$\Delta H_M = 6{,}750$ calories per mole
$B.P. = 1{,}775°$ K. (*6*)
$\Delta H_V = 41{,}275$ calories per mole

Zone I (*c*) (298°–1,130° K.)

$$C_p = 11.02 + 3.12\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -3{,}424 + 11.02T + 1.56\times10^{-3}T^2$$

Zone II (*l*) (1,130°–1,200° K.)

$$C_p = 16.0 \text{ (82)}$$
$$H_T - H_{298} = -310 + 16.0T$$

Formation: $K + 1/2F_2 \longrightarrow KF$

Zone I (298°–336. 7° K.)

$$\Delta C_p = 0.83 - 0.22\times10^{-3}T + 0.40\times10^5T^{-2}$$
$$\Delta H_T = -134{,}600 + 0.83T - 0.11\times10^{-3}T^2 - 0.40\times10^5T^{-1}$$
$$\Delta F_T = -134{,}600 - 0.83T\ln T + 0.11\times10^{-3}T^2 - 0.20\times10^5T^{-1} + 28.95T$$

Zone II (336.7°–1,030° K.)

$$\Delta C_p = 0.84 + 1.91\times10^{-3}T - 1.56\times10^5T^{-2}$$
$$\Delta H_T = -135{,}860 + 0.84T + 0.95\times10^{-3}T^2 + 1.56\times10^5T^{-1}$$
$$\Delta F_T = -135{,}860 - 0.84T\ln T - 0.95\times10^{-3}T^2 + 0.78\times10^5T^{-1} + 32.24T$$

Zone III (1,030°–1,130° K.)

$$\Delta C_p = 1.97 + 2.85\times10^{-3}T + 0.37\times10^5T^{-2}$$
$$\Delta H_T = -156{,}540 + 1.97T + 1.42\times10^{-3}T^2 - 0.37\times10^5T^{-1}$$
$$\Delta F_T = -156{,}540 - 1.97T\ln T - 1.42\times10^{-3}T^2 - 0.18\times10^5T^{-1} + 60.44T$$

Zone IV (1,130°–1,200° K.)

$$\Delta C_p = 6.95 - 0.274\times10^{-3}T + 0.37\times10^5T^{-2}$$
$$\Delta H_T = -151{,}650 + 6.95T - 0.137\times10^{-3}T^2 - 0.37\times10^5T^{-1}$$
$$\Delta F_T = -151{,}650 - 6.95T\ln T + 0.137\times10^{-3}T^2 - 0.185\times10^5T^{-1} + 90.95T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		15.91	−134,500	−127,500
400	1,230	19.46	−134,500	−124,400
500	2,470	22.22	−134,900	−122,400
600	3,760	24.57	−134,750	−119,900
700	5,070	26.59	−134,550	−117,500
800	6,400	28.37	−134,400	−115,100
900	7,770	29.98	−134,150	−112,700
1,000	9,160	31.45	−133,900	−110,300
1,100	10,580	32.80	−152,700	−106,900
1,200	18,890	40.12	−145,300	−103,300
1,500	(23,300)	(43.2)	(−143,700)	(−92,600)

Potassium Chloride, KCl (*c*)

$\Delta H^\circ_{298} = -104{,}175$ calories per mole (*112*)
$S_{298} = 19.76$ *e.u.* (*83*)
$M.P. = 1{,}043°$ K. (*82*)
$\Delta H_M = 6{,}100$ calories per mole
$B.P. = 1{,}680°$ K. (*6*)
$\Delta H_V = 38{,}840$ calories per mole

Zone I (*c*) (298°–1,043° K.)

$$C_p = 9.89 + 5.20\times10^{-3}T + 0.77\times10^5T^{-2} \text{ (82)}$$
$$H_T - H_{298} = -2{,}920 + 9.89T + 2.60\times10^{-3}T^2 - 0.77\times10^5T^{-1}$$

Zone II (*l*) (1,043°–1,200° K.)

$$C_p = 16.00 \text{ (82)}$$
$$H_T - H_{298} = -440 + 16.00T$$

Formation: $K + 1/2Cl_2 \longrightarrow KCl$

Zone I (298°–336.7° K.)

$$\Delta C_p = -0.56 + 2.05\times10^{-3}T + 1.11\times10^5T^{-2}$$
$$\Delta H_T = -103{,}730 - 0.56T + 1.02\times10^{-3}T^2 - 1.11\times10^5T^{-1}$$
$$\Delta F_T = -103{,}730 + 0.56T\ln T - 1.02\times10^{-3}T^2 - 0.56\times10^5T^{-1} + 18.44T$$

Zone II (336.7°–1,030° K.)

$$\Delta C_p = -0.55 + 4.18\times10^{-3}T - 0.85\times10^5T^{-2}$$
$$\Delta H_T = -104{,}990 - 0.55T + 2.09\times10^{-3}T^2 + 0.85\times10^5T^{-1}$$
$$\Delta F_T = -104{,}990 + 0.55T\ln T - 2.09\times10^{-3}T^2 + 0.42\times10^5T^{-1} + 21.78T$$

Zone III (1,043°–1,200° K.)

$$\Delta C_p = 5.69 - 0.084\times10^{-3}T + 0.31\times10^5T^{-2}$$
$$\Delta H_T = -122{,}000 + 5.69T - 0.042\times10^{-3}T^2 - 0.31\times10^5T^{-1}$$
$$\Delta F_T = -122{,}000 - 5.69T\ln T + 0.042\times10^{-3}T^2 - 0.15\times10^5T^{-1} + 79.28T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		19.76	−104,175	−97,550
400	1,260	23.40	−104,650	−95,200
500	2,520	26,21	−104,550	−92,800
600	3,810	28.56	−104,450	−90,500
700	5,150	30.62	−104,250	−88,200
800	6,550	32.49	−104,000	−85,900
900	8,000	34.20	−103.700	−83,650
1,000	9,500	35.78	−103,350	−81,400
1,100	17,160	43.12	−115,800	−78,600
1,200	18,760	44.51	−115,250	−75,300
(1,500)	(23,800)	(48.36)	(−112,950)	(−65,600)

Potassium Bromide, KBr (*c*)

$\Delta H^\circ_{298} = -93{,}730$ calories per mole (*112*)
$S_{298} = 22.6$ *e.u.* (*83*)
$M.P. = 1{,}015°$ K. (*6*)
$\Delta H_M = 5{,}000$ calories per mole
$B.P. = 1{,}656°$ K. (*6*)
$\Delta H_V = 37{,}060$ calories per mole

Zone I (*c*) (298°–1,000°K.)

$$C_p = 11.56 + 3.32\times10^{-3}T \text{ (20)}$$
$$H_T - H_{298} = -3{,}594 + 11.56T + 1.66\times10^{-3}T^2$$

Formation: $K + 1/2Br_2 \longrightarrow KBr$

Zone I (298°–331° K.)

$$\Delta C_p = -3.03 + 0.20\times10^{-3}T$$
$$\Delta H_T = -92{,}840 - 3.03T + 0.10\times10^{-3}T^2$$
$$\Delta F_T = -92{,}840 + 3.03T\ln T - 0.10\times10^{-3}T^2 - 9.13T$$

Zone II (331°–1,015° K.)

$\Delta C_p = 1.01 + 2.33\times10^{-3}T - 1.78\times10^{5}T^{-2}$
$\Delta H_T = -99{,}100 + 1.01T + 1.16\times10^{-3}T^2 + 1.78\times10^{5}T^{-1}$
$\Delta F_T = -99{,}100 - 1.01T\ln T - 1.16\times10^{-3}T^2 + 0.89\times10^{5}T^{-1} + 32.75T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		22.6	−93,750	−90,400
400	1,295	26.33	−98,100	−88,400
500	2,600	29.24	−97,950	−86,000
600	3,940	31.69	−97,800	−83,600
700	5,310	33.80	−97,600	−81,250
800	6,710	35.67	−97,350	−78,950
900	8,150	37.36	−97,100	−76,650
1,000	9,630	38.92	−96,750	−74,400
(1,500)	(22,700)	(50.5)	(−107,700)	−58,200

Potassium Iodide, KI (*c*)

$\Delta H_{298}^\circ = -78{,}310$ calories per mole (*112*)
$S_{298} = 24.9$ *e.u.* (*112*)
M.P. = 955° K. (*6*)
$\Delta H_M = 4{,}100$ calories per mole
B.P. = 1,597° K. (*6*)
$\Delta H_V = 34{,}691$ calories per mole

Zone I (*c*) (298°–950° K.)

$C_p = 11.36 + 4.00\times10^{-3}T$ (*82*)
$H_T - H_{298} = -3{,}565 + 11.36T + 2.00\times10^{-3}T^2$

Formation: $K + 1/2I_2 \longrightarrow KI$

Zone I (298°–337° K.)

$\Delta C_p = 0.53 - 5.07\times10^{-3}T$
$\Delta H_T = -77{,}260 + 0.53T - 2.53\times10^{-3}T^2$
$\Delta F_T = -77{,}260 - 0.53T\ln T + 2.53\times10^{-3}T^2 + 3.14T$

Zone II (337°–387° K.)

$\Delta C_p = 0.54 - 2.94\times10^{-3}T - 1.96\times10^{5}T^{-2}$
$\Delta H_T = -78{,}500 + 0.54T - 1.47\times10^{-3}T^2 + 1.96\times10^{5}T^{-1}$
$\Delta F_T = -78{,}500 - 0.54T\ln T + 1.47\times10^{-3}T^2 + 0.98\times10^{5}T^{-1} + 6.37T$

Zone III (387°–456° K.)

$\Delta C_p = -4.27 + 3.01\times10^{-3}T - 1.96\times10^{5}T^{-2}$
$\Delta H_T = -80{,}000 - 4.27T + 1.50\times10^{-3}T^2 + 1.96\times10^{5}T^{-1}$
$\Delta F_T = -80{,}000 + 4.27T\ln T - 1.50\times10^{-3}T^2 + 0.98\times10^{5}T^{-1} - 16.9T$

Zone IV (456°–955° K.)

$\Delta C_p = 0.89 + 3.01\times10^{-3}T - 1.96\times10^{5}T^{-2}$
$\Delta H_T = -87{,}350 + 0.89T + 1.50\times10^{-3}T^2 + 1.96\times10^{5}T^{-1}$
$\Delta F_T = -87{,}350 - 0.89T\ln T - 1.50\times10^{-3}T^2 + 0.98\times10^{5}T^{-1} + 31.04T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		24.9	−78,310	−77,000
400	1,290	26.62	−80,950	−76,500
500	2,630	31.61	−86,200	−74,800
600	3,990	34.09	−85,900	−72,450
700	5,390	36.21	−85,650	−70,200
800	6,800	38.12	−85,400	−68,000
900	8,250	39.86	−85,100	−65,900

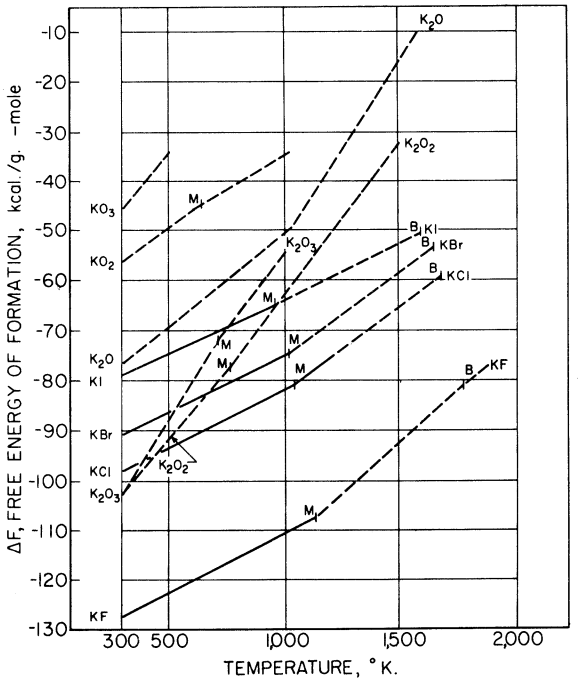

FIGURE 42.—Potassium.

PRASEODYMIUM AND ITS COMPOUNDS

Element, Pr (*c*)

$S_{298} = 17.49$ *e.u.* (*121*)
T.P. = 1,071° K. (*125*)
$\Delta H_T = (320)$ calories per atom
M.P. = 1,208° K. (*125*)
$\Delta H_M = (2{,}400)$ calories per atom
B.P. = (3,290°) K. (*125*)
$\Delta H_V = (2{,}200)$ calories per atom

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		17.49	17.49
400	(670)	(19.39)	(17.72)
500	(1,370)	(20.94)	(18.20)
600	(2,090)	(22.26)	(18.78)
700	(2,850)	(23.43)	(19.36)
800	(3,640)	(24.48)	(19.93)
900	(4,460)	(25.45)	(20.50)
1,000	(5,320)	(26.35)	(21.03)
1,100	(6,500)	(27.47)	(21.57)
1,200	(7,300)	(28.16)	(22.08)
1,300	(8,100)	(30.79)	(24.56)
1,400	(8,900)	(31.39)	(25.04)
1,500	(9,700)	(31.94)	(25.48)
1,600	(10,500)	(32.46)	(25.90)
1,700	(11,300)	(32.94)	(26.30)
1,800	(12,100)	(33.40)	(26.68)
1,900	(12,900)	(33.83)	(27.05)
2,000	(13,700)	(34.24)	(27.39)

Dipraseodymium Trioxide, Pr_2O_3 (*c*)

$\Delta H^\circ_{298} = -437{,}000$ calories per mole (*129*)
$S_{298} = (43.5)$ *e.u.* (*24*)

Formation: $2Pr + 3/2O_2 \longrightarrow Pr_2O_3$
(estimated (*24*))

T, ° K.	ΔH°_T	ΔF°_T
298	−437,000	(−420,500)
400	(−437,000)	(−414,000)
500	(−436,500)	(−407,500)
600	(−436,500)	(−401,000)
700	(−436,000)	(−395,000)
800	(−436,000)	(−388,500)
900	(−436,000)	(−382,500)
1,000	(−435,500)	(−376,000)
1,100	(−435,500)	(−370,000)
1,200	(−435,000)	(−363,500)
1,300	(−440,500)	(−357,000)
1,400	(−440,500)	(−350,000)
1,500	(−440,000)	(−343,000)
1,600	(−440,000)	(−337,000)
1,700	(−439,500)	(−330,500)
1,800	(−439,500)	(−324,000)
1,900	(−439,500)	(−317,000)
2,000	(−439,000)	(−310,500)

Praseodymium Dioxide, PrO_2 (*c*)

$\Delta H^\circ_{298} = -230{,}500$ calories per mole (*24*)
$S_{298} = 22.9$ *e.u.* (*24*)

Formation: $Pr + O_2 \longrightarrow PrO_2$
(estimated (*24*))

T, ° K.	ΔH°_T	ΔF°_T
298	−230,500	−217,500
400	(−230,500)	(−213,000)
500	(−230,500)	(−208,500)
600	(−230,000)	(−204,000)
700	(−230,000)	(−200,000)
800	(−230,500)	(−195,500)
900	(−230,500)	(−191,000)
1,000	(−230,500)	(−187,000)
1,100	(−231,000)	(−182,500)
1,200	(−231,000)	(−178,000)

Praseodymium Trifluoride, PrF_3 (*c*)

$\Delta H^\circ_{298} = (-388{,}000)$ calories per mole (*5*)
$S_{298} = (25)$ *e.u.* (*11*)
M.P. = 1,668° K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (2,600°) K. (*6*)
$\Delta H_V = (62{,}000)$ calories per mole

Formation: $Pr + 3/2F_2 \longrightarrow PrF_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−388,000)	(−369,500)
500	(4,000)	(−388,000)	(−358,000)
1,000	(17,000)	(−385,000)	(−328,000)
1,500	(32,000)	(−381,000)	(−301,000)

Praseodymium Trichloride, $PrCl_3$ (*c*)

$\Delta H^\circ_{298} = -252{,}090$ calories per mole (*127*)
$S_{298} = (34.5)$ *e.u.* (*127*)
M.P. = 1,059° K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (1,980°) K. (*6*)
$\Delta H_V = (46{,}000)$ calories per mole

Formation: $Pr + 3/2Cl_2 \longrightarrow PrCl_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−252,090	(−244,000)
500	(5,000)	(−251,000)	(−224,500)
1,000	(19,000)	(−247,500)	(−199,000)
1,500	(43,000)	(−233,400)	(−180,000)

Praseodymium Tribromide, $PrBr_3$ (*c*)

$\Delta H^\circ_{298} = (-189{,}000)$ calories per mole (*5*)
$S_{298} = (46)$ *e.u.* (*11*)
M.P. = 964° K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (1,820°) K. (*6*)
$\Delta H_V = (45{,}000)$ calories per mole

Formation: $Pr + 3/2Br_2 \longrightarrow PrBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−189,000)	(−182,000)
500	(5,000)	(−199,700)	(−171,500)
1,000	(18,000)	(−197,300)	(−146,000)
1,500	(43,000)	(−194,500)	(−127,000)

Praseodymium Triiodide, PrI_3 (*c*)

$\Delta H^\circ_{298} = -162{,}000$ calories per mole (*5*)
$S_{298} = (50)$ *e.u.* (*11*)
M.P. = 1,010° K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (1,650°) K. (*6*)
$\Delta H_V = (40{,}000)$ calories per mole

Formation: $Pr + 3/2I_2 \longrightarrow PrI_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−162,000	(−160,000)
500	(5,000)	(−183,400)	(−148,500)
1,000	(19,000)	(−180,000)	(−122,000)
1,500	(44,000)	(−166,000)	(−99,000)

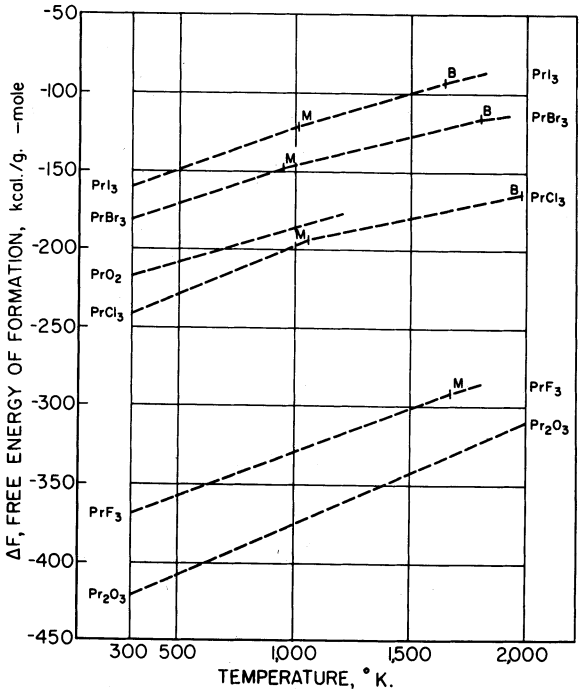

FIGURE 43.—Praseodymium.

PROMETHIUM AND ITS COMPOUNDS

Element, Pm (*c*)

S_{298}=(17.25) *e.u.* (*121*)
M.P.=1,573° K. (*125*)
ΔH_M=(3,000) calories per atom
B.P.=(3,000°) K. (*125*)
ΔH_V=(70,000) calories per atom
(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$\frac{(F_T-H_{298})}{T}$
298		(17.25)	(17.25)
400	(670)	(19.15)	(17.48)
500	(1,360)	(20.69)	(17.97)
600	(2,070)	(21.98)	(18.53)
700	(2,810)	(23.12)	(19.11)
800	(3,570)	(24.14)	(19.68)
900	(4,360)	(25.07)	(20.23)
1,000	(5,170)	(25.92)	(20.75)
1,100	(6,010)	(26.72)	(21.26)
1,200	(6,870)	(27.47)	(21.75)
1,300	(7,760)	(28.19)	(22.22)
1,400	(8,560)	(28.94)	(22.83)
1,500	(9,360)	(29.64)	(23.40)
1,600	(13,160)	(32.15)	(23.93)
1,700	(13,960)	(32.64)	(24.43)
1,800	(14,760)	(33.09)	(24.89)
1,900	(15,560)	(33.53)	(25.35)
2,000	(16,360)	(33.94)	(25.76)

Promethium Trifluoride, PmF_3 (*c*)

ΔH°_{298}=(−383,000) calories per mole (*5*)
S_{298}=(24) *e.u* (*11*)
M.P.=1,680° K. (*6*)
ΔH_M=(8,000) calories per mole
B.P.=(2,600°) K. (*6*)
ΔH_V=(62,000) calories per mole

Formation: $Pm+3/2F_2 \longrightarrow PmF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−383,000)	(−364,500)
500	(4,000)	(−383,000)	(−352,500)
1,000	(17,000)	(−380,000)	(−322,000)
1,500	(32,000)	(−379,000)	(−296,500)

Promethium Trichloride, $PmCl_3$ (*c*)

ΔH°_{298}=(−227,000) calories per mole (*5*)
S_{298}=(39) *e.u.* (*11*)
M.P.=1,010° K. (*6*)
ΔH_M=(8,000) calories per mole
B.P.=(1,940°) K. (*6*)
ΔH_V=(46,000) calories per mole

Formation: $Pm+3/2Cl_2 \longrightarrow PmCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−227,000)	(−211,000)
500	(5,000)	(−225,900)	(−200,000)
1,000	(19,000)	(−222,300)	(−175,000)
1,500	(43,000)	(−209,000)	(−156,500)

Promethium Tribromide, $PmBr_3$ (*c*)

ΔH°_{298}=(−183,000) calories per mole (*5*)
S_{298}=(47) *e.u.* (*11*)
M.P.=950° K. (*6*)
ΔH_M=(8,000) calories per mole
B.P.=(1,800°) K. (*6*)
ΔH_V=(45,000) calories per mole

Formation: $Pm+3/2Br_2 \longrightarrow PmBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−183,000)	(−177,000)
500	(5,000)	(−193,600)	(−167,000)
1,000	(18,000)	(−191,200)	(−142,000)
1,500	(43,000)	(−180,000)	(−123,500)

Promethium Triiodide, PmI_3 (*c*)

ΔH°_{298}=(−131,000) calories per mole (*5*)
S_{298}=(49) *e.u.* (*11*)
M.P.=1,070° K. (*6*)
ΔH_M=(8,000) calories per mole
B.P.=(1,640°) K. (*6*)
ΔH_V=(41,000) calories per mole

Formation: $Pm+3/2I_2 \longrightarrow PmI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−131,000)	(−129,000)
500	(5,000)	(−152,400)	(−124,000)
1,000	(19,000)	(−148,090)	(−97,000)
1,500	(44,000)	(−137,300)	(−73,500)

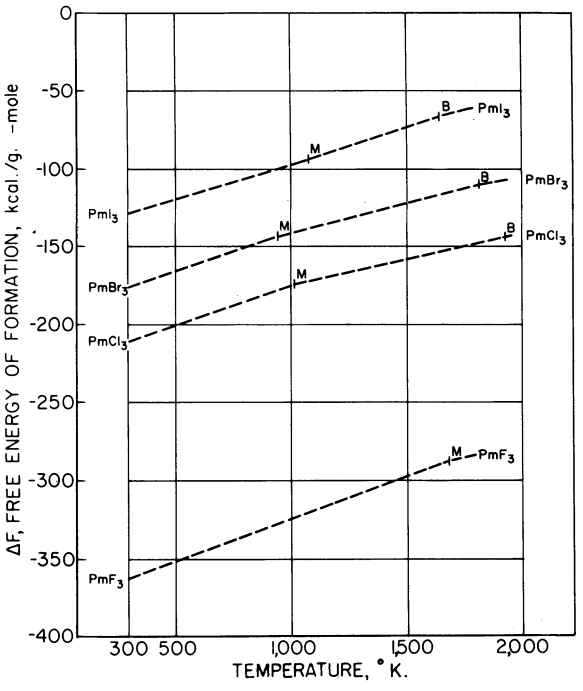

FIGURE 44.—Promethium.

RHENIUM AND ITS COMPOUNDS

Element, Re (*c*)

$S_{298}=8.89$ *e.u.* (*123*)
M.P.$=3{,}453°$ K. (*118*)
$\Delta H_M=(7{,}900)$ calories per atom
B.P.$=5{,}900°$ K. (*118*)

Zone I (*c*) (298°–1,500° K.)

$C_p=5.66+1.30\times10^{-3}T$ (*82*)
$H_T-H_{298}=-1{,}745+5.66T+0.65\times10^{-3}T^2$
$F_T-H_{298}=-1{,}745-5.66T\,lnT-0.65\times10^{-3}T^2+29.39T$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		8.89	8.89
400	620	10.68	9.13
500	1,240	12.06	9.58
600	1,890	13.25	10.10
700	2,550	14.26	10.62
800	3,210	15.14	11.12
900	3,880	15.93	11.62
1,000	4,570	16.66	12.09
1,100	5,270	17.33	12.54
1,200	5,980	17.94	12.96
1,300	6,710	18.53	13.36
1,400	7,460	19.08	13.75
1,500	8,220	19.61	14.13
1,600	(8,990)	(20.10)	(14.48)
1,700	(9,770)	(20.56)	(14.81)
1,800	(10,560)	(21.02)	(15.15)
1,900	(11,370)	(21.45)	(15.47)
2,000	(12,180)	(21.88)	(15.79)

Rhenium Trioxide, ReO_3 (*c*)

$\Delta H^\circ_{298}=(-147{,}000)$ calories per mole (*8*)
$S_{298}=(18.6)$ *e.u.* (*24*)
M.P.$=433°$ K. (*24*)
$\Delta H_M=5{,}200$ calories per mole

Formation: $Re+3/2O_2\longrightarrow ReO_3$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−147, 000)	(−128, 000)
400	(2, 200)	(−146, 500)	(−121, 500)
500	(10, 400)	(−140, 000)	(−116, 500)
600	(13, 700)	(−138, 500)	(−112, 000)
700	(17, 000)	(−137, 000)	(−107, 500)
800	(19, 900)	(−136, 000)	(−103, 500)
900	(23, 300)	(−134, 500)	(−99, 500)
1,000	(26, 700)	(−133, 000)	(−95, 500)

Dirhenium Heptaoxide, Re_2O_7 (*c*)

$\Delta H^\circ_{298}=-297{,}000$ calories per mole (*8*)
$S_{298}=(40)$ *e.u.* (*24*)
M.P.$=569°$ K. (*112*)
$\Delta H_M=15{,}340$ calories per mole
B.P.$=635.5°$ K. (*112*)
$\Delta H_V=18{,}060$ calories per mole

Formation: $2Re+7/2O_2\longrightarrow Re_2O_7$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−297, 000	(−252, 000)
400	(5, 300)	(−295, 500)	(−237, 000)
500	(10, 600)	(−294, 000)	(−223, 000)
600	(32, 000)	(−276, 500)	(−209, 500)
700	(55, 000)	(−257, 500)	(−200, 500)
800	(59, 200)	(−257, 500)	(−192, 000)
900	(62, 900)	(−258, 000)	(−184, 000)
1,000	(67, 100)	(−258, 000)	(−176, 000)
1,100	(71, 200)	(−258, 000)	(−167, 500)
1,200	(75, 300)	(−258, 500)	(−159, 500)
1,300	(79, 500)	(−258, 500)	(−151, 000)
1,400	(83, 900)	(−258, 500)	(−143, 000)
1,500	(88, 800)	(−258, 500)	(−134, 500)

Dirhenium Octaoxide, Re_2O_8 (*c*)

$\Delta H^\circ_{298}=(-308{,}500)$ calories per mole (*24*)
$S_{298}=(41)$ *e.u.* (*24*)
M.P.$=420°$ K. (*24*)
$\Delta H_M=3{,}800$ calories per mole

Formation: $2Re+4O_2\longrightarrow Re_2O_8$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−308, 500)	(−257, 000)
400	(6, 100)	(−306, 500)	(−239, 500)
500	(17, 300)	(−299, 500)	(−224, 000)
600	(25, 600)	(−295, 500)	(−209, 000)

Rhenium Trifluoride, ReF_3 (*c*)

$\Delta H^\circ_{298}=(-170{,}000)$ calories per mole (*42*)
$S_{298}=(26)$ *e.u.* (*11*)
M.P.$=(1{,}380°)$ K. (*42*)
$\Delta H_M=(1{,}100)$ calories per mole
B.P.$=(1{,}530°)$ K. (*42*)
$\Delta H_V=(37{,}000)$ calories per mole

Formation: $Re+3/2F_2 \longrightarrow ReF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−170, 000)	(−153, 300)
500	(4, 000)	(−169, 500)	(−142, 500)
1,000	(17, 000)	(−166, 400)	(−116, 000)

Rhenium Tetrafluoride, ReF_4 (*c*)

$\Delta H_{298}^\circ = (-220{,}000)$ calories per mole (*42*)
$S_{298} = (36)$ *e.u.* (*11*)
$M.P. = 398°$ K. (*6*)
$\Delta H_M = (4{,}500)$ calories per mole
$B.P. = (1{,}070°)$ K. (*6*)
$\Delta H_V = (27{,}000)$ calories per mole

Formation: $Re+2F_2 \longrightarrow ReF_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−220, 000)	(−209, 300)
500	(6, 000)	(−218, 500)	(−201, 000)
1,000	(22, 000)	(−214, 300)	(−169, 000)

Rhenium Pentafluoride, ReF_5 (*c*)

$\Delta H_{298}^\circ = (-225{,}000)$ calories per mole (*11*)
$S_{298} = (59)$ *e.u.* (*11*)
$M.P. = (398°)$ K. (*42*)
$\Delta H_M = (4{,}500)$ calories per mole
$B.P. = (660°)$ K. (*42*)
$\Delta H_V = (15{,}000)$ calories per mole

Formation: $Re+5/2F_2 \longrightarrow ReF_5$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−225, 000)	(−204, 000)
500	(12, 000)	(−218, 000)	(−192, 500)

Rhenium Hexafluoride, ReF_6 (*l*)

$\Delta H_{298}^\circ = -278{,}000$ calories per mole (*112*)
$S_{298} = (78)$ *e.u.* (*11*)
$\Delta F_{298}^\circ = (-255{,}000)$ calories per mole
$M.P. = 292°$ K. (*6*)
$\Delta H_M = 5{,}000$ calories per mole
$B.P. = 321°$ K. (*6*)
$\Delta H_V = 6{,}900$ calories per mole

Rhenium Trichloride, $ReCl_3$ (*c*)

$\Delta H_{298}^\circ = (-55{,}000)$ calories per mole (*11*)
$S_{298} = (38)$ *e.u.* (*11*)
$M.P. = (1{,}000°)$ K. (*6*)
$\Delta H_M = (15{,}000)$ calories per mole
$B.P. = (1{,}100°)$ K. (*6*)
$\Delta H_V = (27{,}000)$ calories per mole

Formation: $Re+3/2Cl_2 \longrightarrow ReCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−55, 000)	(−39, 800)
500	(5, 000)	(−53, 800)	(−29, 500)
1,000	(19, 000)	(−49, 700)	(−6, 000)

Rhenium Tetrachloride, $ReCl_4$ (*c*)

$\Delta H_{298}^\circ = (-60{,}000)$ calories per mole (*11*)
$S_{298} = (50)$ *e.u.* (*11*)
$M.P. = (450°)$ K. (*42*)
$\Delta H_M = (4{,}000)$ calories per mole
$B.P. = 650°$ K. (*42*)
$\Delta H_V = (14{,}000)$ calories per mole

Formation: $Re+2Cl_2 \longrightarrow ReCl_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−60, 000)	(−41, 000)
500	(6, 000)	(−58, 600)	(−28, 000)

Rhenium Pentachloride, $ReCl_5$ (*c*)

$\Delta H_{298}^\circ = (-70{,}000)$ calories per mole (*11*)
$S_{298} = (66)$ *e.u.* (*11*)
$M.P. = (530°)$ K. (*6*)
$\Delta H_M = (9{,}000)$ calories per mole
$B.P. = (600°)$ K. (*6*)
$\Delta H_V = (14{,}000)$ calories per mole

Formation: $Re+5/2Cl_2 \longrightarrow ReCl_5$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−70, 000)	(−47, 400)
500	(7, 000)	(−68, 000)	(−33, 000)

Rhenium Tribromide, $ReBr_3$ (*c*)

$\Delta H_{298}^\circ = (-32{,}700)$ calories per mole (*11*)
$S_{298} = (44)$ *e.u.* (*11*)
$M.P. = (900°)$ K. (*6*)
$\Delta H_M = (13{,}500)$ calories per mole
$B.P. = (1{,}000°)$ K. (*6*)
$\Delta H_V = (25{,}000)$ calories per mole

Formation: $Re+3/2Br_2 \longrightarrow ReBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−32, 700)	(−23, 400)
500	(5, 000)	(−43, 200)	(−12, 700)
1,000	(18, 000)	(−40, 300)	(+10, 700)

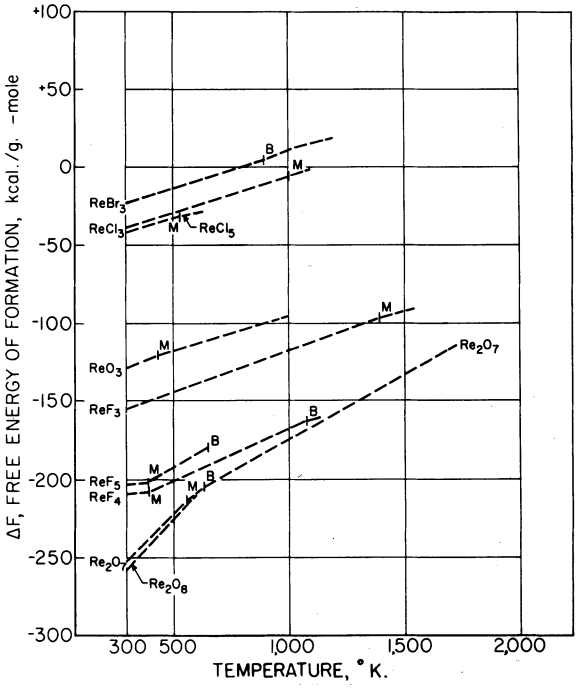

FIGURE 45.—Rhenium.

SAMARIUM AND ITS COMPOUNDS

Element, Sm (*c*)

S_{298} = (16.32) *e.u.* (*121*)
T.P. = 1,190° K. (*125*)
ΔH_T = (360) calories per atom
M.P. = (1,325°) K. (*125*)
ΔH_M = (2,650) calories per atom
B.P. = 1,860° K. (*125*)
ΔH_V = (45,800) calories per atom

(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		(16.32)	(16.32)
400	(675)	(18.23)	(16.55)
500	(1,370)	(19.77)	(17.03)
600	(2,090)	(21.08)	(17.60)
700	(2,835)	(22.23)	(18.18)
800	(3,610)	(23.27)	(18.76)
900	(4,415)	(24.22)	(19.32)
1,000	(5,250)	(25.09)	(19.84)
1,100	(6,110)	(25.91)	(20.36)
1,200	(7,350)	(26.98)	(20.86)
1,300	(8,150)	(27.62)	(21.36)
1,400	(11,600)	(30.21)	(21.93)
1,500	(12,400)	(30.76)	(22.50)
1,600	(13,200)	(31.28)	(23.03)
1,700	(14,000)	(31.76)	(23.53)
1,800	(14,800)	(32.22)	(24.00)
1,900	(61,340)	(57.04)	(24.76)
2,000	(61,970)	(57.36)	(26.38)

Disamarium Trioxide, Sm_2O_3 (*c*)

ΔH°_{298} = −433,890 calories per mole (*64*)
S_{298} = (41) *e.u.* (*24*)

Formation: $2Sm+3/2O_2 \longrightarrow Sm_2O_3$
(estimated (*24*))

T, ° K.	ΔH°_T	ΔF°_T
298	−434,000	(−410,500)
400	(−434,000)	(−404,000)
500	(−433,500)	(−397,500)
600	(−433,500)	(−391,000)
700	(−433,000)	(−385,000)
800	(−433,000)	(−378,500)
900	(−433,000)	(−372,500)
1,000	(−425,500)	(−366,000)
1,100	(−425,500)	(−360,000)
1,200	(−425,000)	(−353,500)
1,300	(−425,000)	(−347,500)
1,400	(−425,000)	(−341,000)
1,500	(−424,500)	(−335,000)
1,600	(−424,500)	(−329,000)
1,700	(−438,500)	(−322,500)
1,800	(−438,500)	(−315,500)
1,900	(−438,000)	(−309,000)
2,000	(−438,000)	(−302,500)

Samarium Difluoride, SmF_2 (*c*)

ΔH°_{298} = (−272,000) calories per mole (*5*)
S_{298} = (23) *e.u.* (*11*)
M.P. = (1,603°) K. (*29*)
ΔH_M = (5,000) calories per mole
B.P. = (2,700°) K. (*6*)
ΔH_V = (78,000) calories per mole

Formation: $Sm+F_2 \longrightarrow SmF_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−272,000)	(−259,500)
500	(4,000)	(−271,000)	(−251,000)
1,000	(13,000)	(−270,100)	(−232,000)
1,500	(24,000)	(−270,600)	(−213,500)

Samarium Trifluoride, SmF_3 (*c*)

ΔH°_{298} = (−380,000) calories per mole (*5*)
S_{298} = 27 *e.u.* (*11*)
M.P. = (1,579°) K. (*29*)
ΔH_M = (8,000) calories per mole
B.P. = (2,600°) K. (*6*)
ΔH_V = (62,000) calories per mole

Formation: $Sm+3/2F_2 \longrightarrow SmF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−380,000)	(−361,500)
500	(4,000)	(−379,700)	(−349,500)
1,000	(17,000)	(−377,000)	(−319,000)
1,500	(32,000)	(−375,800)	(−291,500)

Samarium Dichloride, $SmCl_2$ (*c*)

ΔH°_{298} = −195,600 calories per mole (*96*)
S_{298} = 30 *e.u.* (*11*)
M.P. = 835° K. (*29*)
ΔH_M = (6,000) calories per mole
B.P. = (2,300°) K. (*6*)
ΔH_V = (55,000) calories per mole

Formation: $Sm+Cl_2 \longrightarrow SmCl_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−195,600	(−184,000)
500	(4,000)	(−194,500)	(−177,000)
1,000	(13,000)	(−193,900)	(−160,000)
1,500	(31,000)	(−187,400)	(−149,000)

Samarium Trichloride, $SmCl_3$ (*c*)

$\Delta H_{298}^\circ = (-223{,}000)$ calories per mole (*11*)
$S_{298} = (39)$ *e.u.* (*11*)
$M.P. = 955°$ K. (*29*)
$\Delta H_M = (8{,}000)$ calories per mole
Decomposes (*6*)

Formation: $Sm + 3/2Cl_2 \longrightarrow SmCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−223,000)	(−206,500)
500	(5,000)	(−221,900)	(−196,000)
1,000	(19,000)	(−218,700)	(−172,000)
1,500	(43,000)	(−208,000)	(−152,000)

Samarium Dibromide, $SmBr_2$ (*c*)

$\Delta H_{298}^\circ = (-157{,}000)$ calories per mole (*5*)
$S_{298} = (35)$ *e.u.* (*11*)
$M.P. = 781°$ K. (*29*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = (2{,}150°)$ K. (*6*)
$\Delta H_V = (50{,}000)$ calories per mole

Formation: $Sm + Br_2 \longrightarrow SmBr_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−157,000)	(−152,000)
500	(4,000)	(−163,900)	(−145,000)
1,000	(20,000)	(−156,700)	(−127,000)
1,500	(32,000)	(−155,900)	(−115,000)

Samarium Tribromide, $SmBr_3$ (*c*)

$\Delta H_{298}^\circ = (-180{,}000)$ calories per mole (*5*)
$S_{298} = (47)$ *e.u.* (*11*)
$M.P. = 937°$ K. (*6*)
$\Delta H_M = (8{,}000)$ calories per mole
$B.P. = 1{,}675°$ K. (*51*)
$\Delta H_V = 46{,}100$ calories per mole

Formation: $Sm + 3/2Br_2 \longrightarrow SmBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−180,000)	(−173,500)
500	(5,000)	(−190,600)	(−163,000)
1,000	(18,000)	(−188,300)	(−138,000)
1,500	(43,000)	(−177,200)	(−119,500)

Samarium Diiodide, SmI_2 (*c*)

$\Delta H_{298}^\circ = (-122{,}000)$ calories per mole (*5*)
$S_{298} = (40)$ *e.u.* (*11*)
$M.P. = (773°)$ K. (*29*)
$\Delta H_M = (5{,}000)$ calories per mole
$B.P. = (1{,}850°)$ K. (*6*)
$\Delta H_V = (40{,}000)$ calories per mole

Formation: $Sm + I_2 \longrightarrow SmI_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−122,000)	(−121,000)
500	(4,000)	(−136,000)	(−114,500)
1,000	(19,000)	(−129,400)	(−99,000)
1,500	(31,000)	(−128,000)	(−88,500)

Samarium Triiodide, SmI_3 (*c*)

$\Delta H_{298}^\circ = (-127{,}000)$ calories per mole (*5*)
$S_{298} = (49)$ *e.u.* (*11*)
$M.P. = 1{,}123°$ K. (*5*)
$\Delta H_M = (9{,}000)$ calories per mole
Decomposes (*6*)

Formation: $Sm + 3/2I_2 \longrightarrow SmI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−127,000)	(−125,000)
500	(5,000)	(−148,400)	(−113,000)
1,000	(19,000)	(−144,900)	(−86,000)
1,500	(44,000)	(−133,800)	(−62,500)

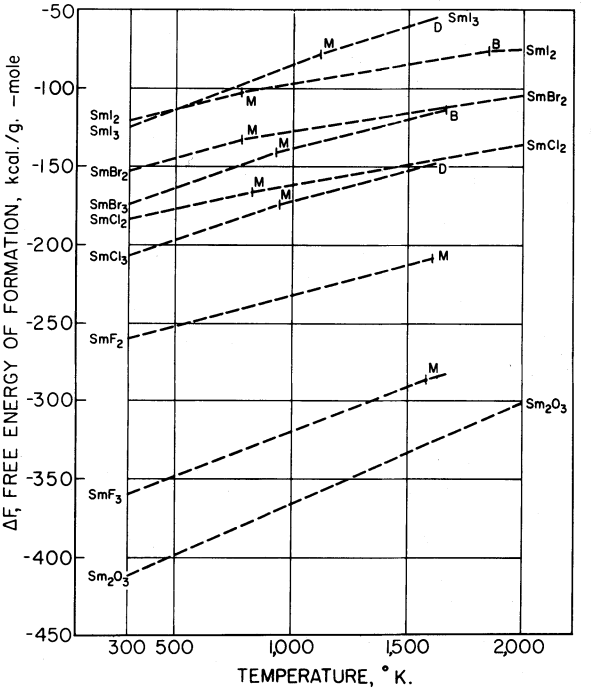

FIGURE 46.—Samarium.

SCANDIUM AND ITS COMPOUNDS

Element, Sc (*c*)

S_{298}=(9.00) *e.u.* (*7*)
M.P.=1,673° K. (*130*)
ΔH_M=(3,850) calories per atom
B.P.=(2,750°) K. (*130*)
ΔH_V=(72,850) calories per atom
(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		(9.00)	(9.00)
400	(617)	(10.78)	(9.24)
500	(1,235)	(12.16)	(9.69)
600	(1,860)	(13.30)	(10.20)
700	(2,500)	(14.29)	(10.72)
800	(3,150)	(15.15)	(11.22)
900	(3,850)	(15.93)	(11.70)
1,000	(4,480)	(16.64)	(12.16)
1,100	(5,170)	(17.29)	(12.59)
1,200	(5,860)	(17.89)	(13.01)
1,300	(6,560)	(18.46)	(13.42)
1,400	(7,280)	(18.99)	(13.79)
1,500	(8,010)	(19.49)	(14.15)
1,600	(8,760)	(19.96)	(14.50)
1,700	(13,350)	(22.72)	(14.87)
1,800	(14,150)	(23.18)	(15.32)
1,900	(14,950)	(23.61)	(15.75)
2,000	(15,750)	(24.02)	(16.15)
2,500	(19,750)	(25.81)	(17.91)

Discandium Trioxide, Sc_2O_3 (*c*)

ΔH°_{298}=(−411,000) calories per mole (*8*)
S_{298}=(18) *e.u.* (*24*)

Formation: $2Sc+3/2O_2 \longrightarrow Sc_2O_3$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−411,000)	(−389,000)
400	(2,300)	(−411,000)	(−381,000)
500	(4,650)	(−411,500)	(−373,500)
600	(7,050)	(−411,500)	(−366,000)
700	(9,500)	(−411,500)	(−358,500)
800	(12,000)	(−411,500)	(−351,000)
900	(14,600)	(−411,500)	(−343,500)
1,000	(17,100)	(−411,500)	(−336,000)
1,100	(19,650)	(−411,500)	(−328,000)
1,200	(22,300)	(−411,500)	(−320,000)
1,300	(24,900)	(−411,500)	(−313,000)
1,400	(27,600)	(−411,000)	(−305,500)
1,500	(30,550)	(−411,000)	(−298,000)
1,600	(33,200)	(−410,500)	(−290,000)
1,700	(43,700)	(−418,000)	(−283,000)
1,800	(46,600)	(−418,000)	(−275,000)
1,900	(49,600)	(−417,500)	(−267,000)
2,000	(52,700)	(−417,500)	(−259,000)

Scandium Trifluoride, ScF_3 (*c*)

ΔH°_{298}=(−367,000) calories per mole (*11*)
S_{298}=(24) *e.u.* (*11*)
M.P.=(1,500°) K. (*6*)
ΔH_M=(12,000) calories per mole
B.P.=(1,800°) K. (*6*)
ΔH_V=(55,000) calories per mole

Formation: $Sc+3/2F_2 \longrightarrow ScF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−367,000)	(−349,700)
500	(4,000)	(−366,500)	(−338,000)
1,000	(17,000)	(−363,000)	(−311,000)
1,500	(43,000)	(−347,500)	(−287,500)

Scandium Trichloride, $ScCl_3$ (*c*)

ΔH°_{298}=−221,000 calories per mole (*11*)
S_{298}=(32) *e.u.* (*11*)
M.P.=1,213° K. (29)
ΔH_M=(19,000) calories per mole
B.P.=1,240° K. (*6*)
ΔH_V=46,000 calories per mole

Formation: $Sc+3/2Cl_2 \longrightarrow ScCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−221,000	(−204,000)
500	(4,000)	(−220,800)	(−193,000)
1,000	(17,000)	(−217,600)	(−166,000)
1,500	(97,000)	(−147,500)	(−146,000)

Scandium Tribromide, $ScBr_3$ (*c*)

ΔH°_{298}=−183,000 calories per mole (*11*)
S_{298}=(40) *e.u.* (*11*)
M.P.=1,213° K. (29)
ΔH_M=(19,000) calories per mole

Formation: $Sc+3/2Br_2 \longrightarrow ScBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−183,000	(−165,000)
500	(5,000)	(−193,500)	(−161,000)
1,000	(18,000)	(−190,500)	(−136,000)
1,500	(58,000)	(−160,800)	(−117,000)

Scandium Triiodide, ScI_3 (*c*)

ΔH°_{298}=(−109,000) calories per mole (*11*)
S_{298}=(44) *e.u.* (*11*)
M.P.=1,218° K. (*6*)
ΔH_M=(18,000) calories per mole

Formation: $Sc+3/2I_2 \longrightarrow ScI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_L	ΔF°_T
298		(−109,000)	(−102,500)
500	(5,000)	(−130,200)	(−94,000)
1,000	(19,000)	(−126,200)	(−69,000)
1,500	(52,000)	(−103,400)	(−51,000)

Scandium Nitride, ScN (*c*)

ΔH°_{298}=−68,000 calories per mole (*9*)
S_{298}=7 *e.u.* (*9*)
ΔS_{298}=(−25) *e.u.*
ΔF_{298}=(−60,500) calories per mole
M.P.=2,923° K. (*9*)

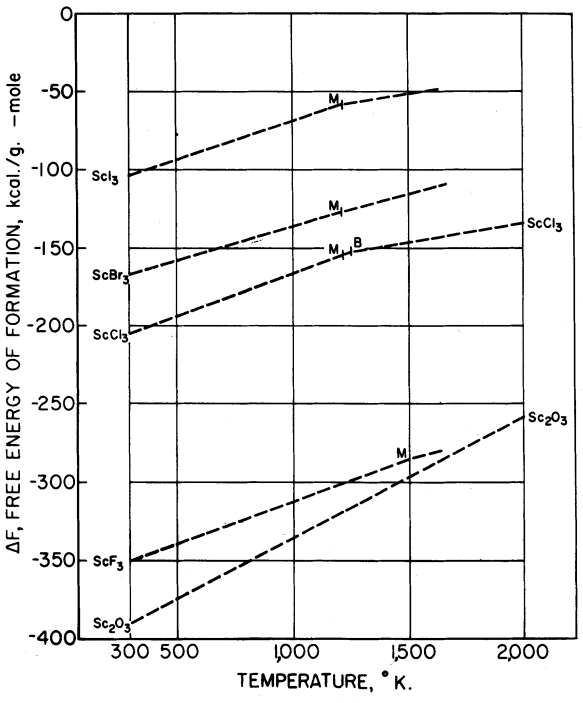

FIGURE 47.—Scandium.

SILICON AND ITS COMPOUNDS

Element, Si (*c*)

$S_{298}=4.5$ *e.u.* (*83*)
M.P.$=1{,}683°$ K. (*130*)
$\Delta H_M=11{,}100$ calories per atom
B.P.$=(2{,}950°)$ K. (*130*)

Zone I (*c*) (298°–1,200° K.)

$$C_p=5.79+0.56\times10^{-3}T-1.09\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-2{,}117+5.79T+0.28\times10^{-3}T^2+1.09\times10^{5}T^{-1}$$
$$F_T-H_{298}=-2{,}117-5.79T\ln T-0.28\times10^{-3}T^2+0.54\times10^{5}T^{-1}+35.05T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		4.5	4.5
400	515	5.98	4.69
500	1,060	7.2	5.08
600	1,640	8.25	5.52
700	2,230	9.16	5.97
800	2,830	9.96	6.42
900	3,440	10.68	6.85
1,000	4,060	11.34	7.28
1,100	4,690	11.94	7.67
1,200	5.340	12.5	8.05
1,300	(6,030)	(13.1)	(8.47)
1,400	(6,700)	(13.59)	(8.81)
1,500	(7,380)	(14.06)	(9.14)
1,600	(8,070)	(14.51)	(9.47)
1,700	(19,860)	(21.53)	(9.85)
1,800	(20,560)	(21.93)	(10.51)
1,900	(21,260)	(22.31)	(11.13)
2,000	(21,960)	(22.66)	(11.68)

Silicon Dioxide (Quartz), SiO_2 (*c*)

$\Delta H^\circ_{298}=-209{,}900$ calories per mole (*24*)
$S_{298}=9.9$ *e.u.* (*83*)
T.P.$=848°$ K. (*82*)
$\Delta H_T=290$ calories per mole
M.P.$=1{,}883°$ K. (*24*)
$\Delta H_M=2{,}040$ calories per mole

Zone I (α) (298°–848° K.)

$$C_p=11.22+8.20\times10^{-3}T-2.70\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-4{,}615+11.22T+4.10\times10^{-3}T^2+2.70\times10^{5}T^{-1}$$

Zone II (β) (848°–1,883° K.)

$$C_p=14.41+1.94\times10^{-3}T\ (82)$$
$$H_T-H_{298}=-4{,}455+14.41T+0.97\times10^{-3}T^2$$

Formation: $Si+O_2 \longrightarrow SiO_2$

Zone I (298°–848° K.)

$$\Delta C_p=-1.73+6.64\times10^{-3}T-1.21\times10^{5}T^{-2}$$
$$\Delta H_T=-210{,}100-1.73T+3.32\times10^{-3}T^2+1.21\times10^{5}T^{-1}$$
$$\Delta F_T=-210{,}100+1.73T\ln T-3.32\times10^{-3}T^2+0.60\times10^{5}T^{-1}+34.68T$$

Zone II (848°–1,200° K.)

$$\Delta C_p=1.46+0.38\times10^{-3}T+1.49\times10^{5}T^{-2}$$
$$\Delta H_T=-209{,}950+1.46T+0.19\times10^{-3}T^2-1.49\times10^{5}T^{-1}$$
$$\Delta F_T=-209{,}950-1.46T\ln T-0.19\times10^{-3}T^2-0.74\times10^{5}T^{-1}+53.57T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		9.9	−209,900	−196,900
400	1,200	13.35	−209,900	−192,400
500	2,560	16.38	−209,850	−188,050
600	4,040	19.07	−209,700	−183,750
700	5,630	21.52	−209,500	−178,450
800	7,320	23.88	−209,300	−175,350
900	9,300	26.11	−208,650	−170,950
1,000	10,920	27.82	−208,450	−166,700
1,100	12,570	29.39	−208,250	−162,500
1,200	14,250	30.85	−208,050	−158,400
1,300	15,940	32.20	(−207,850)	(−154,150)
1,400	17,650	33.46	(−207,700)	(−150,100)
1,500	19,360	34.65	(−207,500)	(−146,000)
1,600	21,100	35.78	(−207,300)	(−141,800)
1,700	22,860	36.84	(−218,250)	(−137,650)
1,800	24,630	37.86	(−218,050)	(−133,100)

Silicon Dioxide (Cristobalite), SiO_2 (*c*)

$\Delta H^\circ_{298}=-209{,}500$ calories per mole (*69*)
$S_{298}=10.19$ *e.u.* (*112*)
T.P.$=523°$ K. (*82*)
$\Delta H_T=200$ calories per mole
M.P.$=2{,}001°$ K. (*112*)
$\Delta H_M=1{,}840$ calories per mole

Zone I (α) (298°–523° K.)

$$C_p=4.28+21.06\times10^{-3}T\ (82)$$
$$H_T-H_{298}=-2{,}212+4.28T+10.53\times10^{-3}T$$

Zone II (β) (523°–2,000° K.)

$$C_p=14.40+2.04\times10^{-3}T\ (82)$$
$$H_T-H_{298}=-4{,}696+14.40T+1.02\times10^{-3}T^2$$

Formation: $Si+O_2 \longrightarrow SiO_2$

Zone I (298°–523° K.)

$$\Delta C_p = -8.67 + 19.50\times10^{-3}T + 1.49\times10^{5}T^{-2}$$
$$\Delta H_T = -207{,}280 - 8.67T + 9.75\times10^{-3}T^2 - 1.49\times10^{5}T^{-1}$$
$$\Delta F_T = -207{,}280 + 8.67T\ln T - 9.75\times10^{-3}T^2 - 0.74\times10^{5}T^{-1} - 9.76T$$

Zone II (523°–2,000° K.)

$$\Delta C_p = 1.45 + 0.48\times10^{-3}T + 1.49\times10^{5}T^{-2}$$
$$\Delta H_T = -209{,}690 + 1.45T + 0.24\times10^{-3}T^2 - 1.49\times10^{5}T^{-1}$$
$$\Delta F_T = -209{,}690 - 1.45T\ln T - 0.24\times10^{-3}T^2 - 0.74\times10^{5}T^{-1} + 53.38T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		10.19	−209,500	−196,600
400	1,210	13.67	−209,500	−192,150
500	2,560	16.67	−209,450	−187,800
600	4,310	19.87	−209,050	−183,550
700	5,850	22.24	−208,850	−179,300
800	7,460	24.39	−208,650	−175,100
900	9,090	26.31	−208,450	−170,900
1,000	10,730	28.04	−208,150	−166,650
1,100	12,390	29.62	−218,100	−162,650
1,200	14,080	31.09	−207,800	−158,450
1,300	15,790	32.46	(−207,600)	(−154,250)
1,400	17,510	33.73	(−207,400)	(−150,200)
1,500	19,240	34.92	(−207,300)	(−146,100)
1,600	20,990	36.06	(−207,000)	(−141,950)
1,700	22,750	37.12	(−217,950)	(−137,850)
1,800	24,530	38.14	(−217,750)	(−133,550)
1,900	26,320	39.11	(−217,550)	(−128,500)
2,000	28,120	40.03	(−217,500)	(−123,800)

Silicon Dioxide (Tridymite), SiO_2 (*c*)

$\Delta H_{298}^\circ = -209{,}400$ calories per mole (*24*)
$S_{298} = 10.22$ *e.u.* (*83*)
T.P. = 390° K. (*82*)
$\Delta H_T = 40$ calories per mole
M.P. = 1,953° K. (*24*)
$\Delta H_M = 2{,}150$ calories per mole

Zone I (α) (298°–390° K.)

$$C_p = 3.27 + 24.80\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -2{,}077 + 3.27T + 12.40\times10^{-3}T^2$$

Zone II (β) (390°–1,953° K.)

$$C_p = 13.64 + 2.64\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -4{,}395 + 13.64T + 1.32\times10^{-3}T^2$$

Formation: $Si + O_2 \longrightarrow SiO_2$

Zone I (298°–390° K.)

$$\Delta C_p = -9.68 + 23.24\times10^{-3}T + 1.49\times10^{5}T^{-2}$$
$$\Delta H_T = -207{,}050 - 9.68T + 11.62\times10^{-3}T^2 - 1.49\times10^{5}T^{-1}$$
$$\Delta F_T = -207{,}050 + 9.68T\ln T - 11.62\times10^{-3}T^2 - 0.74\times10^{5}T^{-1} - 15.45T$$

Zone II (390°–1,200° K.)

$$\Delta C_p = 0.69 + 1.08\times10^{-3}T + 1.49\times10^{5}T^{-2}$$
$$\Delta H_T = -209{,}380 + 0.69T + 0.54\times10^{-3}T^2 - 1.49\times10^{5}T^{-1}$$
$$\Delta F_T = -209{,}380 - 0.69T\ln T - 0.54\times10^{-3}T^2 - 0.74\times10^{5}T^{-1} + 48.12T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		10.22	−209,400	−196,500
400	1,270	13.85	−209,350	−192,050
500	2,710	17.06	−209,200	−187,750
600	4,170	19.72	−209,100	−183,500
700	5,710	22.09	−208,900	−179,250
800	7,320	24.24	−208,700	−175,050
900	8,950	26.18	−208,500	−170,850
1,000	10,590	27.89	−208,300	−166,650
1,100	12,250	29.47	−208,050	−162,400
1,200	13,940	30.94	−207,850	−158,350
1,300	15,650	32.31	(−207,650)	(−154,100)
1,400	17,370	33.57	(−207,450)	(−150,000)
1,500	19,100	34.78	(−207,350)	(−145,950)
1,600	20,850	35.91	(−207,050)	(−141,750)
1,700	22,610	36.97	(−218,000)	(−137,650)
1,800	24,390	37.99	(−217,800)	(−133,100)
1,900	26,180	38.96	(−217,600)	(−128,300)

Silicon Dioxide (Vitreous Glass), SiO_2

$\Delta H_{298}^\circ = -202{,}500$ calories per mole (*112*)
$S_{298} = 11.2$ *e.u.* (*112*)

Zone I (298°–2,000° K.)

$$C_p = 13.38 + 3.68\times10^{-3}T - 3.45\times10^{5}T^{-2} \text{ (79)}$$
$$H_T - H_{298} = -5{,}310 + 13.38T + 1.84\times10^{-3}T^2 + 3.45\times10^{5}T^{-1}$$

Formation: $Si + O_2 \longrightarrow SiO_2$

Zone I (298°–1,200° K.)

$$\Delta C_p = 0.43 + 2.12\times10^{-3}T - 1.96\times10^{5}T^{-2}$$
$$\Delta H_T = -203{,}380 + 0.43T + 1.06\times10^{-3}T^2 + 1.96\times10^{5}T^{-1}$$
$$\Delta F_T = -203{,}380 - 0.43T\ln T - 1.06\times10^{-3}T^2 + 0.98\times10^{5}T^{-1} + 47.01T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		11.2	−202,500	−189,900
400	1,230	14.74	−202,500	−185,600
500	2,550	17.68	−202,450	−181,300
600	3,950	20.23	−202,400	−177,100
700	5,430	22.51	−202,300	−172,900
800	6,990	24.59	−202,150	−168,700
900	8,610	26.50	−201,950	−164,600
1,000	10,280	28.26	−201,700	−160,400
1,100	11,980	29.88	−201,450	−156,300
1,200	13,700	31.27	−201,200	−152,200
1,300	15,450	32.77	(−200,950	(−148,100)
1,400	17,240	34.1	(−200,700)	(−144,000)
1,500	19,080	35.37	(−200,500)	(−139,900)
1,600	20,980	36.59	(−200,050)	(−135,800)
1,700	22,930	37.77	(−210,750)	(−131,700)
1,800	24,920	38.91	(−210,350)	(−127,300)
1,900	26,950	40.01	(−209,900)	(−122,600)
2,000	29,010	41.07	(−209,600)	(−118,000)

Silicon Tetrafluoride, SiF_4 (*g*)

$\Delta H_{298}^\circ = -370{,}000$ calories per mole (*112*)
$S_{298} = 68.0$ *e.u.* (*112*)
S.P. = 178° K. (*112*)
$\Delta H_{subl} = 6{,}130$ calories per mole

Zone I (*g*) (298°–2,000° K.)

$$C_p = 21.95 + 2.66\times10^{-3}T - 4.72\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -8{,}250 + 21.95T + 1.33\times10^{-3}T^2 + 4.72\times10^{5}T^{-1}$$

Formation: $Si + 2F_2 \longrightarrow SiF_4$

Zone I (298°–2,000° K.)

$$\Delta C_p = 0.42 + 1.22\times10^{-3}T - 2.03\times10^{5}T^{-2}$$
$$\Delta H_T = -370{,}600 - 0.42T + 0.61\times10^{-3}T^2 + 2.03\times10^{5}T^{-1}$$
$$\Delta F_T = -370{,}600 + 0.42T\ln T - 0.61\times10^{-3}T^2 + 1.01\times10^{5}T^{-1} + 32.2T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		68.0	−370,000	−360,000
400	1,905	73.48	−370,200	−356,500
500	3,965	78.07	−370,300	−353,100
600	6,160	82.07	−370,300	−349,600
700	8,445	85.59	−370,300	−346,200
800	10,795	88.73	−370,300	−342,800
900	13,185	91.54	−370,200	−339,400
1,000	15,610	94.10	−370,200	−336,000
1,100	17,940	96.40	−370,100	−332,500
1,200	20,545	98.60	(−370,000)	(−329,000)
1,300	23,900	100.58	(−370,100)	(−325,700)
1,400	25,535	102.44	(−369,900)	(−322,200)
1,500	27,986	104.27	(−369,900)	(−319,000)
1,600	30,570	105.80	(−369,800)	(−315,400)
1,700	33,190	107.49	(−380,700)	(−312,000)
1,800	35,630	108.78	(−380,700)	(−307,800)
1,900	38,508	110.46	(−379,300)	(−303,000)
2,000	40,720	111.46	(−380,600)	(−297,700)

Silicon Tetrachloride, $SiCl_4$ (*l*)

$\Delta H^\circ_{298} = -150{,}100$ calories per mole (*11*)
$S_{298} = 57.3$ *e.u.* (*80*)
$\Delta S_{298} = -54.8$ *e.u.*
$\Delta F^\circ_{298} = -132{,}700$ calories per mole
M.P. = 205° K. (*6*)
$\Delta H_M = 1{,}840$ calories per mole
B.P. = 330° K. (*6*)
$\Delta H_V = 7{,}000$ calories per mole

Silicon Tetrabromide, $SiBr_4$ (*l*)

$\Delta H^\circ_{298} = -93{,}500$ calories per mole (*11*)
$S_{298} = (63)$ *e.u.* (*11*)
$\Delta S_{298} = (-14)$ *e.u.*
$\Delta F^\circ_{298} = (-89{,}300)$ calories per mole
M.P. = 278° K. (*6*)
$\Delta H_M = (800)$ calories per mole
B.P. = 426° K.
$\Delta H_V = 9{,}050$ calories per mole

Silicon Tetraiodide, SiI_4 (*c*)

$\Delta H^\circ_{298} = -29{,}900$ calories per mole (*11*)
$S_{298} = (63)$ *e.u.* (*11*)
$\Delta S_{298} = (-3.0)$ *e.u.*
$\Delta F^\circ_{298} = (-29{,}000)$ calories per mole
M.P. = 394° K. (*6*)
$\Delta H_M = (1{,}200)$ calories per mole
B.P. = 561° K. (*6*)
$\Delta H_V = (12{,}500)$ calories per mole

Silicon Carbide, SiC (*c*)

$\Delta H^\circ_{298} = -13{,}000$ calories per mole (*72*)
$S_{298} = 3.95$ *e.u.* (*83*)
M.P. = >2,970° K. (*9*)

Zone I (*c*) (298°–1,700° K.)

$$C_p = 8.93 + 3.00\times10^{-3}T - 3.07\times10^{5}T^{-2} \quad (79)$$
$$H_T - H_{298} = -3{,}825 + 8.93T + 1.50\times10^{-3}T^2 + 3.07\times10^{5}T^{-1}$$

Formation: $Si + C \longrightarrow SiC$

Zone I (298°–1,200° K.)

$$\Delta C_p = -0.96 + 1.42\times10^{-3}T + 0.12\times10^{5}T^{-2}$$
$$\Delta H_T = -12{,}740 - 0.96T + 0.71\times10^{-3}T^2 - 0.12\times10^{5}T^{-1}$$
$$\Delta F_T = -12{,}740 + 0.96T\ln T - 0.71\times10^{-3}T^2 - 0.06\times10^{5}T^{-1} - 4.08T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		3.95	−13,000	−12,400
400	760	6.13	−13,000	−12,200
500	1,610	8.02	−13,000	−12,000
600	2,570	9.77	−13,000	−11,800
700	3,600	11.35	−13,000	−11,600
800	4,670	12.78	−13,000	−11,400
900	5,780	14.09	−13,000	−11,300
1,000	6,920	15.29	−12,950	−11,100
1,100	8,080	16.40	−12,950	−10,900
1,200	9,270	17.43	(−12,900)	(−10,700)
1,300	10,510	18.42	(−12,900)	(−10,500)
1,400	11,800	19.38	(−12,800)	(−10,300)
1,500	13,140	20.30	(−12,800)	(−10,200)
1,600	14,530	21.20	(−12,800)	(−10,000)
1,700	15,970	22.07	(−23,500)	(−9,800)

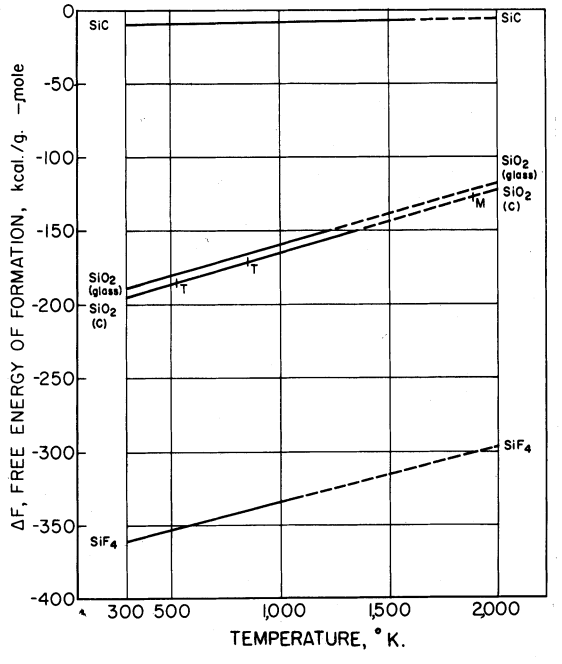

FIGURE 48.—Silicon.

SILVER AND ITS COMPOUNDS

Element, Ag (*c*)

$S_{298}=10.20$ *e.u.* (*83*)
M.P.$=1{,}234°$ K. (*82*)
$\Delta H_M=2{,}855$ calories per atom
B.P.$=2{,}450°$ K. (*7*)
$\Delta H_V=60{,}720$ calories per atom

Zone I (*c*) (298°–1,234° K.)

$$C_p=5.09+2.04\times10^{-3}T+0.36\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-1{,}488+5.09T+1.02\times10^{-3}T^2-0.36\times10^{5}T^{-1}$$
$$F_T-H_{298}=-1{,}488-5.09T\ln T-1.02\times10^{-3}T^2-0.18\times10^{5}T^{-1}+24.29T$$

Zone II (*l*) (1,234°–1,600° K.)

$$C_p=7.30\ (82)$$
$$H_T-H_{298}=+160+7.30T$$
$$F_T-H_{298}=+160-7.30T\ln T+37.42T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		10.20	10.20
400	615	11.78	10.25
500	1,240	13.37	10.90
600	1,885	14.55	11.42
700	2,535	15.55	11.93
800	3,195	16.43	12.44
900	3,880	17.24	12.93
1,000	4,585	17.98	13.40
1,100	5,310	18.67	13.84
1,200	6,060	19.32	14.27
1,300	9,650	22.22	14.80
1,400	10,380	22.76	15.34
1,500	11,110	23.26	15.85
1,600	11,840	23.74	16.33
1,700	(12,570)	(24.18)	(16.78)
1,800	(13,300)	(24.60)	(17.21)
1,900	(14,030)	(24.99)	(17.55)
2,000	(14,760)	(25.36)	(17.96)

Disilver Oxide, Ag_2O (*c*)

$\Delta H^\circ_{298}=-7{,}200$ calories per mole (*24*)
$S_{298}=29.1$ *e.u.* (*24*)

Formation: $2Ag+1/2O_2\longrightarrow Ag_2O$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−7,200	−2,500
400	(1,800)	(−7,000)	(−900)
500	(3,550)	(−6,850	(600)
600	(5,400)	(−6,650)	(2,050)
700	(7,250)	(−6,500)	(3,500)
800	(9,200)	(−6,300)	(4,900)
900	(11,150)	(−6,100	(6,300)
1,000	(13,100)	(−5,950)	(7,700)

Disilver Dioxide, Ag_2O_2 (*c*)

$\Delta H^\circ_{298}=-6{,}200$ calories per mole (*112*)
$S_{298}=(26.4)$ *e.u.* (*24*)

Formation: $2Ag+O_2\longrightarrow Ag_2O_2$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−6,200	(+6,600)
400	(2,050)	(−6,100)	(+10,900)
500	(4,250)	(−5,900)	(+15,100)

Silver Fluoride, AgF (*c*)

$\Delta H^\circ_{298}=-48{,}700$ calories per mole (*112*)
$S_{298}=(21)$ *e.u.* (*11*)
M.P.$=708°$ K. (*6*)
B.P.$=1{,}420°$ K. (*6*)

Formation: $Ag+1/2F_2\longrightarrow AgF$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−48,700	(−44,500)
500	(3,000)	(−47,700)	(−41,700)
1,000	(12,000)	(−44,200)	(−38,700)
1,500	(19,000)	(−45,900)	(−35,200)

Silver Difluoride, AgF_2 (*c*)

$\Delta H^\circ_{298}=-83{,}000$ calories per mole (*11*)
$S_{298}=(25)$ *e.u.* (*11*)
M.P.$=>963°$ K. (*6*)

Formation: $Ag+F_2\longrightarrow AgF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−83,000	(−72,900)
500	(4,000)	(−81,800)	(−66,000)
1,000	(17,000)	(−76,400)	(−51,000)

Silver Chloride, AgCl (*c*)

$\Delta H^\circ_{298}=-30{,}360$ calories per mole (*112*)
$S_{298}=22.97$ *e.u.* (*83*)
M.P.$=728°$ K. (*6*)
$\Delta H_M=3{,}155$ calories per mole
B.P.$=1{,}837°$ K. (*6*)
$\Delta H_V=42{,}520$ calories per mole

Zone I (*c*) (298°–728° K.)

$$C_p=14.88+1.00\times10^{-3}T-2.70\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-5{,}390+14.88T+0.50\times10^{-3}T^2+2.70\times10^{5}T^{-1}$$

Zone II (*l*) (728°–900° K.)

$$C_p=16.0\ (82)$$
$$H_T-H_{298}=-2{,}490+16.0T$$

Formation: $Ag+1/2Cl_2\longrightarrow AgCl$

Zone I (298°–728° K.)

$$\Delta C_p=5.38-1.07\times10^{-3}T-2.72\times10^{5}T^{-2}$$
$$\Delta H_T=-32{,}830+5.38T-0.535\times10^{-3}T^2+2.72\times10^{5}T^{-1}$$
$$\Delta F_T=-32{,}830-5.38T\ln T+0.535\times10^{-3}T^2+1.36\times10^{5}T^{-1}+51.2T$$

Zone II (728°–900° K.)

$\Delta C_p = 6.50 - 2.07\times10^{-3}T - 0.02\times10^{5}T^{-2}$
$\Delta H_T = -29{,}940 + 6.50T - 1.03\times10^{-3}T^2 + 0.02\times10^{5}T^{-1}$
$\Delta F_T = -29{,}940 - 6.50T\ln T + 1.03\times10^{-3}T^2 + 0.01\times10^{5}T^{-1} + 54.5T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		22.97	−30,350	−26,200
400	1,320	26.78	−30,100	−25,900
500	2,720	29.89	−29,700	−23,550
600	4,150	32.51	−29,350	−22,350
700	5,660	34.83	−28,950	−21,250
800	10,310	41.16	−25,400	−20,450
900	11,910	42.94	−24,900	−19,800
1,000	(13,500)	(44.64)	(−24,500)	(−19,100)
1,500	(20,200)	(50.0)	(−26,450)	(−16,000)

Silver Bromide, AgBr (*c*)

$\Delta H_{298}^\circ = -20{,}060$ calories per mole (*112*)
$S_{298} = 25.60$ *e.u.* (*83*)
$M.P. = 703°$ K. (*82*)
$\Delta H_M = 2{,}190$ calories per mole
$B.P. = (1{,}810°)$ K. (*6*)
$\Delta H_V = (37{,}000)$ calories per mole

Zone I (*c*) (298°–703° K.)

$C_p = 7.93 + 15.40\times10^{-3}T$ (*82*)
$H_T - H_{298} = -3{,}049 + 7.93T + 7.70\times10^{-3}T^2$

Zone II (*l*) (703°–900° K.)

$C_p = 14.9$ (*82*)
$H_T - H_{298} = 1{,}950 + 14.9T$

Formation: $Ag + 1/2Br_2 \longrightarrow AgBr$

Zone I (298°–331° K.)

$\Delta C_p = -5.71 + 13.36\times10^{-3}T - 0.36\times10^{5}T^{-2}$
$\Delta H_T = -19{,}050 - 5.71T + 6.68\times10^{-3}T^2 + 0.36\times10^{5}T^{-1}$
$\Delta F_T = -19{,}050 + 5.71T\ln T - 6.68\times10^{-3}T^2 + 0.18\times10^{5}T^{-1} - 31.2T$

Zone II (331°–703° K.)

$\Delta C_p = -1.68 + 13.36\times10^{-3}T - 0.18\times10^{5}T^{-2}$
$\Delta H_T = -24{,}100 - 1.68T + 6.68\times10^{-3}T^2 + 0.18\times10^{5}T^{-1}$
$\Delta F_T = -24{,}100 + 1.68T\ln T - 6.68\times10^{-3}T^2 + 0.09\times10^{5}T^{-1} + 7.35T$

Zone III (703°–900° K.)

$\Delta C_p = 5.29 - 2.04\times10^{-3}T - 0.18\times10^{5}T^{-2}$
$\Delta H_T = -22{,}950 + 5.29T - 1.02\times10^{-3}T^2 + 0.18\times10^{5}T^{-1}$
$\Delta F_T = -22{,}950 - 5.29T\ln T + 1.02\times10^{-3}T^2 + 0.09\times10^{5}T^{-1} + 46.22T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		25.60	−20,060	−19,200
400	1,355	29.50	−23,650	−18,200
500	2,840	32.81	−23,200	−16,750
600	4,480	35.79	−22,650	−15,500
700	6,275	38.56	−22,000	−14,400
800	9,970	43.68	−19,400	−13,650
900	11,460	45.43	−19,000	−12,900
1,000	(12,950)	(47.00)	(−18,700)	(12,300)

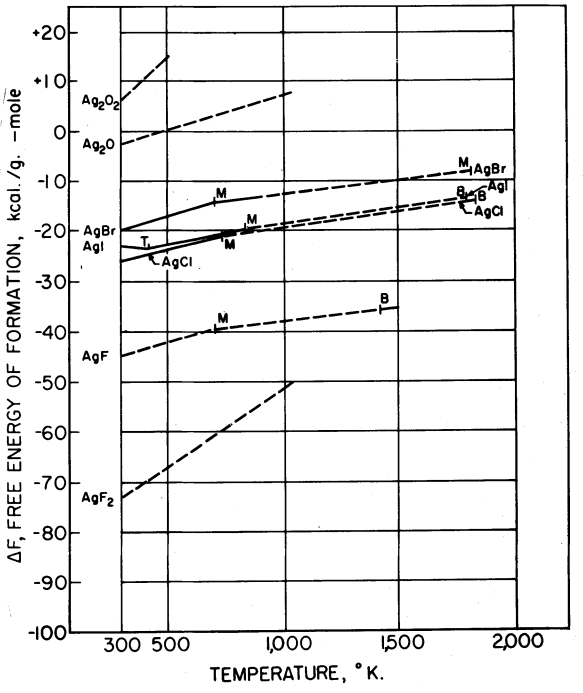

FIGURE 49.—Silver.

Silver Iodide, AgI (*c*)

$\Delta H_{298}^\circ = -22{,}300$ calories per mole (*112*)
$S_{298} = 27.6$ *e.u.* (*83*)
$T.P. = 423°$ K. (*82*)
$\Delta H_T = 1{,}470$ calories per mole
$M.P. = 830°$ K. (*6*)
$\Delta H_M = 2{,}250$ calories per mole
$B.P. = 1{,}779°$ K. (*6*)
$\Delta H_V = 34{,}447$ calories per mole

Zone I (α) (298°–423° K.)

$C_p = 5.82 + 24.10\times10^{-3}T$ (*82*)
$H_T - H_{298} = -2{,}806 + 5.82T + 12.05\times10^{-3}T^2$

Zone II (β) (423°–600° K.)

$C_p = 13.5$ (*82*)
$H_T - H_{298} = -2{,}430 + 13.5T$

Formation: $Ag + 1/2I_2 \longrightarrow AgI$

Zone I (298°–386.8° K.)

$\Delta C_p = -4.06 + 16.11\times10^{-3}T - 0.36\times10^{5}T^{-2}$
$\Delta H_T = -21{,}925 - 4.06T + 8.05\times10^{-3}T^2 + 0.36\times10^{5}T^{-1}$
$\Delta F_T = -21{,}925 + 4.06T\ln T - 8.05\times10^{-3}T^2 + 0.18\times10^{5}T^{-1} - 25.44T$

Zone II (386.8°–423° K.)

$\Delta C_p = -8.87 + 22.06\times10^{-3}T - 0.36\times10^{5}T^{-2}$
$\Delta H_T = -22{,}390 - 8.87T + 11.03\times10^{-3}T^2 + 0.36\times10^{5}T^{-1}$
$\Delta F_T = -22{,}390 + 8.87T\ln T - 11.03\times10^{-3}T^2 + 0.18\times10^{5}T^{-1} - 52.11T$

Zone III (423°–600° K.)

$$\Delta C_p = 3.97 - 2.04\times10^{-3}T - 0.36\times10^{5}T^{-2}$$
$$\Delta H_T = -29{,}350 + 3.97T - 1.02\times10^{-3}T^2 + 0.36\times10^{5}T^{-1}$$
$$\Delta F_T = -29{,}350 - 3.97T\ln T + 1.02\times10^{-3}T^2 + 0.18\times10^{5}T^{-1} + 36.18T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		27.6	−22,300	−23,300
400	1,450	31.77	−24,100	−23,700
500	4,320	38.38	−27,550	−23,300
600	5,670	40.84	−27,300	−22,500
1,000	(12,900)	(49.1)	(−24,550)	(−18,950)
1,500	(20,400)	(55.2)	(−25,800)	(−16,100)

SODIUM AND ITS COMPOUNDS

Element, Na (*c*)

$S_{298} = 12.23$ *e.u.* (*83*)
$M.P. = 371°$ K. (*41*)
$\Delta H_M = 630$ calories per atom
$B.P. = 1{,}162°$ K. (*41*)
$\Delta H_V = 23{,}120$ calories per atom

Zone I (*c*) (298°–391° K.)

$$C_p = 9.9261 - 28.038\times10^{-3}T + 5.785\times10^{-5}T^2 \quad (41)$$
$$H_T - H_{298} = -2{,}235 + 9.93T - 14.02\times10^{-3}T^2 + 1.93\times10^{-5}T^3$$
$$F_T - H_{298} = -2{,}235 - 9.93T\ln T + 14.02\times10^{-3}T^2 - 0.96\times10^{-5}T^3 + 48.35T$$

Zone II (*l*) (391°–1,162° K.)

$$C_p = 9.0696 - 45.765\times10^{-4}T + 2.54\times10^{-6}T^2 \quad (41)$$
$$H_T - H_{298} = -1{,}960 + 9.07T - 22.88\times10^{-4}T^2 + 0.85\times10^{-6}T^3$$
$$F_T - H_{298} = -1{,}960 - 9.07T\ln T + 22.88\times10^{-4}T^2 - 0.42\times10^{-6}T^3 + 45.66T$$

Zone III (*g*) (1,162°–2,500° K.)

$$C_p = 4.87 \quad (34)$$
$$H_T - H_{298} = 24{,}530 + 4.87T$$
$$F_T - H_{298} = 24{,}530 - 4.87T\ln T - 4.23T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		12.23	12.23
400	1,355	16.08	12.69
500	2,097	17.73	13.52
600	2,819	19.05	14.33
700	3,521	20.13	15.11
800	4,218	21.06	15.79
900	4,909	21.88	16.44
1,000	5,597	22.60	17.00
1,100	6,294	23.26	17.55
1,200	30,380	43.63	18.58
1,300	30,877	44.03	20.46
1,400	31,374	44.40	22.07
1,500	31,871	44.74	23.60
1,600	32,367	45.06	24.94
1,700	32,864	45.36	26.12
1,800	33,361	45.65	27.17
1,900	33,858	45.91	28.10
2,000	34,255	46.17	28.95
2,500	36,847	47.28	32.64

Disodium Oxide, Na_2O (*c*)

$\Delta H_{298}^\circ = -99{,}400$ calories per mole (*112*)
$S_{298} = 17.4$ *e.u.* (*112*)
$M.P. = 1{,}190°$ K. (*24*)
$\Delta H_M = 7{,}140$ calories per mole
$B.P. = >2{,}500°$ K. (*42*)

Zone I (*c*) (298°–1,100° K.)

$$C_p = 15.70 + 5.40\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -4{,}920 + 15.70T + 2.70\times10^{-3}T^2$$

Formation: $2Na + 1/2O_2 \longrightarrow Na_2O$

Zone I (298°–391° K.)

$$\Delta C_p = -7.74 + 60{,}98\times10^{-3}T - 11.57\times10^{5}T^2 + 0.20\times10^{5}T^{-2}$$
$$\Delta H_T = -98{,}700 - 7.74T + 30.49\times10^{-3}T^2 - 3.86\times10^{5}T^3 - 0.2\times10^{5}T^{-1}$$
$$\Delta F_T = -98{,}700 + 7.74T\ln T - 30.49\times10^{-3}T^2 + 1.92\times10^{5}T^3 - 0.10\times10^{5}T^{-1} - 7.14T$$

Zone II (391°–1,100° K.)

$$\Delta C_p = -6.02 + 14.05\times10^{-3}T - 5.08\times10^{-6}T^2 + 0.20\times10^{5}T^{-2}$$
$$\Delta H_T = -99{,}300 - 6.02T + 7.02\times10^{-3}T^2 - 1.69\times10^{-6}T^3 - 0.20\times10^{5}T^{-1}$$
$$\Delta F_T = -99{,}300 + 6.02T\ln T - 7.02\times10^{-3}T^2 + 0.85\times10^{-6}T^3 - 0.10\times10^{5}T^{-1} - 1.61T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		17.4	−99,400	−89,950
400	1,750	22.45	−100,700	−86,600
500	3,600	26.57	−100,700	−83,100
600	5,500	30.03	−100,650	−79,600
700	7,400	32.96	−100,550	−76,100
800	9,350	35.56	−100,400	−72,400
900	11,350	37.92	−100,150	−69,200
1,000	13,500	40.18	−99,800	−65,700
1,100	15,750	42.33	−99,350	−62,000
1,200	(25,050)		(−138,100)	(−58,200)
1,300	(27,450)		(−137,100)	(−51,600)
1,400	(29,900)		(−136,100)	(−45,100)
1,500	(32,350)		(−135,100)	(−38,600)
1,600	(34,700)		(−134,100)	(−32,200)
1,700	(37,200)		(−133,100)	(−25,900)
1,800	(39,600)		(−132,100)	(−19,600)
1,900	(42,050)		(−131,100)	(−13,400)
2,000	(44,660)		(−130,100)	(−7,200)

Disodium Dioxide, Na_2O_2 (*c*)

$\Delta H_{298}^\circ = -122{,}100$ calories per mole (*40*)
$S_{298} = 22.6$ *e.u.* (*133*)
$M.P. = 733°$ K. (*24*)
$\Delta H_M = 5.860$ calories per mole
Decomposes = 919° K. (*3*)

Formation: $2Na + O_2 \longrightarrow Na_2O_2$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−122,100	−107,000
400	(2,600)	(−123,300)	(−101,800)
500	(4,600)	(−123,100)	(−96,400)
600	(7,100)	(−122,800)	(−91,100)
700	(9,500)	(−122,600)	(−85,900)
800	(18,300)	(−116,000)	(−81,200)
900	(21,400)	(−115,100)	(−76,900)

Sodium Dioxide, NaO_2 (*c*)

$\Delta H_{298}^\circ = -62{,}100$ calories per mole (*40*)
$S_{298} = 27.7$ *e.u.* (*133*)

Formation: $Na+O_2 \longrightarrow NaO_2$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−62,100	−52,100
400	(2,200)	(−62,000)	(−48,500)
500	(4,150)	(−61,500)	(−45,000)
600	(6,100)	(−61,000)	(−42,000)
700	(8,100)	(−60,500)	(−39,000)
800	(10,100)	(−60,000)	(−35,500)
900	(12,100)	(−59,500)	(−32,500)
1,000	(14,100)	(−59,000)	(−29,500)

Sodium Fluoride, NaF (*c*)

$\Delta H_{298}^\circ = -136{,}000$ calories per mole (*112*)
$S_{298} = 13.1$ *e.u.* (*11*)
$M.P. = 1{,}265°$ K. (*82*)
$\Delta H_M = 7{,}780$ calories per mole
$B.P. = 1{,}977°$ K. (*6*)
$\Delta H_V = 53{,}260$ calories per mole

Zone I (*c*) (298°–1,265° K.)

$$C_p = 9.66 + 4.50\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -3{,}080 + 9.66T + 2.25\times10^{-3}T^2$$

Zone II (*l*) (1,265–1,300° K.)

$$C_p = 16.0 \quad (82)$$
$$H_T - H_{298} = 280 + 16.0T$$

Formation: $Na+1/2F_2 \longrightarrow NaF$

Zone I (298°–371° K.)

$$\Delta C_p = -4.42 + 32.32\times10^{-3}T - 5.78\times10^{-5}T^2 + 0.40\times10^5T^{-2}$$
$$\Delta H_T = -135{,}500 - 4.42T + 16.16\times10^{-3}T^2 - 1.93\times10^{-5}T^3 - 0.40\times10^5T^{-1}$$
$$\Delta F_T = -135{,}500 + 4.42T\ln T - 16.16\times10^{-3}T^2 + 0.96\times10^{-5}T^3 - 0.20\times10^5T^{-1} + 0.66T$$

Zone II (391°–1,162° K.)

$$\Delta C_p = -3.56 + 8.86\times10^{-3}T - 2.54\times10^{-6}T^2 + 0.40\times10^5T^{-2}$$
$$\Delta H_T = -135{,}700 - 3.56T + 4.43\times10^{-3}T^2 - 0.85\times10^{-6}T^3 - 0.40\times10^5T^{-1}$$
$$\Delta F_T = -135{,}700 + 3.56T\ln T - 4.43\times10^{-3}T^2 + 0.42\times10^{-6}T^3 - 0.20\times10^5T^{-1} + 3.56T$$

Zone III (1,162°–1,265° K.)

$$\Delta C_p = 0.64 + 4.28\times10^{-3}T + 0.40\times10^5T^{-2}$$
$$\Delta H_T = -162{,}040 + 0.64T + 2.14\times10^{-3}T^2 - 0.40\times10^5T^{-1}$$
$$\Delta F_T = -162{,}040 - 0.64T\ln T - 2.14\times10^{-3}T^2 - 0.20\times10^5T^{-1} + 53.19T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		13.1	−136,000	−129,000
400	1,140	16.39	−136,600	−126,500
500	2,310	19.0	−136,600	−124,050
600	3,530	21.22	−136,550	−121,550
700	4,780	23.15	−136,350	−119,050
800	6,080	24.88	−136,200	−116,600
900	7,420	26.46	−136,000	−114,200
1,000	8,810	27.92	−135,700	−111,800
1,100	10,260	29.30	−135,400	−109,350
1,200	11,760	30.61	−158,150	−106,550
1,300	21,080	37.98	−149,750	−105,000

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Sodium Chloride, NaCl (*c*)

$\Delta H_{298}^\circ = -98{,}330$ calories per mole (*11*)
$S_{298} = 17.3$ *e.u.* (*112*)
$M.P. = 1{,}073°$ K. (*82*)
$\Delta H_M = 6{,}850$ calories per mole
$B.P. = 1{,}738°$ K. (*6*)
$\Delta H_V = 40{,}800$ calories per mole

Zone I (*c*) (298°–1,073° K.)

$$C_p = 10.98 + 3.90\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -3{,}447 + 10.98T + 1.95\times10^{-3}T^2$$

Zone II (*l*) (1,073°–1,300° K.)

$$C_p = 16.0 \quad (82)$$
$$H_T - H_{298} = +260 + 16.0T$$

Formation: $Na+1/2Cl_2 \longrightarrow NaCl$

Zone I (298°–391° K.)

$$\Delta C_p = -3.36 + 31.9\times10^{-3}T - 5.78\times10^{-5}T^2 + 0.34\times10^5T^{-2}$$
$$\Delta H_T = -98{,}100 - 3.36T + 15.95\times10^{-3}T^2 - 1.93\times10^{-5}T^3 - 0.34\times10^5T^{-1}$$
$$\Delta F_T = -98{,}100 + 3.36T\ln T - 15.95\times10^{-3}T^2 + 0.96\times10^{-5}T^3 - 0.17\times10^5T^{-1} + 5.88T$$

Zone II (391°–1,073° K.)

$$\Delta C_p = -2.5 + 8.45\times10^{-3}T - 2.54\times10^{-6}T^2 + 0.34\times10^5T^{-2}$$
$$\Delta H_T = -98{,}400 - 2.5T + 4.22\times10^{-3}T^2 - 0.85\times10^{-6}T^3 - 0.34\times10^5T^{-1}$$
$$\Delta F_T = -98{,}400 + 2.5T\ln T - 4.22\times10^{-3}T^2 + 0.42\times10^{-6}T^3 - 0.17\times10^5T^{-1} + 8.71T$$

Zone III (1,073°–1,162° K.)

$$\Delta C_p = 2.52 + 4.55\times10^{-3}T - 2.54\times10^{-6}T^2 + 0.34\times10^5T^{-2}$$
$$\Delta H_T = -94{,}500 + 2.52T + 2.27\times10^{-3}T^2 - 0.85\times10^{-6}T^3 - 0.34\times10^5T^{-1}$$
$$\Delta F_T = -94{,}500 - 2.52T\ln T - 2.27\times10^{-3}T^2 + 0.42\times10^{-6}T^3 - 0.17\times10^5T^{-1} + 38.02T$$

Zone IV (1,162°–1,300° K.)

$$\Delta C_p = 6.72 - 0.03\times10^{-3}T + 0.34\times10^5T^{-2}$$
$$\Delta H_T = -120{,}900 + 6.72T - 0.015\times10^{-3}T^2 - 0.34\times10^5T^{-1}$$
$$\Delta F_T = -120{,}900 - 6.72T\ln T + 0.015\times10^{-3}T^2 - 0.17\times10^5T^{-1} + 88.05T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		17.30	−98,330	−91,900
400	1,240	20.88	−98,850	−89,600
500	2,510	23.71	−98,750	−87,500
600	3,830	26.12	−98,600	−85,050
700	5,190	28.21	−98,350	−82,850
800	6,590	30.08	−98,100	−80,600
900	8,020	31.76	−97,800	−78,400
1,000	9,480	33.30	−97,500	−76,250
1,100	17,860	41.14	−90,150	−74,350
1,200	19,460	42.53	−112,900	−72,500
1,300	21,060	43.81	−112,200	−69,000

Sodium Bromide, NaBr (*c*)

$\Delta H_{298}^\circ = -86{,}500$ calories per mole (*11*)
$S_{298} = 20.1$ *e.u.* (*83*)
$M.P. = 1{,}020°$ K. (*6*)
$\Delta H_M = 6{,}140$ calories per mole
$B.P. = 1{,}665°$ K. (*6*)
$\Delta H_V = 37{,}950$ calories per mole

Zone I (*c*) (298°–550° K.)

$$C_p = 11.87 + 2.10 \times 10^{-3} T \quad (82)$$
$$H_T - H_{298} = -3{,}632 + 11.87T + 1.05 \times 10^{-3} T^2$$

Formation: $Na + 1/2Br_2 \longrightarrow NaBr$

Zone I (298°–331° K.)

$$\Delta C_p = -6.61 + 30.14 \times 10^{-3} T - 5.78 \times 10^{-5} T^2$$
$$\Delta H_T = -85{,}350 - 6.61T + 15.07 \times 10^{-3} T^2 - 1.93 \times 10^{-5} T^3$$
$$\Delta F_T = -85{,}350 + 6.61 T \ln T - 15.07 \times 10^{-3} T^2 + 0.96 \times 10^{-5} T^3 - 27.42T$$

Zone II (331°–391° K.)

$$\Delta C_p = -2.58 + 30.14 \times 10^{-3} T - 5.78 \times 10^{-5} T^2 + 0.18 \times 10^5 T^{-2}$$
$$\Delta H_T = -90{,}250 - 2.58T + 15.07 \times 10^{-3} T^2 - 1.93 \times 10^{-5} T^3 - 0.18 \times 10^5 T^{-1}$$
$$\Delta F_T = -90{,}250 + 2.58 T \ln T - 15.07 \times 10^{-3} T^2 + 0.96 \times 10^{-5} T^3 - 0.09 \times 10^5 T^{-1} + 12.33T$$

Zone III (391°–550° K.)

$$\Delta C_p = -1.72 + 6.68 \times 10^{-3} T - 2.54 \times 10^{-6} T^2 + 0.18 \times 10^5 T^{-2}$$
$$\Delta H_T = -90{,}640 - 1.72T + 3.34 \times 10^{-3} T^2 - 0.85 \times 10^{-6} T^3 - 0.18 \times 10^5 T^{-1}$$
$$\Delta F_T = -90{,}640 + 1.72 T \ln T - 3.34 \times 10^{-3} T^2 + 0.42 \times 10^{-6} T^3 - 0.09 \times 10^5 T^{-1} + 14.04T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		20.1	−86,500	−83,400
400	1,285	23.81	−90,900	−81,450
500	2,565	26.66	−90,800	−79,100
1,000	(9,300)		(−89,000)	(−68,000)
1,500	(23,400)		(−104,000)	(−61,050)

Sodium Iodide, NaI (*c*)

$\Delta H_{298}^\circ = -70{,}650$ calories per mole (*112*)
$S_{298} = 22.50$ *e.u.* (*112*)
$M.P. = 935°$ K. (*6*)
$\Delta H_M = 5{,}240$ calories per mole
$B.P. = 1{,}577°$ K. (*6*)
$\Delta H_V = 38{,}160$ calories per mole

Formation: $Na + 1/2I_2 \longrightarrow NaI$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−70,650	−69,200
500	(2,650)	(−78,400)	(−64,800)
1,000	(14,800)	(−71,900)	(−54,700)
1,500	(22,800)	(−92,100)	(−47,800)

Disodium Dicarbide, Na_2C_2 (*c*)

$\Delta H_{298}^\circ = -9{,}660$ calories per mole (*81*)
$S_{298} = 16.9$ *e.u.* (*81*)
$\Delta F_{298}^\circ = -6{,}570$ calories per mole
Decomposes = 1,073° K.

Sodium Trinitride, NaN_3 (*c*)

$\Delta H_{298}^\circ = +5{,}080$ calories per mole (*43*)
$S_{298} = 16.85$ *e.u.* (*43*)
$\Delta F_{298}^\circ = +24{,}180$ calories per mole
Decomposes = 548° K.

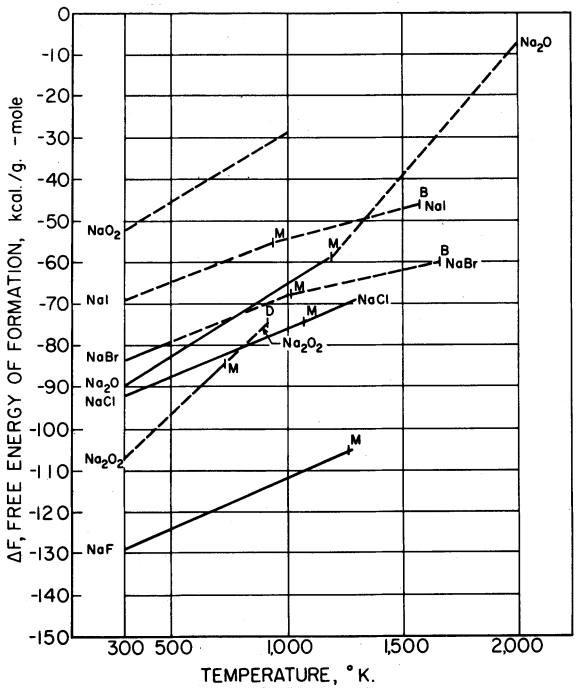

FIGURE 50.—Sodium.

STRONTIUM AND ITS COMPOUNDS

Element, Sr (*c*)

$S_{298} = 12.50$ *e.u.* (*83*)
$T.P. = 862°$ K. (*82*)
$\Delta H_T = 200$ calories per atom
$M.P. = 1{,}043°$ K. (*112*)
$\Delta H_M = 2{,}200$ calories per atom
$B.P. = 1{,}657°$ K. (*79*)
$\Delta H_V = 33{,}610$ calories per atom

Zone I (α) (298°–862° K.)

$$C_p = 5.31 + 3.32 \times 10^{-3} T \text{ (estimated (84))}$$
$$H_T - H_{298} = -1{,}731 + 5.31T + 1.66 \times 10^{-3} T^2$$
$$F_T - H_{298} = -1{,}731 - 5.31 T \ln T - 1.66 \times 10^{-3} T^2 + 24.04T$$

Zone II (β) (862°–1,043° K.)

$$C_p = 9.12 \text{ (estimated (94))}$$
$$H_T - H_{298} = -3{,}582 + 9.12T$$
$$F_T - H_{298} = -3{,}582 - 9.12 T \ln T + 50.54T$$

Zone III (*l*) (1,043°–1,600° K.)

$$C_p = 7.40 \text{ (estimated (84))}$$
$$H_T - H_{298} = 610 + 7.40T$$
$$F_T - H_{298} = 610 - 7.40 T \ln T + 34.66T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		12.50	12.50
400	(660)	(14.40)	(12.75)
500	(1,340)	(15.92)	(13.24)
600	(2,050)	(17.22)	(13.81)
700	(2,800)	(18.37)	(14.37)
800	(3,500)	(19.41)	(14.94)
900	(4,610)	(20.62)	(15.50)
1,000	(5,520)	(21.58)	(16.06)
1,100	(8,550)	(24.56)	(16.79)
1,200	(9,290)	(25.21)	(17.47)
1,300	(10,040)	(25.80)	(18.08)
1,400	(10,780)	(26.35)	(18.65)
1,500	(11,520)	(26.86)	(19.18)
1,600	(12,260)	(27.34)	(19.68)
1,700	(46,070)	(47.97)	(20.87)
1,800	(46,570)	(48.26)	(22.39)
1,900	(47,070)	(48.53)	(23.76)
2,000	(47,570)	(48.79)	(25.01)

Strontium Oxide, SrO (*c*)

$\Delta H^\circ_{298}=-141{,}000$ calories per mole (*112*)
$S_{298}=13.0$ *e.u.* (*83*)
$M.P.=2{,}688°$ K. (*112*)

Zone I (*c*) (298°–1,265.5° K.)

$C_p=12.34+1.12\times10^{-3}T-1.806\times10^{5}T^{-2}$ (*95*)
$H_T-H_{298}=-4{,}327+12.34T+0.56\times10^{-3}T^2+1.806\times10^{5}T^{-1}$

Formation: $Sr+1/2O_2\longrightarrow SrO$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		13.0	−141,000	−133,850
400	1,143	16.29	(−140,900)	(−131,450)
500	2,334	18.96	(−140,750)	(−129,100)
600	3,565	21.21	(−140,600)	(−126,750)
700	4,824	23.15	(−140,400)	(−124,400)
800	6,104	24.88	(−140,400)	(−122,250)
900	7,401	26.41	(−140,600)	(−120,000)
1,000	8,714	27.80	(−140,300)	(−117,400)
1,100	9,940	29.05	(−142,700)	(−115,200)
1,200	11,380	30.24	(−141,400)	(−112,600)
1,500	(16,600)		(−140,800)	(−106,000)

Strontium Dioxide, SrO_2 (*c*)

$\Delta H^\circ_{298}=-150{,}800$ calories per mole (*139*)
$S_{298}=(19.6)$ *e.u.* (*24*)

Formation: $Sr+O_2\longrightarrow SrO_2$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−150,800	−138,300
400	(1,900)	(−150,300)	(−134,300)
500	(3,300)	(−150,300)	(−130,300)
600	(5,250)	(−149,800)	(−126,300)
700	(6,300)	(−149,300)	(−122,300)
800	(9,350)	(−148,800)	(−118,800)
900	(11,700)	(−148,300)	(−114,800)
1,000	(14,000)	(−147,800)	(−111,300)

Strontium Difluoride, SrF_2 (*c*)

$\Delta H^\circ_{298}=-290{,}300$ calories per mole (*112*)
$S_{298}=(18)$ *e.u.* (*11*)
$M.P.=1{,}673°$ K. (*6*)
$\Delta H_M=4{,}260$ calories per mole
$B.P.=2{,}750°$ K. (*6*)
$\Delta H_V=71{,}000$ calories per mole

Formation: $Sr+F_2\longrightarrow SrF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−290,300	(−277,200)
500	(3,600)	(−289,600)	(−268,500)
1,000	(13,000)	(−288,700)	(−247,900)
1,500	(23,300)	(−288,800)	(−227,800)

Strontium Dichloride, $SrCl_2$ (*c*)

$\Delta H^\circ_{298}=-198{,}000$ calories per mole (*112*)
$S_{298}=28$ *e.u.* (*112*)
$M.P.=1{,}145°$ K. (*6*)
$\Delta H_M=4{,}100$ calories per mole
$B.P.=(2{,}300°)$ K. (*6*)
$\Delta H_V=(55{,}000)$ calories per mole

Zone I (*c*) (298°–1,145° K.)

$C_p=18.2+2.45\times10^{-3}T$ (*110*)
$H_T-H_{298}=-5{,}533+18.2T+1.225\times10^{-3}T^2$

Formation: $Sr+Cl_2\longrightarrow SrCl_2$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		28.0	−198,000	−186,750
400	1,943	33.61	(−197,550)	(−182,900)
500	3,873	37.92	(−197,150)	(−179,300)
600	5,828	41.48	(−196,750)	(−175,700)
700	7,807	44.53	(−196,400)	(−172,300)
800	9,811	47.21	(−196,050)	(−168,800)
900	11,833	49.59	(−195,950)	(−165,500)
1,000	13,892	51.77	(−195,700)	(−162,000)
1,100	15,969	53.72	(−195,400)	(−158,500)
1,500	(29,600)	(65.0)	(−190,300)	(−146,500)

Strontium Dibromide, $SrBr_2$ (*c*)

$\Delta H^\circ_{298}=-171{,}100$ calories per mole (*112*)
$S_{298}=(34)$ *e.u.* (*11*)
$M.P.=926°$ K. (*6*)
$\Delta H_M=4{,}780$ calories per mole
$B.P.=(2{,}150°)$ K. (*6*)
$\Delta H_V=(50{,}000)$ calories per mole

Zone I (*c*) (298°–926° K.)

$C_p=18.1+3.15\times10^{-3}T$ (*73*)
$H_T-H_{298}=-5{,}535+18.1T+1.57\times10^{-3}T^2$

Formation: $Sr+Br_2\longrightarrow SrBr_2$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		(34.0)	−171,100	(−166,700)
400	1,958	(39.6)	(−178,400)	(−163,400)
500	3,910	(44.0)	(−178,050)	(−159,700)
600	5,893	(47.6)	(−177,700)	(−156,100)
700	7,908	(50.7)	(−177,300)	(−153,200)
800	9,954	(53.5)	(−176,900)	(−149,100)
900	12,031	(55.9)	(−176,800)	(−145,600)
1,000	(19,200)	(63.0)	(−171,400)	(−141,900)
1,500	(31,200)	(73.0)	(−170,000)	(−127,400)

Strontium Diiodide, SrI_2 (*c*)

$\Delta H^\circ_{298}=-135{,}500$ calories per mole (*112*)
$S_{298}=(38.0)$ *e.u.* (*11*)
$M.P.=788°$ K. (*6*)
$\Delta H_M=(5{,}400)$ calories per mole
$B.P.=(1{,}850°)$ K. (*6*)
$\Delta H_V=(40{,}000)$ calories per mole

Zone I (*c*) (298°–788° K.)

$C_p = 18.6 + 3.05 \times 10^{-3} T$ (*73*)
$H_T - H_{298} = -5{,}680 + 18.6T + 1.52 \times 10^{-3} T^2$
Formation: $Sr + I_2 \longrightarrow SrI_2$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298	----------	(38.0)	−135,500	(−134,800)
400	1,000	(43.8)	(−140,400)	(−135,400)
500	4,000	(48.2)	(−149,500)	(−132,100)
600	6,030	(51.9)	(−149,300)	(−128,900)
700	8,075	(55.1)	(−148,700)	(−125,400)
1,000	(20,400)	(60.0)	(−141,800)	(−117,000)
1,500	(32,400)	(79.0)	(−140,200)	(−103,200)

Tristrontium Dinitride, Sr_3N_2 (*c*)

$\Delta H_{298}^\circ = -92{,}200$ calories per mole (*9*)
$S_{298} = 57.8$ *e.u.* (*9*)
$\Delta F_{298}^\circ = -77{,}000$ calories per mole
$M.P. = 1{,}300°$ K. (*9*)

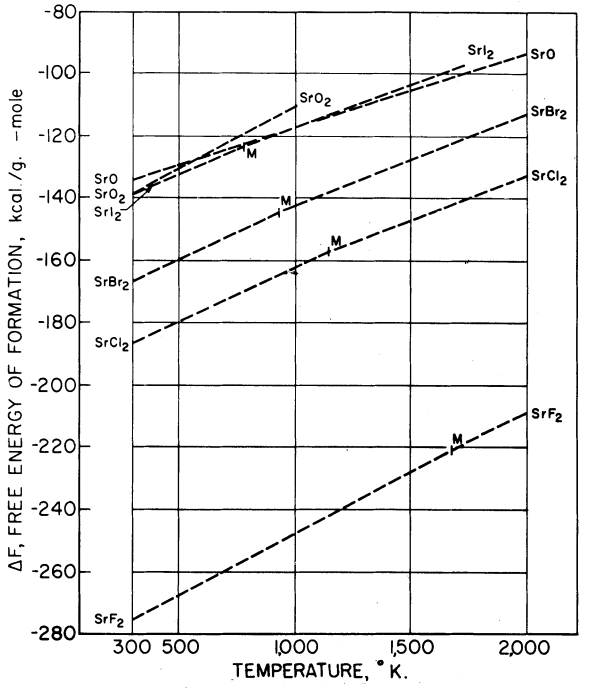

FIGURE 51.—Strontium.

TANTALUM AND ITS COMPOUNDS

Element, Ta (*c*)

$S_{298} = 9.94$ *e.u.* (*83*)
$M.P. = 3{,}269°$ K. (*130*)
$\Delta H_M = (7{,}500)$ calories per mole
$B.P. = 5{,}700°$ K. (*130*)
$\Delta H_V = 180{,}000$ calories per mole

Zone I (*c*) (298–1,900° K.)

$C_p = 5.82 + 0.78 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -1{,}770 + 5.82T + 0.39 \times 10^{-3} T^2$
$F_T - H_{298} = -1{,}770 - 5.82 T \ln T - 0.39 \times 10^{-3} T^2 + 29.21T$

T, ° K.	$H_T - H_{298}$	S_T	$\frac{(F_T - H_{298})}{T}$
298	----------	9.94	9.94
400	620	11.73	10.20
500	1,230	13.09	10.65
600	1,845	14.22	11.16
700	2,470	15.18	11.61
800	3,120	16.05	12.12
900	3,780	16.83	12.64
1,000	4,440	17.53	13.09
1,100	5,100	18.16	13.53
1,200	5,770	18.74	13.94
1,300	6,445	19.29	14.31
1,400	7,130	19.80	14.66
1,500	7,825	20.28	15.05
1,600	8,530	20.73	14.42
1,700	9,250	21.17	15.71
1,800	9,980	21.59	16.03
1,900	10,720	21.98	16.25

Ditantalum Pentaoxide, Ta_2O_5 (*c*)

$\Delta H_{298}^\circ = -488{,}800$ calories per mole (*24*)
$S_{298} = 34.2$ *e.u.* (*83*)
$M.P. = 2{,}150°$ K. (*8*)
$\Delta H_M = 48{,}000$ calories per mole
$B.P. = >2{,}500°$ K. (*24*)

Zone I (*c*) (298°–1,800° K.)

$C_p = 37.00 + 6.56 \times 10^{-3} T - 5.92 \times 10^5 T^{-2}$ (*107*)
$H_T - H_{298} = -13{,}215 + 37.00T + 3.28 \times 10^{-3} T^2 + 5.92 \times 10^5 T^{-1}$

Formation: $2Ta + 5/2O_2 \longrightarrow Ta_2O_5$

Zone I (298°–1,700° K.)

$\Delta C_p = 7.46 + 2.50 \times 10^{-3} T - 4.92 \times 10^5 T^{-2}$
$\Delta H_T = -492{,}780 + 7.46T + 1.25 \times 10^{-3} T^2 + 4.92 \times 10^5 T^{-1}$
$\Delta F_T = -492{,}780 - 7.46 T \ln T - 1.25 \times 10^{-3} T^2 + 2.46 \times 10^5 T^{-1} + 161.6T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298	----------	34.2	−488,800	−456,500
400	3,430	44.07	−488,350	−445,650
500	7,070	52.18	−487,750	−435,000
600	10,950	59.25	−487,050	−424,400
700	14,990	66.08	−486,250	−414,250
800	19,130	71.01	−485,400	−404,150
900	23,340	75,96.	−484,500	−393,800
1,000	27,630	80.49	−483,600	−383,700
1,100	31,990	84.64	−482,600	−373,550
1,200	36,410	88.49	−481,600	−363,850
1,300	40,880	92.06	−480,600	−354,200
1,400	45,390	95.4	−479,550	−344,550
1,500	49,970	98.56	−478,450	−335,350
1,600	54,630	101.57	−477,350	−325,850
1,700	59,380	104.45	−476,300	−316,300

Tantalum Pentachloride, $TaCl_5$ (*c*)

$\Delta H_{298}^\circ = -205{,}500$ calories per mole (*48*)
$S_{298} = (66)$ *e.u.* (*11*)
$M.P. = 480°$ K. (*6*)
$\Delta H_M = 9{,}000$ calories per mole
$B.P. = 507°$ K. (*6*)
$\Delta H_V = 12{,}500$ calories per mole

Formation: $Ta+5/2Cl_2 \longrightarrow TaCl_5$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−205,500	(−182,500)
500	(13,000)	(−199,000)	(−168,000)
1,000	(30,000)	(−195,000)	(−152,000)

Tantalum Pentabromide, $TaBr_5$ (*c*)

$\Delta H_{298}^\circ = -142{,}900$ calories per mole (*49*)
$S_{298} = (78)$ *e.u.* (*11*)
M.P. = 513° K. (*6*)
$\Delta H_M = (9{,}000)$ calories per mole
B.P. = 622° K.
$\Delta H_V = 14{,}900$ calories per mole

Formation: $Ta+5/2Br_2 \longrightarrow TaBr_5$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−143,000	(−135,000)
500	(8,000)	(−159,000)	(−122,000)

Tantalum Carbide, TaC (*c*)

$\Delta H_{298}^\circ = -38{,}500$ calories per mole (*66*)
$S_{298} = 10.1$ *e.u.* (*112*)
M.P. = 4,070° K. (*9*)

Zone I (*c*) (298°–1,800° K.)

$C_p = 7.28+1.65\times10^{-3}T$ (*94*)
$H_T-H_{298} = -2{,}242+7.28T+0.825\times10^{-3}T^2$

Formation: $Ta+C \longrightarrow TaC$

Zone I (298°–1,800° K.)

$\Delta C_p = -2.64-0.15\times10^{-3}T+2.10\times10^{5}T^{-2}$
$\Delta H_T = -37{,}000-2.64T-0.075\times10^{-3}T^2-2.10\times10^{5}T^{-1}$
$\Delta F_T = -37{,}000+2.64T\ln T+0.075\times10^{-3}T^2-1.05\times10^{5}T^{-1}-17.64T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		10.1	−38,500	−38,090
400	800	12.41	−38,600	−38,000
500	1,604	14.20	−38,750	−37,800
600	2,423	15.70	−38,950	−37,650
700	3,258	16.98	−39,200	−37,350
800	4,110	18.12	−39,400	−37,100
900	4,978	19.14	−39,650	−36,750
1,000	5,863	20.08	−39,900	−36,450
1,100	6,764	20.92	−40,200	−36,050
1,200	7,682	21.73	−40,450	−35,800
1,300	8,616	22.48	−40,700	−35,500
1,400	9,567	23.19	−41,000	−34,900
1,500	10,534	23.85	−41,250	−34,300
1,600	11,516	24.49	−41,550	−33,850
1,700	12,518	25.09	−41,800	−33,500
1,800	13,535	25.68	−42,100	−33,000

Tantalum Nitride, TaN (*c*)

$\Delta H_{298}^\circ = -60{,}000$ calories per mole (*100*)
$S_{298} = 12.4$ *e.u.* (*94*)
M.P. = (3,360°) K. (*9*)

Zone I (*c*) (298°–773° K.)

$C_p = 7.73+7.80\times10^{-3}T$ (*82*)
$H_T-H_{298} = -2{,}652+7.73T+3.90\times10^{-3}T^2$

Formation: $Ta+1/2N_2 \longrightarrow TaN$

Zone I (298°–773° K.)

$\Delta C_p = -1.42+6.51\times10^{-3}T$
$\Delta H_T = -59{,}900-1.42T+3.25\times10^{-3}T^2$
$\Delta F_T = -59{,}900+1.42T\ln T-3.25\times10^{-3}T^2+12.87T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		12.4	−60,000	−53,930
400	1,050	15.43	−59,900	−51,850
500	2,190	17.97	−59,750	−49,950
600	3,400	20.17	−59,500	−47,900
700	4,680	22.14	−59,200	−45,950
800	6,030	23.94	−58,900	−44,100
900	(7,460)		(−58,500)	(−43,300)
1,000	(8,980)		(−58,050)	(−40,500)
1,100	(10,570)		(−57,550)	(−38,750)
1,200	(12,240)		(−56,900)	(−37,300)
1,300	(13,990)		(−56,250)	(−35,450)
1,400	(15,810)		(−55,550)	(−33,850)
1,500	(17,720)		(−54,750)	(−32,300)
1,600	(19,700)		(−53,850)	(−30,850)
1,700	(21,760)		(−52,900)	(−29,550)
1,800	(23,590)		(−51,900)	(−28,150)
1,900	(26,110)		(−50,850)	(−26,850)
2,000	(28,410)		(−49,700)	(−25,600)

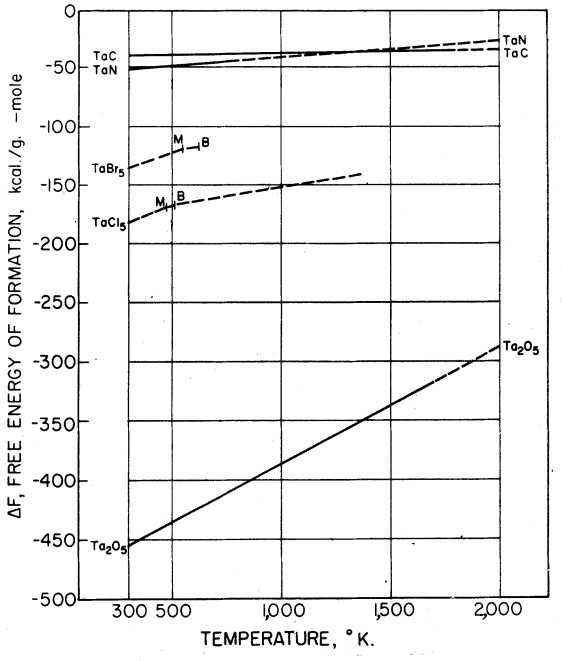

FIGURE 52.—Tantalum.

TERBIUM AND ITS COMPOUNDS

Element, Tb (*c*)

$S_{298}=(17.50)$ *e.u.* (*121*)
M.P.$=(1{,}638°)$ K. (*125*)
$\Delta H_M=(3{,}900)$ calories per atom
B.P.$=(2{,}800°)$ K. (*125*)
$\Delta H_V=(70{,}000)$ calories per atom
(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$\frac{(F_T-H_{298})}{T}$
298		(17.50)	(17.50)
400	(675)	(19.41)	(17.73)
500	(1,360)	(20.92)	(18.20)
600	(2,055)	(22.20)	(18.78)
700	(2,770)	(23.30)	(19.35)
800	(3,510)	(24.28)	(19.90)
900	(4,260)	(25.17)	(20.44)
1,000	(5,030)	(25.98)	(20.95)
1,100	(5,820)	(26.74)	(21.45)
1,200	(6,630)	(27.44)	(21.92)
1,300	(7,450)	(28.10)	(22.37)
1,400	(8,300)	(28.72)	(22.80)
1,500	(9,160)	(29.32)	(23.22)
1,600	(10,040)	(29.88)	(23.61)
1,700	(14,830)	(32.72)	(24.00)
1,800	(15,630)	(33.17)	(24.49)
1,900	(16,430)	(33.61)	(25.41)
2,000	(17,230)	(34.02)	(25.83)

Diterbium Trioxide, Tb_2O_3 (*c*)

$\Delta H^\circ_{298}=-436{,}800\pm2{,}000$ calories per mole (*129*)

Heptaterbium Dodecaoxide, Tb_7O_{12} (*c*)

$\Delta H^\circ_{298}=-1{,}563{,}000\pm7{,}000$ calories per mole (*129*)

Pentaterbium Enneaoxide, Tb_5O_9 (*c*)

$\Delta H^\circ_{298}=-1{,}132{,}000\pm5{,}000$ calories per mole (*129*)

Terbium Trifluoride, TbF_3 (*c*)

$\Delta H^\circ_{298}=(-375{,}000)$ calories per mole (*5*)
$S_{298}=(25)$ *e.u.* (*11*)
M.P.$=(1{,}445°)$ K. (*29*)
$\Delta H_M=(8{,}000)$ calories per mole
B.P.$=(2{,}550°)$ K. (*6*)
$\Delta H_V=(60{,}000)$ calories per mole

Formation: $Tb+3/2F_2\longrightarrow TbF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−375,000)	(−357,000)
500	(4,000)	(−374,700)	(−345,000)
1,000	(17,000)	(−371,800)	(−315,000)
1,500	(32,000)	(−368,000)	(−289,500)

Terbium Trichloride, $TbCl_3$ (*c*)

$\Delta H^\circ_{298}=(-216{,}000)$ calories per mole (*5*)
$S_{298}=(41)$ *e.u.* (*11*)
T.P.$=770°$ K. (*29*)
M.P.$=855°$ K. (*29*)
$\Delta H_M=(7{,}000)$ calories per mole
B.P.$=(1{,}820°)$ K. (*6*)
$\Delta H_V=(45{,}000)$ calories per mole

Formation: $Tb+3/2Cl_2\longrightarrow TbCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−216,000)	(−200,500)
500	(5,000)	(−214,900)	(−190,000)
1,000	(19,000)	(−211,100)	(−167,000)
1,500	(43,000)	(−197,600)	(−148,500)

Terbium Tribromide, $TbBr_3$ (*c*)

$\Delta H^\circ_{298}=(-175{,}000)$ calories per mole (*5*)
$S_{298}=(46)$ *e.u.* (*11*)
M.P.$=(1{,}100°)$ K. (*29*)
$\Delta H_M=(9{,}000)$ calories per mole
B.P.$=(1{,}760°)$ K. (*6*)
$\Delta H_V=(44{,}000)$ calories per mole

Formation: $Tb+3/2Br_2\longrightarrow TbBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−175,000)	(−168,500)
500	(5,000)	(−185,600)	(−157,500)
1,000	(18,000)	(−183,000)	(−133,000)
1,500	(43,000)	(−181,000)	(−94,500)

Terbium Triiodide, TbI_3 (*c*)

$\Delta H^\circ_{298}=(-122{,}000)$ calories per mole (*5*)
$S_{298}=(48)$ *e.u.* (*11*)
M.P.$=(1{,}219°)$ K. (*29*)
$\Delta H_M=(10{,}000)$ calories per mole
B.P.$=(1{,}600°)$ K. (*6*)
$\Delta H_V=(40{,}000)$ calories per mole

Formation: $Tb+3/2I_2\longrightarrow TbI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−122,000)	(−124,000)
500	(5,000)	(−143,400)	(−112,000)
1,000	(19,000)	(−139,500)	(−84,000)
1,500	(44,000)	(−125,000)	(−59,500)

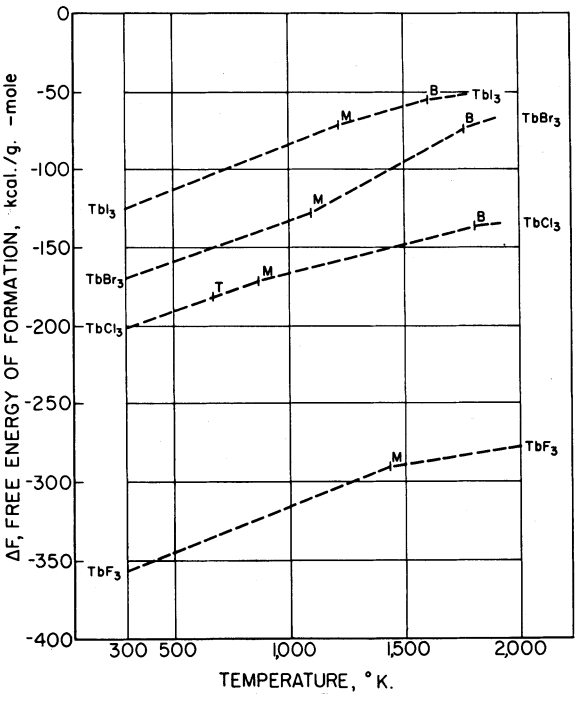

FIGURE 53.—Terbium.

THORIUM AND ITS COMPOUNDS

Element, Th (*c*)

$S_{298}=12.76$ *e.u.* (*46*)
T.P.$=1{,}673°$ K. (*130*)
$\Delta H_T=(670)$ calories per atom
M.P.$=1{,}968°$ K. (*130*)
$\Delta H_M=(3{,}740)$ calories per atom
B.P.$=4{,}500°$ K. (*130*)
$\Delta H_V=(130{,}000)$ calories per atom

Zone I (*c*) (298°–1,500° K.)

$$C_p=6.40+3.06\times10^{-3}T+0.35\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-1{,}927+6.40T+1.53\times10^{-3}T^2-0.35\times10^{5}T^{-1}$$
$$F_T-H_{298}=-1{,}927-6.40T\ln T-1.53\times10^{-3}T^2-0.175\times10^{5}T^{-1}+30.71T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		12.76	12.76
400	790	15.04	13.09
500	1,600	16.85	13.65
600	2,420	18.34	14.31
700	3,260	19.64	14.97
800	4,120	20.79	15.64
900	5,010	21.85	16.28
1,000	5,930	22.80	16.87
1,100	6,880	23.71	17.45
1,200	7,870	24.57	18.01
1,300	8,910	25.40	18.55
1,400	10,000	26.21	19.07
1,500	11,130	26.99	19.57
1,600	(12,200)	(27.59)	(19.98)
1,700	(13,200)	(28.30)	(20.54)
1,800	(14,500)	(29.06)	(21.01)

Thorium Oxide, ThO (*c*)

$\Delta H^{\circ}_{298}=-145{,}000$ calories per mole (*42*)
$S_{298}=16.1$ *e.u.* (*42*)
M.P.$=>2{,}500°$ K. (*42*)

Formation: $Th+1/2O_2\longrightarrow ThO$ (estimated (*42*))

T, ° K.	ΔF°_T	T, ° K.	ΔF°_T
298	(−138,000)	1,500	(−113,000)
500	(−134,000)	2,000	(−102,000)
1,000	(−123,000)	2,500	(−91,000)

Thorium Dioxide, ThO_2 (*c*)

$\Delta H^{\circ}_{298}=-293{,}200$ calories per mole (*63*)
$S_{298}=15.59$ *e.u.* (*24*)
M.P.$=3{,}225°$ K. (*8*)
$\Delta H_M=291{,}100$ calories per mole
B.P.$=4{,}670°$ K. (*8*)

Zone I (*c*) (298°–1,800° K.)

$$C_p=15.84+2.88\times10^{-3}T-1.60\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-5{,}388+15.84T+1.44\times10^{-3}T^2+1.60\times10^{5}T^{-1}$$

Formation: $Th+O_2\longrightarrow ThO_2$

Zone I (298°–1,500° K.)

$$\Delta C_p=2.28-1.18\times10^{-3}T-1.55\times10^{5}T^{-2}$$
$$\Delta H_T=-294{,}350+2.28T-0.59\times10^{-3}T^2+1.55\times10^{5}T^{-1}$$
$$\Delta F_T=-294{,}350-2.28T\ln T+0.59\times10^{-3}T^2+0.775\times10^{5}T^{-1}+61.96T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		15.59	−293,200	−279,450
400	1,600	20.20	−293,100	−274,700
500	3,210	23.79	−293,050	−270,150
600	4,890	26.85	−292,950	−265,600
700	6,620	29.91	−292,850	−261,050
800	8,390	31.88	−292,700	−256,500
900	10,200	34.01	−292,600	−251,950
1,000	12,050	35.96	−292,500	−247,450
1,100	13,940	37.76	−292,350	−242,450
1,200	15,860	39.43	−292,250	−238,400
1,300	17,800	40.98	−292,200	−233,900
1,400	19,760	42.43	−292,150	−229,450
1,500	21,740	43.80	−292,250	−225,000
1,600	23,740	45.09	(−292,100)	(−220,550)
1,700	25,750	46.31	(−292,000)	(−216,000)
1,800	27,770	47.46	(−292,150)	(−211,700)

Thorium Tetrafluoride, ThF_4 (*c*)

$\Delta H^{\circ}_{298}=(-477{,}000)$ calories per mole (*11*)
$S_{298}=(35)$ *e.u.* (*11*)
M.P.$=(1{,}300°)$ K. (*11*)
$\Delta H_M=(17{,}000)$ calories per mole
B.P.$=(2{,}000°)$ K. (*11*)
$\Delta H_V=(50{,}000)$ calories per mole

Formation: $Th+2F_2\longrightarrow ThF_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−477,000)	(−454,000)
500	(6,000)	(−475,800)	(−438,000)
1,000	(22,000)	(−472,600)	(−403,000)
1,500	(59,000)	(−449,600)	(−373,000)

Thorium Trichloride, $ThCl_3$ (*c*)

$\Delta H_{298}^\circ = (-242{,}000)$ calories per mole (*42*)
$S_{298} = (43.2)$ *e.u.* (*42*)
$M.P. = (1{,}100°)$ K. (*6*)
$\Delta H_M = (9{,}000)$ calories per mole
$B.P. = (1{,}890°)$ K. (*6*)
$\Delta H_V = (46{,}000)$ calories per mole

Formation: $Th + 3/2Cl_2 \longrightarrow ThCl_3$ (estimated (*42*))

T, ° K.	ΔF_T°	T, ° K.	ΔF_T°
298	(−227,000)	1,500	(−179,000)
500	(−218,000)	2,000	(−172,000)
1,000	(−196,000)	2,500	(−161,000)

Thorium Tetrachloride, $ThCl_4$ (*c*)

$\Delta H_{298}^\circ = -285{,}200$ calories per mole (*11*)
$S_{298} = (44)$ *e.u.* (*11*)
$M.P. = 1{,}038°$ K. (*6*)
$\Delta H_M = 22{,}500$ calories per mole
$B.P. = 1{,}195°$ K. (*6*)
$\Delta H_V = 36{,}500$ calories per mole

Formation: $Th + 2Cl_2 \longrightarrow ThCl_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−285,200	(−262,600)
500	(6,000)	(−284,000)	(−247,200)
1,000	(23,000)	(−280,000)	(−211,000)
1,500	(84,500)	(−232,500)	(−198,000)

Thorium Tetrabromide, $ThBr_4$ (*c*)

$\Delta H_{298}^\circ = (-230{,}300)$ calories per mole (*11*)
$S_{298} = (56)$ *e.u.* (*11*)
$M.P. = 953°$ K. (*6*)
$\Delta H_M = 9{,}500$ calories per mole
$B.P. = 1{,}130°$ K. (*6*)
$\Delta H_V = 34{,}500$ calories per mole

Formation: $Th + 2Br_2 \longrightarrow ThBr_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−230,300)	(−221,200)
500	(6,000)	(−244,900)	(−207,000)
1,000	(33,000)	(−231,200)	(−172,500)
1,500	(88,500)	(−189,700)	

Thorium Tetraiodide, ThI_4 (*c*)

$\Delta H_{298}^\circ = (-161{,}200)$ calories per mole (*11*)
$S_{298} = (63)$ *e.u.* (*11*)
$M.P. = 839°$ K. (*6*)
$\Delta H_M = 8{,}000$ calories per mole
$B.P. = 1{,}110°$ K. (*6*)
$\Delta H_V = 31{,}500$ calories per mole

Formation: $Th + 2I_2 \longrightarrow ThI_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−161,200)	(−159,000)
500	(6,000)	(−189,900)	(−154,200)
1,000	(33,000)	(−176,200)	(−118,000)
1,500	(85,500)	(−137,800)	(−72,000)

Thorium Dicarbide, ThC_2 (*c*)

$\Delta H_{298}^\circ = -45{,}600$ calories per mole (*9*)
$S_{298} = (30)$ *e.u.* (*9*)
$\Delta F_{298}^\circ = (-50{,}000)$ calories per mole (*9*)

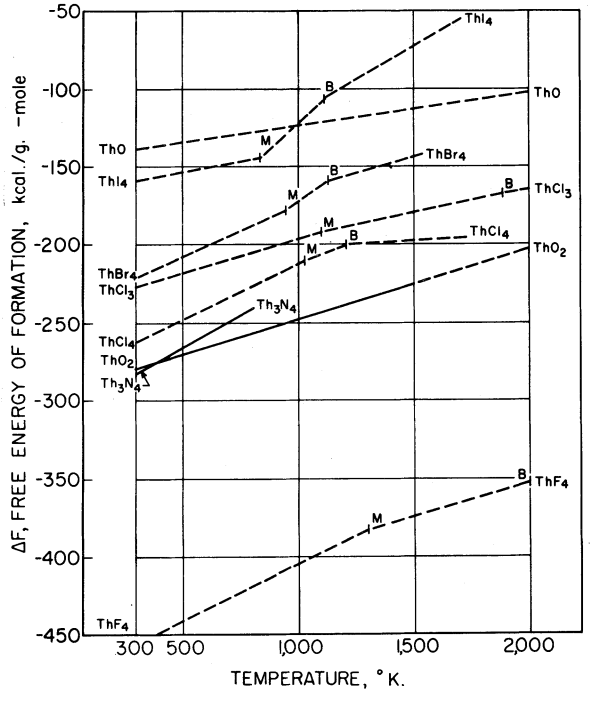

FIGURE 54.—Thorium.

Trithorium Tetranitride, Th_3N_4 (*c*)

$\Delta H_{298}^\circ = -308{,}400$ calories per mole (*9*)
$S_{298} = 42.7$ *e.u.* (*9*)

Zone I (*c*) (298°–800° K.)

$C_p = 27.78 + 31.8 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -9{,}696 + 27.78T + 15.9 \times 10^{-3} T^2$

Formation: $3Th + 2N_2 \longrightarrow Th_3N_4$

Zone I (298°–800° K.)

$\Delta C_p = -4.74 + 20.58 \times 10^{-3} T - 1.05 \times 10^5 T^{-2}$
$\Delta H_T = -308{,}250 - 4.74T + 10.29 \times 10^{-3} T^2 + 1.05 \times 10^5 T^{-1}$
$\Delta F_T = -308{,}250 + 4.74 T \ln T - 10.29 \times 10^{-3} T^2 + 0.525 \times 10^5 T^{-1} + 62.07 T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH_T°	ΔF_T°
298		42.7	−308,400	−282,450
400	3,960	54.11	−308,250	−273,600
500	8,180	63.51	−307,850	−264,950
600	12,720	71.78	−307,200	−256,400
700	17,540	79.20	−306,350	−248,000
800	22,540	85.87	−305,400	−239,700

THULIUM AND ITS COMPOUNDS

Element, Tm (*c*)

$S_{298} = (17.10)$ *e.u.* (*127*)
M.P. = (1,900°) K. (*125*)
$\Delta H_M = (4{,}400)$ calories per atom
B.P. = (2,400°) K. (*125*)
$\Delta H_V = (51{,}000)$ calories per atom

(estimated (*130*))

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		(17.10)	(17.10)
400	(660)	(18.97)	(17.32)
500	(1,330)	(20.46)	(17.80)
600	(2,010)	(21.71)	(18.36)
700	(2,710)	(22.78)	(18.91)
800	(3,420)	(23.73)	(19.46)
900	(4,150)	(24.59)	(19.98)
1,000	(4,890)	(25.37)	(20.48)
1,100	(5,650)	(26.09)	(20.96)
1,200	(6,420)	(26.77)	(21.42)
1,300	(7,210)	(27.40)	(21.86)
1,400	(8,010)	(27.99)	(22.27)
1,500	(8,830)	(28.56)	(22.68)
1,600	(9,660)	(29.09)	(23.06)
1,700	(10,510)	(29.61)	(23.43)
1,800	(11,370)	(30.10)	(23.79)
1,900	(16,650)	(32.89)	(24.13)
2,000	(17,450)	(33.30)	(24.58)

Thulium Trifluoride, TmF_3 (*c*)

$\Delta H_{298}^\circ = (-366{,}000)$ calories per mole (*5*)
$S_{298} = (25)$ *e.u.* (*11*)
M.P. = (1,610°) K. (*6*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = (2,500°) K. (*6*)
$\Delta H_V = (60{,}000)$ calories per mole

Formation: $Tm + 3/2F_2 \longrightarrow TmF_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		(−366,000)	(−348,000)
500	(4,000)	(−365,700)	(−336,500)
1,000	(17,000)	(−362,600)	(−308,000)
1,500	(32,000)	(−378,000)	(−282,000)

Thulium Trichloride, $TmCl_3$ (*c*)

$\Delta H_{298}^\circ = -229{,}000$ calories per mole (*5*)
$S_{298} = (39)$ *e.u.* (*11*)
M.P. = 1,094° K. (*6*)
$\Delta H_M = (9{,}000)$ calories per mole
B.P. = (1,760°) K. (*6*)
$\Delta H_V = (44{,}000)$ calories per mole

Formation: $Tm + 3/2Cl_2 \longrightarrow TmCl_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		−229,000	(−212,500)
500	(5,000)	(−227,900)	(−201,500)
1,000	(19,000)	(−224,000)	(−176,000)
1,500	(43,000)	(−210,400)	(−157,000)

Thulium Tribromide, $TmBr_3$ (*c*)

$\Delta H_{298}^\circ = (-167{,}000)$ calories per mole (*5*)
$S_{298} = (44)$ *e.u.* (*11*)
M.P. = (1,225°) K. (*6*)
$\Delta H_M = (10{,}000)$ calories per mole
B.P. = (1,710°) K. (*6*)
$\Delta H_V = (43{,}000)$ calories per mole

Formation: $Tm + 3/2Br_2 \longrightarrow TmBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH_T°	ΔF_T°
298		(−167,000)	(−160,000)
500	(5,000)	(−177,600)	(−148,500)
1,000	(18,000)	(−174,900)	(−123,000)
1,500	(43,000)	(−160,600)	(−103,500)

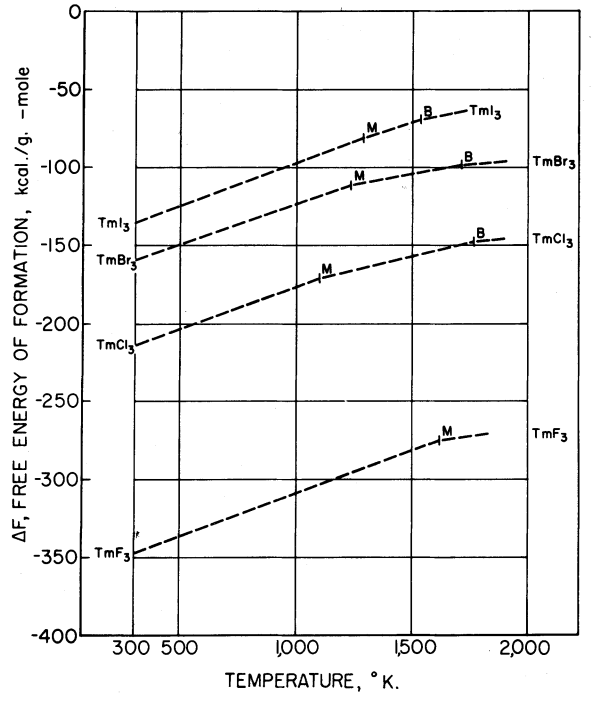

FIGURE 55.—Thulium.

Thulium Triiodide, TmI_3 (*c*)

$\Delta H^\circ_{298} = (-138{,}000)$ calories per mole (*5*)
$S_{298} = (47)$ *e.u.* (*11*)
$M.P. = 1{,}288°$ K. (*6*)
$\Delta H_M = (10{,}000)$ calories per mole
$B.P. = (1{,}530°)$ K. (*6*)
$\Delta H_V = (40{,}000)$ calories per mole

Formation: $Tm + 3/2I_2 \longrightarrow TmI_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−138,000)	(−135,500)
500	(5,000)	(−159,300)	(−123,500)
1,000	(19,000)	(−155,600)	(−95,000)
1,500	(44,000)	(−142,000)	(−70,500)

TIN AND ITS COMPOUNDS

Element, Sn (*c*)

$S_{298} = 12.29$ *e.u.* (*83*)
$M.P. = 505°$ K. (*82*)
$\Delta H_M = 1{,}720$ calories per atom
$B.P. = 2{,}960°$ K. (*130*)
$\Delta H_V = 69{,}400$ calories per atom

Zone I (*c*) (298°–505° K.)

$C_p = 4.42 + 6.30\times10^{-3}T$ (*82*)
$H_T - H_{298} = -1{,}598 + 4.42T + 3.15\times10^{-3}T^2$
$F_T - H_{298} = -1{,}598 - 4.42T\ln T - 3.15\times10^{-3}T^2 + 19.19T$

Zone II (*l*) (505°–1,300° K.)

$C_p = 7.30$ (*82*)
$H_T - H_{298} = -526 + 7.30T$
$F_T - H_{298} = -526 - 7.30T\ln T + 33.41T$

Zone III (*l*) (1,300°–2,000° K.) (estimated (*130*))

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		12.29	12.29
400	680	14.25	12.55
500	1,400	15.85	13.05
600	3,850	20.59	14.17
700	4,580	21.72	15.17
800	5,310	22.69	16.05
900	6,040	23.55	16.83
1,000	6,770	24.32	17.55
1,100	7,500	25.02	18.20
1,200	8,230	25.65	18.79
1,300	8,960	26.23	19.34
1,400	(9,690)	(26.77)	(19.85)
1,500	(10,420)	(27.28)	(20.34)
1,600	(11,150)	(27.75)	(20.79)
1,700	(11,880)	(28.19)	(21.21)
1,800	(12,610)	(28.61)	(21.61)
1,900	(13,340)	(29.00)	(21.98)
2,000	(14,070)	(29.38)	(22.35)

Tin Oxide, SnO (*c*)

$\Delta H^\circ_{298} = -68{,}350$ calories per mole (*71*)
$S_{298} = 13.5$ *e.u.* (*83*)
$M.P. = (1{,}315°)$ K. (*42*)
$\Delta H_M = (6{,}400)$ calories per mole
$B.P. = (1{,}800°)$ K. (*42*)
$\Delta H_V = (60{,}000)$ calories per mole

Zone I (*c*) (298°–1,273° K.)

$C_p = 9.95 + 3.50\times10^{-3}T$
$H_T - H_{298} = -3{,}120 + 9.95T + 1.75\times10^{-3}T^2$

Formation: $Sn + 1/2O_2 \longrightarrow SnO$

Zone I (298°–505° K.)

$\Delta C_p = 1.95 - 3.3\times10^{-3}T + 0.20\times10^5T^{-2}$
$\Delta H_T = -68{,}720 + 1.95T - 1.65\times10^{-3}T^2 - 0.20\times10^5T^{-1}$
$\Delta F_T = -68{,}720 - 1.95T\ln T + 1.65\times10^{-3}T^2 - 0.10\times10^5T^{-1} + 35.26T$

Zone II (505°–1,300° K.)

$\Delta C_p = -0.93 + 3.0\times10^{-3}T + 0.20\times10^5T^{-2}$
$\Delta H_T = -69{,}800 - 0.93T + 1.5\times10^{-3}T^2 - 0.20\times10^5T^{-1}$
$\Delta F_T = -69{,}800 + 0.93T\ln T - 1.5\times10^{-3}T^2 - 0.10\times10^5T^{-1} + 21.07T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		13.5	−68,350	−61,400
400	1,130	16.79	−68,250	−59,000
500	2,280	19.37	−68,200	−56,800
600	3,460	21.53	−69,850	−54,200
700	4,680	23.41	−69,750	−51,600
800	5,930	25.09	−69,700	−49,100
900	7,210	26.61	−69,500	−46,500
1,000	8,580	28.01	−69,250	−43,900
1,100	9,880	29.30	−69,050	−41,300
1,200	11,270	30.52	−68,850	−38,800
1,300	12,690	31.67	−68,550	−36,300

Tin Dioxide, SnO_2 (*c*)

$\Delta H^\circ_{298} = -138{,}820$ calories per mole (*71*)
$S_{298} = 12.5$ *e.u.* (*83*)
$S.P. = 2{,}123°$ K. (*94*)

Zone I (c) (298°–1,500° K.)

$C_p = 17.66 + 2.40\times10^{-3}T - 5.16\times10^5T^{-2}$ (*82*)
$H_T - H_{298} = -7{,}100 + 17.66T + 1.20\times10^{-3}T^2 + 5.16\times10^5T^{-1}$

Formation: $Sn + O_2 \longrightarrow SnO_2$

Zone I (298°–505° K.)

$\Delta C_p = 6.08 - 4.90\times10^{-3}T - 4.76\times10^5T^{-2}$
$\Delta H_T = -142{,}010 + 6.08T - 2.45\times10^{-3}T^2 + 4.76\times10^5T^{-1}$
$\Delta F_T = -142{,}010 - 6.08T\ln T + 2.45\times10^{-3}T^2 + 2.38\times10^5T^{-1} + 90.74T$

Zone II (505°–1,300° K.)

$\Delta C_p = 3.2 + 1.4\times10^{-3}T - 4.76\times10^5T^{-2}$
$\Delta H_T = -143{,}190 + 3.2T + 0.7\times10^{-3}T^2 + 4.76\times10^5T^{-1}$
$\Delta F_T = -143{,}190 - 3.2T\ln T - 0.7\times10^{-3}T^2 + 2.38\times10^5T^{-1} + 76.58T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		12.5	−138,820	−124,300
400	1,510	16.84	−138,700	−119,300
500	3,100	20.38	−138,600	−114,500
600	4,780	23.45	−140,100	−109,300
700	6,550	26.18	−139,800	−104,300
800	8,390	28.63	−139,500	−99,200
900	10,280	30.85	−139,200	−94,200
1,000	12,210	32.88	−138,800	−89,200
1,100	14,190	34.77	−138,300	−84,200
1,200	16,210	36.53	−137,900	−79,300
1,300	18,260	38.17	−137,400	−74,400
1,400	20,340	39.71	−136,800	−69,500
1,500	22,440	41.16	−136,500	−64,800

Tin Difluoride, SnF_2 (*c*)

$\Delta H^\circ_{298} = (-158{,}000)$ calories per mole (*11*)
$S_{298} = 29$ *e.u.* (*11*)
M.P. = >900° K. (*6*)
B.P. = >1,500° K. (*6*)

Formation: $Sn + F_2 \longrightarrow SnF_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−158,000)	(−148,500)
500	(4,000)	(−157,000)	(−141,500)

Tin Dichloride, $SnCl_2$ (*c*)

$\Delta H^\circ_{298} = -81{,}100$ calories per mole (*11*)
$S_{298} = (34)$ *e.u.* (*11*)
M.P. = 500° K. (*6*)
$\Delta H_M = 3{,}050$ calories per mole
B.P. = 925° K. (*6*)
$\Delta H_V = 19{,}500$ calories per mole

Formation: $Sn + Cl_2 \longrightarrow SnCl_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−81,000	(−71,600)
500	(4,000)	(−80,000)	(−65,500)

Tin Tetrachloride, $SnCl_4$ (*l*)

$\Delta H^\circ_{298} = -127{,}400$ calories per mole (*11*)
$S_{298} = 62.2$ *e.u.* (*83*)
$\Delta F^\circ_{298} = -16{,}900$ calories per mole
M.P. = 240° K. (*6*)
$\Delta H_M = 2{,}190$ calories per mole
B.P. = 386° K.
$\Delta H_V = 8{,}325$ calories per mole

Zone I (*g*) (298°–1,000° K.)

$C_p = 25.57 + 0.20 \times 10^{-3} T - 1.87 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -8{,}260 + 25.57T + 0.10 \times 10^{-3} T^2 + 1.87 \times 10^5 T^{-1}$

Formation: $Sn + 2Cl_2 \longrightarrow SnCl_4$ (estimated (*11*))

Tin Dibromide, $SnBr_2$ (*c*)

$\Delta H^\circ_{298} = -61{,}400$ calories per mole (*11*)
$S_{298} = (39)$ *e.u.* (*11*)
M.P. = 505° K. (*6*)
$\Delta H_M = 1{,}720$ calories per mole
B.P. = 912° K. (*6*)
$\Delta H_V = 23{,}500$ calories per mole

Formation: $Sn + Br_2 \longrightarrow SnBr_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−61,400	(−58,500)
500	(4,000)	(−68,400)	(−52,000)

Tin Tetrabromide, $SnBr_4$ (*c*)

$\Delta H^\circ_{298} = -94{,}700$ calories per mole (*11*)
$S_{298} = (62)$ *e.u.* (*11*)
M.P. = 303° K. (*6*)
$\Delta H_M = 3{,}000$ calories per mole
B.P. = 480° K. (*6*)
$\Delta H_V = (10{,}500)$ calories per mole

Formation: $Sn + 2Br_2 \longrightarrow SnBr_4$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−94,700	(−87,000)
500	(22,000)	(−98,000)	(−79,000)

Tin Diiodide, SnI_2 (*c*)

$\Delta H^\circ_{298} = -38{,}900$ calories per mole (*11*)
$S_{298} = (41)$ *e.u.* (*11*)
M.P. = 593° K. (*6*)
$\Delta H_M = (3{,}000)$ calories per mole
B.P. = 987° K. (*6*)
$\Delta H_V = 24{,}000$ calories per mole

Formation: $Sn + I_2 \longrightarrow SnI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−38,900	(−39,100)
500	(4,000)	(−53,000)	(−36,800)

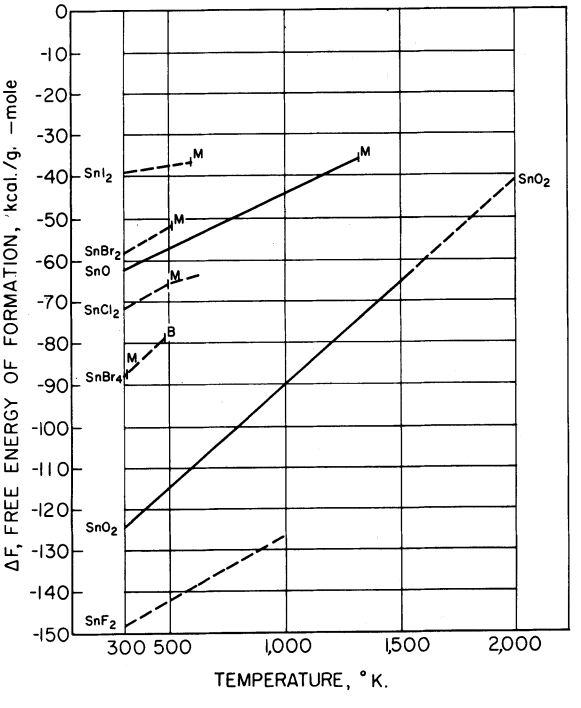

FIGURE 56.—Tin.

TITANIUM AND ITS COMPOUNDS

Element, Ti(*c*)

$S_{298}=7.24$ *e.u.* (*83*)
T.P.$=1{,}150°$ K. (*82*)
$\Delta H_T=950$ calories per atom
M.P.$=1{,}998°$ K. (*94*)
$\Delta H_M=4{,}500$ calories per atom
B.P.$=3{,}550°$ K. (*7*)
$\Delta H_V=101{,}000$ calories per atom

Zone I (α) (298°–1,150° K.)

$$C_p=5.25+2.52\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-1{,}677+5.25T+1.26\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}677-5.25T\ln T-1.26\times10^{-3}T^2+28.66T$$

Zone II (β) (1,150°–1,988° K.)

$$C_p=7.50 \text{ (82)}$$
$$H_T-H_{298}=-1{,}650+7.50T$$
$$F_T-H_{298}=-1{,}650-7.50T\ln T+43.1T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		7.24	7.24
400	625	9.04	7.50
500	1,250	10.44	7.90
600	1,920	11.66	8.47
700	2,610	12.72	9.07
800	3,330	13.68	9.56
900	4,070	14.55	10.03
1,000	4,840	15.36	10.52
1,100	5,630	16.11	10.99
1,200	7,350	17.62	11.51
1,300	8,100	18.22	12.00
1,400	8,850	18.77	12.40
1,500	9,600	19.29	12.84
1,600	10,350	19.70	13.22
1,700	11,100	20.15	13.59
1,800	11,850	20.5	13.92
1,900	12,590	20.95	14.32
2,000	17,850	23.65	14.72

Titanium Oxide, TiO (*c*)

$\Delta H^\circ_{298}=-123{,}900$ calories per mole (*68*)
$S_{298}=8.31$ *e.u.* (*83*)
T.P.$=1{,}264°$ K. (*82*)
$\Delta H_T=820$ calories per mole
M.P.$=2{,}293°$ K. (*94*)
$\Delta H_M=14{,}000$ calories per mole

Zone I (*c*) (298°–1,264° K.)

$$C_p=10.57+3.60\times10^{-3}T-1.86\times10^5T^{-2} \text{ (82)}$$
$$H_T-H_{298}=-3{,}935+10.57T+1.80\times10^{-3}T^2+1.86\times10^5T^{-1}$$

Zone II (*l*) (1,264°–2,000° K.)

$$C_p=11.85+3.00\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-4{,}100+11.85T+1.50\times10^{-3}T^2$$

Formation: $Ti+1/2O_2\longrightarrow TiO$

Zone I (298°–1,150° K.)

$$\Delta C_p=1.74+0.58\times10^{-3}T-1.66\times10^5T^{-2}$$
$$\Delta H_T=-125{,}000+1.74T+0.29\times10^{-3}T^2+1.66\times10^5T^{-1}$$
$$\Delta F_T=-125{,}000-1.74T\ln T-0.29\times10^{-3}T^2+0.83\times10^5T^{-1}+36.12T$$

Zone II (1,150°–1,264° K.)

$$\Delta C_p=-0.51+3.10\times10^{-3}T-1.66\times10^5T^{-2}$$
$$\Delta H_T=-125{,}050-0.51T+1.55\times10^{-3}T^2+1.66\times10^5T^{-1}$$
$$\Delta F_T=-125{,}050+0.51T\ln T-1.55\times10^{-3}T^2+0.83\times10^5T^{-1}+21.80T$$

Zone III (1,264°–1,800° K.)

$$\Delta C_p=0.77+2.50\times10^{-3}T+0.20\times10^5T^{-2}$$
$$\Delta H_T=-125{,}245+0.77T+1.25\times10^{-3}T^2-0.20\times10^5T^{-1}$$
$$\Delta F_T=-125{,}245-0.77T\ln T-1.25\times10^{-3}T^2-0.10\times10^5T^{-1}+30.8T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		8.31	−123,900	−116,900
400	1,080	11.42	−123,800	−113,550
500	2,220	13.96	−123,650	−112,250
600	3,410	16.13	−123,500	−110,000
700	4,640	18.02	−123,350	−107,700
800	5,910	19.72	−123,200	−105,500
900	7,240	21.27	−123,050	−103,300
1,000	8,600	22.71	−122,850	−101,100
1,100	10,020	24.06	−122,600	−98,900
1,200	11,490	25.34	−123,300	−96,700
1,300	13,840	27.21	−122,100	−94,500
1,400	15,430	28.39	−121,700	−92,500
1,500	17,050	29.51	−121,300	−90,350
1,600	18,700	30.57	−120,750	−88,350
1,700	20,380	31.59	−120,300	−86,400
1,800	22,090	32.57	−119,750	−84,750

Dititanium Trioxide, Ti_2O_3 (*c*)

$\Delta H^\circ_{298}=-362{,}900$ calories per mole (*68*)
$S_{298}=18.83$ *e.u.* (*83*)
T.P.$=473°$ K. (*82*)
$\Delta H_T=215$ calories per mole
M.P.$=2{,}400°$ K. (*8*)
$\Delta H_M=38{,}400$ calories per mole

Zone I (α) (298°–473° K.)

$$C_p=7.31+53.52\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-4{,}558+7.31T+26.76\times10^{-3}T^2$$

Zone II (β) (473°–1,800° K.)

$$C_p=34.68+1.30\times10^{-3}T-10.20\times10^5T^{-2} \text{ (82)}$$
$$H_T-H_{298}=-13{,}605+34.68T+0.65\times10^{-3}T^2+10.20\times10^5T^{-1}$$

Formation: $2Ti+3/2O_2\longrightarrow Ti_2O_3$

Zone I (298°–473° K.)

$$\Delta C_p=-13.93+46.98\times10^{-3}T+0.60\times10^5T^{-2}$$
$$\Delta H_T=-360{,}630-13.93T+23.49\times10^{-3}T^2-0.60\times10^5T^{-1}$$
$$\Delta F_T=-360{,}630+13.93T\ln T-23.49\times10^{-3}T^2-0.30\times10^5T^{-1}-17.41T$$

Zone II (473°–1,150° K.)

$$\Delta C_p=13.44-5.24\times10^{-3}T-9.60\times10^5T^{-2}$$
$$\Delta H_T=-369{,}620+13.44T-2.62\times10^{-3}T^2+9.60\times10^5T^{-1}$$
$$\Delta F_T=-369{,}620-13.44T\ln T+2.62\times10^{-3}T^2+4.80\times10^5T^{-1}+163.11T$$

Zone III (1,150°–1,800° K.)

$$\Delta C_p=8.94-0.2\times10^{-3}T-9.60\times10^5T^{-2}$$
$$\Delta H_T=-369{,}730+8.94T-0.10\times10^{-3}T^2+9.60\times10^5T^{-1}$$
$$\Delta F_T=-369{,}730-8.94T\ln T+0.10\times10^{-3}T^2+4.80\times10^5T^{-1}+133.85T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		18.83	−362,900	−344,000
400	2,610	26.32	−362,600	−335,200
500	5,940	33.70	−361,600	−328,250
600	9,140	39.54	−360,900	−322,000
700	12,440	44.62	−360,150	−315,550
800	15,930	49.14	−359,400	−309,300
900	19,270	53.19	−358,650	−303,050
1,000	22,740	56.85	−358,000	−297,800
1,100	26,260	60.21	−357,200	−290,600
1,200	29,800	63.29	−358,350	−284,350
1,300	33,360	66.13	−357,550	−278,550
1,400	36,950	68.79	−356,700	−272,300
1,500	40,560	71.29	−356,050	−266,450
1,600	44,180	73.62	−355,100	−260,600
1,700	47,830	75.83	−354,300	−254,750
1,800	51,490	77.93	−353,450	−249,450

Trititanium Pentaoxide, Ti_3O_5 (*c*)

$\Delta H_{298}^\circ = -587{,}000$ calories per mole (*68*)
$S_{298} = 30.9$ *e.u.* (*83*)
$T.P. = 405°$ K. (*82*)
$\Delta H_T = 2{,}240$ calories per mole
$M.P. = >2{,}500°$ K. (*42*)

Zone I (α) (298°–405° K.)

$$C_p = 35.47 + 29.50\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -11{,}887 + 35.47T + 14.75\times10^{-3}T^2$$

Zone II (β) (405°–1, 400° K.)

$$C_p = 41.60 + 8.00\times10^{-3}T \text{ (82)}$$
$$H_T - H_{298} = -10{,}230 + 41.60T + 4.00\times10^{-3}T^2$$

Formation: $3Ti + 5/2O_2 \longrightarrow Ti_3O_5$

Zone I (298°–450° K.)

$$\Delta C_p = 1.82 + 19.44\times10^{-3}T + 1.0\times10^{5}T^{-2}$$
$$\Delta H_T = -588{,}070 + 1.82T + 9.72\times10^{-3}T^2 - 1.0\times10^{5}T^{-1}$$
$$\Delta F_T = -588{,}070 - 1.82T\ln T - 9.72\times10^{-3}T^2 - 0.50\times10^{5}T^{-1} + 130.7T$$

Zone II (450°–1, 150° K.)

$$\Delta C_p = 7.95 - 2.06\times10^{-3}T + 1.0\times10^{5}T^{-2}$$
$$\Delta H_T = -586{,}330 + 7.95T - 1.03\times10^{-3}T^2 - 1.0\times10^{5}T^{-1}$$
$$\Delta F_T = -586{,}330 - 7.95T\ln T + 1.03\times10^{-3}T^2 - 0.50\times10^{5}T^{-1} + 159.57T$$

Zone III (1, 150°–1, 400° K.)

$$\Delta C_p = 1.20 + 5.50\times10^{-3}T + 1.0\times10^{5}T^{-2}$$
$$\Delta H_T = -586{,}460 + 1.20T + 2.75\times10^{-3}T^2 - 1.0\times10^{5}T^{-1}$$
$$\Delta F_T = -586{,}460 - 1.20T\ln T - 2.75\times10^{-3}T^2 - 0.50\times10^{5}T^{-1} + 116.2T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		30.9	−587,000	−553,200
400	4,660	44.33	−586,000	−541,900
500	11,570	59.75	−582,800	−531,100
600	16,220	68.22	−582,050	−520,650
700	20,880	75,40	−581,400	−510,700
800	25,550	81.64	−580,900	−500,700
900	30,290	87.21	−580,400	−491,600
1,000	35,030	92.42	−580,050	−480,900
1,100	40,270	97.42	−579,150	−471,050
1,200	45,510	101.79	−581,150	−460,850
1,300	50,660	105.91	−580,300	−450,500
1,400	55,810	109.73	−579,550	−440,750

Titanium Dioxide (Rutile), TiO_2 (*c*)

$\Delta H_{298}^\circ = -225{,}600$ calories per mole (*68*)
$S_{298} = 12.01$ *e.u.* (*83*)
$M.P. = 2{,}123°$ K. (*94*)
$\Delta H_M = 15{,}500$ calories per mole
$B.P. = 3{,}273°$ K. (*94*)

Zone I (*c*) (298°–1,800° K.)

$$C_p = 17.97 + 0.28\times10^{-3}T - 4.35\times10^{5}T^{-2} \text{ (83)}$$
$$H_T - H_{298} = -6{,}829 + 17.97T + 0.14\times10^{-3}T^2 + 4.35\times10^{5}T^{-1}$$

Formation: $Ti + O_2 \longrightarrow TiO_2$

Zone I (298°–1,150° K.)

$$\Delta C_p = 5.56 - 3.24\times10^{-3}T - 3.95\times10^{5}T^{-2}$$
$$\Delta H_T = -228{,}520 + 5.56T - 1.62\times10^{-3}T^2 + 3.95\times10^{5}T^{-1}$$
$$\Delta F_T = -228{,}520 - 5.56T\ln T + 1.62\times10^{-3}T^2 + 1.97\times10^{5}T^{-1} + 82.64T$$

Zone II (1,150°–1,800° K.)

$$\Delta C_p = 3.31 - 0.72\times10^{-3}T - 3.95\times10^{5}T^{-2}$$
$$\Delta H_T = -228{,}570 + 3.31T - 0.36\times10^{-3}T^2 + 3.95\times10^{5}T^{-1}$$
$$\Delta F_T = -228{,}570 - 3.31T\ln T + 0.36\times10^{-3}T^2 + 1.95\times10^{5}T^{-1} + 68.47T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		12.01	−225,600	−212,400
400	1,540	16,44	−225,400	−207,900
500	3,100	19.92	−225,200	−203,600
600	4,735	22.90	−225,000	−199,300
700	6,440	25.52	−224,750	−194,950
800	8,160	27.82	−224,550	−190,750
900	9,900	29.87	−224,350	−186,550
1,000	11,650	31.71	−224,200	−182,350
1,100	13,420	33.40	−224,000	−178,000
1,200	15,200	34.95	−224,800	−173,890
1,300	17,000	36.39	−224,550	−169,550
1,400	18,820	37.74	−224,350	−165,450
1,500	20,660	39.01	−224,200	−161,200
1,600	22,540	40.22	−223,850	−157,250
1,700	24,340	41.37	−223,600	−153,100
1,800	26,340	42.46	−223,350	−149,350

Titanium Difluoride, TiF_2 (*c*)

$\Delta H_{298}^\circ = (-198{,}000)$ calories per mole (*11*)
$S_{298} = (18)$ *e.u.* (*11*)

Formation: $Ti + F_2 \longrightarrow TiF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−198,000)	(−187,000)
500	(4,000)	(−197,000)	(−179,000)
1,000	(14,000)	(−195,000)	(−160,000)
1,500	(25,000)	(−193,000)	(−142,000)

Titanium Trifluoride, TiF_3 (*c*)

$\Delta H_{298}^\circ = (-315{,}000)$ calories per mole (*11*)
$S_{298} = (28)$ *e.u.* (*11*)
$M.P. = (1{,}500°)$ K. (*6*)
$\Delta H_M = (12{,}000)$ calories per mole
$B.P. = (1{,}700°)$ K. (*6*)
$\Delta H_V = (49{,}000)$ calories per mole

Formation: $Ti+3/2F_2 \longrightarrow TiF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−315,000)	(−299,500)
500	(4,000)	(−314,600)	(−289,000)
1,000	(17,000)	(−309,000)	(−262,000)
1,500	(32,000)	(−303,000)	(−237,000)

Titanium Dichloride, $TiCl_2$ (*c*)

$\Delta H_{298}^\circ = -123{,}700$ calories per mole (*86*)
$S_{298} = (24.3)$ *e.u.* (*86*)

Formation: $Ti+Cl_2 \longrightarrow TiCl_2$
(estimated (*86*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−123,000	(−112,150)
400	(1,790)	(−122,700)	(−108,500)
500	(3,600)	(−122,350)	(−105,000)
600	(5,450)	(−122,050)	(−101,550)
700	(7,340)	(−121,700)	(−98,200)
800	(9,280)	(−121,400)	(−94,850)
900	(11,270)	(−121,000)	(−91,550)
1,000	(13,300)	(−120,650)	(−88,300)
1,100	(15,380)	(−120,050)	(−85,100)
1,200	(17,500)	(−120,750)	(−81,850)

Titanium Trichloride, $TiCl_3$ (*c*)

$\Delta H_{298}^\circ = -172{,}000$ calories per mole (*86*)
$S_{298} = (33.4)$ *e.u.* (*86*)
Disproportionates (1,200°) K. (*6*)

Formation: $Ti+3/2Cl_2 \longrightarrow TiCl_3$
(estimated (*86*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−172,000	(−155,950)
400	(2,320)	(−171,550)	(−150,500)
500	(4,660)	(−171,150)	(−145,300)
600	(7,070)	(−170,700)	(−140,150)
700	(9,560)	(−170,200)	(−135,100)
800	(12,110)	(−169,700)	(−130,150)
900	(14,740)	(−169,150)	(−125,200)
1,000	(17,430)	(−168,600)	(−120,350)
1,100	(20,190)	(−167,950)	(−115,600)
1,200	(23,030)	(−168,200)	(−110,750)

Titanium Tetrachloride, $TiCl_4$ (*l*)

$\Delta H_{298}^\circ = -192{,}100$ calories per mole (*86*)
$S_{298} = 59.50$ *e.u.* (*86*)
$M.P. = 250°$ K. (*6*)
$\Delta H_M = 2{,}240$ calories per mole
$B.P. = 409°$ K. (*6*)
$\Delta H_V = 8{,}346$ calories per mole

Zone I (*g*) (409°–2,000° K.)

$$C_p = 25.45 + 0.24\times10^{-3}T - 2.36\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -8{,}390 + 25.45T + 0.12\times10^{-3}T^2 + 2.36\times10^{5}T^{-1}$$

Formation: $Ti+2Cl_2 \longrightarrow TiCl_4$

Zone I (298°–409° K.)

Zone II (409°–1,150° K.)

$$\Delta C_p = 2.56 - 2.4\times10^{-3}T - 1.0\times10^{5}T^{-2}$$
$$\Delta H_T = -183{,}300 + 2.56T - 1.2\times10^{-3}T^2 + 1.0\times10^{5}T^{-1}$$
$$\Delta F_T = -183{,}300 - 2.56T\ln T + 1.2\times10^{-3}T^2 + 0.5\times10^{5}T^{-1} + 46.78T$$

Zone III (1,150°–1,900° K.)

$$\Delta C_p = 0.31 + 0.12\times10^{-3}T - 1.0\times10^{5}T^{-2}$$
$$\Delta H_T = -183{,}300 + 0.31T + 0.06\times10^{-3}T^2 + 1.0\times10^{5}T^{-1}$$
$$\Delta F_T = -183{,}300 - 0.31T\ln T - 0.06\times10^{-3}T^2 + 0.5\times10^{5}T^{-1} + 32.41T$$

(estimated (86))

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		59.50	−192,100	−175,900
400	3,820	70.52	−190,600	−170,550
500	14,670	96.94	−182,100	−167,450
600	17,150	101.16	−181,950	−164,500
700	19,655	105.02	−181,900	−161,600
800	22,180	108.39	−181,850	−158,700
900	24,720	111.38	−181,800	−155,850
1,000	27,265	114.06	−181,800	−152,950
1,100	29,805	116.49	−181,750	−150,050
1,200	32,375	118.72	−182,750	−147,100
1,300	34,915	120.77	−182,750	−144,150
1,400	37,505	122.67	−182,650	−141,150
1,500	40,150	124.44	−182,600	−138,150
1,600	42,640	126.10	−182,600	−135,200
1,700	45,200	127.66	−182,600	−132,250
1,800	47,785	129.13	−182,600	−129,250
1,900	50,360	130.52	−182,600	−126,250

Titanium Dibromide, $TiBr_2$ (*c*)

$\Delta H_{298}^\circ = (-95{,}000)$ calories per mole (*11*)
$S_{298} = (30)$ *e.u.* (*11*)
$M.P. = (900°)$ K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = (1{,}500°)$ K. (*6*)
$\Delta H_V = (33{,}000)$ calories per mole

Formation: $Ti+Br_2 \longrightarrow TiBr_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−95,000)	(−91,000)
500	(4,000)	(−102,000)	(−84,000)
1,000	(21,000)	(−93,000)	(−65,000)
1,500	(33,000)	(−90,000)	(−53,000)

Titanium Tribromide, $TiBr_3$ (*c*)

$\Delta H_{298}^\circ = (-132{,}000)$ calories per mole (*11*)
$S_{298} = (43)$ *e.u.* (*11*)
Disproportionates (1,200°) K. (*6*)

Formation: $Ti+3/2Br_2 \longrightarrow TiBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−132,000)	(−126,500)
500	(5,000)	(−142,500)	(−117,000)
1,000	(19,000)	(−139,000)	(−91,000)

Titanium Tetrabromide, $TiBr_4$ (*c*)

$\Delta H^\circ_{298} = -148{,}200$ calories per mole (*86*)
$S_{298} = 58.0$ *e.u.* (*86*)
$M.P. = 311°$ K. (*6*)
$\Delta H_M = 2{,}060$ calories per mole
$B.P. = 503°$ K. (*6*)
$\Delta H_V = (11{,}000)$ calories per mole

Formation: $Ti + 2Br_2 \longrightarrow TiBr_4$
(estimated (*86*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−148,200	−142,000
500	(11,000)	(−159,000)	(−132,000)

Titanium Diiodide, TiI_2 (*c*)

$\Delta H^\circ_{298} = (-61{,}100)$ calories per mole (*11*)
$S_{298} = (33)$ *e.u.* (*11*)
$M.P. = (900°)$ K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = (1{,}300°)$ K. (*6*)
$\Delta H_V = (27{,}000)$ calories per mole

Formation: $Ti + I_2 \longrightarrow TiI_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−61,100)	(−60,500)
500	(4,000)	(−75,000)	(−57,000)
1,000	(21,000)	(−66,000)	(−39,000)
1,500	(60,000)	(−36,000)	(−25,000)

Titanium Triiodide, TiI_3 (*c*)

$\Delta H^\circ_{298} = (-80{,}000)$ calories per mole (*11*)
$S_{298} = (47)$ *e.u.* (*11*)
Disproportionates >1,200° K. (*6*)

Formation: $Ti + 3/2I_2 \longrightarrow TiI_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−80,000)	(−79,000)
500	(5,000)	(−102,000)	(−75,000)
1,000	(20,000)	(−97,500)	(−48,000)

Titanium Tetraiodide, TiI_4 (*c*)

$\Delta H^\circ_{298} = (-101{,}000)$ calories per mole (*11*)
$S_{298} = (64)$ *e.u.* (*11*)
$M.P. = 423°$ K. (*6*)
$\Delta H_M = (3{,}000)$ calories per mole
$B.P. = 650°$ K. (*6*)
$\Delta H_V = 13{,}500$ calories per mole

Formation: $Ti + 2I_2 \longrightarrow TiI_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−101,000)	(−101,000)
500	(11,000)	(−124,600)	(−89,500)

Titanium Carbide, TiC (*c*)

$\Delta H^\circ_{298} = -44{,}100$ calories per mole (*86*)
$S_{298} = 5.79$ *e.u.* (*88*)
$M.P. = 3{,}450°$ K. (*9*)

Zone I (*c*) (298°–1,800° K.)

$$C_p = 11.83 + 0.80 \times 10^{-3} T - 3.58 \times 10^5 T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}764 + 11.83T + 0.40 \times 10^{-3} T^2 + 3.58 \times 10^5 T^{-1}$$

Formation: $Ti + C \longrightarrow TiC$

Zone I (298°–1,150° K.)

$$\Delta C_p = 2.48 - 2.74 \times 10^{-3} T - 1.48 \times 10^5 T^{-2}$$
$$\Delta H_T = -45{,}100 + 2.48T - 1.37 \times 10^{-3} T^2 + 1.48 \times 10^5 T^{-1}$$
$$\Delta F_T = -45{,}100 - 2.48 T \ln T + 1.37 \times 10^{-3} T^2 + 0.74 \times 10^5 T^{-1} + 19.41T$$

Zone II (1,150°–1,800° K.)

$$\Delta C_p = 0.23 - 0.22 \times 10^{-3} T - 1.48 \times 10^5 T^{-2}$$
$$\Delta H_T = -45{,}200 + 0.23T - 0.11 \times 10^{-3} T^2 + 1.48 \times 10^5 T^{-1}$$
$$\Delta F_T = -45{,}200 - 0.23 T \ln T + 0.11 \times 10^{-3} T^2 + 0.74 \times 10^5 T^{-1} + 4.96T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		5.79	−44,100	−43,300
400	945	8.51	−44,050	−43,000
500	1,957	10.8	−43,950	−42,700
600	3,085	12.82	−43,900	−42,500
700	4,225	14.58	−43,850	−42,250
800	5,395	16.14	−43,850	−42,050
900	6,600	17.56	−43,900	−41,800
1,000	7,830	18.86	−43,900	−41,600
1,100	9,080	20.05	−43,950	−41,350
1,200	10,330	21.04	−44,950	−40,950
1,300	11,590	22.14	−45,000	−40,700
1,400	12,860	23.08	−45,000	−40,400
1,500	14,130	23.96	−45,050	−40,050
1,600	15,400	24.78	−45,100	−39,850
1,700	16.670	25.55	−45,150	−39,550
1,800	17,940	26.28	−45,150	−39,400

Titanium Nitride, TiN (*c*)

$\Delta H^\circ_{298} = -80{,}700$ calories per mole (*86*)
$S_{298} = 7.24$ *e.u.* (*83*)
$M.P. = 3{,}200°$ K. (*9*)

Zone I (*c*) (298°–1,800° K.)

$$C_p = 11.91 + 0.94\times10^{-3}T - 2.96\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}586 + 11.91T + 0.47\times10^{-3}T^2 + 2.96\times10^{5}T^{-1}$$

Formation: $Ti + 1/2N_2 \longrightarrow TiN$

Zone I (298°–1,150° K.)

$$\Delta C_p = 3.33 - 2.09\times10^{-3}T - 2.96\times10^{5}T^{-2}$$
$$\Delta H_T = -82{,}590 + 3.33T - 1.04\times10^{-3}T^2 + 2.96\times10^{5}T^{-1}$$
$$\Delta F_T = -82{,}590 - 3.33T\ln T + 1.04\times10^{-3}T^2 + 1.48\times10^{5}T^{-1} + 46.13T$$

Zone II (1,150°–1,800° K.)

$$\Delta C_p = 1.08 + 0.43\times10^{-3}T - 2.96\times10^{5}T^{-2}$$
$$\Delta H_T = -82{,}650 + 1.08T + 0.21\times10^{-3}T^2 + 2.96\times10^{5}T^{-1}$$
$$\Delta F_T = -82{,}650 - 1.08T\ln T - 0.21\times10^{-3}T^2 + 1.48\times10^{5}T^{-1} + 31.86T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		7.24	−80,700	−73,870
400	1,000	10.12	−80,700	−71,550
500	2,090	12.54	−80,600	−69,100
600	3,230	14.63	−80,450	−65,700
700	4,400	16.43	−80,350	−64,300
800	5,590	18.02	−80,250	−61,900
900	6,810	19.45	−80,150	−59,550
1,000	8,050	20.76	−80,050	−58,200
1,100	9,310	21.96	−80,000	−55,000
1,200	10,600	23.08	−80,800	−53,800
1,300	11,910	24.13	−80,650	−51,450
1,400	13,230	25.11	−80,450	−49,200
1,500	14,550	26.02	−80,350	−47,250
1,600	15,870	26.87	−80,150	−44,950
1,700	17,190	27.67	−80,000	−42,800
1,800	18,510	28.43	−79,850	−40,650

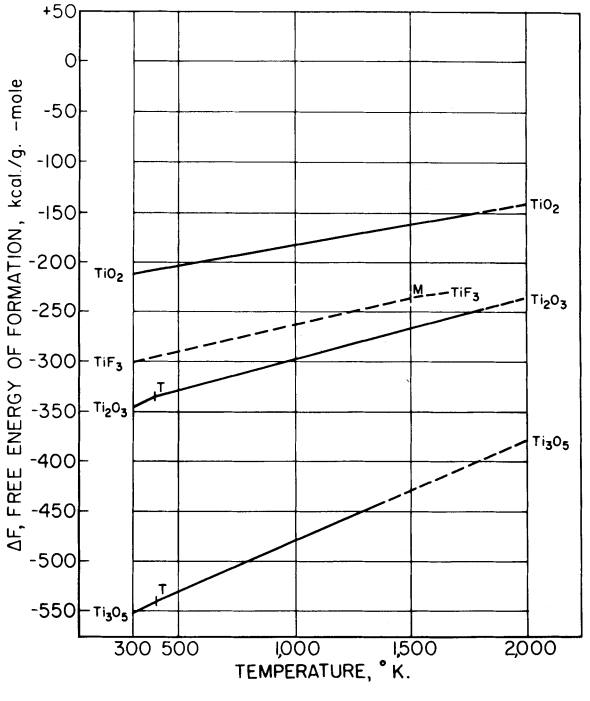

FIGURE 57.—Titanium (a).

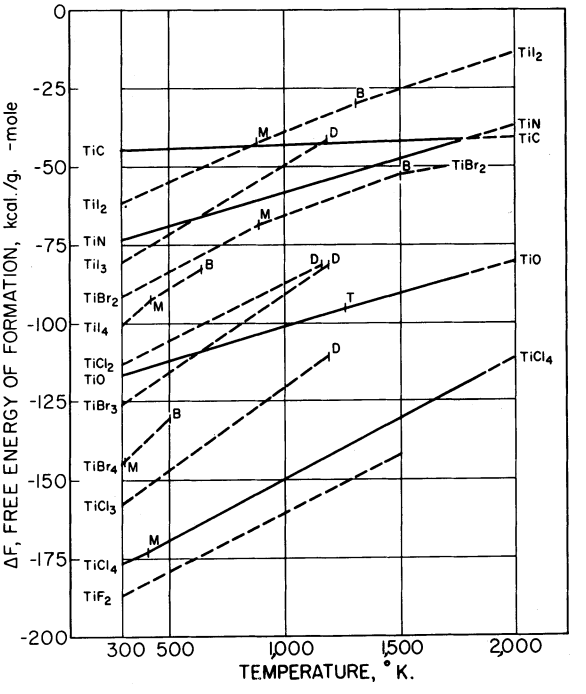

FIGURE 58.—Titanium (b).

TUNGSTEN AND ITS COMPOUNDS

Element, W (*c*)

$$S_{298} = 8.0 \pm 0.2 \text{ e.u. } (83)$$
$$M.P. = 3{,}650° \text{ K. } (7)$$
$$\Delta H_M = 8{,}420 \text{ calories per atom}$$
$$B.P. = 5{,}950° \text{ K. } (7)$$
$$\Delta H_V = 184{,}580 \text{ calories per atom}$$

Zone I (*c*) (298°–2,000° K.)

$$C_p = 5.74 + 0.76\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -1{,}745 + 5.74T + 0.38\times10^{-3}T^2$$
$$F_T - H_{298} = -1{,}745 - 5.74T\ln T - 0.38\times10^{-3}T^2 + 30.61T$$

T, ° K.	$H_T - H_{298}$	S_T	$-\frac{(F_T - H_{298})}{T}$
298		8.0	8.0
400	615	9.77	8.23
500	1,220	11.12	8.68
600	1,830	12.23	9.18
700	2,450	13.19	9.69
800	3,080	14.03	10.18
900	3,710	14.77	10.65
1,000	4,360	15.46	11.10
1,100	5,010	16.08	11.53
1,200	5,670	16.65	11.92
1,300	6,340	17.19	12.31
1,400	7,030	17.70	12.68
1,500	7,730	18.18	13.03
1,600	8,430	18.63	13.36
1,700	9,130	19.06	13.69
1,800	9,840	19.47	14.00
1,900	10,550	19.85	14.30
2,000	11,260	20.21	14.58

Tungsten Dioxide, WO_2 (*c*)

$\Delta H^\circ_{298} = (-137{,}000)$ calories per mole (*24*)
$S_{298} = (15.5)$ *e.u.* (*24*)
M.P. = 1,543° K. (*42*)
$\Delta H_M = 11{,}500$ calories per mole
Decomposes = 2,125° K. (*42*)

Formation: $W + O_2 \longrightarrow WO_2$
(estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−137,000)	(−124,600)
400	(1,440)	(−136,900)	(−120,400)
500	(2,775)	(−136,900)	(−116,300)
600	(4,240)	(−136,800)	(−112,100)
700	(5,640)	(−136,800)	(−108,000)
800	(7,170)	(−136,700)	(−103,900)
900	(8,710)	(−136,600)	(−99,800)
1,000	(10,200)	(−136,600)	(−95,800)
1,100	(11,720)	(−136,500)	(−91,700)
1,200	(13,210)	(−136,500)	(−87,600)
1,300	(14,810)	(−136,400)	(−83,500)
1,400	(16,450)	(−136,300)	(−79,500)
1,500	(18,100)	(−136,300)	(−75,400)

Tungsten Trioxide, WO_3 (*c*)

$\Delta H^\circ_{298} = -200{,}850$ calories per mole (*65*)
$S_{298} = 19.9$ *e.u.* (*83*)
M.P. = 1,743° K. (*24*)
$\Delta H_M = 13{,}940$ calories per mole
B.P. = >2,500° K. (*42*)

Formation: $W + 3/2O_2 \longrightarrow WO_3$
(estimated (*24*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−200,850	−182,450
400	(3,000)	(−197,850)	(−176,250)
500	(4,050)	(−196,800)	(−170,200)
600	(6,150)	(−194,700)	(−164,200)
700	(8,750)	(−192,100)	(−158,300)
800	(10,450)	(−190,400)	(−152,450)
900	(12,800)	(−188,050)	(−146,650)
1,000	(15,200)	(−185,650)	(−140,900)
1,100	(17,500)	(−183,350)	(−135,200)
1,200	(20,000)	(−180,850)	(−129,550)
1,300	(22,500)	(−178,350)	(−123,900)
1,400	(25,050)	(−175,800)	(−118,350)
1,500	(27,850)	(−173,000)	(−112,850)
1,600	(30,400)	(−170,450)	(−107,400)
1,700	(33,200)	(−167,650)	(−101,950)
1,800	(48,100)	(−152,750)	(−97,050)
1,900	(53,300)	(−147,550)	(−92,500)
2,000	(56,700)	(−144,150)	(−88,050)

Tungsten Dichloride, WCl_2 (*c*)

$\Delta H^\circ_{298} = (-36{,}000)$ calories per mole (*11*)
$S_{298} = (31)$ *e.u.* (*11*)

Formation: $W + Cl_2 \longrightarrow WCl_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−36,000)	(−27,000)
500	(4,000)	(−35,000)	(−21,000)
1,000	(15,000)	(−31,000)	(−9,000)

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Tungsten Tetrachloride, WCl_4 (*c*)

$\Delta H^\circ_{298} = (-69{,}000)$ calories per mole (*11*)
$S_{298} = (50)$ *e.u.* (*11*)
M.P. = (600°) K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (605°) K. (*6*)
$\Delta H_V = (17{,}000)$ calories per mole

Formation: $W + 2Cl_2 \longrightarrow WCl_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−69,000)	(−50,000)
500	(6,000)	(−68,000)	(−37,000)
1,000	(41,000)	(−44,000)	(−21,000)
1,500	(53,000)	(−44,000)	(−10,000)

Tungsten Pentachloride, WCl_5 (*c*)

$\Delta H^\circ_{298} = (-82{,}000)$ calories per mole (*11*)
$S_{298} = (66)$ *e.u.* (*11*)
M.P. = 517° K. (*6*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = 549° K. (*6*)
$\Delta H_V = (12{,}500)$ calories per mole

Formation: $W + 5/2Cl_2 \longrightarrow WCl_5$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−82,000)	(−60,000)
500	(7,000)	(−80,000)	(−45,000)
1,000	(44,000)	(−57,000)	(−30,000)
1,500	(59,000)	(−57,000)	(−17,000)

Tungsten Hexachloride, WCl_6 (*c*)

$\Delta H^\circ_{298} = (-96{,}900)$ calories per mole (*11*)
$S_{298} = (75)$ *e.u.* (*11*)
M.P. = 548° K. (*6*)
$\Delta H_M = (5{,}700)$ calories per mole
B.P. = 610° K. (*6*)
$\Delta H_V = (15{,}200)$ calories per mole

Formation: $W + 3Cl_2 \longrightarrow WCl_6$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−96,900)	(−74,000)
500	(9,000)	(−94,000)	(−50,600)
1,000	(50,000)	(−69,000)	(−24,000)
1,500	(67,000)	(−69,000)	(−2,000)

Tungsten Dibromide, WBr_2 (*c*)

$\Delta H^\circ_{298} = (-18{,}700)$ calories per mole (*11*)
$S_{298} = (36)$ *e.u.* (*11*)
M.P. = (1,000°) K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (1,500°) K. (*6*)
$\Delta H_V = (33{,}000)$ calories per mole

Formation: $W+Br_2 \longrightarrow WBr_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−18, 700)	(−16, 000)
500	(4, 000)	(−25, 000)	(−11, 000)
1,000	(16, 000)	(−21, 000)	(+1, 000)
1,500	(68, 000)	(+23, 000)	(+8, 000)

Tungsten Tetrabromide, WBr_4 (*c*)

$\Delta H_{298}^\circ = (-35{,}000)$ calories per mole (*11*)
$S_{298} = (59)$ *e.u.* (*11*)
S.P. = (600°) K. (*6*)
$\Delta H_{subl} = (24{,}000)$ calories per mole

Formation: $W+2Br_2 \longrightarrow WBr_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−35, 000)	(−28, 500)
500	(5, 000)	(−50, 000)	(−18, 000)
1,000	(42, 000)	(−25, 000)	(−5, 000)
1,500	(55, 000)	(−25, 000)	(+4, 000)
2,000			(+14, 000)

Tungsten Pentabromide, WBr_5 (*c*)

$\Delta H_{298}^\circ = (42{,}000)$ calories per mole (*11*)
$S_{298} = (78)$ *e.u.* (*11*)
M.P. = 549° K. (*6*)
$\Delta H_M = (8{,}000)$ calories per mole
B.P. = 606° K. (*6*)
$\Delta H_V = (14{,}000)$ calories per mole

Formation: $W+5/2Br_2 \longrightarrow WBr_5$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−42, 000)	(−35, 000)
500	(7, 000)	(−60, 000)	(−29, 000)
1,000	(43, 000)	(−38, 000)	(1, 000)
1,500	(58, 000)	(−38, 000)	(19, 000)

Tungsten Hexabromide, WBr_6 (*c*)

$\Delta H_{298}^\circ = (-44{,}000)$ calories per mole (*11*)
$S_{298} = (89)$ *e.u.* (*11*)

Formation: $W+3Br_2 \longrightarrow WBr_6$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−44, 000)	(−36, 000)
500	(35, 000)	(−39, 000)	(−14, 000)
1,000	(51, 000)	(−39, 000)	(+11, 000)

Tungsten Diiodide, WI_2 (*c*)

$\Delta H_{298}^\circ = (-1{,}000)$ calories per mole (*11*)
$S_{298} = (38)$ *e.u.* (*11*)
M.P. = (1,000°) K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (1,260°) K. (*6*)
$\Delta H_V = (27{,}000)$ calories per mole

Formation: $W+I_2 \longrightarrow WI_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔH_T°
298		(−1, 000)	(−1, 500)
500	(4, 000)	(−15, 000)	(0)
1,000	(17, 000)	(−11, 000)	(+13, 000)
1,500	(59, 000)	(+25, 000)	(+16, 000)

Tungsten Tetraiodide, WI_4 (*c*)

$\Delta H_{298}^\circ = (-500)$ calories per mole (*11*)
$S_{298} = (65)$ *e.u.* (*11*)
S.P. = (690°) K. (*6*)
$\Delta H_{subl} = (20{,}000)$ calories per mole

Formation: $W+2I_2 \longrightarrow WI_4$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−500)	(−500)
500	(6, 000)	(−29, 000)	(+3, 000)
1,000	(47, 000)	(0)	(+26, 000)
1,500	(59, 000)	(0)	(+39, 000)

Tungsten Carbide, WC (*c*)

$\Delta H_{298} = -9{,}100$ calories per mole (*112*)
$S_{298} = 8.5$ *e.u.* (*94*)
Decomposes = 2,900° K. (*9*)

Zone I (*c*) (298°–2,000° K.)

$$C_p = 7.98 + 2.17\times10^{-3}T$$
$$H_T - H_{298} = -2{,}470 + 7.98T + 1.08\times10^{-3}T^2$$

Formation: $W+C \longrightarrow WC$

Zone I (298°–2,000° K.)

$$\Delta C_p = -1.86 + 0.39\times10^{-3}T + 2.10\times10^{5}T^{-2}$$
$$\Delta H_T = -7{,}860 - 1.86T + 0.20\times10^{-3}T^2 - 2.10\times10^{5}T^{-1}$$
$$\Delta F_T = -7{,}860 + 1.86T\ln T - 0.20\times10^{-3}T^2 - 1.05\times10^{5}T^{-1} - 12.63T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		8. 5	−9, 100	−8, 800
400	920	11. 12	−9, 050	−8, 800
500	1, 810	13. 14	−9, 080	−8, 700
600	2, 730	15. 75	−9, 150	−8, 600
700	3, 670	16. 12	−9, 250	−8, 500
800	4, 630	17. 49	−9, 380	−8, 400
900	5, 610	18. 61	−9, 510	−8, 200
1,000	6, 610	19. 72	−9, 660	−8, 000
1,100	7, 650	20. 64	−9, 780	−7, 800
1,200	8, 690	21. 66	−9, 930	−7, 600
1,300	9, 760	22. 37	−10, 070	−7, 400
1,400	10, 850	23. 29	−10, 210	−7, 300
1,500	11, 970	24. 01	−10, 340	−7, 100
1,600	13, 100	24. 83	−10, 470	−7, 000
1,700	14, 260	25. 55	−10, 580	−6, 800
1,800	15, 440	26. 16	−10, 690	−6, 500
1,900	16, 630	26. 78	−10, 800	−6, 200
2,000	17, 830	27. 40	−10, 910	−6, 000

Ditungsten Nitride, W_2N (*c*)

$\Delta H_{298}^\circ = -17{,}000$ (*9*)
$S_{298} = (18.0)$ *e.u.* (*9*)
$\Delta F_{298}^\circ = (-11{,}000)$ calories per mole

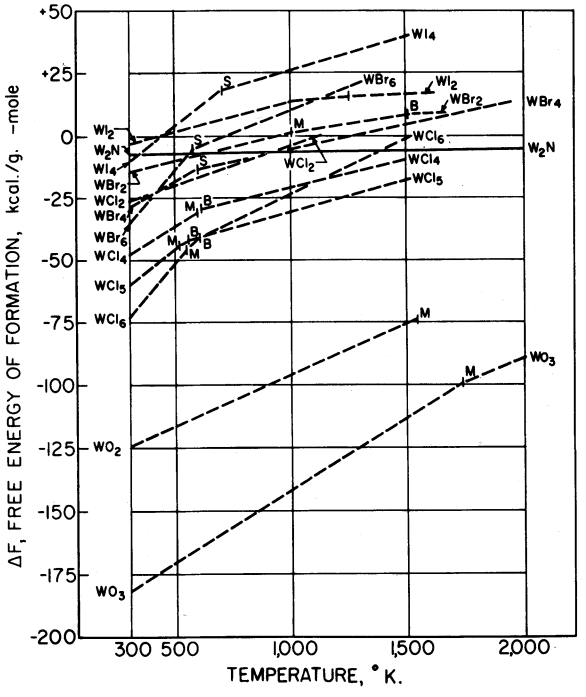

FIGURE 59.—Tungsten.

URANIUM AND ITS COMPOUNDS

Element, U (*c*)

$S_{298}=12.03$ *e.u.* (*77*)
T.P.$=935°$ K. (*82*)
$\Delta H_T=700$ calories per atom
T.P.$=1,045°$ K. (*82*)
$\Delta H_T=1,145$ calories per atom
M.P.$=1,405°$ K. (*24*)
$\Delta H_M=3,200$ calories per atom
B.P.$=3,800°$ K. (*8*)
$\Delta H_V=110,000$ calories per atom

Zone I (α) (298°–935° K.)

$$C_p=3.39+8.02\times10^{-3}T+0.70\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-1,132+3.39T+4.01\times10^{-3}T^{2}-0.70\times10^{5}T^{-1}$$
$$F_T-H_{298}=-1,132-3.39T\ln T-4.01\times10^{-3}T^{2}-0.35\times10^{5}T^{-1}+12.67T$$

Zone II (β) (935°–1,045° K.)

$$C_p=10.18\ (82)$$
$$H_T-H_{298}=-3,348+10.18T$$
$$F_T-H_{298}=-3,348-10.18T\ln T+57.69T$$

Zone III (γ) (1,045°–1,300° K.)

$$C_p=9.20\ (82)$$
$$H_T-H_{298}=-1,180+9.20T$$
$$F_T-H_{298}=-1,180-9.2T\ln T+48.76T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		12.03	12.03
400	690	14.02	12.29
500	1,430	15.67	12.81
600	2,230	17.12	13.40
700	3,100	18.47	14.04
800	4,050	19.74	14.68
900	5,090	20.96	15.30
1,000	6,830	22.81	15.98
1,100	8,940	24.84	16.71
1,200	9,860	25.64	17.42
1,300	10,780	26.37	18.08
1,500	(15,700)	(30.52)	(20.05)
2,000	(20,000)	(32.88)	(22.80)

Uranium Dioxide, UO_2 (*c*)

$\Delta H^{\circ}_{298}=-259,200$ calories per mole (*63*)
$S_{298}=18.63$ *e.u.* (*52*)
M.P.$=3,000°$ K. (*8*)

Zone I (*c*) (298°–1,500° K.)

$$C_p=19.20+1.62\times10^{-3}T-3.96\times10^{5}T^{-2}\ (82)$$
$$H_T-H_{298}=-7,125+19.20T+0.81\times10^{-3}T^{2}+3.96\times10^{5}T^{-1}$$

Formation: $U+O_2\longrightarrow UO_2$

Zone I (298°–935° K.)

$$\Delta C_p=8.65-7.4\times10^{-3}T-4.26\times10^{5}T^{-2}$$
$$\Delta H_T=-262,880+8.65T-3.7\times10^{-3}T^{2}+4.26\times10^{5}T^{-1}$$
$$\Delta F_T=-262,880-8.65T\ln T+3.7\times10^{-3}T^{2}+2.13\times10^{5}T^{-1}+100.55T$$

Zone II (935°–1,045° K.)

$$\Delta C_p=1.86+0.62\times10^{-3}T-3.56\times10^{5}T^{-2}$$
$$\Delta H_T=-260,700+1.86T+0.31\times10^{-3}T^{2}+3.56\times10^{5}T^{-1}$$
$$\Delta F_T=-260,700-1.86T\ln T-0.31\times10^{-3}T^{2}+1.78\times10^{5}T^{-1}+55.55T$$

Zone III (1,045°–1,300° K.)

$$\Delta C_p=2.84+0.62\times10^{-3}T-3.56\times10^{5}T^{-2}$$
$$\Delta H_T=-262,820+2.84T+0.31\times10^{-3}T^{2}+3.56\times10^{5}T^{-1}$$
$$\Delta F_T=-262,820-2.84T\ln T-0.31\times10^{-3}T^{2}+1.78\times10^{5}T^{-1}+64.45T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		18.63	−259,200	−246,550
400	1,680	23.47	−258,900	−242,300
500	3,470	27.46	−258,600	−238,100
600	5,340	30.86	−258,300	−234,100
700	7,280	33.85	−258,000	−230,100
800	9,250	36.48	−257,800	−226,100
900	11,250	38.86	−257,600	−222,100
1,000	13,280	40.97	−258,200	−218,100
1,100	15,340	42.94	−259,000	−214,000
1,200	17,420	44.75	−258,700	−210,000
1,300	19,510	46.42	−258,300	−205,900
1,400	21,620	47.98		
1,500	23,750	49.45	(−260,800)	(−196,700)

Triuranium Octaoxide, U_3O_8 (*c*)

$\Delta H^{\circ}_{298}=-853,500$ calories per mole (*52*)
$S_{298}=66$ *e.u.* (*52*)
Decomposes $=1,950°$ K. (*10*)

Formation: $3U+4O_2\longrightarrow U_3O_8$ (estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−853, 500	−804, 000
400	(5, 860)	(−852, 600)	(−787, 200)
500	(11, 910)	(−851, 700)	(−770, 900)
600	(18, 330)	(−850, 700)	(−754, 800)
700	(24, 860)	(−849, 900)	(−738, 900)
800	(31, 750)	(−849, 200)	(−723, 100)
900	(38, 380)	(−848, 800)	(−707, 400)
1,000	(45, 410)	(−850, 300)	(−691, 500)
1,100	(52, 150)	(−853, 000)	(−675, 500)
1,200	(59, 240)	(−852, 000)	(−659, 400)
1,300	(66, 330)	(−851, 000)	(−643, 400)
1,400	(73, 450)	(−850, 000)	(−627, 500)
1,500	(80, 530)	(−858, 800)	(−611, 000)

Uranium Trioxide, UO_3 (*c*)

$\Delta H_{298}^\circ = -291{,}600$ calories per mole (*52*)
$S_{298} = 23.57$ *e.u.* (*52*)
Decomposes = 925° K. (*10*)

Zone I (*c*) (298°–925° K.)

$C_p = 22.09 + 2.54\times10^{-3}T - 2.97\times10^{5}T^{-2}$ (*82*)
$H_T - H_{298} = -7{,}695 + 22.09T + 1.27\times10^{-3}T^2 + 2.97\times10^{5}T^{-1}$

Formation: $U + 3/2O_2 \longrightarrow UO_3$

Zone I (298°–925° K.)

$\Delta C_p = 7.96 - 6.98\times10^{-3}T - 3.07\times10^{5}T^{-2}$
$\Delta H_T = -294{,}690 + 7.96T - 3.49\times10^{-3}T^2 + 3.07\times10^{5}T^{-1}$
$\Delta F_T = -294{,}690 - 7.96T\ln T + 3.49\times10^{-3}T^2 + 1.53\times10^{5}T^{-1} + 114.92T$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		23. 57	−291, 600	−273, 200
400	2, 090	29. 59	−291, 300	−266, 800
500	4, 260	34. 43	−290, 950	−260, 800
600	6, 510	38. 53	−290, 650	−254, 800
700	8, 820	42. 09	−290, 350	−249, 800
800	11, 160	45. 21	−290, 150	−242, 900
900	13, 540	48. 01	−290, 050	−237, 000

Uranium Trifluoride, UF_3 (*c*)

$\Delta H_{298}^\circ = (-357{,}000)$ calories per mole (*10*)
$S_{298} = (26)$ *e.u.* (*10*)
$M.P. = (1{,}700°)$ K. (*10*)
$\Delta H_M = (8{,}500)$ calories per mole
$B.P. = (2{,}550°)$ K. (*10*)
$\Delta H_V = (61{,}000)$ calories per mole

Formation: $U + 3/2F_2 \longrightarrow UF_3$ (estimated (*10*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−357, 000)	(−339, 500)
500	(4, 000)	(−356, 800)	(−328, 000)
1,000	(17, 000)	(−355, 600)	(−299, 000)
1,500	(32, 000)	(−356, 000)	(−281, 000)

Uranium Tetrafluoride, UF_4 (*c*)

$\Delta H_{298}^\circ = (-443{,}000)$ calories per mole (*10*)
$S_{298} = 36.13$ *e.u.* (*10*)
$M.P. = 1{,}309°$ K. (*10*)
$\Delta H_M = 5{,}700$ calories per mole
$B.P. = 1{,}690°$ K. (*10*)
$\Delta H_V = 57{,}500$ calories per mole

Formation: $U + 2F_2 \longrightarrow UF_4$ (estimated (*10*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−443, 000)	(−421, 200)
500	(6, 300)	(−441, 300)	(−406, 500)
1,000	(25, 500)	(−436, 000)	(−375, 000)
1,500	(57, 000)	(−422, 200)	(−347, 000)

Uranium Pentafluoride, UF_5 (*c*)

$\Delta H_{298}^\circ = (-488{,}000)$ calories per mole (10)
$S_{298} = (43)$ *e.u.* (*10*)
$M.P. = (600°)$ K. (*10*)
$\Delta H_M = (8{,}000)$ calories per mole
$B.P. = (1{,}000°)$ K. (*10*)
$\Delta H_V = (23{,}000)$ calories per mole

Formation: $U + 5/2F_2 \longrightarrow UF_5$ (estimated (*10*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−488, 000)	(−461, 200)
500	(7, 000)	(−486, 400)	(−443, 500)

Uranium Hexafluoride, UF_6 (*c*)

$\Delta H_{298}^\circ = -517{,}000$ calories per mole (*52*)
$S_{298} = 54.45$ *e.u.* (*52*)
$S.P. = 337°$ K. (*101*)
$\Delta H_{subl} = 11{,}430$ calories per mole

Formation: $U + 3F_2 \longrightarrow UF_6$ (estimated (*10*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		−517, 000	−486, 300
500	(18, 600)	(−516, 000)	(−471, 750)
1,000		(−515, 400)	(−440, 200)

Uranyl Fluoride, UO_2F_2

$\Delta H_{298}^\circ = -64{,}500$ calories per mole (*140*)
$S_{298} = 32.4$ *e.u.* (*52*)
$\Delta F_{298}^\circ = -41{,}500$ calories per mole

Uranium Trichloride, UCl_3 (*c*)

$\Delta H^\circ_{298} = -213{,}000$ calories per mole (*52*)
$S_{298} = 37.99$ *e.u.* (*52*)
$M.P. = 1{,}108°$ K. (*10*)
$\Delta H_M = 9{,}000$ calories per mole
$B.P. = 2{,}000°$ K. (*10*)
$\Delta H_V = 41{,}000$ calories per mole

Zone I (*c*) (298°–1,000° K.)

$$C_p = 20.98 + 7.44\times10^{-3}T + 1.16\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -6{,}200 + 20.98T + 3.72\times10^{-3}T^2 - 1.16\times10^{5}T^{-1}$$

Formation: $U + 3/2Cl_2 \longrightarrow UCl_3$

Zone I (298°–935° K.)

$$\Delta C_p = 4.36 - 0.67\times10^{-3}T + 1.48\times10^{5}T^{-2}$$
$$\Delta H_T = -213{,}770 + 4.36T - 0.33\times10^{-3}T^2 - 1.48\times10^{5}T^{-1}$$
$$\Delta F_T = -213{,}770 - 4.36T\ln T + 0.33\times10^{-3}T^2 - 0.74\times10^{5}T^{-1} + 82.17T$$

Zone II (935°–1,045° K.)

$$\Delta C_p = -2.43 + 7.35\times10^{-3}T + 2.18\times10^{5}T^{-2}$$
$$\Delta H_T = -211{,}900 - 2.43T + 3.67\times10^{-3}T^2 - 2.18\times10^{5}T^{-1}$$
$$\Delta F_T = -211{,}900 + 2.43T\ln T - 3.67\times10^{-3}T^2 - 1.09\times10^{5}T^{-1} + 37.35T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		37.99	−213,000	−196,900
400	2,500	45.21	−212,450	−191,400
500	5,000	50.78	−212,000	−186,200
600	7,540	55.41	−211,500	−181,100
700	10,140	59.42	−211,100	−176,150
800	12,810	62.98	−210,700	−171,050
900	15,570	66.23	−210,300	−166,250
1,000	18,430	69.24	−210,900	−161,600
1,100	(21,280)		(−210,800)	(−156,200)

Uranium Tetrachloride, UCl_4 (*c*)

$\Delta H^\circ_{298} = -251{,}200$ calories per mole (*52*)
$S_{298} = 62$ *e.u.* (*52*)
$M.P. = 863°$ K. (*10*)
$\Delta H_M = 10{,}300$ calories per mole
$B.P. = 1{,}060°$ K. (*10*)
$\Delta H_V = 33{,}000$ calories per mole

Zone I (*c*) (298°–700° K.)

$$C_p = 26.64 + 9.60\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -8{,}370 + 26.64T + 4.80\times10^{-3}T^2$$

Formation: $U + 2Cl_2 \longrightarrow UCl_4$

Zone I (298°–700° K.)

$$\Delta C_p = 5.61 + 1.46\times10^{-3}T + 0.66\times10^{5}T^{-2}$$
$$\Delta H_T = -252{,}700 + 5.61T + 0.73\times10^{-3}T^2 - 0.66\times10^{5}T^{-1}$$
$$\Delta F_T = -252{,}700 - 5.61T\ln T - 0.73\times10^{-3}T^2 - 0.33\times10^{5}T^{-1} + 94.27T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		62.0	−251,200	−234,300
400	3,030	70.74	−250,550	−228,550
500	6,150	77.70	−249,850	−223,100
600	9,330	83.50	−249,200	−217,900
700	12,630	88.58	−248,500	−212,800

Uranium Pentachloride, UCl_5 (*c*)

$\Delta H^\circ_{298} = (-262{,}100)$ calories per mole (*10*)
$S_{298} = (62)$ *e.u.* (*10*)
$M.P. = 600°$ K. (*10*)
$\Delta H_M = 8{,}500$ calories per mole
$B.P. = 800°$ K. (*10*)
$\Delta H_V = (18{,}000)$ calories per mole

Formation: $U + 5/2Cl_2 \longrightarrow UCl_5$ (estimated (*10*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−262,100)	(−237,400)
500	(7,000)	(−260,700)	(−221,600)

Uranium Hexachloride, UCl_6 (*c*)

$\Delta H^\circ_{298} = (-272{,}400)$ calories per mole (*10*)
$S_{298} = 68.3$ *e.u.* (*10*)
$M.P. = 452°$ K. (*10*)
$\Delta H_M = (5{,}000)$ calories per mole
$B.P. = 550°$ K. (*10*)
$\Delta H_V = (11{,}000)$ calories per mole

Formation: $U + 3Cl_2 \longrightarrow UCl_6$ (estimated (*10*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−272,400)	(−241,500)
500	(14,000)	(−264,900)	(−221,400)

Uranium (IV) Oxychloride, $UOCl_2$

$\Delta H^\circ_{298} = -261{,}700$ calories per mole (*44*)
$S_{298} = 33.06$ *e u.* (*44*)
$\Delta F^\circ_{298} = -244{,}800$ calories per mole

Uranyl Chloride, UO_2Cl_2 (*c*)

$\Delta H^\circ_{298} = -300{,}000$ calories per mole (*45*)
$S_{298} = 35.98$ *e.u.* (*45*)
$\Delta F^\circ_{298} = -276{,}700$ calories per mole

Uranium Tribromide, UBr_3 (*c*)

$\Delta H^\circ_{298} = (-170{,}100)$ calories per mole (*10*)
$S_{298} = (49)$ *e.u.* (*10*)
$M.P. = 1{,}025°$ K. (*10*)
$\Delta H_M = 11{,}000$ calories per mole
$B.P. = (1{,}840°)$ K. (*10*)
$\Delta H_V = 45{,}000$ calories per mole

Formation: $U + 3/2Br_2 \longrightarrow UBr_3$ (estimated (*10*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−170,000)	(−164,900)
500	(5,000)	(−180,800)	(−155,500)
1,000	(18,000)	(−179,900)	(−133,000)
1,500	(43,000)	(−170,600)	(−112,000)

Uranium Tetrabromide, UBr_4 (*c*)

$\Delta H^\circ_{298} = (-196{,}600)$ calories per mole (*10*)
$S_{298} = (58)$ *e.u.* (*10*)
M.P. = 792° K. (*10*)
$\Delta H_M = 7{,}200$ calories per mole
B.P. = 1,039° K. (*10*)
$\Delta H_V = 31{,}000$ calories per mole

Formation: $U + 2Br_2 \longrightarrow UBr_4$ (estimated (*10*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−196,600)	(−188,600)
500	(6,000)	(−206,300)	(−175,800)
1,000	(34,300)	(−196,400)	(−146,500)

Uranium (IV) Oxybromide, $UOBr_2$

$\Delta H^\circ_{298} = -246{,}900$ calories per mole (*44*)
$S_{298} = 37.66$ *e.u.* (*44*)
$\Delta F^\circ_{298} = -236{,}400$ calories per mole

Uranium Triiodide, UI_3 (*c*)

$\Delta H^\circ_{298} = (-114{,}700)$ calories per mole (*10*)
$S_{298} = (56)$ *e.u.* (*10*)
M.P. = (1,030°) K. (*10*)
$\Delta H_M = (7{,}500)$ calories per mole
B.P. = (1,700°) K. (*10*)
$\Delta H_V = (40{,}800)$ calories per mole

Formation: $U + 3/2I_2 \longrightarrow UI_3$ (estimated (*10*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−114,700)	(−115,100)
500	(5,000)	(−136,100)	(−112,000)
1,000	(20,000)	(−133,200)	(−90,000)
1,500	(43,000)	(−103,600)	(−68,000)

Uranium Tetraiodide, UI_4 (*c*)

$\Delta H^\circ_{298} = (-127{,}000)$ calories per mole (*10*)
$S_{298} = (65)$ *e.u.* (*10*)
M.P. = 779° K. (*10*)
$\Delta H_M = 15{,}000$ calories per mole
B.P. = 1,032° K. (*10*)
$\Delta H_V = 30{,}700$ calories per mole

Formation: $U + 2I_2 \longrightarrow UI_4$ (estimated (*10*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−127,000)	(−125,900)
500	(6,000)	(−145,800)	(−121,000)
1,000	(34,000)	(−142,100)	(−93,500)

Uranium Carbide, UC (*c*)

$\Delta H^\circ_{298} = -43{,}000$ calories per mole (*10*)
$S_{298} = (15.4)$ *e.u.* (*10*)
$\Delta F^\circ_{298} = (-43{,}600)$ calories per mole
M.P. = 2,550° K. (*10*)

Diuranium Tricarbide, U_2C_3 (*c*)

$\Delta H^\circ_{298} = -76{,}000$ calories per mole (*10*)
$S_{298} = (24)$ *e.u.* (*10*)
$\Delta F^\circ_{298} = (-78{,}400)$ calories per mole
M.P. = 2,700° K. (*10*)

Uranium Dicarbide, UC_2 (*c*)

$\Delta H^\circ_{298} = -36{,}000$ calories per mole (*10*)
$S_{298} = (20)$ *e.u.* (*10*)
$\Delta F^\circ_{298} = (-37{,}500)$ calories per mole
M.P. = 2,700° K. (*10*)

Uranium Nitride, UN (*c*)

$\Delta H^\circ_{298} = -80{,}000$ calories per mole (*10*)
$S_{298} = (18.0)$ *e.u.* (*10*)
$\Delta F^\circ_{298} = (-74{,}900)$ calories per mole
M.P. = 2,900° K. (*10*)

Diuranium Trinitride, U_2N_3 (*c*)

$\Delta H^\circ_{298} = -213{,}000$ calories per mole (*10*)
$S_{298} = (29)$ *e.u.* (*10*)
$\Delta F^\circ_{298} = (-193{,}900)$ calories per mole

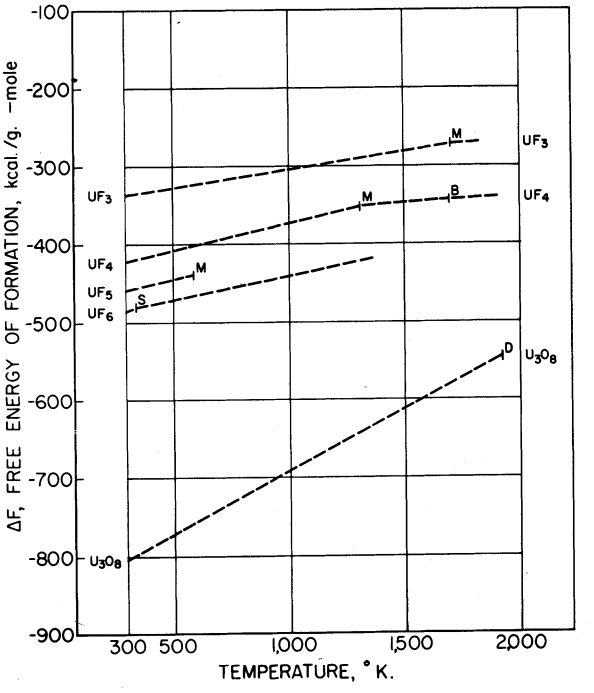

FIGURE 60.—Uranium (a).

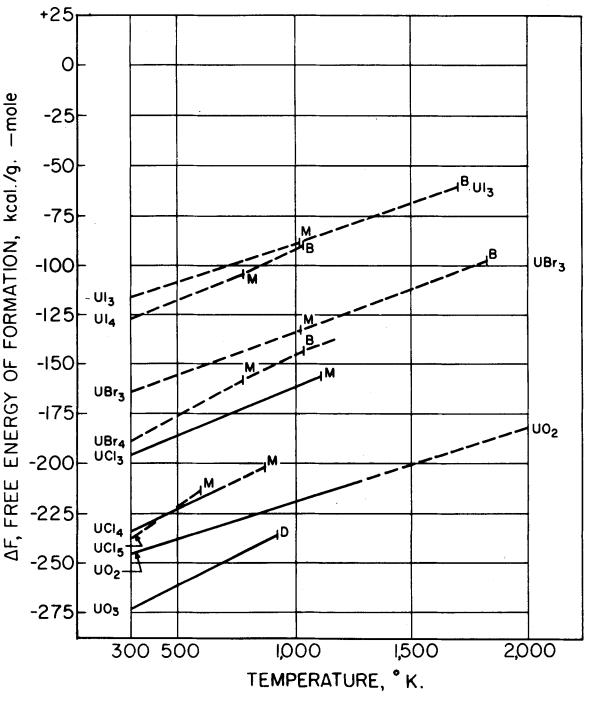

FIGURE 61.—Uranium (b).

VANADIUM AND ITS COMPOUNDS

Element, V (*c*)

$S_{298}=7.01$ *e.u.* (*83*)
$M.P.=2{,}190°$ K. (*130*)
$\Delta H_M=(4{,}200)$ calories per atom
$B.P.=3{,}650°$ K. (*130*)
$\Delta H_V=109{,}600$ calories per atom

Zone I (*c*) (298°–1,900° K.)

$$C_p=5.40+2.00\times10^{-3}T \text{ (82)}$$
$$H_T-H_{298}=-1{,}699+5.40T+1.00\times10^{-3}T^2$$
$$F_T-H_{298}=-1{,}699-5.40T\ln T-1.00\times10^{-3}T^2+29.73T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		7.01	7.01
400	630	8.83	7.25
500	1,270	10.25	7.71
600	1,920	11.44	8.24
700	2,580	12.46	8.77
800	3,260	13.36	9.28
900	3,960	14.19	9.80
1,000	4,680	14.95	10.27
1,100	5,410	15.64	10.72
1,200	6,160	16.29	11.15
1,300	6,930	16.91	11.58
1,400	7,740	17.51	11.98
1,500	8,600	18.10	12.37
1,600	9,510	18.69	12.74
1,700	10,450	19.26	13.11
1,800	11,420	19.82	13.48
1,900	12,420	20.36	13.82
2,000	13,140		

Vanadium Oxide, VO (*c*)

$\Delta H^\circ_{298}=-98{,}000$ calories per mole (*112*)
$S_{298}=9.3$ *e.u.* (*135*)
$M.P.=2{,}350°$ K. (*42*)
$\Delta H_M=15{,}000$ calories per mole
$B.P.=3{,}400°$ K. (*42*)
$\Delta H_V=70{,}000$ calories per mole

Zone I (*c*) (298°–1,700° K.)

$$C_p=11.32+3.22\times10^{-3}T-1.26\times10^5T^{-2} \text{ (106)}$$
$$H_T-H_{298}=-3{,}940+11.32T+1.61\times10^{-3}T^2+1.26\times10^5T^{-1}$$

Formation: $V+1/2O_2\longrightarrow VO$

Zone I (298°–1,700° K.)

$$\Delta C_p=2.34+0.72\times10^{-3}T-1.06\times10^5T^{-2}$$
$$\Delta H_T=-99{,}100+2.34T+0.36\times10^{-3}T^2+1.06\times10^5T^{-1}$$
$$\Delta F_T=-99{,}100-2.34T\ln T-0.36\times10^{-3}T^2+0.53\times10^5T^{-1}+38.64T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		9.3	−98,000	−91,400
400	1,160	12.64	−97,800	−89,100
500	2,380	15.36	−97,600	−87,000
600	3,640	17.65	−97,400	−84,900
700	4,940	19.66	−97,150	−82,800
800	6,280	21.45	−96,850	−80,800
900	7,660	23.07	−96,600	−78,800
1,000	9,090	24.58	−96,300	−76,800
1,100	10,560	25.98	−95,950	−74,900
1,200	12,070	27.29	−95,600	−73,000
1,300	13,610	28.52	−95,250	−71,100
1,400	15,170	29.68	−94,950	−69,300
1,500	16,760	30.78	−94,700	−67,500
1,600	18,370	31.82	−94,350	−65,600
1,700	20,000	32.80	−94,100	−63,900

Divanadium Trioxide, V_2O_3 (*c*)

$\Delta H^\circ_{298}=-296{,}000$ calories per mole (*8*)
$S_{298}=23.58$ *e.u.* (*83*)
$M.P.=2{,}250°$ K. (*112*)
$\Delta H_M=(28{,}000)$ calories per mole

Zone I (*c*) (298°–1,800° K.)

$$C_p=29.35+4.76\times10^{-3}T-5.42\times10^5T^{-2}$$
$$H_T-H_{298}=-10{,}780+29.35T+2.38\times10^{-3}T^2+5.42\times10^5T^{-1}$$

Formation: $2V+3/2O_2\longrightarrow V_2O_3$

Zone I (298°–1,800° K.)

$$\Delta C_p=7.81-0.74\times10^{-3}T-4.82\times10^5T^{-2}$$
$$\Delta H_T=-299{,}900+7.81T-0.37\times10^{-3}T^2+4.82\times10^5T^{-1}$$
$$\Delta F_T=-299{,}900-7.81T\ln T+0.37\times10^{-3}T^2+2.41\times10^5T^{-1}+118.8T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		23.58	−296,000	−276,970
400	2,720	31.41	−295,600	−268,150
500	5,990	37.81	−294,700	−263,850
600	8,600	43.30	−294,550	−258,150
700	11,700	48.07	−293,950	−252,150
800	14,870	52.30	−293,350	−246,250
900	18,100	56.11	−292,700	−240,250
1,000	21,370	59.55	−292,150	−234,500
1,100	24,660	62.69	−291,450	−229,950
1,200	27,960	65.56	−290,900	−223,700
1,300	31,360	68.28	−290,300	−217,900
1,400	34,940	70.93	−289,600	−212,300
1,500	38,940	73.50	−288,800	−205,900
1,600	42,480	75.96	−288,200	−201,800
1,700	46,370	78.31	−287,550	−196,050
1,800	50,350	80.59	−286,800	−191,100

Divanadium Tetraoxide, V_2O_4 (*c*)

$\Delta H^\circ_{298} = -342{,}000$ calories per mole (*24*)
$S_{298} = 24.5$ *e.u.* (*8*)
T.P. = 345° K. (*82*)
$\Delta H_T = 2{,}050$ calories per mole
M.P. = 1,818° K. (*82*)
$\Delta H_M = 27{,}210$ calories per mole

Zone I (α) (298°–345° K.)

$$C_p = 29.91 \ (82)$$
$$H_T - H_{298} = -8{,}918 + 29.91T$$

Zone II (β) (345°–1,818° K.)

$$C_p = 35.70 + 3.40\times10^{-3}T - 7.89\times10^{5}T^{-2} \ (82)$$
$$H_T - H_{298} = -11{,}355 + 35.70T + 1.70\times10^{-3}T^2 + 7.89\times10^{5}T^{-1}$$

Zone III (*l*) (1,818°–1,900° K.)

$$C_p = 51.0 \ (82)$$
$$H_T - H_{298} = -5{,}910 + 51.00T$$

Formation: $2V + 2O_2 \longrightarrow V_2O_4$

Zone I (298°–345° K.)

$$\Delta C_p = 4.79 - 6.00\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -342{,}900 + 4.79T - 3.00\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -342{,}900 - 4.79T\ln T + 3.00\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 117.46T$$

Zone II (345°–1,818° K.)

$$\Delta C_p = 10.58 - 2.60\times10^{-3}T - 7.09\times10^{5}T^{-2}$$
$$\Delta H_T = -345{,}270 + 10.58T - 1.30\times10^{-3}T^2 + 7.09\times10^{5}T^{-1}$$
$$\Delta F_T = -345{,}270 - 10.58T\ln T + 1.30\times10^{-3}T^2 + 3.54\times10^{5}T^{-1} + 155.21T$$

Zone III (1,818°–1,900° K.)

$$\Delta C_p = 25.88 - 6.00\times10^{-3}T + 0.80\times10^{5}T^{-2}$$
$$\Delta H_T = -339{,}820 + 25.88T - 3.00\times10^{-3}T^2 - 0.80\times10^{5}T^{-1}$$
$$\Delta F_T = -339{,}820 - 25.88T\ln T + 3.00\times10^{-3}T^2 - 0.40\times10^{5}T^{-1} + 264T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		24.5	−342,000	−315,950
400	5,270	39.7	−339,500	−307,400
500	8,600	47.12	−338,850	−299,450
600	12,000	53.29	−338,250	−291,450
700	15,560	58.79	−337,600	−283,900
800	19,230	63.69	−336,850	−276,250
900	22,990	68.11	−336,150	−268,750
1,000	26,830	72.16	−335,400	−261,250
1,100	30,730	75.88	−334,500	−253,800
1,200	34,670	79.31	−333,750	−245,650
1,300	38,630	82.47	−333,000	−239,250
1,400	42,600	85.42	−332,300	−232,100
1,500	46,590	88.17	−331,950	−225,050
1,600	50,620	90.77	−331,300	−218,400
1,700	54,710	93.25	−330,850	−211,000
1,800	58,850	95.62	−330,450	−203,850
1,900	91,000	113.25	−301,500	−199,000

Divanadium Pentaoxide, V_2O_5 (*c*)

$\Delta H^\circ_{298} = -372{,}500$ calories per mole (*8*)
$S_{298} = 31.3$ *e.u.* (*83*)
M.P. = 943° K. (*24*)
$\Delta H_M = 15{,}560$ calories per mole
B.P. = 2,325° K. (*42*)
$\Delta H_V = 63{,}000$ calories per mole

Zone I (*c*) (298°–943° K.)

$$C_p = 46.54 = 3.90\times10^{-3}T - 13.22\times10^{5}T^{-2} \ (82)$$
$$H_T - H_{298} = -18{,}137 + 46.54T - 1.95\times10^{-3}T^2 + 13.22\times10^{5}T^{-1}$$

Zone II (*l*) (943°–1,500° K.)

$$C_p = 45.60 \ (82)$$
$$H_T - H_{298} = -2{,}020 + 45.60T$$

Formation: $2V + 5/2O_2 \longrightarrow V_2O_5$

Zone I (298°–943° K.)

$$\Delta C_p = 17.84 - 10.40\times10^{-3}T - 12.22\times10^{5}T^{-2}$$
$$\Delta H_T = -381{,}450 + 17.84T - 5.20\times10^{-3}T^2 + 12.22\times10^{5}T^{-1}$$
$$\Delta F_T = -381{,}450 - 17.84T\ln T + 5.20\times10^{-3}T^2 + 6.11\times10^{5}T^{-1} + 228.56T$$

Zone II (943°–1,500° K.)

$$\Delta C_p = 16.90 - 6.50\times10^{-3}T + 1.0\times10^{5}T^{-2}$$
$$\Delta H_T = -365{,}400 + 16.90T - 3.25\times10^{-3}T^2 - 1.0\times10^{5}T^{-1}$$
$$\Delta F_T = -365{,}400 - 16.90T\ln T + 3.25\times10^{-3}T^2 - 0.50\times10^{5}T^{-1} + 207.16T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		31.3	−372,500	−341,250
400	3,650	41.79	−371,900	−330,500
500	7,400	50.15	−371,300	−320,200
600	11,290	57.24	−370,550	−310,500
700	15,290	63.40	−369,850	−300,000
800	19,390	68.88	−369,100	−290,100
900	23,590	73.82	−368,350	−280,300
1,000	43,580	94.99	−351,850	−271,400
1,100	48,140	99.34	−351,700	−264,300
1,200	52,700	103.30	−349,700	−255,300
1,300	57,260	106.95	−348,800	−247,800
1,400	61,820	110.33	−347,950	−239,900
1,500	66,380	113.48	−347,500	−232,500

Vanadium Difluoride, VF_2 (*c*)

$\Delta H^\circ_{298} = (-180{,}000)$ calories per mole (*11*)
$S_{298} = (19)$ *e.u.* (*11*)
M.P. = (1,400°) K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
B.P. = (2,500°) K. (*6*)
$\Delta H_V = (65{,}000)$ calories per mole

Formation: $V + F_2 \longrightarrow VF_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−180,000)	(−169,000)
500	(3,000)	(−179,900)	(−162,000)
1,000	(12,000)	(−178,500)	(−144,000)
1,500	(29,000)	(−169,800)	(−127,500)

Vanadium Trifluoride, VF_3 (*c*)

$\Delta H^\circ_{298} = (-285{,}000)$ calories per mole (*11*)
$S_{298} = (28)$ *e.u.* (*11*)
M.P. = (1,400°) K. (*6*)
$\Delta H_M = (11{,}000)$ calories per mole
B.P. = (1,700°) K. (*6*)
$\Delta H_V = (49{,}000)$ calories per mole

Formation: $V + 3/2F_2 \longrightarrow VF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−285,000)	(−269,500)
500	(4,000)	(−284,700)	(−259,500)
1,000	(17,000)	(−281,500)	(−234,000)
1,500	(32,000)	(−277,000)	(−212,000)

Vanadium Tetrafluoride, VF_4 (*c*)

$\Delta H_{298}^\circ = (-325{,}000)$ calories per mole (*11*)
$S_{298} = (38)$ *e.u.* (*11*)
S.P. = (600°) K. (*6*)
$\Delta H_{subl} = (23{,}000)$ calories per mole

Formation: $V + 2F_2 \longrightarrow VF_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−325,000)	(−305,000)
500	(6,000)	(−323,500)	(−291,000)

Vanadium Pentafluoride, VF_5 (*c*)

$\Delta H_{298}^\circ = (-335{,}000)$ calories per mole (*11*)
$S_{298} = (50)$ *e.u.* (*11*)
M.P. = (375°) K. (*6*)
B.P. = 384° K. (*6*)
$\Delta H_V = 8{,}500$ calories per mole

Formation: $V + 5/2F_2 \longrightarrow VF_5$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−335,000)	(−312,000)
500	(10,000)	(−330,200)	(−298,000)

Vanadium Dichloride, VCl_2 (*c*)

$\Delta H_{298}^\circ = (-117{,}000)$ calories per mole (*11*)
$S_{298} = 23.2$ *e.u.* (*83*)
M.P. = 1,300° K. (*6*)
$\Delta H_M = 8{,}000$ calories per mole
B.P. = (1,650°) K. (*6*)
$\Delta H_V = (35{,}000)$ calories per mole

Zone I (*c*) (298°–1,300° K.)

$$C_p = 17.25 + 2.72\times10^{-3}T - 0.71\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -5{,}500 + 17.25T + 1.36\times10^{-3}T^2 + 0.71\times10^{5}T^{-1}$$

Formation: $V + Cl_2 \longrightarrow VCl_2$

Zone I (298°–1,300° K.)

$$\Delta C_p = 3.03 + 0.66\times10^{-3}T - 0.03\times10^{5}T^{-2}$$
$$\Delta H_T = -117{,}950 + 3.03T + 0.33\times10^{-3}T^2 + 0.03\times10^{5}T^{-1}$$
$$\Delta F_T = -117{,}950 - 3.03T\ln T - 0.33\times10^{-3}T^2 + 0.015\times10^{5}T^{-1} + 57.61T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		23.2	(−117,000)	(−105,900)
400	1,840	28.5	(−116,650)	(−102,100)
500	3,620	32.47	(−116,350)	(−98,600)
600	5,450	35.81	(−116,000)	(−95,000)
700	7,330	38.7	(−115,650)	(−91,700)
800	9,250	41.27	(−115,300)	(−88,200)
900	11,200	43.56	(−114,950)	(−84,800)
1,000	13,180	45.65	(−114,550)	(−81,400)
1,100	15,190	47.56	(−114,150)	(−78,200)
1,200	17,220	49.33	(−113,750)	(−75,000)
1,300	19,270	50.97	(−113,350)	(−71,800)
1,500			(−84,000)	(−67,000)

Vanadium Trichloride, VCl_3 (*c*)

$\Delta H_{298}^\circ = (-139{,}000)$ calories per mole (*11*)
$S_{298} = 31.3$ *e.u.* (*83*)
Disproportionates $<1{,}000°$ K. (*6*)

Zone I (*c*) (298°–900° K.)

$$C_p = 22.99 + 3.92\times10^{-3}T - 1.68\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -7{,}592 + 22.99T + 1.96\times10^{-3}T^2 + 1.68\times10^{5}T^{-1}$$

Formation: $V + 3/2Cl_2 \longrightarrow VCl_3$

Zone I (298°–900° K.)

$$\Delta C_p = 4.36 + 1.83\times10^{-3}T - 0.64\times10^{5}T^{-2}$$
$$\Delta H_T = -140{,}600 + 4.36T + 0.915\times10^{-3}T^2 + 0.64\times10^{5}T^{-1}$$
$$\Delta F_T = -140{,}600 - 4.36T\ln T - 0.915\times10^{-3}T^2 + 0.32\times10^{5}T^{-1} + 85.82T$$

T, ° K.	H_T-H_{298}	S_T	ΔH_T°	ΔF_T°
298		31.3	(−139,000)	(−123,400)
400	2,360	38.1	(−138,500)	(−116,700)
500	4,730	43.39	(−138,100)	(−111,200)
600	7,180	47.85	(−137,500)	(−106,100)
700	9,700	51.73	(−137,000)	(−100,900)
800	12,270	55.15	(−136,400)	(−95,600)
900	14,860	58.20	(−135,900)	(−90,700)

Vanadium Tetrachloride, VCl_4 (*l*)

$\Delta H_{298}^\circ = (-141{,}000)$ calories per mole (*11*)
$S_{298} = (61)$ *e.u.* (*11*)
M.P. = 247° K. (*6*)
$\Delta H_M = (2{,}200)$ calories per mole
B.P. = 437° K. (*6*)
$\Delta H_V = 7{,}700$ calories per mole

Formation: $V + 2Cl_2 \longrightarrow VCl_4$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH_T°	ΔF_T°
298		(−141,000)	(−125,000)
500	(14,700)	(−131,000)	(−115,000)

Vanadium Dibromide, VBr_2 (*c*)

$\Delta H^\circ_{298} = (-97{,}000)$ calories per mole (*11*)
$S_{298} = (30)$ *e.u.* (*11*)
$M.P. = (1{,}100°)$ K. (*6*)
$\Delta H_M = (7{,}000)$ calories per mole
$B.P. = (1{,}500°)$ K. (*6*)
$\Delta H_V = (32{,}000)$ calories per mole

Formation: $V + Br_2 \longrightarrow VBr_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−97,000)	(−93,000)
500	(4,000)	(−103,800)	(−86,000)
1,000	(14,000)	(−101,700)	(−70,000)

Vanadium Tribromide, VBr_3 (*c*)

$\Delta H^\circ_{298} = (-109{,}000)$ calories per mole (*11*)
$S_{298} = (43)$ *e.u.* (*11*)
Decomposes to VBr_2

Formation: $V + 3/2Br_2 \longrightarrow VBr_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−109,000)	(−103,500)
500	(5,000)	(−119,600)	(−94,000)
1,000	(20,000)	(−114,700)	(−70,000)

Vanadium Diiodide, VI_2 (*c*)

$\Delta H^\circ_{298} = (-62{,}000)$ calories per mole (*11*)
$S_{298} = (33)$ *e.u.* (*11*)
$M.P. = (1{,}050°)$ K. (*6*)
$\Delta H_M = (6{,}000)$ calories per mole
$B.P. = (1{,}200°)$ K. (*6*)
$\Delta H_V = (25{,}000)$ calories per mole

Formation: $V + I_2 \longrightarrow VI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−62,000)	(−62,000)
500	(4,000)	(−75,900)	(−59,000)
1,000	(14,000)	(−73,800)	(−44,000)

Vanadium Pentaiodide, VI_5 (*c*)

$\Delta H^\circ_{298} = (-42{,}000)$ calories per mole (*11*)
$S_{298} = (78)$ *e.u.* (*11*)

Formation: $V + 5/2I_2 \longrightarrow VI_5$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−42,000)	(−42,000)
500	(8,000)	(−77,000)	(−25,500)

Vanadium Carbide, VC (*c*)

$\Delta H^\circ_{298} = -28{,}000$ calories per mole (*9*)
$S_{298} = 6.77$ *e.u.*
$M.P. = 3{,}100°$ K. (*9*)

Zone I (*c*) (298°–1,600° K.)

$C_p = 9.18 + 3.30 \times 10^{-3}T - 1.95 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -3{,}725 + 9.18T + 1.65 \times 10^{-3}T^2 + 1.95 \times 10^5 T^{-1}$

Formation: $V + C \longrightarrow VC$

Zone I (298°–1,600° K.)

$\Delta C_p = -0.32 + 0.28 \times 10^{-3}T + 0.15 \times 10^5 T^{-2}$
$\Delta H_T = -27{,}870 - 0.32T + 0.14 \times 10^{-3}T^2 - 0.15 \times 10^5 T^{-1}$
$\Delta F_T = -27{,}870 + 0.32\,T \ln T - 0.14 \times 10^{-3}T^2 - 0.075 \times 10^5 T^{-1} - 0.53T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		6.77	−28,000	−27,525
400	990	9.32	−28,000	−27,350
500	1,850	11.47	−28,000	−27,200
600	2,870	13.32	−28,000	−27,050
700	3,950	14.99	−28,000	−26,900
800	5,090	16.51	−28,000	−26,750
900	6,280	17.91	−28,000	−26,550
1,000	7,510	19.20	−28,000	−26,400
1,100	8,770	20.41	−27,950	−26,250
1,200	10,060	21.53	−27,950	−26,100
1,300	11,380	22.58	−27,950	−25,950
1,400	12,720	23.57	−27,950	−25,800
1,500	14,080	24.51	−27,900	−25,650
1,600	15,450	25.40	−27,800	−25,600

Vanadium Nitride, VN (*c*)

$\Delta H^\circ_{298} = -40{,}800$ calories per mole (*94*)
$S_{298} = 8.9$ *e.u.* (*83*)
$M.P. = 2{,}320°$ K. (*9*)

Zone I (*c*) (298°–1, 600° K.)

$C_p = 10.94 + 2.10 \times 10^{-3}T - 2.21 \times 10^5 T^{-2}$ (*82*)
$H_T - H_{298} = -4{,}096 + 10.94T + 1.05 \times 10^{-3}T^2 + 2.21 \times 10^5 T^{-1}$

Formation: $V + 1/2N_2 \longrightarrow VN$

Zone I (298°–1, 600° K.)

$\Delta C_p = 2.21 - 0.41 \times 10^{-3}T - 2.21 \times 10^5 T^{-2}$
$\Delta H_T = -42{,}180 + 2.21T - 0.205 \times 10^{-3}T^2 + 2.21 \times 10^5 T^{-1}$
$\Delta F_T = -42{,}180 - 2.21\,T \ln T + 0.205 \times 10^{-3}T^2 + 1.105 \times 10^5 T^{-1} + 36.91T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		8.9	−40,800	−34,550
400	1,010	11.81	−40,750	−32,400
500	2,080	14.20	−40,700	−30,300
600	3,200	16.24	−40,600	−28,250
700	4,370	18.04	−40,450	−26,200
800	5,590	19.66	−40,250	−24,150
900	6,750	21.15	−40,100	−22,200
1,000	8,130	22.50	−39,900	−20,200
1,100	9,430	23.74	−39,750	−18,250
1,200	10,750	24.89	−39,550	−16,350
1,300	12,090	25.96	−39,400	−14,350
1,400	13,450	26.97	−39,250	−12,450
1,500	14,820	27.91	−39,150	−10,600
1,600	16,200	28.80	−39,100	−8,650

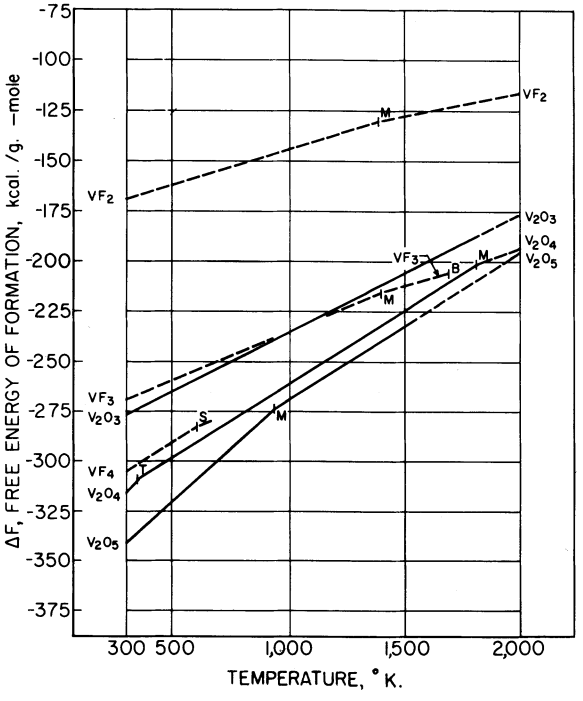

FIGURE 62.—Vanadium (a).

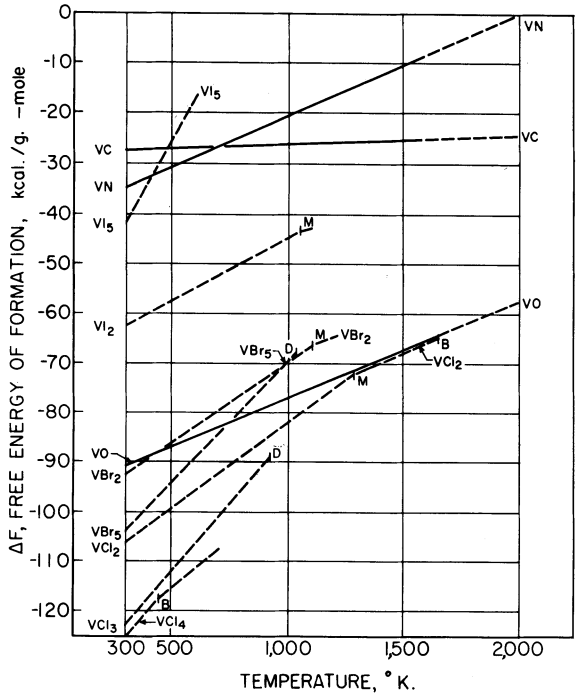

FIGURE 63.—Vanadium (b).

YTTERBIUM AND ITS COMPOUNDS

Element, Yb (*c*)

S_{298}=15.0 *e.u.* (*130*)
M.P.=1,097° K. (*125*)
ΔH_M=(2,200) calories per atom
B.P.=1,800° K. (*125*)
ΔH_V=37,100 calories per atom

(estimated (*124*))

T, ° K.	H_T-H_{298}	S_T	$\frac{(F_T-H_{298})}{T}$
298		15.0	15.0
400	(620)	(16.79)	(15.24)
500	(1,250)	(18.19)	(15.69)
600	(1,900)	(19.38)	(16.22)
700	(2,570)	(20.41)	(16.74)
800	(3,260)	(21.33)	(17.26)
900	(3,970)	(22.17)	(17.76)
1,000	(4,700)	(22.94)	(18.24)
1,100	(7,950)	(25.94)	(18.72)
1,200	(8,700)	(26.59)	(19.34)
1,300	(9,450)	(27.19)	(19.93)
1,400	(10,200)	(27.75)	(20.47)
1,500	(10,950)	(28.27)	(20.97)
1,600	(11,700)	(28.75)	(21.44)
1,700	(12,450)	(29.20)	(21.88)
1,800	(13,200)	(29.64)	(22.31)
1,900	(50,860)	(50.55)	(23.79)
2,000	(51,360)	(50.81)	(25.13)

Ytterbium Difluoride, YbF_2 (*c*)

ΔH°_{298}=(−262,000) calories per mole (*5*)
S_{298}=(20) *e.u.* (*11*)
M.P.=1,325° K. (*29*)
ΔH_M=5,000 calories per mole
B.P.=(2,650°) K. (*6*)
ΔH_V=(75,000) calories per mole

Formation: $Yb+F_2 \longrightarrow YbF_2$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−262,000)	(−250,000)
500	(4,000)	(−260,800)	(−241,000)
1,000	(13,000)	(−259,500)	(−223,000)
1,500	(24,000)	(−259,200)	(−203,000)

Ytterbium Trifluoride, YbF_3 (*c*)

ΔH°_{298}=(−351,000) calories per mole (*5*)
S_{298}=(26) *e.u.* (*11*)
M.P.=1,430° K. (*29*)
ΔH_M=8,000 calories per mole
B.P.=(2,500°) K. (*6*)
ΔH_V=(60,000) calories per mole

Formation: $Yb+3/2F_2 \longrightarrow YbF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−351,000)	(−333,000)
500	(4,000)	(−350,600)	(−321,000)
1,000	(17,000)	(−347,500)	(−293,000)
1,500	(32,000)	(−345,300)	(−367,000)

Ytterbium Dichloride, $YbCl_2$ (*c*)

$\Delta H^\circ_{298} = (-162{,}000)$ calories per mole (*5*)
$S_{298} = (30)$ *e.u.* (*11*)
M.P. = 975° K. (*29*)
$\Delta H_M = 6{,}000$ calories per mole
B.P. = (2,200°) K. (*6*)
$\Delta H_V = (50{,}000)$ calories per mole

Formation: $Yb + Cl_2 \longrightarrow YbCl_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−162,000)	(−161,000)
500	(4,000)	(−160,900)	(−153,500)
1,000	(13,000)	(−159,700)	(−128,000)
1,500	(31,000)	(−152,300)	(−115,500)

Ytterbium Trichloride, $YbCl_3$ (*c*)

$\Delta H^\circ_{298} = (-189{,}000)$ calories per mole (*5*)
$S_{298} = (38)$ *e.u.* (*11*)
M.P. = 1,138° K. (*29*)
$\Delta H_M = (9{,}000)$ calories per mole
Decomposes above 1,500° K.

Formation: $Yb + 3/2Cl_2 \longrightarrow YbCl_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−189,000)	(−173,000)
500	(5,000)	(−187,800)	(−161,500)
1,000	(19,000)	(−184,800)	(−136,000)
1,500	(43,000)	(172,500)	(−117,000)

Ytterbium Dibromide, $YbBr_2$ (*c*)

$\Delta H^\circ_{298} = (-132{,}000)$ calories per mole (*5*)
$S_{298} = (36)$ *e.u.* (*11*)
M.P. = 945° K. (*29*)
$\Delta H_M = 6{,}000$ calories per mole
B.P. = (2,100°) K. (*6*)
$\Delta H_V = (48{,}000)$ calories per mole

Formation: $Yb + Br_2 \longrightarrow YbBr_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−132,000)	(−127,000)
500	(4,000)	(−150,000)	(−120,500)
1,000	(20,000)	(−140,000)	(−104,000)
1,500	(32,000)	(−129,500)	(−93,000)

Ytterbium Tribromide, $YbBr_3$ (*c*)

$\Delta H^\circ_{298} = (-149{,}000)$ calories per mole (*5*)
$S_{298} = (44)$ *e.u.* (*11*)
M.P. = 1,227° K. (*29*)
$\Delta H_M = 10{,}000$ calories per mole
Decomposes above 1,500° K. (*6*)

Formation: $Yb + 3/2Br_2 \longrightarrow YbBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−149,000)	(−142,000)
500	(5,000)	(−170,800)	(−132,500)
1,000	(18,000)	(−166,700)	(−106,000)
1,500	(43,000)	(−144,700)	(−86,500)

Ytterbium Diiodide, YbI_2 (*c*)

$\Delta H^\circ_{298} = (-102{,}000)$ calories per mole (*5*)
$S_{298} = (40)$ *e.u.* (*11*)
M.P. = 1,045° K. (*29*)
$\Delta H_M = 5{,}000$ calories per mole
B.P. = (1,600°) K. (*6*)
$\Delta H_V = (37{,}000)$ calories per mole

Formation: $Yb + I_2 \longrightarrow YbI_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−102,000)	(−102,000)
500	(4,000)	(−115,900)	(−99,500)
1,000	(19,000)	(−108,800)	(−85,000)
1,500	(31,000)	(−107,500)	(−73,500)

Ytterbium Triiodide, YbI_3 (*c*)

$\Delta H^\circ_{298} = (-96{,}000)$ calories per mole (*5*)
$S_{298} = (47)$ *e.u.* (*11*)
M.P. = (1,300°) K. (*29*)
$\Delta H_M = (10{,}000)$ calories per mole
Decomposes above 1,500° K. (*6*)

Formation: $Yb + 3/2I_2 \longrightarrow YbI_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−96,000)	(−93,500)
500	(5,000)	(−120,200)	(−88,500)
1,000	(19,000)	(−116,200)	(−60,000)
1,500	(44,000)	(−95,500)	(−35,500)

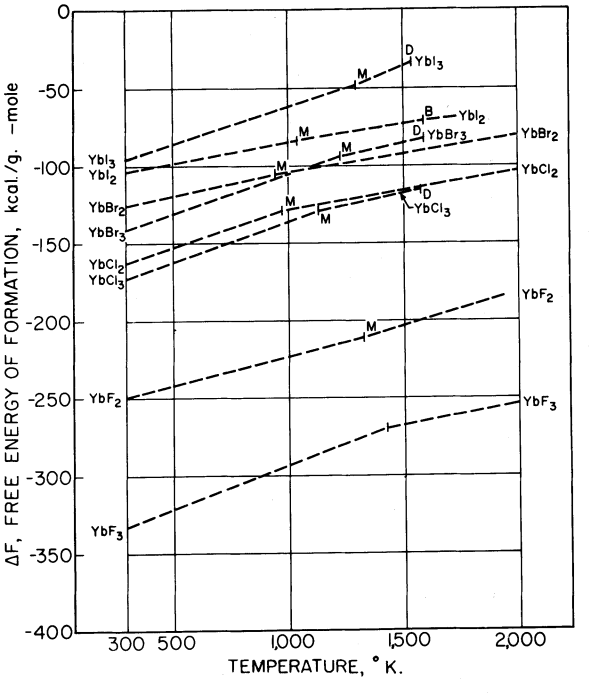

FIGURE 64.—Ytterbium.

YTTRIUM AND ITS COMPOUNDS

Element, Y (*c*)

S_{298}=11.3 *e.u.* (*127*)
M.P.=(1,773°) K. (*125*)
ΔH_M=(4,100) calories per atom
B.P.=(3,500°) K. (*125*)
ΔH_V=(94,000) calories per atom
(estimated (*130*))

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		11.30	11.30
400	(617)	(13.08)	(11.52)
500	(1,233)	(14.45)	(11.98)
600	(1,859)	(15.59)	(12.50)
700	(2,495)	(16.57)	(13.00)
800	(3,141)	(17.44)	(13.51)
900	(3,798)	(18.21)	(13.99)
1,000	(4,465)	(18.91)	(14.45)
1,100	(5,142)	(19.56)	(14.88)
1,200	(5,829)	(20.16)	(15.40)
1,300	(6,527)	(20.71)	(15.70)
1,400	(7,235)	(21.24)	(16.07)
1,500	(7,935)	(21.73)	(16.44)
1,600	(8,681)	(22.20)	(16.77)
1,700	(9,419)	(22.65)	(17.11)
1,800	(14,280)	(25.40)	(17.46)
1,900	(15,080)	(25.83)	(17.90)
2,000	(15,880)	(26.24)	(18.30)

Diyttrium Trioxide, Y_2O_3 (*c*)

ΔH°_{298}=−455,450 calories per mole (*62*)
S_{298}=27.1 *e.u.* (*8*)
M.P.=2,500° K. (*42*)
ΔH_M=25,000 calories per mole
B.P.=4,570±300° K. (*42*)

Formation: $2Y+3/2O_2 \longrightarrow Y_2O_3$
(estimated (*24*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−455,450	−433,450
400	(2,320)	(−455,400)	(−425,500)
500	(4,800)	(−455,400)	(−418,500)
600	(7,030)	(−455,400)	(−411,500)
700	(9,930)	(−455,000)	(−404,000)
800	(12,460)	(−455,000)	(−396,500)
900	(15,000)	(−455,000)	(−389,500)
1,000	(17,800)	(−454,500)	(−382,000)
1,100	(20,900)	(−454,500)	(−375,000)
1,200	(23,700)	(−454,000)	(−368,000)
1,300	(26,360)	(−454,000)	(−360,500)
1,400	(29,550)	(−453,500)	(−353,500)
1,500	(32,800)	(−453,000)	(−346,500)
1,600	(36,030)	(−452,500)	(−339,000)
1,700	(39,340)	(−452,000)	(−332,000)
1,800	(46,000)	(−460,000)	(−325,000)
1,900	(49,000)	(−459,500)	(−317,500)
2,000	(52,700)	(−459,000)	(−309,500)

Yttrium Trifluoride, YF_3 (*c*)

ΔH°_{298}=(−372,000) calories per mole (*5*)
S_{298}=(23) *e.u.* (*11*)
M.P.=1,425° K. (*29*)
ΔH_M=(13,000) calories per mole
B.P.=(2,500°) K. (*6*)
ΔH_V=(60,000) calories per mole

Formation: $Y+3/2F_2 \longrightarrow YF_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−372,000)	(−353,800)
500	(4,000)	(−371,000)	(−342,000)
1,000	(17,000)	(−369,300)	(−314,000)
1,500	(32,000)	(−364,900)	(−288,000)

Yttrium Trichloride, YCl_3 (*c*)

ΔH°_{298}=−232,690 calories per mole (*127*)
S_{298}=32.7 *e.u.* (*127*)
M.P.=982° K. (*29*)
ΔH_M=(9,000) calories per mole
B.P.=(1,780°) K. (*6*)
ΔH_V=(45,000) calories per mole

Formation: $Y+3/2Cl_2 \longrightarrow YCl_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−232,700	−215,200
500	(5,000)	(−231,800)	(−206,200)
1,000	(28,000)	(−229,600)	(−183,700)
1,500	(44,000)	(−214,000)	(−163,700)

Yttrium Tribromide, YBr_3 (*c*)

ΔH°_{298}=(−172,000) calories per mole (*5*)
S_{298}=(42) *e.u.* (*11*)
M.P.=1,186° K. (*29*)
ΔH_M=(9,000) calories per mole
B.P.=(1,740°) K. (*6*)
ΔH_V=(44,000) calories per mole

Formation: $Y+3/2Br_2 \longrightarrow YBr_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔH°_T
298		(−172,000)	(−166,000)
500	(5,000)	(−183,000)	(−155,000)
1,000	(18,000)	(−180,000)	(−129,000)
1,500	(44,000)	(−165,300)	(−108,000)

Yttrium Triiodide, YI_3 (*c*)

ΔH°_{298}=−143,000 calories per mole (*5*)
S_{298}=(45) *e.u.* (*11*)
M.P.=1,238° K. (*29*)
ΔH_M=(12,000) calories per mole
B.P.=(1,580°) K. (*6*)
ΔH_V=(41,000) calories per mole

Formation: $Y+3/2I_2 \longrightarrow YI_3$
(estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		−143,000	(−140,500)
500	(5,000)	(−164,300)	(−135,000)
1,000	(19,000)	(−161,200)	(−109,000)
1,500	(46,000)	(−145,000)	(−87,000)

Yttrium Nitride, YN (*c*)

$\Delta H^\circ_{298} = -71{,}500$ calories per mole (*9*)
$S_{298} = (14.2)$ *e.u.* (*9*)
$\Delta F^\circ_{298} = -64{,}000$ calories per mole

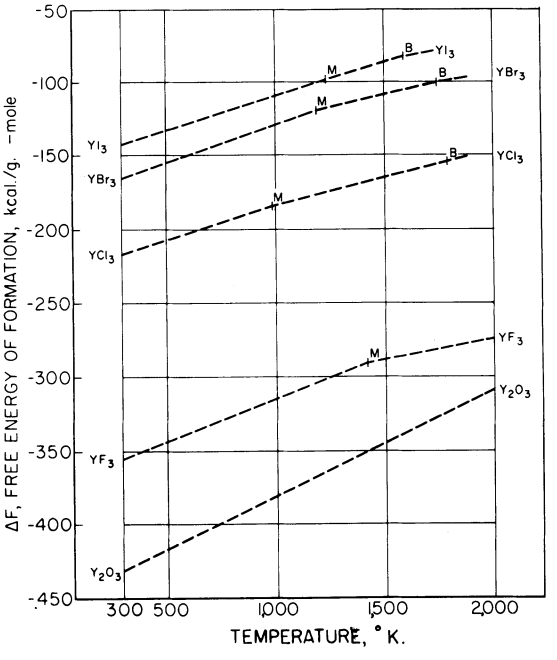

FIGURE 65.—Yttrium.

ZINC AND ITS COMPOUNDS

Element, Zn (*c*)

$S_{298} = 9.95$ *e.u.* (*83*)
$M.P. = 692.7°$ K. (*82*)
$\Delta H_M = 1{,}765$ calories per atom
$B.P. = 1{,}181°$ K. (*130*)
$\Delta H_V = 27{,}560$ calories per atom

Zone I (*c*) (298°–692.7° K.)

$$C_p = 5.35 + 2.40\times10^{-3}T \quad (82)$$
$$H_T - H_{298} = -1{,}702 + 5.35T + 1.20\times10^{-3}T^2$$
$$F_T - H_{298} = -1{,}702 - 5.35T\ln T - 1.20\times10^{-3}T^2 + 26.56T$$

Zone II (*l*) (692.7°–1,181° K.)

$$C_p = 7.50 \quad (82)$$
$$H_T - H_{298} = -850 + 7.50T$$
$$F_T - H_{298} = -850 - 7.50T\ln T + 38.57T$$

Zone III (*g*) (1,181°–2,000° K.)

T, ° K.	$H_T - H_{298}$	S_T	$\frac{(F_T - H_{298})}{T}$
298		9.95	9.95
400	625	11.75	10.19
500	1,270	13.19	10.65
600	1,940	14.41	11.18
700	4,400	18.03	11.74
800	5,150	19.03	12.59
900	5,900	19.91	13.36
1,000	6,650	20.70	14.05
1,100	7,400	21.42	14.69
1,200	(35,660)	(45.37)	(15.66)
1,300	(36,160)	(45.77)	(17.96)
1,400	(36,650)	(46.14)	(19.96)
1,500	(37,150)	(46.48)	(21.72)
1,600	(37,650)	(46.80)	(23.28)
1,700	(38,140)	(47.10)	(24.67)
1,800	(38,640)	(47.38)	(25.92)
1,900	(39,140)	(47.65)	(27.06)
2,000	(39,630)	(47.91)	(28.10)
2,500	(42,120)	(49.02)	(32.18)

Zinc Oxide, ZnO (*c*)

$\Delta H^\circ_{298} = -83{,}250$ calories per mole (*24*)
$S_{298} = 10.43$ *e.u.* (*83*)
$M.P. = 2{,}248°$ K. (*112*)

Zone I (*c*) (298°–1,600° K.)

$$C_p = 11.71 + 1.22\times10^{-3}T - 2.18\times10^{5}T^{-2} \quad (82)$$
$$H_T - H_{298} = -4{,}280 + 11.71T + 0.61\times10^{-3}T^2 + 2.18\times10^{5}T^{-1}$$

Formation: $Zn + 1/2O_2 \longrightarrow ZnO$

Zone I (298°–692.7° K.)

$$\Delta C_p = 2.78 - 1.68\times10^{-3}T - 1.98\times10^{5}T^{-2}$$
$$\Delta H_T = -84{,}670 + 2.78T - 0.84\times10^{-3}T^2 + 1.98\times10^{5}T^{-1}$$
$$\Delta F_T = -84{,}670 - 2.78T\ln T + 0.84\times10^{-3}T^2 + 0.99\times10^{5}T^{-1} + 43.24T$$

Zone II (692.7–1,181° K.)

$$\Delta C_p = 0.63 + 0.72\times10^{-3}T - 1.98\times10^{5}T^{-2}$$
$$\Delta H_T = -85{,}600 + 0.63T + 0.36\times10^{-3}T^2 + 1.98\times10^{5}T^{-1}$$
$$\Delta F_T = -85{,}600 - 0.63T\ln T - 0.36\times10^{-3}T^2 + 0.99\times10^{5}T^{-1} + 31.28T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		10.43	−83,250	−76,100
400	1,070	13.51	−83,200	−74,650
500	2,190	16.01	−83,050	−71,300
600	3,350	18.12	−82,950	−68,950
700	4,530	19.94	−84,600	−66,600
800	5,740	21.56	−84,550	−64,000
900	6,970	23.00	−84,500	−61,500
1,000	8,220	24.32	−84,400	−59,000
1,100	9,500	25.54	−84,000	−56,100
1,200	10,800	26.67	(−111,600)	(−53,400)
1,300	12,120	27.72	(−111,200)	(−50,700)
1,400	13,450	28.71	(−110,800)	(−47,900)
1,500	14,800	29.64	(−110,400)	(−45,100)
1,600	16,160	30.52	(−110,000)	(−42,200)

Zinc Difluoride, ZnF_2 (*c*)

$\Delta H^\circ_{298} = -176{,}000$ calories per mole (*11*)
$S_{298} = (24)$ *e.u.* (*11*)
M.P. = 1,145° K. (*6*)
$\Delta H_M = (7{,}000)$ calories per mole
B.P. = 1,775° K. (*6*)
$\Delta H_V = 44{,}000$ calories per mole

Formation: $Zn + F_2 \longrightarrow ZnF_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−176,000	(−165,600)
500	(4,000)	(−174,900)	(−158,500)
1,000	(14,000)	(−174,500)	(−142,000)
1,500	(32,000)	(−191,400)	(−123,000)

Zinc Dichloride, $ZnCl_2$ (*c*)

$\Delta H^\circ_{298} = -99{,}600$ calories per mole (*11*)
$S_{298} = 25.9$ *e.u.* (*11*)
M.P. = 556° K. (*6*)
$\Delta H_M = 5{,}540$ calories per mole
B.P. = 1,005° K. (*6*)
$\Delta H_V = 28{,}700$ calories per mole

Formation: $Zn + Cl_2 \longrightarrow ZnCl_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔH°_T
298		−99,600	−88,450
500	(4,000)	(−98,600)	(−81,100)
1,000	(21,000)	(−91,300)	(−70,000)
1,500	(61,000)	(−86,000)	(−53,600)

Zinc Dibromide, $ZnBr_2$ (*c*)

$\Delta H^\circ_{298} = -78{,}200$ calories per mole (*11*)
$S_{298} = (33)$ *e.u.* (*11*)
M.P. = 665° K. (*6*)
$\Delta H_M = 4{,}000$ calories per mole
B.P. = 975° K. (*6*)
$\Delta H_V = 24{,}250$ calories per mole

Formation: $Zn + Br_2 \longrightarrow ZnBr_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−78,200	(−74,400)
500	(4,000)	(−71,400)	(−68,000)
1,000	(21,000)	(−78,500)	(−56,800)
1,500	(56,000)	(−77,700)	(−39,000)

Zinc Diiodide, ZnI_2 (*c*)

$\Delta H^\circ_{298} = -49{,}980$ calories per mole (*112*)
$S_{298} = (38)$ *e.u.* (*112*)
M.P. = 719° K. (*6*)
$\Delta H_M = 4{,}500$ calories per mole
B.P. = 1,000° K. (*6*)
$\Delta H_V = 23{,}000$ calories per mole

Formation: $Zn + I_2 \longrightarrow ZnI_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		−49,980	(−50,000)
500	(4,000)	(−63,900)	(−48,000)
1,000	(20,000)	(−57,800)	(−36,600)
1,500	(54,000)	(−58,500)	(−19,800)

Trizinc Dinitride, Zn_3N_2 (*c*)

$\Delta H^\circ_{298} = -5{,}300$ calories per mole (*9*)
Metastable (*9*)

Zone I (c) (298°–700° K.)

$C_p = 19.93 + 20.80 \times 10^{-3} T$ (*82*)
$H_T - H_{298} = -6{,}867 + 19.93T + 10.40 \times 10^{-3} T^2$

T, ° K.	$H_T - H_{298}$	$S_T - S_{298}$	ΔH_{298}
298			−5,300
400	2,770	7.98	−5,100
500	5,700	14.51	−4,800
600	8,880	20.30	−4,400
700	12,180	25.38	−9,150

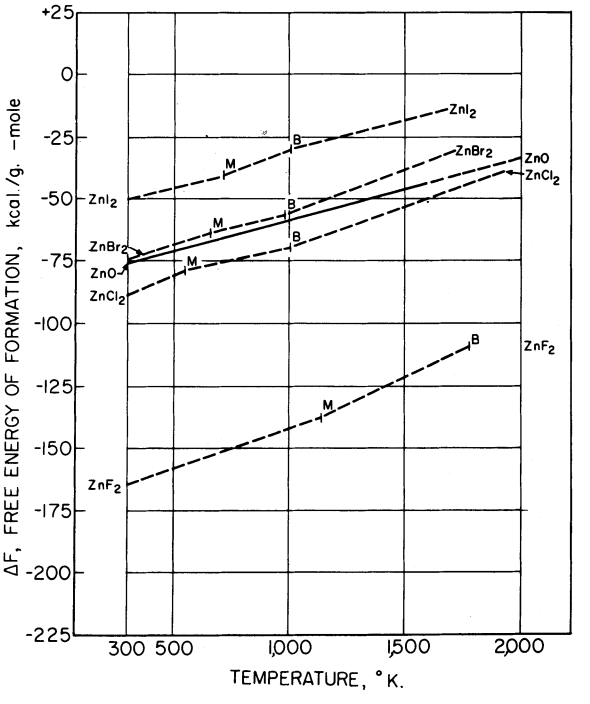

FIGURE 66.—Zinc.

ZIRCONIUM AND ITS COMPOUNDS

Element, Zr (*c*)

$T.P.=1{,}135°$ K. (*26*)
$\Delta H_T=920$ calories per atom
$M.P.=2{,}125°$ K. (*130*)
$\Delta H_M=(5{,}500)$ calories per atom

Zone I (α) (298°–1,135° K.)

$$C_p=6.83+1.12\times10^{-3}T-0.87\times10^{5}T^{-2}\ (26)$$
$$H_T-H_{298}=-2{,}380+6.83T+0.56\times10^{-3}T^2+0.87\times10^{5}T^{-1}$$
$$F_T-H_{298}=-2{,}380-6.83T\ln T-0.56\times10^{-3}T^2+0.43\times10^{5}T^{-1}+37.25T$$

Zone II (β) (1,135°–2,133° K.)

$$C_p=7.27\ (26)$$
$$H_T-H_{298}=-1{,}170+7.27T$$
$$F_T-H_{298}=-1{,}170-7.27T\ln T+38.67T$$

T, ° K.	H_T-H_{298}	S_T	$-\frac{(F_T-H_{298})}{T}$
298		9.29	9.29
400	665	11.20	9.57
500	1,350	12.73	10.02
600	2,065	14.03	10.61
700	2,800	15.17	11.14
800	3,550	16.17	11.71
900	4,315	17.07	12.29
1,000	5,095	17.89	12.80
1,100	5,895	18.65	13.28
1,200	7,560	20.11	13.82
1,300	8,290	20.69	14.28
1,400	9,015	21.23	14.85
1,500	(9,730)	(21.70)	(15.18)
1,600	(10,450)	(22.15)	(15.67)
1,700	(11,210)	(22.65)	(16.16)
1,800	(11,930)	(23.10)	(16.46)
1,900	(12,640)	(23.50)	(16.72)
2,000	(13,380)	(23.85)	(17.13)

Zirconium Dioxide, ZrO_2 (*c*)

$\Delta H^\circ_{298}=-261{,}500$ calories per mole (*24*)
$S_{298}=12.12$ *e.u.* (*83*)
$T.P.=1{,}478°$ K. (*26*)
$\Delta H_T=1{,}420$ calories per mole
$M.P.=2{,}950°$ K. (*42*)
$\Delta H_M=20{,}800$ calories per mole
$B.P.=4{,}570°$ K.

Zone I (α) (298°–1,478° K.)

$$C_p=16.64+1.80\times10^{-3}T-3.36\times10^{5}T^{-2}\ (26)$$
$$H_T-H_{298}=-6{,}160+16.64T+0.90\times10^{-3}T^2+3.36\times10^{5}T^{-1}$$

Zone II (β) (1,478°–2,100° K.)

$$C_p=17.80\ (26)$$
$$H_T-H_{298}=-4{,}267+17.80T$$

Formation: $Zr+O_2\longrightarrow ZrO_2$

Zone I (298°–1,135° K.)

$$\Delta C_p=2.65-0.32\times10^{-3}T-2.09\times10^{5}T^{-2}$$
$$\Delta H_T=-262{,}960+2.65T-0.16\times10^{-3}T^2+2.09\times10^{5}T^{-1}$$
$$\Delta F_T=-262{,}960-2.65T\ln T+0.16\times10^{-3}T^2+1.04\times10^{5}T^{-1}+65.0T$$

Zone II (1,135°–1,478° K.)

$$\Delta C_p=2.21+0.80\times10^{-3}T-2.96\times10^{5}T^{-2}$$
$$\Delta H_T=-264{,}360+2.21T+0.40\times10^{-3}T^2+2.96\times10^{5}T^{-1}$$
$$\Delta F_T=-264{,}360-2.21T\ln T-0.40\times10^{-3}T^2+1.48\times10^{5}T^{-1}+63.5T$$

Zone III (1,478°–2,100° K.)

$$\Delta C_p=3.37-1.00\times10^{-3}T+0.40\times10^{5}T^{-2}$$
$$\Delta H_T=-262{,}400+3.37T-0.50\times10^{-3}T^2-0.40\times10^{5}T^{-1}$$
$$\Delta F_T=-262{,}400-3.37T\ln T+0.50\times10^{-3}T^2-0.20\times10^{5}T^{-1}+69.44T$$

T, ° K.	H_T-H_{298}	S_T	ΔH°_T	ΔF°_T
298		12.12	−261,500	−247,750
400	1,475	16.36	−261,400	−243,100
500	3,050	19.87	−261,250	−239,450
600	4,690	22.86	−261,100	−233,900
700	6,380	25.46	−260,900	−229,400
800	8,120	27.80	−260,700	−224,900
900	9,990	29.91	−260,450	−220,450
1,000	11,730	31.82	−260,300	−216,000
1,100	13,570	33.58	−260,150	−211,550
1,200	15,420	35.19	−260,900	−207,400
1,300	17,280	36.67	−260,400	−202,800
1,400	19,150	38.06	−260,100	−198,350
1,500	22,430	40.30	(−258,500)	(−193,900)
1,600	24,210	41.45	(−258,200)	(−189,700)
1,700	25,990	42.53	(−258,050)	(−185,250)
1,800	27,770	43.55	(−257,850)	(−180,950)

Zirconium Difluoride, ZrF_2 (*c*)

$\Delta H^\circ_{298}=(-230{,}000)$ calories per mole (*11*)
$S_{298}=(21)$ *e.u.* (*11*)
$M.P.=1{,}800°$ K. (*6*)
$\Delta H_M=14{,}500$ calories per mole
$B.P.=>2{,}500°$ K. (*6*)

Formation: $Zr+F_2\longrightarrow ZrF_2$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔH°_T
298		(−230,000)	(−219,000)
500	(4,000)	(−229,000)	(−211,500)
1,000	(14,000)	(−227,500)	(−196,000)
1,500	(25,000)	(−225,000)	(−182,000)

Zirconium Trifluoride, ZrF_3 (*c*)

$\Delta H^\circ_{298}=(-350{,}000)$ calories per mole (*11*)
$S_{298}=(24)$ *e.u.* (*11*)
$M.P.=(1{,}600°)$ K. (*6*)
$\Delta H_M=(13{,}000)$ calories per mole
$B.P.=(2{,}400°)$ K. (*6*)
$\Delta H_V=(58{,}000)$ calories per mole

Formation: $Zr+3/2F_2\longrightarrow ZrF_3$ (estimated (*11*))

T, ° K.	H_T-H_{298}	ΔH°_T	ΔF°_T
298		(−350,000)	(−333,000)
500	(4,000)	(−349,500)	(−321,000)
1,000	(17,000)	(−347,000)	(−293,000)
1,500	(32,000)	(−344,000)	(−269,000)

Zirconium Tetrafluoride, ZrF_4 (*c*)

$\Delta H^\circ_{298} = (-445{,}000)$ calories per mole (*11*)
$S_{298} = (33)$ *e.u.* (*11*)
S.P. = (1,200°) K. (*6*)
$\Delta H_{subl} = (45{,}000)$ calories per mole

Formation: $Zr + 2F_2 \longrightarrow ZrF_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−445,000)	(−423,000)
500	(6,000)	(−443,500)	(−408,000)
1,000	(22,000)	(−439,800)	(−375,000)

Zirconium Dichloride, $ZrCl_2$ (*c*)

$\Delta H^\circ_{298} = (-145{,}000)$ calories per mole (*11*)
$S_{298} = (27)$ *e.u.* (*11*)
M.P. = (1,000°) K. (*6*)
$\Delta H_M = 7{,}300$ calories per mole
B.P. = (1,750°) K. (*6*)
$\Delta H_V = (35{,}000)$ calories per mole

Formation: $Zr + Cl_2 \longrightarrow ZrCl_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−145,000)	(−134,000)
500	(4,000)	(−144,000)	(−127,000)
1,000	(21,000)	(−135,000)	(−112,000)

Zirconium Trichloride, $ZrCl_3$ (*c*)

$\Delta H^\circ_{298} = (-208{,}000)$ calories per mole (*11*)
$S_{298} = (40)$ *e.u.* (*11*)
M.P. = (900°) K. (*6*)
Disproportionates above 1,000° K. (*6*)

Formation: $Zr + 3/2Cl_2 \longrightarrow ZrCl_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−208,000)	(−193,000)
500	(5,000)	(−207,000)	(−183,000)
1,000	(20,000)	(−202,000)	(−162,000)

Zirconium Tetrachloride, $ZrCl_4$ (*c*)

$\Delta H^\circ_{298} = (-230{,}000)$ calories per mole (*11*)
$S_{298} = 44.5$ *e.u.* (*83*)
S.P. = 604° K. (*6*)
$\Delta H_{subl} = 25{,}290$ calories per mole

Zone I (*c*) (298°–604° K.)

$C_p = 31.92 - 2.91 \times 10^5 T^{-2}$ (*26*)
$H_T - H_{298} = -10{,}495 + 31.92T + 2.91 \times 10^5 T^{-1}$

Formation: $Zr + 2Cl_2 \longrightarrow ZrCl_4$

Zone I (298°–604° K.)

$\Delta C_p = 7.45 - 1.24 \times 10^{-3} T - 0.68 \times 10^5 T^{-2}$
$\Delta H_T = -232{,}400 + 7.45T - 0.62 \times 10^{-3} T^2 + 0.68 \times 10^5 T^{-1}$
$\Delta F_T = -232{,}400 - 7.45 T \ln T + 0.62 \times 10^{-3} T^2 + 0.34 \times 10^5 T^{-1} + 121.27T$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		44.5	(−230,000)	(−208,750)
400	3,000	53.15	(−229,360)	(−201,400)
500	6,050	59.94	(−228,670)	(−194,550)
600	9,120	65.60	(−227,560)	(−187,450)
1,000				(−177,000)
1,500				(−164,000)
2,000				(−149,000)

Zirconium Dibromide, $ZrBr_2$ (*c*)

$\Delta H^\circ_{298} = (-120{,}000)$ calories per mole (*11*)
$S_{298} = (32)$ *e.u.* (*11*)
M.P. = (900°) K. (*6*)
B.P. = (1,500°) K. (*6*)
$\Delta H_V = (33{,}000)$ calories per mole

Formation: $Zr + Br_2 \longrightarrow ZrBr_2$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−120,000)	(−116,000)
500	(4,000)	(−127,000)	(−109,500)
1,000	(22,000)	(−117,000)	(−94,000)

Zirconium Tribromide, $ZrBr_3$ (*c*)

$\Delta H^\circ_{298} = (-174{,}000)$ calories per mole (*11*)
$S_{298} = (42)$ *e.u.* (*11*)
Disproportionates above 1,100° K. (*6*)

Formation: $Zr + 3/2Br_2 \longrightarrow ZrBr_3$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−174,000)	(−168,000)
500	(5,000)	(−185,000)	(−157,000)
1,000	(19,000)	(−181,000)	(−132,000)

Zirconium Tetrabromide, $ZrBr_4$ (*c*)

$\Delta H^\circ_{298} = (-192{,}300)$ calories per mole (*11*)
$S_{298} = (54)$ *e.u.* (*11*)
S.P. = 595° K.
$\Delta H_{subl} = 24{,}000$ calories per mole

Formation: $Zr + 2Br_2 \longrightarrow ZrBr_4$
(estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−192,300)	(−183,000)
500	(6,000)	(−206,400)	(−171,500)

Zirconium Diiodide, ZrI_2 (*c*)

$\Delta H^\circ_{298} = (-90{,}000)$ calories per mole (*11*)
$S_{298} = (35)$ *e.u.* (*11*)
M.P. = (700°) K. (*6*)
B.P. = (1,300°) K. (*6*)
$\Delta H_V = (27{,}000)$ calories per mole

Formation: $Zr + I_2 \longrightarrow ZrI_2$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−90,000)	(−89,500)
500	(4,000)	(−97,000)	(−87,000)
1,000	(22,000)	(−87,000)	(−71,000)

Zirconium Triiodide, ZrI_3 (*c*)

$\Delta H^\circ_{298} = (-128{,}000)$ calories per mole (*11*)
$S_{298} = (45)$ *e.u.* (*11*)
Disproportionates above 1,200° K. (*6*)

Formation: $Zr + 3/2I_2 \longrightarrow ZrI_3$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−128,000)	(−126,000)
500	(5,000)	(−149,000)	(−121,000)
1,000	(19,000)	(−146,000)	(− 95,000)

Zirconium Tetraiodide, ZrI_4 (*c*)

$\Delta H^\circ_{298} = (-130{,}000)$ calories per mole (*11*)
$S_{298} = (60)$ *e.u.* (*11*)
S.P. = 704° K. (*6*)
$\Delta H_{subl} = 29{,}000$ calories per mole

Formation: $Zr + 2I_2 \longrightarrow ZrI_4$ (estimated (*11*))

T, ° K.	$H_T - H_{298}$	ΔH°_T	ΔF°_T
298		(−130,000)	(−129,000)
500	(6,000)	(−158,700)	(−124,000)

Zirconium Carbide, ZrC (*c*)

$\Delta H^\circ_{298} = -44{,}100$ calories per mole (*99*)
$S_{298} = (8.5)$ *e.u.* (*94*)
$\nabla F^\circ_{298} = (-43{,}450)$ calories per mole
M.P. = 3,805° K. (*9*)

Zirconium Nitride, ZrN (*c*)

$\Delta H^\circ_{298} = -87{,}300$ calories per mole (*100*)
$S_{298} = 9.29$ *e.u.* (*83*)
M.P. = 3,255° K. (*9*)

Zone I (*c*) (298°–1,700° K.)

$$C_p = 11.0 + 1.68\times10^{-3}T - 1.72\times10^{5}T^{-2} \quad (26)$$
$$H_T - H_{298} = -3{,}930 + 11.0T + 0.84\times10^{-3}T^2 + 1.72\times10^{5}T^{-1}$$

Formation: $Zr + 1/2N_2 \longrightarrow ZrN$

Zone I (298°–1,135° K.)

$$\Delta C_p = 0.94 + 0.05\times10^{-3}T - 0.85\times10^{5}T^{-2}$$
$$\Delta H_T = -87{,}870 + 0.94T + 0.025\times10^{-3}T^2 + 0.85\times10^{5}T^{-1}$$
$$\Delta F_T = -87{,}870 - 0.94T\ln T - 0.025\times10^{-3}T^2 + 0.42\times10^{5}T^{-1} + 28.77T$$

Zone II (1,135°–1,700° K.)

$$\Delta C_p = 0.40 + 1.17\times10^{-3}T - 1.72\times10^{5}T^{-2}$$
$$\Delta H_T = -89{,}100 + 0.40T + 0.58\times10^{-3}T^2 + 1.72\times10^{5}T^{-1}$$
$$\Delta F_T = -89{,}100 - 0.40T\ln T - 0.58\times10^{-3}T^2 + 0.86\times10^{5}T^{-1} + 28.0T$$

T, ° K.	$H_T - H_{298}$	S_T	ΔH°_T	ΔF°_T
298		9.29	−87,300	−80,500
400	1,040	12.29	−87,300	−78,150
500	2,120	14.69	−87,250	−75,900
600	3,260	16.77	−87,150	−73,600
700	4,450	18.60	−87,100	−71,350
800	5,670	20.23	−87,000	−69,100
900	6,920	21.70	−86,850	−66,850
1,000	8,190	23.04	−86,750	−64,650
1,100	9,470	24.26	−86,700	−62,500
1,200	10,660	25.39	−87,550	−60,350
1,300	12,060	26.43	−87,300	−58,000
1,400	13,370	27.40	−87,100	−55,600
1,500	14,690	28.31	(−86,950)	(−53,550)
1,600	16,020	29.17	(−86,700)	(−51,300)
1,700	17,360	29.98	(−86,500)	(−49,100)

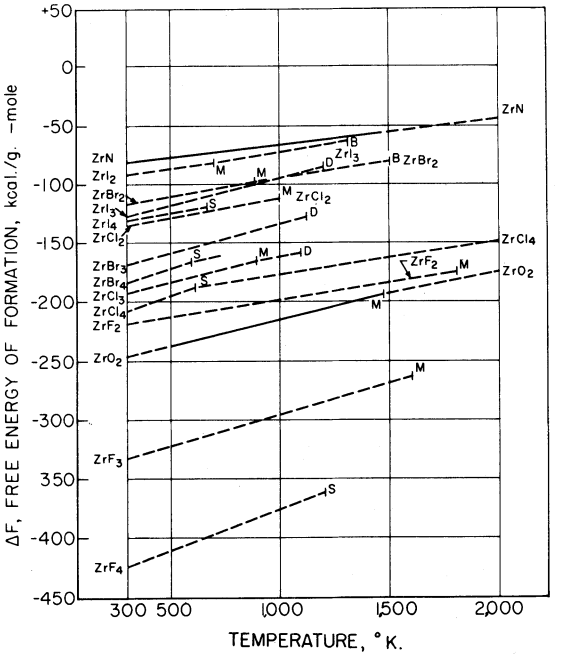

FIGURE 67.—Zirconium.

REFERENCES

1. ALTMAN, D., FARBER, M., AND MASON, D. M. Thermodynamic Properties of the Titanium Chlorides. Jour. Chem. Phys., vol. 25, 1956, p. 531.
2. BALESDENT, D. Determination of the Heats of Formation of the Oxides of Copper. Compt. rend., vol. 240, 1955, p. 1884.
3. BLOMEKE, J. O., AND ZIEGLER, W. T. Heat Content, Specific Heat and Entropy of La_2O_3, Pr_6O_{11} and Nd_2O_3 Between 30° and 900°. Jour. Am. Chem. Soc., vol. 73, 1951, p. 5099.
4. BOYLE, B. J., KING, E. G., AND CONWAY, K. C. Heats of Formation of Nickel and Cobalt Oxides (NiO and CoO) of Combustion Calorimetry. Jour. Am. Chem. Soc., vol. 76, 1954, p. 3835.
5. BREWER, L. Private Communications, 1958. Available for inspection at the Albany Metallurgy Research Center, Bureau of Mines, Albany, Oreg.
6. ———. Fusion and Vaporization Data of the Halides. Paper 7 in National Nuclear Energy Series IV, vol. 19B, Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics, by L. L. Quill. McGraw-Hill Book Co., Inc., New York, N.Y., 1950, p. 193.
7. ———. Thermodynamic and Physical Properties of the Elements. Paper 3 in National Nuclear Energy Series IV, vol. 19B, Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics, by L. L. Quill. McGraw-Hill Book Co., Inc., New York, N.Y., 1950, p. 13.
8. ———. Thermodynamic Properties of the Oxides and Their Vaporization Processes. Chem. Reviews, vol. 52, 1953, p. 1.
9. BREWER L., BROMLEY, L. A., GILLES, P. W., AND LOFGREN, N. L. Thermodynamic and Physical Properties of Nitrides, Carbides, Sulfides, Silicides and Phosphides. Paper 4 in National Nuclear Energy Series IV, vol. 19B, Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics, by L. L. Quill. McGraw-Hill Book Co., Inc., New York, N.Y., 1950, p. 40.
10. ———. Thermodynamic Properties and Equilibria at High Temperatures of Uranium Halides, Oxides, Nitrides, and Carbides. AEC MDDC–1543, Sept. 20, 1945, 84 pp.
11. ———. Thermodynamic Properties of the Halides. Paper 6 in National Nuclear Energy Series IV, vol. 19B, Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics, by L. L. Quill. McGraw-Hill Book Co., Inc., New York, N.Y., 1950, p. 76.
12. ———. Thermodynamic Properties of Molybdenum and Tungsten Halides and the Use of These Metals as Refractories. Paper 8 in National Nuclear Energy Series IV, vol. 19B, Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics, by L. L. Quill. McGraw-Hill Book Co., Inc., New York, N.Y., 1950, p. 276.
13. BREWER, L., AND SEARCY, A. W. Gaseous Species of the Al-Al_2O_3 System. Jour. Am. Chem. Soc., vol. 73, 1951, p. 5308.
14. BRITZKE, E. V., KAPUSTINSKII, A. F., AND CHENZOVA, L. G. Die Affintat von Metallen zu Schwefel, III Mitteilung. Verbrennungs und Bildungswarmen von Sulfide von Arsen und der Verbindungen As_2O_3, As_2O_5 and As_2O_3, SO_3. Ztschr. anorg. allgem. Chem., vol. 213, 1933, p. 58.
15. BRÖNSTED, J. N. Untersuchungen über die Spezifiche Wärme. I. Ztschr. Elektrochem., vol. 18, 1912, p. 714.
16. BUSEY, R. H., AND GIAUQUE, W. F. Heat Capacity of Anhydrous $NiCl_2$ From 15° to 300° K. The Antiferromagnetic Anomaly Near 52° K. Entropy and Free Energy. Jour. Am. Chem. Soc., vol. 74, 1952, p. 4443.
17. ———. Heat Capacity of Nickel From 15° to 300° K. Entropy and Free Energy Functions. Jour. Am. Chem. Soc., vol. 74, 1952, p. 3157.
18. CATALANO, E., AND STOUT, J. W. Heat Capacity and Entropy of FeF_2 and CoF_2 From 11° to 300° K. The Thermal Anomalies Associated With Antiferromagnetic Ordering. Jour. Chem. Phys., vol. 23, 1955, p. 1803.
19. ———. Heat Capacity of NiF_2 From 12° to 300° K. Thermodynamic Functions of NiF_2. The Thermal Anomaly Associated With the Antiferromagnetic Ordering. Jour. Chem. Phys., vol. 23, 1955, p. 1284.
20. COOPER, C. B. Precision Measurements of the Enthalpy of KB_r and KI at High Temperatures. Jour. Chem Phys., vol. 21, 1953, p. 777.
21. CORBETT, J. D., AND GREGORY, N. W. AlI_3–HCl–$AlCl_3$–HI System. The Free Energy of Formation of Aluminum Iodide. Jour. Am. Chem. Soc., vol. 76, 1954, p. 1446.
22. COSGROVE, L. A., AND SNYDER, P. E. Heat of Formation of Beryllium Oxide. Jour. Am. Chem. Soc., vol. 75, 1953, p. 3102.
23. ———. High Temperature Thermodynamic Properties of Molybdenum Trioxide. Jour. Am. Chem. Soc., vol. 75, 1953, p. 1227.
24. COUGHLIN, J. P. Contributions to the Data on Theoretical Metallurgy. XII. Heats and Free Energies of Formation of Inorganic Oxides. Bureau of Mines Bull. 542, 1954, 80 pp.
25. ———. High Temperature Heat Contents of Nickel Chloride. Jour. Am. Chem. Soc., vol. 73, 1951, p. 5314.
26. COUGHLIN, J. P., AND KING, E. G. High-Temperature Heat Contents of Some Zirconium-Containing Substances. Jour. Am. Chem. Soc., vol. 72, 1950, p. 2262.
27. COUGHLIN, J. P., KING, E. G., AND BONNICKSON, K. R. High Temperature Heat Contents of Ferrous Oxide, Magnetite, and Ferric Oxide. Jour. Am. Chem. Soc., vol. 73, 1951, p. 3891.
28. CRAIG, R. S., KRIER, C. A., COFFER, L. W., BATES, E. A., AND WALLACE, W. E. Magnesium-Cadmium Alloys. VI. Heat Capacities Between 12 and 320° K. and the Entropies at 25° C. of Magnesium and Cadmium. Jour. Am. Chem. Soc., vol. 76, 1954, 238.

29. DAANE, A. H. Private Communications, 1959. Available for inspection at the Albany Metallurgy Research Center, Bureau of Mines, Albany, Oreg.
30. DARKEN, L. S., AND GURRY, R. W. System Iron-Oxygen. II. Equilibrium and Thermodynamics of Liquid Oxide and Other Phases. Jour. Am. Chem. Soc., vol. 68, 1946, p. 799.
31. DE SORBO, W. Heat Capacity of Chromium Carbide (Cr_3C_2) From 13° to 300° K. Jour. Am. Chem. Soc., vol. 75, 1953, p. 1825.
32. DOUGLAS, T. B., BALL, A. F., GINNINGS, D. C., AND DAVIS, W. D. Heat Capacity of Potassium and Three Potassium-Sodium Alloys Between 0° and 800°, the Triple Point and Heat of Fusion of Potassium. Jour. Am. Chem. Soc., vol. 74, 1952, p. 2472.
33. DWORKIN, A. S., SASMOR, D. J., AND VAN ARTSDALEN, E. R. Thermodynamics of Boron Nitride; Low-Temperature Heat Capacity and Entropy; Heats of Combustion and Formation. Jour. Chem. Phys., vol. 22, 1954, p. 837.
34. EVANS, W. H., JACOBSON, R., MUNSON, T. R., AND WAGMAN, D. D. Thermodynamic Properties of the Alkali Metals. Nat. Bureau of Standards Res. Jour., vol. 55, 1955, RP 2608, p. 83.
35. FARBER, M., AND DARNELL, A. J. Heat of Formation and Entropy of Titanium Tetrachloride From an Investigation of the Equilibrium: $TiO_2(s) + 4HCl(g) = TiCl_4(g) + 2H_3O(g)$. Jour. Chem. Phys., vol. 23, 1955, p. 1460.
36. FOLEY, W. T., AND GIGUERE, P. A. Hydrogen Peroxide and Its Analogs. IV. Some Thermal Properties of Hydrogen Peroxide. Canadian Jour. Chem., vol. 29, 1951, p. 895.
37. GEBALLE, T. H., AND GIAUQUE, W. F. Heat Capacity and Entropy of Gold From 15° to 300° K. Jour. Am. Chem. Soc., vol. 74, 1952, p. 2368.
38. GIAUQUE, W. F., AND JONES, W. M. Carbonyl Chloride, Entropy, Heat Capacity. Vapor Pressure, Heats of Fusion and Vaporization. Comments on Solid Sulfur Dioxide Structure. Jour. Am. Chem. Soc., vol. 70, 1948, p. 120.
39. GIGUERE, P. A., LIU, I. D., DUGDALE, J. S., AND MORRISON, J. A. Hydrogen Peroxide: The Low-Temperature Heat Capacity of the Solid and the Third Law Entropy. Canadian Jour. Chem., vol. 32, 1954, p. 117.
40. GILLES, P. W., AND MARGRAVE, J. L. Heats of Formation of Na_2O_2, NaO_2 and KO_2. Jour. Phys. Chem., vol. 60, 1956, p. 1333.
41. GINNINGS, D. C., DOUGLAS, T. B., AND BALL, A. F. Heat Capacity of Sodium Between 0° and 900° C., the Triple Point and Heat of Fusion. Nat. Bureau of Standards Res. Jour., vol. 45, 1950, RP 2110, p. 23.
42. GLASSNER, A. Thermochemical Properties of the Oxides, Fluorides, and Chlorides to 2500° K. Argonne Nat. Lab., ANL–5750, 1957, 70 pp.
43. GRAY, P., AND WADDINGTON, T. C. Thermochemistry and Reactivity of the Azides. I. Thermochemistry of the Inorganic Azides. Proc. Royal Soc. (London), Math. and Phys. Sci., vol. 235A, 1956, p. 106.
44. GREENBERG, E., AND WESTRUM, E. F., JR. Heat Capacity and Thermodynamic Functions of Uranium (IV) Oxychloride and Uranium (IV) Oxybromide From 10° to 350° K. Jour. Am. Chem. Soc., vol. 78, 1956, p. 5144.
45. ———. Heat Capacity and Thermodynamic Functions of Uranyl Chloride From 6° to 350° K. Jour. Am. Chem. Soc., vol. 78, 1956, p. 4526.
46. GRIFFEL, M., AND SKOCHDOPOLE, R. E. The Heat Capacity and Entropy of Thorium From 18° to 300° K. Jour. Am. Chem. Soc., vol. 75, 1953, p. 5250.
47. GRIFFEL, M., SKOCHDOPOLE, R. E., AND SPEDDING, F. H. The Heat Capacity of Dysprosium From 15° to 300° K. Jour. Chem. Phys., vol. 25, 1956, p.75.
48. GROSS, P., HAYMAN, C., AND LEVI, D. L. Heats of Formation of Metallic Halides. Titanium Tetrachloride. Trans. Faraday Soc., vol. 51, 1955, p. 626.
49. GROSS, P., HAYMAN, C., LEVI, D. L., AND WILSON, G. Studies and Experimental Investigations in the Field of Measurements of the Heat or Free Energy of Formation of the Chlorides and Bromides of Niobium and Tantalum. Fulmer Research Inst., Ltd., Bucks, England, R–115/5/23, NP–7847, 1959, 44 pp.
50. GUNTZ, M. Heats of Formation of Barium Compounds. Compt. rend., vol. 136, 1903, p. 1071.
51. HARRISON, E. R. Vapor Pressures of Some Rare-Earth Halides. Jour. Applied Chem. (London), vol. 2, 1952, p. 601.
52. HOEKSTRA, H. R., AND KATZ, J. J. Chemistry of Uranium. Ch. 6 in The Actinide Elements, by G. T. Seaborg and J. J. Katz. McGraw-Hill Book Co., Inc., New York, N.Y., 1954, p. 130.
53. HOLLEY, C. E., JR., AND HUBER, E. J., JR. Heats of Combustion of Magnesium and Aluminum. Jour. Am. Chem. Soc., vol. 73, 1951, p. 5577.
54. HORNING, R. Private Communications, 1957. Available for inspection at the Albany Metallurgy Research Center, Bureau of Mines, Albany, Oreg.
55. HU, J. H., AND JOHNSTON, H. L. Low Temperature Heat Capacities of Inorganic Solids. XII. Heat Capacity and Thermodynamic Properties of Cuprous Bromide From 16° to 300° K. Jour. Am. Chem. Soc., vol. 74, 1952, p. 4771.
56. ———. Low Temperature Heat Capacities of Inorganic Solids. XVI. Heat Capacity of Cupric Oxide From 15° to 300° K. Jour. Am. Chem. Soc., vol. 75, 1953, p. 2471.
57. HUBER, E. J., JR., AND HOLLEY, C. E., JR. Heat of Combustion of Calcium. Jour. Phys. Chem., vol. 60, 1956, p. 498.
58. ———. Heat of Combustion of Cerium. Jour. Am. Chem. Soc., vol. 75, 1953, p. 5645.
59. ———. Heat of Combustion of Gadolinium. Jour. Am. Chem. Soc., vol. 75, 1953, p. 1444.
60. ———. Heat of Combustion of Lanthanum. Jour. Am. Chem. Soc., vol. 75, 1953, p. 3594.
61. ———. Heat of Combustion of Neodymium. Jour. Am. Chem. Soc., vol. 74, 1952, p. 5530.
62. ———. Heat of Combustion of Yttrium. Jour. Phys. Chem., vol. 61, 1957, p. 497.
63. HUBER, E. J., JR., HOLLEY, C. E., JR., AND MEIERKORD, E. H. Heats of Combustion of Thorium and Uranium. Jour. Am. Chem. Soc., vol. 74, 1952, p. 3406.
64. HUBER, E. J., JR., MATTHEWS, C. O., AND HOLLEY, C. E., JR. Heat of Combustion of Samarium. Jour. Am. Chem. Soc., vol. 77, 1955, p. 6493.
65. HUFF, G., SQUITIERE, E., AND SNYDER, P. E. Heat of Formation of Tungstic Oxide, WO_3. Jour. Am. Chem. Soc., vol. 70, 1948, p. 3380.
66. HUMPHREY, G. L. Heats of Formation of Hafnium Oxide and Hafnium Nitride. Jour. Am. Chem. Soc., vol. 75, 1953, p. 2806.
67. ———. Heats of Formation of Tantalum, Niobium and Zirconium Oxides, and Tantalum Carbide. Jour. Am. Chem. Soc., vol. 76, 1954, p. 978.
68. ———. Heats of Formation of TiO, Ti_2O_3, Ti_3O_5, and TiO_2 From Combustion Calorimetry. Jour. Am. Chem. Soc., vol. 73, 1951, p. 1587.
69. HUMPHREY, G. L., AND KING, E. G. Heats of Formation of Quartz and Cristobalite. Jour. Am. Chem. Soc., vol. 74, 1952, p. 2041.

70. Humphrey, G. L., King, E. G., and Kelley, K. K. Some Thermodynamic Values of Ferrous Oxide. Bureau of Mines Rept. of Investigations 4870, 1952, 16 pp.
71. Humphrey, G. L., and O'Brien, C. J. Heats of Formation of Stannic and Stannous Oxides From Combustion Calorimetry. Jour. Am. Chem. Soc., vol. 75, 1953, p. 2805.
72. Humphrey, G. L., Todd, S. S., Coughlin, J. P., and King, E. G. Some Thermodynamic Properties of Silicon Carbide. Bureau of Mines Rept. of Investigations 4888, 1952, 23 pp.
73. Hüttig, G. F., and Slonim, Ch. Die Spezifischen Wärmen, Bildungswärmen und Zersetzungsdrucke der Strontiumhalogenidhydrate. Ztsch. anorg. allgem. Chem., vol. 181, 1929, p. 65.
74. Hüttig, G. F., and Wehling, W. Zur Kenntnis der Spezisfichen Wärmen Homogener Phasen, an deren Aufbau Wasser beteiligtist. Kolloidchem. Beihefte, vol. 23, 1926, p. 354.
75. Johnston, H. L., and Bauer, T. W. Low Temperature Heat Capacities of Inorganic Solids. VII. Heat Capacity and Thermodynamic Functions of Li_2O. Thermodynamics of the Li_2O–H_2O System. Jour. Am. Chem. Soc., vol. 73, 1951, p. 1119.
76. Johnston, H. L., Hersch, H. N., and Kerr, E. C. Low-Temperature Heat Capacities of Inorganic Solids. V. The Heat Capacity of Pure Elementary Boron in Both Amorphous and Crystalline Conditions Between 13° and 305° K. Some Free Energies of Formation. Jour. Am. Chem. Soc., vol. 73, 1951, p. 1112.
77. Jones, W. M., Gordon, J., and Long, E. A. The Heat Capacities of Uranium, Uranium Trioxide, and Uranium Dioxide From 15° K to 300° K. Jour. Chem. Phys., vol. 20, 1952, p. 695.
78. Kelley, K. K. Private Communication, 1959. Available for inspection at the Albany Metallurgy Research Center, Bureau of Mines, Albany, Oreg.
79. ———. Contributions to the Data on Theoretical Metallurgy. III. The Free Energies of Vaporization and Vapor Pressures of Inorganic Substances. Bureau of Mines Bull. 383, 1935, 132 pp.
80. ———. Contributions to the Data on Theoretical Metallurgy. V. Heats of Fusion of Inorganic Substances. Bureau of Mines Bull. 393, 1936, 166 pp.
81. ———. Contributions to the Data on Theoretical Metallurgy. VIII. The Thermodynamic Properties of Metal Carbides and Nitrides. Bureau of Mines Bull. 407, 1937, 66 pp.
82. ———. Contributions to the Data on Theoretical Metallurgy. X. High Tempertaure Heat-Content, Heat-Capacity, and Entropy Data for Inorganic Compounds. Bureau of Mines Bull. 476, 1949, 241 pp.
83. ———. Contributions to the Data on Theoretical Metallurgy. XI. Entropies of Inorganic Substances. Revision (1948) of Data and Methods of Calculation. Bureau of Mines Bull. 477, 1950, 147 pp.
84. ———. Contributions to the Data on Theoretical Metallurgy. XIII. High-Temperature Heat-Content, Heat-Capacity, and Entropy Data for the Elements and Inorganic Compounds. Bureau of Mines Bull. 584, 1960, 232 pp.
85. ———. Thermodynamic Properties of Zirconium Compounds. Ch. 4 in National Nuclear Energy Series 7, vol. 4, Metallurgy of Zirconium, by B. Lustman and F. Kerze, Jr. McGraw-Hill Book Co., Inc., New York, N.Y., 1955, p. 59.
86. Kelley, K. K., and Mah, A. D. Metallurgical Thermochemistry of Titanium. Bureau of Mines Rept. of Investigations 5490, 1959, 48 pp.
87. Kerr, E. C., Johnston, H. L., and Hallett, N. C. Low Temperature Heat Capacities of Inorganic Solids. III. Heat Capacity of Aluminum Oxide (Synthetic Sapphire) From 19° to 300° K. Jour. Am. Chem. Soc., vol. 72, 1950, p. 4740.
88. King, E. G. Heat Capacities at Low Temperature and Entropies at 298.15° K. of Nickelous Oxide, Cobaltous Oxide and Cobalt Spinel. Jour. Am. Chem. Soc., vol. 79, 1957, p. 2399.
89. ———. Low Temperature Heat Capacities and Entropies at 298.15° K. of Lead Sesquioxide and Red and Yellow Lead Monoxide. Jour. Am. Chem. Soc., vol. 80, 1958, p. 2400.
90. ———. Low Temperature Heat Capacities and Entropies at 298.16° K. of Manganese Sesquioxide and Niobium Pentoxide. Jour. Am. Chem. Soc., vol. 76, 1954, p. 3289.
91. King, E. G., and Christensen, A. U., Jr. Heat Contents Above 298.15° K. of Oxides of Cobalt and Nickel. Jour. Am. Chem. Soc., vol. 80, 1958, p. 1800.
92. Koehler, M. F., and Coughlin, J. P. Heats of Formation of Ferrous Chloride, Ferric Chloride and Manganous Chloride. Jour. Phys. Chem., vol. 63, 1959, p. 605.
93. Kubaschewski, O., Brizgys, P., Huchler, O., Jauch, R., and Reinartz, K. Heats of Fusion and Transformation of Metals. Ztschr. Elektrochem., vol. 54, 1950, p. 275.
94. Kubaschewski, O., and Evans, E. L. International Series of Monographs on Metal Physics and Physical Metallurgy. Metallurgical Thermochemistry. Pergamon Press, New York, N.Y., vol. 1, 3d ed., 1958, 426 pp.
95. Lander, J. J. Experimental Heat Contents of SrO, BaO, CaO, $BaCO_3$, and $SrCO_3$ at High Temperatures. Dissociation Pressures of $BaCO_3$ and $SrCO_3$. Jour. Am. Chem. Soc., vol. 73, 1951, p. 5794.
96. Machlan, G. R., Stubblefield, C. T., and Eyring L. Heats of Reaction of the Dichlorides of Samarium and Ytterbium With Hydrochloric Acid. A Microcalorimeter. Jour. Am. Chem. Soc., vol. 77, 1955, p. 2975.
97. Mah, A. D. Heats of Combustion and Formation of Two Manganese Nitrides, Mn_5N_2 and Mn_4N. Jour. Am. Chem. Soc., vol. 80, 1958, p. 2954.
98. ———. Heats of Formation of Chromium Oxide and Cadmium Oxide From Combustion Calorimetry. Jour. Am. Chem. Soc., vol. 76, 1954, p. 3363.
99. Mah, A. D., and Boyle, B. J. Heats of Formation of Niobium Carbide and Zirconium Carbide From Combustion Calorimetry. Jour. Am. Chem. Soc., vol. 77, 1955, p. 6512.
100. Mah, A. D., and Gellert, N. L. Heats of Formation of Niobium Nitride, Tantalum Nitride and Zirconium Nitride From Combustion Calorimetry. Jour. Am. Chem. Soc., vol. 78, 1956, p. 3261.
101. Masi, J. F. Heats of Vaporization of Uranium Hexafluoride. Jour. Chem. Phys., vol. 17, 1949, p. 755.
102. Mitchell, D. W. Heat Contents and Heat of Formation of Magnesium Nitride. High-Temperature Measurements. Ind. Eng. Chem., vol. 41, 1949, p. 2027.
103. Murphy, G. M., and Rubin, E. L. Thermodynamic Calculations on Some Equilibria Between Alkaline Earth Fluorides and Hydrogen Fluoride. AEC NYO–3505, July 24, 1952, 21 pp.
104. Nikol'ski, G. P., Kazarnovskaya, L. I., Bagdasar'yan, Z. A., and Kazarnovskii, I. A. Heat of Formation of Potassium Ozonide and Electron Affinity of the Ozone Molecule. Doklady Akad. Nauk U.S.S.R., vol. 72, 1950, p. 713.

105. ORR, R. L. High Temperature Heat Contents of Hafnium Dioxide and Hafnium Tetrachloride. Jour. Am. Chem. Soc., vol. 75, 1953, p. 1231.
106. ———. High Temperature Heat Contents of Manganese Sesquioxide and Vanadium Monoxide. Jour. Am. Chem. Soc., vol. 76, 1954, p. 857.
107. ORR, R. L. High-Temperature Heat Contents of Tantalum and Niobium Oxides. Jour. Am. Chem. Soc., vol. 75, 1953, p. 2808.
108. OSBORNE, D. W., WESTRUM, E. F., JR., AND LOHR, H. R. Heat Capacity of Uranium Tetrafluoride From 5° to 300° K. Jour. Am. Chem. Soc., vol. 77, 1955, p. 2737.
109. PARKINSON, D. H., SIMON F. E., AND SPEDDING, F. H. The Atomic Heats of the Rare Earth Elements. Proc. Roy Soc. (London), vol. 207–A, 1951, p. 137.
110. REGNAULT, V. Untersuchungen über die spezifische Wärme einfacher und zusammengesetzter Körper. Poggendorf's Ann., vol. 53, 1841, p. 61.
111. ROBERTS, E. J., AND FENWICK, F. Antimony-Antimony Trioxide Electrode and Its Use as a Measure of Acidity. Jour. Am. Chem. Soc., vol. 50, 1928, p. 2125.
112. ROSSINI, F. D., WAGMAN, D. D., EVANS, W. H., LEVINE, S., AND JAFFE, I. Selected Values of Chemical Thermodynamic Properties. Nat. Bureau of Standards Circ. 500, 1952, 1266 pp.
113. SCHUHMANN, R. Free Energy of Antimony Trioxide and the Reduction Potential of Antimony. Jour. Am. Chem. Soc., vol. 46, 1924, p. 52.
114. ———. Free Energy and Heat Content of Arsenic Trioxide and the Reduction Potential of Arsenic. Jour. Am. Chem. Soc., vol. 46, 1924, p. 1444.
115. SHOMATE, C. H. Heats of Formation of Manganomanganic Oxide and Manganese Dioxide. Jour. Am. Chem. Soc., vol. 65, 1943, p. 785.
116. SHOMATE, C. H., AND COHEN, A. J. High-Temperature Heat Content and Entropy of Lithium Oxide and Lithium Hydroxide. Jour. Am. Chem. Soc., vol. 77, 1955, p. 285.
117. SHOMATE, C. H., AND HUFFMAN, E. H. Heats of Formation of MgO, $MgCl_2$, $MgCl_2$, H_2O, $MgCl_2 \cdot 2H_2O$, $MgCl_2 \cdot 4H_2O$ and $MgCl_2 \cdot 6H_2O$. Jour. Am. Chem. Soc., vol. 65, 1943, p. 1625.
118. SIMS, C. T., CRAIGHEAD, C. M., AND JAFFE, R. I. Physical and Mechanical Properties of Rhenium. Jour. Metals, vol. 7, 1955, p. 168.
119. SKINNER, G. B., AND JOHNSTON, H. L. Low Temperature Heat Capacities of Inorganic Solids. VIII. Heat Capacity of Zirconium From 14° to 300°K. Jour. Am. Chem. Soc., vol. 73, 1951, p. 4549.
120. SKINNER, H. A., AND SMITH, N. B. Heat of Hydrolysis of Boron Tribromide. Trans. Faraday Soc., vol. 51, 1955, p. 19.
121. SKOCHDOPOLE, R. E., GRIFFEL, M., AND SPEDDING, F. H. Heat Capacity of Erbium From 15° to 320° K. Jour. Chem. Phys., vol. 23, 1955, p. 2258.
122. SMITH, D., DWORKIN, A. S., AND VAN ARTSDALEN, E. R. Heats of Combustion and Formation of Boron Carbide. Jour. Am. Chem. Soc., vol. 77, 1955, p. 2654.
123. SMITH, W. T., JR., OLIVER, G. D., AND COBBLE, J. W. Thermodynamic Properties of Technetium and Rhenium Compounds. IV. Low Temperature Heat Capacity and Thermodynamics of Rhenium. Jour. Am. Chem. Soc., vol. 75, 1953, p. 5785.
124. SOUTHARD, J. C., AND SHOMATE, C. H. Heats of Formation and High-Temperature Heat Contents of Manganous Oxide and Manganous Sulfate. High-Temperature Heat Content of Manganese. Jour. Am. Chem. Soc., vol. 64, 1942, p. 1770.
125. SPEDDING, F. H. Private Communications, 1956. Available for inspection at the Albany Metallurgy Research Center, Bureau of Mines, Albany, Oreg.
126. SPEDDING, F. H., AND DAANE, A. H. Production of Rare Earth Metals in Quantity Allows Testing of Physical Properties. Jour. Metals, vol. 6, 1954, p. 504.
127. SPEDDING, F. H., AND FLYNN, J. P. Thermochemistry of the Rare Earths. II. Lanthanum, Praseodymium, Samarium, Gadolinium, Erbium, Ytterbium and Yttrium. Jour. Am. Chem. Soc., vol. 76, 1959, p. 1474.
128. SPEDDING, F. H., AND MILLER, C. F. Thermochemistry of Rare Earths. I. Cerium and Neodymium. Jour. Am. Chem. Soc., vol. 74, 1952, p. 4195.
129. STUBBLEFIELD, C. T., EICK, H., AND EYRING, L. Praseodymium Oxides. III. Heats of Formation of Several Oxides. Jour. Am. Chem. Soc., vol. 78, 1956, p. 3018.
130. STULL, D. R., AND SINKE, G. C. Thermodynamic Properties of the Elements. Am. Chem. Soc., Washington, D.C., 1956, 233 pp.
131. SUZUKI, S. Thermodynamic Studies of Cuprous Azide. Jour. Chem. Soc. (Japan), vol. 74, 1953, p. 269.
132. TODD. S, S. Heat Capacities at Low Temperatures and Entropies at 298.16° K. of Hafnium Dioxide and Hafnium Tetrachloride. Jour. Am. Chem. Soc., vol. 75, 1953, p. 3055.
133. ———. Heat Capacities at Low-Temperatures and Entropies at 298.16° K. of Sodium Superoxide, Potassium Superoxide, and Sodium Peroxide. Jour. Am. Chem. Soc., vol. 75, 1953, p. 1229.
134. ———. Heat Capacities at Low-Temperatures and Entropies of Magnesium and Calcium Fluorides. Jour. Am. Chem. Soc., vol. 71, 1949, p. 4115.
135. TODD, S. S., AND BONNICKSON, K. R. Low-Temperature Heat Capacities and Entropies at 298.16° K. of Ferrous Oxide, Manganous Oxide, and Vanadium Monoxide. Jour. Am. Chem. Soc., vol. 73, 1951, p. 3894.
136. TODD, S. S., AND COUGHLIN, J. P. Low-Temperature Heat Capacity, Entropy at 298.16° K, and High-Temperature Heat Content of Ferric Chloride. Jour. Am. Chem. Soc., vol. 73, 1951, p. 4184.
137. UDY, M. C., AND BOULGER, F. W. Properties of Beryllium Oxide. AEC BMI–T–18, 1949, 28, pp.
138. UDY, M. C., SHAW, H. L., AND BOULGER, F. W. Properties of Beryllium. Nucleonics, vol. 11, May 1953, p. 52.
139. VEDENEEV, A. V., KAZARNOVSKAYA, L. I., AND KAZARNOVSKII, I. A. Heats of Formation of Barium, Strontium, and Calcium Peroxides, and the Affinity of the Oxygen Molecule for Two Electrons. Zhur. Fiz. Khim., vol. 26, 1952, p. 1808.
140. WACKER, P. F., AND CHENEY, R. K. Specific Heat, Enthalpy, and Entropy of Uranyl Fluoride. Nat. Bureau of Standards Res. Jour., vol. 39, 1947, RP 1832, p. 317.
141. WHITE, J. L., ORR, R. L., AND HULTGREN, R. Selected Values for the Thermodynamic Properties of Metals and Alloys. Minerals Research Laboratory Reports. Institute of Eng. Res., Berkeley, Calif., 1956 and supplements.

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