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CONTRIBUTIONS TO THE DATA ON THEORETICAL METALLURGY

XI. Entropies of Inorganic Substances. Revision (1948) of Data and Methods of Calculation

By

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CONTRIBUTIONS TO THE DATA ON THEORETICAL METALLURGY

XI. Entropies of Inorganic Substances. Revision (1948) of Data and Methods of Calculation[1]

By K. K. KELLEY[2]

INTRODUCTION

The first bulletin (*269*)[3] in this series, which appeared in 1932, compiled the entropy values then available for the elements and inorganic compounds, results being listed for some 150 substances. Elaborations and revisions followed in 1936 (*272*) and 1941 (*280*), when over 500 usable entropy values were tabulated. The present bulletin constitutes a further elaboration and revision. The accumulation of data since 1940 has been marked, and 800 entropy values now are available.

The present bulletin also contains all the pertinent explanatory matter that appeared in its predecessors. Thus, it retains the same dual purpose of assembling the available values of the entropies at 298.16° K. of the elements and inorganic compounds and giving enough explanation of methods of calculating entropies to make the results comprehensible.

VALUE OF ENTROPY DATA

In the study of chemical and metallurgical reactions the two factors of predominant importance are the free energy of reaction and the rate of reaction. Although entropy data sometimes are of value in the study of reaction rates—a subject best treated by the methods of statistical mechanics—this matter will not be discussed here. By far the greatest value of entropy data is their usage in the derivation of reaction free energies. Knowlege of the free energy of reaction is adequate for determining whether or not the reaction will occur and, if it will, to what extent it will proceed under the conditions that may be imposed by practical considerations. Metallurgists have been slower than chemists in adopting thermodynamic methods of study, possibly because the labor involved in obtaining adequate free-energy data usually is irksome and sometimes may appear to be an indirect approach to the problem at hand. However, failure to consider

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[3] Italicized numbers in parentheses refer to citations in the bibliography at the end of this bulletin; page numbers refer to the citation and not to this bulletin.

available thermodynamic data sometimes has been expensive and is to be deplored.

Four general methods are available for obtaining free-energy changes accompanying reactions:

1. The reaction equilibrium may be studied, in which instance the reaction free energy is given by (*335*):

$$\Delta F^\circ_T = -R\,T\ln K, \qquad (1)$$

in which ΔF°_T is the standard free-energy change at the temperature $T^\circ K.$, R is the gas constant per mole, and $\ln K$ is the natural logarithm of the equilibrium constant.

2. The reaction may be allowed to take place reversibly in a galvanic cell and the electromotive force measured. Then (*335*),

$$\Delta F^\circ_T = -nf\epsilon^\circ, \qquad (2)$$

in which n is the number of chemical equivalents involved, ϵ° is the standard electromotive force of the cell, and f is Faraday's constant.

3. The free energy may be obtained in the form $\Delta F^\circ_T - \Delta H^\circ_0$ directly from spectroscopic data by methods analogous to those discussed later for calculating entropies. This method alone is applicable at present only to reactions for which all the reactants and products are gases. In conjunction with other methods, however, it often is useful for reactions in which at least one reactant or product is a gas. In either case data other than spectroscopic ordinarily are required for evaluating ΔH°_0.

4. Use may be made of the expression for the second law of thermodynamics (*335*),

$$\Delta F^\circ_T = \Delta H^\circ_T - T\Delta S^\circ_T, \qquad (3)$$

in which ΔH°_T is the heat of reaction and ΔS°_T is the entropy of reaction, both at temperature $T^\circ K$.

Only a few reactions have been made to take place in reversible cells free from objectionable features; and, generally, experimental difficulties at high temperatures almost preclude adequate equilibrium measurements for many reactions of greatest metallurgical interest. These and the limitations already indicated for method (3) mean that, in the great majority of instances, method (4) is the only one available. Consequently, it is not surprising that several times as many free-energy values have been obtained from method (4) as from the other three methods combined. The evaluation of entropies for this usage is therefore a problem of considerable importance.

METHODS OF CALCULATING ENTROPIES FROM EXPERIMENTAL DATA

CALCULATIONS BASED UPON LOW-TEMPERATURE HEAT-CAPACITY DATA

Of the various methods of obtaining entropies that based upon low-temperature heat-capacity data is of greatest importance. This method is intimately connected with the third law of thermodynamics. As the substances to be considered by this method are, with one exception, crystalline at low temperatures, the discussion is restricted to this field. It is recognized, of course, that crystals usually are solutions of isotopes; but this need not be considered, as the corresponding entropy effect balances out in chemical reactions, excluding phenomena that may occur with substances containing comparable amounts of light and heavy hydrogen. Moreover, it is not considered necessary to trace the early history of the third law. It will suffice to say that for several years the statement of this principle generally accepted was that given by Lewis and Gibson (*332*) in 1920:

> If the entropy of each element in some crystalline form be taken as zero at the absolute zero, the entropy of any pure crystal at the absolute zero is zero, and the entropy of any other substance is greater than zero.

So far as crystalline substances are concerned, this statement may still be used, provided the definition of "pure crystal" is made stringent enough. It does not suffice that a substance be chemically pure and be in a well-defined macrocrystalline form as the absolute zero is approached, but certain ideas of "internal purity" also must be included. There must be no randomness of position of the constituent atoms, ions, or groups in the crystal such as Pauling (*385*) has discussed for the magnetic form of ferric oxide and other substances or such as are thought to exist in ordinary crystals of carbon monoxide (*73*, *74*) and nitrous oxide (*47*), to be mentioned later. There must be no randomness of position or orientation of bonds, such as Pauling (*385*) has discussed for ice crystals and for which the effects on the application of the third law have been demonstrated experimentally (*187*, *339*). There must be no "freezing-in" of a high-temperature equilibrium, such as is known to occur in the case of ordinary hydrogen crystals (*171*). The inclusion of these and other qualifying conditions would maintain the correctness of Lewis and Gibson's statement. That such qualifications may include more than was originally intended by their statement is no argument against the validity of the principle involved. In fact, modification and extension of definitions are the common methods by which so-called laws of nature are maintained in a currently valid form.

An analogous procedure may be traced in the history of the first law of thermodynamics, the validity of which has been maintained by broadening the concept of energy to include forms and manifestations of energy entirely unknown to the original propounders. All the necessary qualifications are included in and taken care of by Giauque's (*171*) clarification that, for the third law to be obeyed, there must be a condition of true equilibrium in the distribution of energy among such energy states as are actually occupied by the system as absolute zero is approached. Eastman (*136*) has pointed out that Gianque's statement sometimes is too restrictive and prefers to say that "the entropy at the absolute zero of any phase of sharply defined energy is zero." Tolman (*488*) also has discussed this subject and has stated that the entropy of a system may be taken as zero at the absolute zero only when the system is known to be in a single pure quantum mechanical state.

For the present purpose, the statements of Giauque, Eastman, and Tolman may be considered as equivalent. When they are true, the usual methods of calculation lead to the correct entropy; otherwise some correction must be made. The point of view to be emphasized is that the difficulty lies not in the third law itself, as now stated, but in the lack of knowledge sometimes existing as to the true internal condition of the crystals on which low-temperature heat-capacity measurements are made. Fortunately, the number of substances with which there has been difficulty so far is only a small fraction of the total number that have been studied.

The increase in entropy in warming a substance from 0° to T_1°K., is, by definition,

$$\Delta S=S_{T_1}-S_0=\int_0^{T_1}\frac{dQ}{T}. \tag{4}$$

Here, S_{T_1} is the entropy at T_1, S_0 is the entropy at 0°, and dQ is the increment of heat absorbed at the temperature T. If the substance has been cooled and the measurements made under conditions of complete equilibrium, then $S_0=0$, and

$$S_{T_1}=\int_0^{T_1}\frac{dQ}{T}. \tag{5}$$

Consider first a crystalline substance in complete equilibrium whose change in heat content, $\int_0^{T_1} dQ$, and the first derivative of heat content are continuous in the range 0° to T_1°. In such a case, $dQ=C_pdT$ or $dQ=C_vdT$, depending on whether the substance is heated at constant pressure or at constant volume. The symbol C_p represents the true or "instantaneous" heat capacity at constant pressure, and C_v, the true heat capacity at constant volume. The integral (5) gives the entropy either at constant pressure or constant volume, depending on which heat capacity is employed. We shall be concerned here only with the calculation of entropies for a constant pressure of 1 atmosphere. Returning to equation (5), then

$$S_{T_1}=\int_0^{T_1}\frac{C_pdT}{T}. \tag{6}$$

In such a simple case, specific-heat measurements down to very low temperatures are all that is required for computing S_{T_1}. Discussion concerning evaluation of this integral will be given later.

Suppose now a more complicated state of affairs and assume a substance in equilibrium crystalline condition as 0° is approached, but which undergoes a transition at some temperature, T', melts at temperature T'', and boils under 1 atmosphere pressure at temperature T''' (T', T'', and T''' all lying in the range 0° to T_1°). The integral in equation (5) may now be separated into several constituent parts as

$$S_{T_1}=\int_0^{T'}\frac{C_p\text{ (crystals II)}}{T}dT+\frac{\Delta H'}{T'}+\int_{T'}^{T''}\frac{C_p\text{ (crystals I)}}{T}dT+\frac{\Delta H''}{T''}$$

$$+\int_{T''}^{T'''}\frac{C_p\text{ (liquid)}}{T}dT+\frac{\Delta H'''}{T'''}+\int_{T'''}^{T_1}\frac{C_p\text{ (gas)}}{T}dT, \tag{7}$$

in which $\Delta H'$, $\Delta H''$, and $\Delta H'''$ are, respectively, the heats of transition, fusion, and vaporization.

The integrals of equation (7), except the first, are evaluated readily by plotting C_p against $ln\ T$ or $\frac{C_p}{T}$ against T and mechanically computing the area bounded by the resulting curve, the $ln\ T$ or T axis, and the two ordinates corresponding to the limits of integration. The first integral of equation (7) and that of equation (6) need further consideration, as an extrapolation of the heat-capacity curve, between the lowest temperature reached in the measurements and the absolute zero, is required for their evaluation.

As a crystal is cooled to low temperatures the difference between the heat capacities at constant pressure and constant volume gradually diminishes and usually is nearly negligible for inorganic crystals around 50° K. Debye (*123*), assuming a monatomic solid to be an isotropic, elastic medium, deduces for the energy relationship

$$E=9N\,k\,T\left(\frac{kT}{h\nu_m}\right)^3\int_0^{\frac{h\nu_m}{kT}}\frac{\left(\frac{h\nu}{kT}\right)^3 d\left(\frac{h\nu}{kT}\right)}{e^{h\nu/kT}-1}. \tag{8}$$

Differentiating with respect to the temperature at constant volume, there is obtained

$$C_v=9N\,k\left[4\left(\frac{kT}{h\nu_m}\right)^3\int_0^{h\nu_m/kT}\frac{\left(\frac{h\nu}{kT}\right)^3 d\left(\frac{h\nu}{kT}\right)}{e^{h\nu/kT}-1}-\frac{\frac{h\nu_m}{kT}}{e^{h\nu_m/kT}-1}\right]. \tag{9}$$

In these equations,

N= Avogadro's number,
k= gas constant per molecule,
h= Planck's constant,
ν= frequency of vibration, and
ν_m= limiting frequency of vibration.

By substituting $\frac{h\nu_m}{kT}=\frac{\theta_D}{T}$,

$$C_v=9\,N\,k\left[4\left(\frac{T}{\theta_D}\right)^3\int_0^{\theta_D/T}\frac{\left(\frac{h\nu}{kT}\right)^3 d\left(\frac{h\nu}{kT}\right)}{e^{h\nu/kT}-1}-\frac{\frac{\theta_D}{T}}{e^{\theta_D/T}-1}\right]. \tag{10}$$

θ_D is a characteristic constant for each substance and has the dimensions of temperature. Equation (10) expresses the heat capacity at constant volume as a function of this characteristic constant divided by the temperature. When T is large, so that $h\nu/kT$ is small, $e^{h\nu/kT}$ may be approximated as $1+\frac{h\nu}{kT}$, and equation (8) approaches

$$E=3\ N\ k\ T, \tag{11}$$

and C_v approaches $3\ N\ k=3R$, where R is the gas constant per mole. The latter is the rule of Dulong and Petit (*132*, *330*), which holds approximately for many elements near room temperature. When T is small, the upper limit of integration in equation (8) may be taken as infinite and the integral evaluated as $\pi^4/15$. At low temperatures, then,

$$E=\frac{3\pi^4 NK^4 T^4}{5h^3\nu_m{}^3}, \tag{12}$$

and

$$C_v=\frac{12\pi^4 NK^4}{5h^3\nu m^3}\,T^3=aT^3,$$

where a is substituted for the more-complicated constant multiplier.

Many substances have been studied to low enough temperatures to demonstrate that the T^3-law and general Debye equation usually are adequate means of extrapolating heat-capacity data for the evaluation of entropies. Consequently, for substances whose heat capacities have been determined to low enough temperatures, these relationships are employed in evaluating the first integral of equation (7) and the integral of equation (6). The procedure is to consider these integrals in two parts, the first of which accounts for the temperature range covered by the measured heat capacities and is evaluated mechanically, as are the other integrals of equation (7). The second part is entirely extrapolation. Tables of the heat capacity at constant volume and the entropy for values of θ_D/T for the Debye function may be found in several places (*208, 309, 374, 375*), so that the labor involved in the extrapolation is slight. When the T^3-law is obeyed below a temperature T, the entropy at T is simply $C_v/3$ for

$$S_T=\int_0^T\frac{C_v dT}{T}=\int_0^T aT^2dT=\frac{aT^3}{3}=\frac{C_v}{3}. \tag{14}$$

The fact that the heat capacities of some substances, such as lead and mercury, have been shown to deviate in various ways from Debye behavior need not be considered here. The fluctuations that have been observed up to the present do not produce errors in the extrapolations that are of much importance, relatively speaking, in the entropies at 298.16° K. However, they are of great theoretical interest. The above remarks do not apply to the departure from Debye behavior caused by splitting a multiple lowest-energy state, such as was observed for $Gd_2(SO_4)_3.8H_2O$ (to be discussed later).

Unfortunately, the Debye function alone is of little aid in the extrapolation of the entropies of many substances as they are not monatomic solids and their heat-capacity curves have been extended experimentally down only to some point in the range 50° to 100°, which, except for some metals, is rarely low enough to give coincidence with a Debye function. For such substances, it is necessary to employ a more-complicated and less-sure method of extrapolation based upon a simplified version of the theory of Born and von Karman (*49, 50, 51*). It is assumed here that, at low enough temperatures, any substance will obey the Debye law well enough to permit a satisfactory entropy extrapolation. At higher temperatures the Debye equation no longer will suffice, and the specific heat will rise above the Debye function because C_p-C_v becomes appreciable, and, in the case of polyatomic crystals, because degrees of freedom come into play that are not accounted for by the Debye function.

The assumption that the atoms in a crystal behave as harmonic oscillators led Einstein (*141*) to the expression

$$C_v = \frac{Nke^{\frac{h\nu}{kT}}\left(\frac{h\nu}{kT}\right)^2}{\left(e^{\frac{h\nu}{kT}}-1\right)^2} \tag{15}$$

for the contribution of a vibrational degree of freedom. The symbols in this equation have the same meaning as in that of Debye. Tables of Einstein functions for different values of $\frac{\theta_E}{T}=\frac{h\nu}{kT}$ also are available (*208, 309, 374, 375*). Born and von Karman (*49, 50, 51*) have considered the vibrations in a crystal lattice, and Born (*48*) has summed up by stating that the heat content of a p-atomic crystal, which consists of n elementary parallelepipeds, may, to a close approximation, be considered as composed of two portions; the first part is given by the sum of 3 Debye energy-functions of characteristic temperatures θ_{D_1}, θ_{D_2} and θ_{D_3}, which are related closely to the elastic properties, and the second part consists of the sum of 3 $(p-1)$ Einstein energy-functions of θ_E's, which may be found from a study of the infrared dispersion of the crystal. In terms of heat capacity this may be written as

$$C_v=\frac{1}{3}\left[\sum_{i=1}^{3} D\left(\frac{\theta_{D_i}}{T}\right)+\sum_{i=3}^{3(p-1)} E\left(\frac{\theta_{E_i}}{T}\right)\right] \tag{16}$$

where $D\left(\frac{\theta_{D_i}}{T}\right)$ and $E\left(\frac{\theta_{E_i}}{T}\right)$ represent, respectively, Debye and Einstein specific-heat functions. This equation gives the heat capacity per chemical formula mass of the n unit parallelepipeds. The factors "⅓" and "3" occur because crystals generally have different frequencies of vibration in different directions.

Equation (16) must be modified before it is readily and generally adaptable to the extrapolation of heat-capacity curves. As the extrapolated part of the entropy usually is only a relatively small portion of the total at 298.16° K., the assumptions to be made should not be objectionable. First, let p mean the number of atoms in a molecule of the substance, if that is known, or else the number of atoms in the simplest chemical formula that may be written to represent the composition; also instead of having 3 Debye functions and $3(p-1)$ Einstein functions, take 1 Debye function and $(p-1)$ Einstein functions and remove the factor ⅓ from equation (16). The result is

$$C_v=D\left(\frac{\theta_D}{T}\right)+\sum_{i=1}^{p-1} E\left(\frac{\theta_{E_i}}{T}\right). \tag{17}$$

Each Debye and Einstein function now may be considered as being equivalent to one-third the sum of the three it is replacing. In other words, the θ's are, in effect, "mean" values for three mutually perpendicular directions. For an isotropic crystal, equation (16) automatically becomes equation (17), except for modification of the definition of p. This simplified version has been shown to represent specific heats of oxides, sulfides, halides, etc., over rather wide temperature ranges, to a close enough degree in general to permit reasonably accurate extrapolations.

The method of extrapolation by means of equation (17) is one of trial. The measured heat capacities extending down to some point, say in the range 50° to 100°, are plotted against log T, and the curve is extended smoothly into a Debye function. (It is convenient for this purpose to have Debye and Einstein functions cut out of some rigid transparent material.) The Debye function is drawn in, being extended to 298.16° K. The differences between the measured curve and the Debye are read off. These differences are plotted against log T, and the attempt is made to fit them with a series of Einstein functions, using any obvious symmetry relationships for the substance to reduce the number of distinct functions required. Usually the first trial will result in failure to represent satisfactorily the measured heat capacities, but an examination will show the direction and indictate the amount the Debye function should be displaced before the second trial is made. The second trial either will be successful or point the way to placement of the Debye function for the third trial, etc. With a little practice, it is seldom that the heat capacities of even the more-complicated substances are not represented satisfactorily by the third trial, and with care success often is obtained with the second trial. The following random examples of oxides will give an idea of the function sums used and of the temperature interval for which the function sum fits the measured heat capacities. The lower temperature given in each instance is at or near the lower limit of the measurements.

$$C_{SrO}=D\left(\frac{261}{T}\right)+E\left(\frac{444}{T}\right),\ (57^\circ\text{–}298^\circ),$$

$$C_{TiO_2}=D\left(\frac{318}{T}\right)+2E\left(\frac{685}{T}\right),\ (52^\circ\text{–}298^\circ),$$

$$C_{Bi_2O_3}=D\left(\frac{97}{T}\right)+2E\left(\frac{225}{T}\right)+2E\left(\frac{568}{T}\right),\ (60^\circ\text{–}175^\circ),$$

$$C_{Ta_2O_5}=D\left(\frac{170}{T}\right)+2E\left(\frac{265}{T}\right)+2E\left(\frac{528}{T}\right)+2E\left(\frac{880}{T}\right),\ (53^\circ\text{–}298^\circ).$$

After a satisfactory representation of the measured heat capacities is obtained over an adequate temperature interval, the θ-values are computed, and the entropy extrapolation between 0° and the temperature of the lowest measurement is evaluated from the beforementioned tables of Debye and Einstein functions.

Numerous heat-capacity curves of compounds for which data have been obtained down only to some point in the range 50° to 100° K. have been extrapolated by this method for incorporation in this bulletin. In very few instances has there been reason to doubt the extrapolation and then usually because the data themselves were erratic or because of questionable purity of the materials studied. Still it should be emphasized that such curve fitting is largely empirical.

However, except in a few instances, it would seem that allowance for an error of 5 to 10 percent in the extrapolated part of the entropy should be enough to equal or exceed the uncertainties.

A class of substances, exemplified by $Gd_2(So_4)_3 \cdot 8H_2O$, $FeCl_2$, $CoCl_2$, $NiCl_2$, $MnCl_2$, and $CrCl_3$, considered separately later, presents additional difficulties, as the lowest energy levels of the metal ions involved are multiple (that is, have quantum weights greater than 1); and, except for $Gd_2(SO_4)_3 \cdot 8H_2O$, the heat-capacity measurements presumably have not been extended to temperatures low enough to cause splitting of this level. It is not known definitely just what procedure to follow in such instances. For $Gd_2(SO_4) \cdot 8H_2O$ and $Sm_2(So_4)_3 \cdot 8H_2O$ it appears established that $R \ln p$, in which p is the multiplicity of the lowest energy state, should be added to the extrapolation ordinarily made. Incidentally, it also appears reasonably certain that the heat capacities of the constituent metals themselves may be extrapolated by the usual methods. The anhydrous chlorides mentioned above occupy a sort of middle ground with regard to the degree of dilution of their magnetic systems by nonmagnetic mediums. Pending experimental proof of the correct treatment for these substances, generally no allowance can be made in the calculation of entropies for the effects of multiple lowest energy levels.

CALCULATIONS BASED UPON SPECTROSCOPIC DATA

The calculation of entropies from spectroscopic data is restricted to the gaseous state at present. The methods employed have been discussed adequately by Giauque (*170*) and others.

It is customary to separate the translational energy, entropy, and heat capacity of gas molecules from the rotational, vibrational, and electronic contributions. The evaluation of the translational entropy has been the subject of several theoretical investigations (*140*, *334*, *410*, *464*, *465*, *481*, *487*), with the result, first obtained by Sackur (*410*), that

$$S_t = 3/2R \ln M + 3/2R \ln T + R \ln V + 5/2R + S_0. \qquad (18)$$

Here, S_t is the translational entropy, M the molecular mass of the gas, T the absolute temperature, V the molal volume, R the gas constant per mole, and S_0 a constant for all substances, which was shown by Tetrode (*481*) to have the value $R \ln \frac{(2\pi k)^{3/2}}{h^3 N^{5/2}} = -16.043$ calories per mole per degree, k, h, and N being, respectively, the gas constant per molecule, Planck's constant, and Avogadro's number. Substituting for the molal volume at 1 atmosphere and 298.16°K. and inserting the temperature leads to

$$S^\circ_{t,\,298.16} = 3/2R \ln M + 25.996. \qquad (19)$$

(The units employed in this section are taken from National Research Council Annual Tables of Physical Constants (*371*).)

Equations (18) and (19) give the total entropy (excluding that attributed to nuclear spin) of a monatomic gas provided all the atoms are in one energy state of unit quantum weight. This condition is satisfied by the rare gases at 298.16°, and values obtained from equation (19) are shown in column 2 of table 1, where they may be compared with the values in column 3 based upon low-temperature heat-capacity data. The agreement is seen to be highly satisfactory.

TABLE 1.—*Entropies of rare gases at 298.16°*

Substance	$S_{298.16}$ (theor.)	$S_{298.16}$ (exp.)	Substance	$S_{298.16}$ (theor.)	$S_{298.16}$ (exp.)
Argon	36.99±0.01	36.95±0.2	Neon	34.95±0.01	35.01±0.10
Helium	30.13±0.01	----------	Radon	42.10±0.01	----------
Krypton	39.20±0.01	39.17±0.10	Xenon	40.54±0.01	40.7±0.3

Other examples could be given from the list of monatomic metal gases. The comparison, however, would require the use of vapor-pressure data in computing the values based upon heat capacities. There is no objection to such procedure, but the validity of equations (18) and (19) is now so well-established that Kelley (*270*) has employed the calculation in the reverse sense, rectifying the vapor-pressure data for metal gases by means of the theoretical entropies. Incidentally, the experimental justification of Tetrode's value of S_0 does not depend on data for monatomic gases alone, and a variety of checks may be given for gases which are not monatomic, as the translational portions of their entropies also conform to equations (18) and (19). For some examples see table 4.

The other contributions to the entropy will now be considered. Let ϵ_1 be the sum of the rotational, vibrational, and electronic energies of a molecule and let A_0 and A_1 be the numbers of molecules in two energy states ϵ_0 and ϵ_1. Then, according to the Maxwell-Boltzman distribution law,

$$\frac{A_1}{A_0}=e^{\frac{-(\epsilon_1-\epsilon_0)}{kT}}, \tag{20}$$

e being the natural logarithmic base, k the gas constant per molecule, and T the temperature in degrees Kelvin. Suppose A_0 refers to the lowest energy state of the molecule and A_1, A_2, A_3, etc., to the successively higher energy states, and for convenience suppose all the energies, ϵ_i, now are referred to that of the lowest state as a zero base, which obviously leaves the magnitude of the exponent in equation (20) unchanged. Then, considering 1 mole of gas (Avogadro's number of molecules, N), it follows that

$$N=A_0+A_0e^{-\epsilon_1/kT}+A_0e^{-\epsilon_2/kT}+\ .\ .\ . \tag{21}$$

For a group of states, p_i in number, whose energies are so nearly alike that they may be considered together, the corresponding terms in equation (21) may be replaced by $p_iA_0e^{-\epsilon_i/kT}$ or, in general,

$$N=p_0A_0+p_iA_0e^{-\epsilon_1/kT}+p_2A_0e^{-\epsilon_2/kT}+\ .\ .\ .\ =A_0\sum_i p_ie^{-\epsilon_i/kT}. \tag{22}$$

The quantity p_i is termed the quantum weight or the a priori probability of the state of energy ϵ_i. Let the sum of the rotational, vibrational, and electronic energies of 1 mole of gas at any temperature be denoted by E°_{r+v+e} and let E°_0 be the corresponding energy at 0° K., the gas being in the ideal state. As the energy of the molecules in a given state is their number times the energy per molecule, it follows that

$$E^\circ_{r+v+e}-E^\circ_0=0p_0A_0+p_i\epsilon_1A_0e^{-\epsilon_1/kT}+p_2e_2A_0e^{-\epsilon_2/kT}+\ .\ .\ .\ =A_0\sum_i p_i\epsilon_ie^{-\epsilon_i/kT}. \tag{23}$$

Eliminating A_0 between equations (22) and (23),

$$E^\circ_{r+v+e}-E^\circ_0=N\frac{\sum\limits_i p_i\epsilon_ie^{-\epsilon_i/kT}}{\sum\limits_i p_ie^{-\epsilon_i/kT}}. \tag{24}$$

Differentiating equation (24) with respect to T,

$$\frac{dE^\circ_{r+v+e}}{dT}=\frac{N}{kT^2}\left[\frac{\sum\limits_i p_i\epsilon_i^2e^{-\epsilon_i/kT}}{\sum\limits_i p_ie^{-\epsilon_i/kT}}-\left(\frac{\sum\limits_i p_i\epsilon_ie^{-\epsilon_i/kT}}{\sum\limits_i p_ie^{-\epsilon_i/kT}}\right)^2\right]. \tag{25}$$

Equation (25) gives the sum of the rotational, vibrational, and electronic heat capacities of the gas. The total heat capacity at constant pressure is obtained by adding this sum to $5/2\ R=4.969$, the heat capacity at constant pressure of an ideal monatomic gas.

The entropy of the gas, excluding translational entropy, is defined by

$$dS^\circ_{r+v+e}=\frac{dE^\circ_{r+v+e}}{dT}\,d\,ln\,T, \tag{26}$$

or

$$S^\circ_{r+v+e}-S^\circ_0=\int_0^T\frac{dE_{r+v+e}}{dT}\,d\,ln\,T. \tag{27}$$

Writing Q for $\sum\limits_i p_ie^{-\epsilon_i/kt}$, equation (24) becomes

$$E^\circ_{r+v+e}-E^\circ_0=Nk\,T^2\frac{d\,ln\,Q}{dT}=R\,T^2\frac{d\,ln\,Q}{dT}, \tag{28}$$

$R=Nk$ being the gas constant per mole. Therefore,

$$S^\circ_{r+v+e}-S^\circ_0=\int_0^T\frac{d}{dT}\left(R\,T^2\frac{d\,ln\,Q}{dT}\right)d\,ln\,T, \tag{29}$$

$$=-R\int_0^T\frac{d}{dT}\left(\frac{d\,ln\,Q}{d1/T}\right)d\,ln\,T, \tag{30}$$

$$=R\left[ln\,Q+T\frac{d\,ln\,Q}{dT}\right]_0^T, \tag{31}$$

$$=R\left[ln\,Q-ln\,Q_0+T\frac{d\,ln\,Q}{dT}\right], \tag{32}$$

and

$$=R\left[ln\sum_i p_i e^{-\epsilon_i/kT}-ln\, p_0+\frac{1}{kT}\frac{\sum_i p_i\epsilon_i e^{-\epsilon_i/kT}}{\sum_i p_i e^{-\epsilon_i/kT}}\right]. \tag{33}$$

But, as $S_0^\circ=R\, ln\, p_0$,

$$S^\circ_{r+v+e}=R\left[ln\sum_i p_i e^{-\epsilon_i/kT}+\frac{1}{kT}\frac{\sum_i p_i\epsilon_i e^{-\epsilon_i/kT}}{\sum_i p_i e^{-\epsilon_i/kT}}\right]. \tag{34}$$

The quantity given by equation (34) is the sum of the rotational, vibrational, and electronic entropies. This sum must be added to the result given by the Sackur equation (18) to obtain the total entropy (excluding that due to nuclear spin). Evaluation of this sum is possible for gases on which extensive enough spectroscopic measurements have been made to enable an assignment of ϵ_i and p_i values to all the states occupied by the system at the temperature under consideration. It is customary to omit nuclear spin from consideration in the values of p_i, as Gibson and Heitler (*193*) have shown that the resulting entropy contribution balances out in reactions involving diatomic gases, and it is presumed that it always does so. It will be noted that if all the molecules are in their lowest energy state of quantum weight p_0, then equation (34) reduces to $R\, ln\, p_0$.

To illustrate this method of calculation, two simple cases will be considered, nickel gas at 298.16° K., in which only translational and electronic entropies are concerned, and carbon monoxide at 298.16°, in which only translational and rotational entropies are concerned. The question may arise as to why the calculation is made for nickel which does not exist in the gaseous state at any appreciable pressure at 298.16° K. The answer is that it seems desirable to have a fairly simple, but not too simple, example for illustration. The common substances that exist as monatomic gases under measurable pressures at 298.16° K. have electronic states so separated that calculation reduces to the mere addition of $R\, ln\, p_0$ as mentioned above. Moreover, the entropy of Ni(g) at 298.16° K. may be employed formally in the thermodynamic calculations in the same manner as the entropy of $H_2O(g)$ at 298.16° in the hypothetical state of 1 atmosphere fugacity. Only a question of degree is involved.

The data to be considered for Ni(g) (*364*) at 298.16° are shown in table 2. Column 1 gives the designation of the state, column 2 the energies in wave numbers (these usually are called term values), column 3 the quantum weights, and column 4 the energies in ergs per molecule ($\epsilon=hc\nu=1.98572\times10^{-16}\nu$). The calculated items for computing the sums in equation (34) are shown in columns 5 and 6.

TABLE 2.—*Data for Ni(g) at 298.16°K.*

State	ν_i	p_i	ϵ_i	$p_i e^{-\epsilon_i/298.16\ K.}$	$p_i \epsilon_i e^{-\epsilon_i/298.16\ K.}$
$^3F_4$	0	9	0	9.0000	0
$^3D_3$	204.82	7	4.0672×10^{-14}	2.6061	10.599×10^{-14}
$^3D_2$	879.82	5	1.7471×10^{-13}	.0717	1.253×10^{-14}
$^3F_3$	1,332.15	7	2.6453×10^{-13}	.0113	300×10^{-14}
$^3D_1$	1,713.11	3	3.4018×10^{-13}	.0008	$.026\times10^{-14}$
$^3F_2$	2,216.55	5	4.4014×10^{-13}	.0001	$.005\times10^{-14}$
Sum				11.6900	12.183×10^{-14}

Substitution of the summation values in equation (34) leads to

$$S^\circ_{i,\,298.16}=R\left[ln\ 11.6900+\frac{12.183\times10^{-14}}{4.1160\times10^{-14}\times11.6900}\right]=5.390,$$

in which $4.1160\times10^{-14}=kT$ and $R=1.9875$. The translational entropy is $S^\circ_{t,298.16}=3/2\ R\ ln\ 58.69+25.996=38.136$. These two contributions add to give $S^\circ_{298.16}=43.53\pm0.01$ for Ni(*g*) at 298.16°.

In the second example, CO(*g*), considerably more labor is involved in computing the sums in equation (34). Although it is no longer necessary to use the summation method for this and similar cases, as will be mentioned below, the principles involved are best-illustrated by the summation method. Clayton and Giauque (*73*, *74*) have given the rotational energies (in wave numbers) of CO as

$$\epsilon_r=[1.853-0.020(v+1/2)]m^2-[5.418\times10^{-6}-6.918\times10^{-8}(v+1/2)]m^4. \qquad (35)$$

In this expression m takes the values 1/2, 3/2, 5/2, etc., and v the values 0, 1, 2, 3, etc. The vibrational energy, in wave numbers, is (*73*, *74*)

$$\epsilon_v=\omega_e(v+1/2)+\omega_eX_e(v+1/2)^2, \qquad (36)$$

in which $\omega_e=2167.4$, $\omega_eX_e=-12.70$, and v takes the values 0, 1, 2, 3, etc. It is apparent, on preliminary examination, that only the lowest vibration state ($v=0$) need be considered in evaluating the entropy at 298.16°. Consequently, $\epsilon_r=1.843\ m^2-5.383\times10^{-6}m^4$ gives all the pertinent energy values. There must be computed $\epsilon_{r(m)}-\epsilon_{r(1/2)}$ for enough rotational states to give correct sums in equation (34), in this instance about 40 terms. These values in wave numbers are shown in column 2 of table 3. The quantum weights are shown in column 1 and values of $\epsilon_i=hc\nu$, ergs per molecule, are in column 3. The summation items are in columns 4 and 5.

TABLE 3.—*Data for CO(g) at 298.16° K.*

p_i	ν_i	ϵ_i	$p_i e^{-\epsilon_i/298.16K}$.	$p_i \epsilon_i e^{-\epsilon_i/298.16K}$.
1	0	0	1.000	0
3	3.686	7.319×10^{-16}	2.947	$.022\times10^{-13}$
5	11.06	2.196×10^{-15}	4.740	$.104\times10^{-13}$
7	22.12	4.392×10^{-15}	6.292	$.276\times10^{-13}$
9	36.86	7.319×10^{-15}	7.534	$.551\times10^{-13}$
11	55.28	1.098×10^{-14}	8.425	$.925\times10^{-13}$
13	77.40	1.537×10^{-14}	8.948	1.375×10^{-13}
15	103.2	2.049×10^{-14}	9.118	1.869×10^{-13}
17	132.7	2.635×10^{-14}	8.962	2.362×10^{-13}
19	165.8	3.292×10^{-14}	8.541	2.812×10^{-13}
21	202.7	4.025×10^{-14}	7.898	3.179×10^{-13}
23	243.2	4.829×10^{-14}	7.116	3.437×10^{-13}
25	287.4	5.710×10^{-14}	6.242	3.566×10^{-13}
27	335.2	6.656×10^{-14}	5.360	3.567×10^{-13}
29	386.8	7.681×10^{-14}	4.486	3.445×10^{-13}
31	442.0	8.777×10^{-14}	3.677	3.227×10^{-13}
33	500.0	9.929×10^{-14}	2.957	2.937×10^{-13}
35	763.5	1.119×10^{-13}	2.309	2.583×10^{-13}
37	629.7	1.250×10^{-13}	1.775	2.219×10^{-13}
39	699.6	1.389×10^{-13}	1.335	1.855×10^{-13}
41	773.1	1.535×10^{-13}	.984	1.511×10^{-13}
43	850.3	1.688×10^{-13}	.712	1.202×10^{-13}
45	931.1	1.849×10^{-13}	.504	$.932\times10^{-13}$
47	1,016	2.017×10^{-13}	.350	$.706\times10^{-13}$
49	1,104	2.192×10^{-13}	.238	$.523\times10^{-13}$
51	1,196	2.375×10^{-13}	.159	$.378\times10^{-13}$
53	1,291	2.564×10^{-13}	.104	$.268\times10^{-13}$
55	1,390	2.760×10^{-13}	.067	$.186\times10^{-13}$
57	1,493	2.965×10^{-13}	.042	$.126\times10^{-13}$
59	1,599	3.175×10^{-13}	.026	$.084\times10^{-13}$
61	1,709	3.394×10^{-13}	.016	$.054\times10^{-13}$
63	1,823	3.620×10^{-13}	.010	$.035\times10^{-13}$
65	1,940	3.852×10^{-13}	.006	$.022\times10^{-13}$
67	2,061	4.093×10^{-13}	.003	$.013\times10^{-13}$
69	2,185	4.339×10^{-13}	.002	$.008\times10^{-13}$
71	2,313	4.593×10^{-13}	.001	$.005\times10^{-13}$
73	2,445	4.855×10^{-13}	.001	$.003\times10^{-13}$
75	2,580	5.123×10^{-13}	.000	$.002\times10^{-13}$
77	2,719	5.399×10^{-13}		$.001\times10^{-13}$
79	2,862	5.683×10^{-13}		$.000\times10^{-13}$
81	3,008	5.973×10^{-13}		
83	3,158	6.271×10^{-13}		
Sum			112.89	46.37×10^{-13}

From the summation values there is computed

$$S^{\circ}_{r,\,298.16}=R\left[\ln 112.89+\frac{46.37\times10^{-13}}{4.1160\times10^{-14}\times112.89}\right]=11.377.$$

The translational entropy is $S^{\circ}_{t,98,16}=3/2\ R\ ln\ 28.010+25.996=35.931$. The total is $S^{\circ}_{298,16}=47.31\pm0.01$ for CO(*g*). This result may be compared with the value given by Clayton and Giauque (*73*, *74*). These investigators carried out a calculation, which is equivalent to that just made, by means of the approximate integration method of Giauque and Overstreet (*183*). This method gives

$$Q=e^{\frac{hc}{kT}\left(\frac{B}{4}+\frac{D}{16}\right)}\ \frac{kT}{Bhc}\left[\cdot1+\frac{B}{12}\left(\frac{hc}{kT}\right)-\frac{2D}{B^2}\left(\frac{kT}{hc}\right)+\frac{12D^2}{B^4}\left(\frac{kT}{hc}\right)^2+\ .\ .\ .\ \right]\cdot \qquad (37)$$

in which, for CO, $B=1.843$ and $D=-5.383\times10^{-6}$, and the other symbols are used in the previously given sense. This integrated expression for Q and the result obtained by differentiating it with respect to T serve to evaluate equation (32), which is equation (34) in different form. The result obtained, $S^{\circ}_{298.16}=47.31$, is identical with the value from the summation method.

These two rather simple examples should be enough to illustrate the method of obtaining entropies from spectroscopic data as the principles are the same in more complex cases in which rotational, vibrational, and electronic entropies must be considered simultaneously. The labor of calculation, however, generally is much greater in the latter instances. Table 4 shows the agreement between values computed by this method and those based upon low-temperature heat-capacity data. Substances have been chosen for which none of the difficulties mentioned previously in considering the application of the third law are encountered.

TABLE 4.—*Entropies at 298.16° K.*

Substance	$S^\circ_{298.16}$ (spectroscopic)	$S^\circ_{298.16}$ (third law)	Substance	$S^\circ_{298.16}$ (spectroscopic)	$S^\circ_{298.16}$ (third law)
HCl	44.66±0.05	44.47±0.15	N_2	45.77±0.01	45.93±0.15
HBr	47.48±0.05	47.63±0.15	O_2	49.01±0.01	49.10±0.10
HI	49.33±0.05	49.48±0.15	Cl_2	53.31±0.01	53.31±0.10

CALCULATIONS BASED UPON MOLECULAR-CONSTANT DATA

For ordinary temperatures but little is gained by making the laborious calculations just illustrated to determine the rotational and vibrational entropies. The electronic contribution must, of course, be calculated in that manner if more than one electronic state is occupied. The method to be described now may also be used for the more complicated gases on which detailed spectroscopic data have not yet been obtained. The data required are the moments of inertia and the fundamental vibration frequencies of the molecule in addition to knowledge of the quantum weights and separations of the lowest electronic levels. For the majority of substances, other than monatomic gases, for which the above data are available at present, only the lowest electronic level need be considered at 298.16° K.

The entropy of a gas assumed to be composed of rigid molecules is considered to be divided into translational, rotational, vibrational, and electronic portions (nuclear-spin entropy again being omitted from consideration) as

$$S^\circ = S^\circ_t + S^\circ_r + S^\circ_v + S^\circ_e. \qquad (38)$$

The translational part S°_t already was considered, and equations (18) and (19) serve for its calculation.

For a diatomic gas, Tetrode (*481*) has derived

$$S^\circ_r = R\ ln\ I\ T + S'_0, \qquad (39)$$

in which I is the moment of inertia, T is the absolute temperature, and S'_0 is a constant having the value $R\ ln\ \frac{8\pi^2 ke}{h^2} = 177.699$. Equations (18) and (39) may be substituted in equation (38) to make

$$S = 3/2\ R\ ln\ M + 5/2\ R\ ln\ T + R\ ln\ V + R\ ln\ I + S_v + S_e + 166.625. \qquad (40)$$

At 298.16° K. and 1 atmosphere pressure, and with I in c. g. s. units, this last equation reduces to

$$S^{\circ}_{298.16}=3/2\ R\ ln\ M+R\ ln\ I+S_v+S_e+215.019. \tag{41}$$

Equations (40) and (41) are valid for diatomic gases composed of unlike atoms and also for gases composed of unsymmetrical, linear, polyatomic molecules. For diatomic gases composed of like atoms and gases composed of symmetrical, linear, polyatomic molecules equations (40) and (41) must be reduced by $R\ ln\ 2$, as shown by Tetrode (*481*). The more general expressions are

$$S=3/2\ R\ ln\ M+5/2\ R\ ln\ T+R\ ln\ V+R\ ln\ I-R\ ln\ \sigma+S^{\circ}_v+S^{\circ}_e+166.625, \tag{42}$$

and

$$S_{298.16}=3/2\ R\ ln\ M+R\ ln\ I-R\ ln\ \sigma+S^{\circ}_v+S^{\circ}_e+215.019, \tag{43}$$

in which σ, called the symmetry number, has the values 2 or 1, depending on whether the diatomic molecules or linear, polyatomic molecules are symmetric or unsymmetric.

The expression analogous to equation (39), but for gases composed of rigid, nonlinear, polyatomic molecules, is

$$S^{\circ}_r=3/2\ R\ ln\ (I_1I_2I_3)^{1/3}\ T+S''_0, \tag{44}$$

in which I_1, I_2, and I_3 are the principal moments of inertia, T is the absolute temperature, and S''_0 is a constant having the value

$R\ ln\ \frac{8^{3/2}\pi^{7/2}k^{3/2}e^{3/2}}{h^3}=267.686$. Substituting equations (18) and (44) in equation (38), and introducing the term $-R\ ln\ \sigma$ as before, leads to

$$S=3/2\ R\ ln\ M+3\ R\ ln\ T+R\ ln\ V+1/2\ R\ ln\ I_1I_2I_3-R\ ln\ \sigma+S^{\circ}_v+S^{\circ}_e+256.613. \tag{45}$$

Also

$$S^{2}{}_{98.16}=3/2\ R\ ln\ M+1/2\ R\ ln\ I_1I_2I_3-R\ ln\ \sigma+S_v+S_e+310.668 \tag{46}$$

for 1 atmosphere pressure. The symmetry number, σ, is to be considered as the number of permutations of the atoms that can be obtained solely by rotations of the molecule in such ways as to leave its appearance unchanged. If all the atoms in a molecule are different $\sigma=1$. For diatomic molecules composed of like atoms, or symmetrical, linear, polyatomic molecules such as $O=C=O$ and $N\equiv C-C\equiv N$, $\sigma=2$. Pyramidal molecules such as NH_3 have $\sigma=3$, but if the atoms are all in the same plane, as for BCl_3, then $\sigma=6$. Tetrahedral molecules like CH_4 have $\sigma=12$ but CH_3Cl has $\sigma=3$. Molecules like SF_6, in which the S atom is at the center and the F atoms at the midfaces of a cube, have $\sigma=24$.

In computing S°_v it is assumed that the vibrations are purely harmonic, in which case equation (15) may be taken as the specific heat corresponding to a single vibrational degree of freedom. The entropy is computed as follows:

$$S_v^\circ = R\int_0^T \frac{e^{h\nu/kT}\left(\frac{h\nu}{kT}\right)^2}{T(e^{h\nu/kT}-1)^2}\,dT. \tag{47}$$

Replacing $h\nu/kT$ by x leads to

$$S_v^\circ = -R\int_\infty^{h\nu/kT} \frac{xe^x}{(e^x-1)^2}\,dx. \tag{48}$$

Equation (48) is integrated by parts with the result that

$$S_v^\circ = R\left[\frac{x}{e^x-1} - ln\ (1-e^{-x})\right]_\infty^{h\nu/kT}, \tag{49}$$

and

$$S_v^\circ = R\left[\frac{h\nu/kt}{e^{h\nu/kT}-1} - ln\ (1-e^{-h\nu/kT})\right]. \tag{50}$$

Equation (50) gives the entropy associated with a single vibrational degree of freedom. Linear molecules composed of n atoms have $3n-5$ vibrational degrees of freedom and nonlinear molecules composed of n atoms have $3\ n - 6$ vibrational degrees of freedom. All of these are not necessarily active at 298.16°K., and the corresponding vibration frequencies are not necessarily distinct; in fact, the converse usually is true, and more than one degree of freedom may be assigned to a fundamental vibration frequency. Throughout this bulletin vibration frequencies are given in wave numbers or reciprocal centimeters and are designated by the symbol ω. There may be written, then,

$$S_v^\circ = R\sum_{i=1}^{3n-5}\left[\frac{\frac{hc\omega_i}{kT}}{e^{\frac{hc\omega_i}{kT}}-1} - ln\left(1-e^{\frac{-hc\omega_i}{kT}}\right)\right] \tag{51}$$

for linear molecules and

$$S_v = R\sum_{i=1}^{3n-6}\left[\frac{\frac{hc\omega_i}{kT}}{e^{\frac{hcn\omega_i}{kT}}-1} - ln\left(1-e^{-\frac{hc\omega_i}{kT}}\right)\right] \tag{52}$$

for nonlinear molecules. Values of the individual summation items may be found from available tables (*208, 309, 374, 375*) which give S_v° as a function of $\frac{\theta_E}{T}=\frac{hc\omega_i}{kT}$, so that but little computation is necessary.

As mentioned before, quantity S_e° should be evaluated by the method described for treating spectroscopic data. Fortunately, in most instances only the lowest electronic state is occupied at 298.16°, so that this term reduces to $R\ ln\ p_0$, in which p_0 is the quantum weight.

Abbreviating equations (51) and (52) to $S_v^\circ = \sum S$ (Einstein), the relationships of this section may be summarized as follows:

Monatomic gases

$$S = 3/2\ R\ ln\ M + 3/2\ R\ ln\ T + R\ ln\ V + S_e - 11.074. \tag{53}$$

$$S = 3/2\ R\ ln\ M + 5/2\ R\ ln\ T - R\ ln\ P + S_e - 2.314. \tag{54}$$

$$S^\circ_{298.16} = 3/2\ R\ ln\ M + S_e + 25.996. \tag{55}$$

Diatomic and linear, polyatomic gases

$$\begin{aligned} S = 3/2\ R\ ln\ M + 5/2\ R\ ln\ T + R\ ln\ V + R\ ln\ I - R\ ln\ \sigma + \Sigma S\ \text{(Einstein)} \\ + S_e^\circ + 166.625. \end{aligned} \tag{56}$$

$$\begin{aligned} S = 3/2\ R\ ln\ M + 7/2\ R\ ln\ T - R\ ln\ P + R\ ln\ I - R\ ln\ \sigma + \Sigma S\ \text{(Einstein)} \\ + S_e^\circ + 175.385. \end{aligned} \tag{57}$$

$$S^\circ_{298.16} = 3/2\ R\ ln\ M + R\ ln\ I - R\ ln\ \sigma + \Sigma S\ \text{(Einstein)} + S_e^\circ + 215.019. \tag{58}$$

Nonlinear, polyatomic gases

$$\begin{aligned} S = 3/2\ R\ ln\ M + 3\ R\ ln\ T + R\ ln\ V + 1/2\ R\ ln\ I_1I_2I_3 - R\ ln\ \sigma + \\ \Sigma\ S\ \text{(Einstein)} + S_e^\circ + 256.613. \end{aligned} \tag{59}$$

$$\begin{aligned} S = 3/2\ R\ ln\ M + 4\ R\ ln\ T - R\ ln\ P + 1/2\ R\ ln\ I_1I_2I_3 - R\ ln\ \sigma + \\ \Sigma\ S\ \text{(Einstein)} + S_e^\circ + 265.372. \end{aligned} \tag{60}$$

$$\begin{aligned} S^\circ_{298.16} = 3/2\ R\ ln\ M + 1/2\ R\ ln\ I_1I_2I_3 - R\ ln\ \sigma + \\ \Sigma\ S\ \text{(Einstein)} + S_e^\circ + 310.668. \end{aligned} \tag{61}$$

These equations are for the perfect gas state. The units are V in cubic centimeters, P in atmospheres, T in degrees Kelvin, M in grams, and I in gram-centimeters squared. Equations (55), (58), and (61) are for a pressure of 1 atmosphere. The equations containing P are obtained from those containing V by means of the relationship $PV = RT$.

Table 5 compares values computed from these equations, $S^\circ_{298.16}$ (m. c.), with those obtained from spectroscopic data, $S_{298.16}$ (spec.), and from low-temperature heat-capacity data, $S^\circ_{298.16}$ (t. l.). The moments of inertia and vibration frequencies are listed in the next section where the calculations are considered in more detail. Many additional similar comparisons may be made, but table 5 is restricted to gases of metallurgical importance. The procedure followed in arriving at the values given for H_2 and H_2O based upon low-temperature heat-capacity data may be questioned, but it is considered here that both the nature and the magnitude of the correction applied have been established by experiment.

TABLE 5.—*Entropies of gases at 298.16°K*

Substance	$S^\circ_{298.16}$ (spec.)	$S^\circ_{298.16}$ (m. c.)	$S^\circ_{298.16}$ (t. l.)
H_2	31.22±0.01	31.16±0.10	31.30±0.10
O_2	49.01± .01	49.00± .03	49.10± .10
N_2	45.77± .01	45.76± .03	45.93± .15
Cl_2	53.31± .01	53.22± .10	53.31± .10
CO	47.31± .01	47.28± .03	----------
CO_2	----------	51.05± .05	51.11± .10
SO_2	----------	59.29± .15	59.24± .10
H_2O	45.13± .03	45.08± .05	45.13± .10
HCl	44.66± .05	44.61± .03	44.47± .15
H_2S	----------	49.10± .10	49.10± .10
NH_3	----------	45.98± .03	45.96± .10
CH_4	----------	44.47± .10	44.5 ± .2

CALCULATIONS BASED UPON REACTION ENTROPIES

When the heat and free energy of a reaction are known, equation (3), expressed as

$$\Delta S^\circ_T=\frac{\Delta H^\circ_T-\Delta F^\circ_T}{T}, \tag{62}$$

permits the calculation of the entropy of reaction. Moreover, some reactions in galvanic cells have been studied thoroughly enough to permit the direct calculation of the reaction entropy from the temperature coefficient of the electromotive force. The relationship connecting these quantities is

$$\Delta S^\circ_T=nf\,\frac{d\epsilon^\circ}{dT}, \tag{63}$$

in which n is the number of chemical equivalents involved, f Faraday's constant, and ϵ° the standard electromotive force of the cell. If the entropy of reaction is known and if the entropies of all the reactants and products except one are known, then that one may be calculated. For example, Gerke (*169*), from cell measurements, has obtained values leading to $\Delta S_{298.16}=7.8$ for the reaction $Ag+HgCl=AgCl+Hg$. As the entropies of Ag, AgCl, and Hg are known, there may be written $7.8=23.00+18.53-10.20-S_{298.16}$ (HgCl) or $S_{298.16}=23.5$ for HgCl (*c*). This value probably is accurate to within ±0.5 unit.

This method is the basis of calculation of all the values given here as entropies of ions in aqueous solution. These values are taken largely from the compilation of Latimer, Pitzer, and Smith (*325*), and they are relative figures based upon the defining of $S^\circ_{298.16}=0$ for H^+(*aq.*). It is obvious that, as the charges on opposite sides of a chemical equation must balance, relative entropies suffice for thermodynamic calculations, and they may be used directly in conjunction with other values listed in this bulletin. All ionic entropies given are for hypothetical, 1 molal, ideal solutions. For examples of usage of aqueous ions the reader is referred to the paper of Latimer and Buffington (*319*) and the reference book of Latimer (*315*).

CALCULATIONS BASED UPON RESIDUAL-RAY DATA

There are a few substances whose entropies may be approximated from residual-ray data. To illustrate the method of calculation an example, KCl, will be considered in detail. Rubens (*403*) and Rubens and Hollnagel (*404*) have given $\nu = 63.4 \times 10^{-4}$ cm. as the mean residual-ray wave length. Dividing the velocity of light by this figure $\left(\frac{3 \times 10^{10}}{63.4 \times 10^{-4}}\right)$ gives $\nu = 4.73 \times 10^{12}$ as the mean frequency. This frequency is considered to be that associated with the Einstein function, in accordance with the previously mentioned theory of Born and von Karman. The characteristic temperature is $\theta_E = \frac{h\nu}{k} = 227$. From an approximate expression, $\theta_E = 1.35\ \theta_D$, given by Rodebush (*480*), $\theta_D = 168$ is evaluated. The calculation from this point is the same as if, for the specific heat of KCl, $C_v = D\left(\frac{168}{T}\right) + E\left(\frac{227}{T}\right)$. At 298.16°, $\frac{\theta_D}{298.16} = 0.563$ and $\frac{\theta_E}{298.16} = 0.761$. The corresponding entropy values taken from available tables are 11.44 and 7.73, respectively. The sum, 19.17, is the entropy at constant volume. As the difference $S^\circ_p - S^\circ_v$ is about 0.3 for salts of this type, there may be written $S^\circ_{298.16} = 19.5$ for KCl.

Table 6 gives in column 2 entropy values obtained by this method that may be compared with results from low-temperature specific-heat data in column 3. Except for TlCl and HgCl, reasonable agreement is observed.

TABLE 6.—*Entropies of salts at 298.16° K.*

Substance	$S^\circ_{298.16}$ (residual rays)	$S^\circ_{298.16}$ (specific heats)	Substance	$S^\circ_{298.16}$ (residual rays)	$S^\circ_{298.16}$ (specific heats)
NaCl	17.2	17.3±0.3	AgBr	26.1	25.60±0.10
KCl	19.5	19.76± .07	HgCl	24.7	23.0 ± .7
KBr	22.6	22.4 ±1.0	TlCl	23.7	25.9 ± .6
AgCl	22.4	23.00± .10			

ENTROPIES OF INORGANIC SUBSTANCES AT 298.16°K.

In the following pages entropy values are given for the elements, ions, and compounds, based upon the various available data. The elements are considered in alphabetical order, and the compounds usually are classified according to their more electropositive constituents. All selected entropy values are for a constant pressure of 1 atmosphere and a temperature of 298.16° K. (25.00°C.) and are expressed in defined calories (1 calorie=4.1833 int. joules) per degree per gram formula mass.

All temperatures are in degree Kelvin. The symbols (*c*), (*l*), and (*g*) refer, respectively, to the crystalline, liquid, and gaseous states. Glasses are denoted by the symbol (*gl.*). The symbol (*aq.*) following ionic formulas denotes a hypothetical, perfect solution of 1 molal concentration.

The attempt is made to estimate the accuracy of each selected entropy result, but in many instances the estimate is largely a matter of judgment. For values obtained from heat-capacity measurements, the general procedure has been to consider that part of the entropy given by actual measurement separately from the part that is entirely extrapolation. The assumed accuracy of the experimental portion depends partly upon the estimated errors in the heat-capacity data as given by the investigator responsible and partly upon information obtained by intercomparison of results of several workers. The error in the extrapolated portion generally is taken as about 5 to 10 percent, which seems a reasonable procedure, as the uncertainty should increase with the magnitude of the extrapolation and in instances in which the heat capacity has been measured down to very low temperatures an error of this magnitude in the extrapolated part of the entropy is only a negligible portion of the total entropy at 298.16°K.

It should be emphasized that the estimate of error in the third-law calculations applies only to the existing heat-capacity data and the necessary extrapolations as made. Of necessity, it usually is assumed that the substance is in such energy condition at the lowest temperatures reached in the heat-capacity measurements that a normal type of extrapolation may be made. The data and procedure for $Gd_2(SO_4)_3.8H_2O$, for example, illustrate the difficulties that may arise in computing entropies of paramagnetic substances. Moreover, the data and calculations for such substances as CO, H_2O, and N_2O show that correct entropies are not obtained in all instances by indiscriminate application of the usual methods of calculation.

In some instances heat-capacity values of several experimenters have been averaged, while in others the results of a single investigator have been adopted. The bibliography at the end of this bulletin contains a virtually complete (to November 1948) list of references pertaining to true heat-capacity data at low temperatures of the elements and inorganic compounds. A table of heat-capacity values of the substances whose entropies have been calculated from the third law of thermodynamics is given immediately following this entropy section.

ALUMINUM

Element.—The low-temperature heat capacity of Al (*c*) was measured by Giauque and Meads (*182*) (15°–302°), Kok and Keesom (*304*) (1°–20°), Maier and Anderson (*344*) (54°–297°), Nernst (*373, 375*) (32°–89°), and Nernst and Schwers (*377*) (19°–80°). The computed entropy is $S^{\circ}_{298.16}=6.77\pm0.02$. The extrapolated portion, below 1.11°, is negligible, ca. 3×10^{-4} unit.

Spectroscopic data for Al (*g*), listed by Moore (*364*), show that only two energy levels, $^2P^{\circ}_{1/2}$ and $^2P^{\circ}_{3/2}$, separated by 112.04 waves per cm. and having quantum weights of 2 and 4, respectively, need be considered in deriving the entropy at 298.16°. These states add 3.492 to the entropy given by the Sackur equation, to yield $S^{\circ}_{298.16}=39.31\pm 0.01$ for Al (*g*).

Aluminum Ion.—Latimer, Pitzer, and Smith (*325*) have obtained $S^{\circ}_{298,16}=-76\pm10$ for Al^{+++}(*aq.*), based upon data for the reaction CsAl $(SO_4)_2\cdot12H_2O(c)=Cs^{+}(aq.)+Al^{+++}(aq.)+2SO_4^{--}(aq.)+12H_2O(l)$.

Oxides.—Anderson (*24*) (53°–295°), Parks and Kelley (*383*) (91°–292°), and Simon and Swain (*443*) (30°–280°) have measured the heat capacity of granular alundum, sapphire, and corundum, respectively. These are three varieties of the same crystalline modification of Al_2O_3. Considering all the data, there is obtained $S^\circ_{298.16}=12.5\pm0.15$ for $Al_2O_3(c)$, the extrapolation below 28.18° being 0.03.

Molecular constant data for $AlO(g)$ (*212*, *311*) yield $S^\circ_{298.16}=52.14\pm0.10$, of which 0.105 is vibrational entropy. The quantum weight of the ground state is taken as 2.

Hydrated Oxides.—Shomate and Cook (*434*) ($Al_2O_3 \cdot H_2O$, 52°–297°; and $Al_2O_3 \cdot 3H_2O$, 52°–297°) have made low-temperature heat-capacity measurements of two hydrated crystalline aluminum oxides.

The entropy of $Al_2O_3 \cdot H_2O$ (crystal form not designated) is $S^\circ_{298.16}=23.15\pm0.10$. The extrapolation below 52.00° is 0.94.

For $Al_2O_3 \cdot 3H_2O$ (gibbsite) the entropy is $S^\circ_{298.16}=33.5\pm0.2$, of which 1.40 is extrapolation below 52.00°.

Chloride.—Molecular-constant data for $AlCl(g)$ (*212*, *311*) yield $S^\circ_{298.16}=54.4\pm0.5$.

Hydrides.—Molecular-constant data are available for $AlH(g)$ and $AlD(g)$ (*212*, *311*). For the former there is computed $S^\circ_{298.16}=44.84\pm0.10$, and for the latter, $S_{298.16}=46.28\pm0.10$.

Nitrate.—Shomate and Kelley (*435*) (53°–297°) measured the low-temperature heat capacity of $Al(NO_3)_3 \cdot 6H_2O(c)$. The entropy calculation yields $S^\circ_{298.16}=111.8\pm1.1$, with an extrapolation below 53.09° of 15.82.

Silicates.—Simon and Zeidler (*444*) (kyanite, 24°–224°; sillimanite, 17°–282°; and andalusite, 23°–280°) and Todd (*486*) (kyanite, sillimanite, and andalusite, 52°–298°) have measured low-temperature heat capacities of three crystalline varieties of Al_2SiO_5. The data are in disagreement, and only those of Todd are employed in arriving at the following entropy values: Kyanite, $S^\circ_{298.16}=20.02\pm0.08$; sillimanite, $S^\circ_{298.16}=22.97\pm0.10$; and andalusite, $S^\circ_{298.16}=22.28\pm0.10$. The extrapolated portions, below 51.00°, are 0.32, 0.73, and 0.62 unit, respectively.

Sulfates.—Shomate (*426*) ($Al_2(SO_4)_3$, 54°–297°; and $Al_2(SO_4)_3 \cdot 6H_2O$, 54°–297°) measured the heat capacities of anhydrous and hydrated, crystalline aluminum sulfates.

The entropy calculation for $Al_2(SO_4)_3(c)$ yields $S^\circ_{298.16}=57.2\pm0.3$, of which 3.76 is the extrapolation below 53.09°.

For $Al_2(SO_4)_3 \cdot 6H_2O$ there is obtained $S^\circ_{298.16}=112.1\pm0.9$. The extrapolation below 53.09° is 11.23.

ANTIMONY

Element.—Anderson (*10*) (66°–294°), Günther (*205*) (80°–98°), and Simon and Ruhemann (*441*) (71°–82°) measured the heat capacity of $Sb(c)$. The data of Günther and of Simon and Ruhemann do not agree with those of Anderson or with each other, and they have been given no weight as they cover such small temperature ranges. Anderson's measurements yield $S^\circ_{298.16}=10.5\pm0.3$. The extrapolated portion is 2.34 below 63.1°.

The entropy of $Sb(g)$ may be obtained from the Sackur equation with $R\ ln\ 4=2.755$ added to account for the quantum weight of 4 for the lowest energy level. The result is $S^\circ_{298.16}=43.07\pm0.01$.

Almy (*6*) and Naudé (*372*) have reported the vibration frequency of the $Sb_2(g)$ molecule and Genard (*168*) has reported the moment of inertia. From the values, $I=489\times10^{-40}$ and $\omega=269$, there are obtained $S^\circ_{t+r.298.16}=59.28$, $S^\circ_{v298.16}=1.60$, and $S^\circ_{298.16}=60.9\pm0.2$.

Oxides.—Anderson (*10*) (Sb_2O_3, 59°–295°; Sb_2O_4, 59°–285°; and Sb_2O_5, 60°–293°) has made low-temperature heat-capacity measurements of three antimony oxides.

For $Sb_2O_3(c)$ there is obtained $S^\circ_{298.16}=29.4\pm0.6$, of which 4.09 is extrapolation below 56.23°.

A rough value of the entropy of $Sb_4O_6(g)$ may be obtained from that of the solid, 2×29.4, and the entropy of sublimation, $\Delta S_{298.16}=42.9$ (*270*). The result is $S^\circ_{298.16}=102$, in which the error may be several units.

Anderson's data for $Sb_2O_4(c)$ yield $S^\circ_{56.23}=4.31$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{56.23}=26.04$ (measured), making $S^\circ_{298.16}=30.4\pm0.7$.

The corresponding figures for $Sb_2O_5(c)$ are $S^\circ_{56.23}=2.54$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{56.23}=27.32$ (measured). The sum is $S^\circ_{298.16}=29.9\pm1.0$. The estimated error includes allowance for uncertainty in correcting the heat-capacity values for water and lower oxide impurities.

Sulfide.—From heat and free-energy equations given by Kelley (*273*) there is estimated $S^\circ_{298.16}=39.6$ for $Sb_2S_3(c)$, in which the error may be a few units.

Trichloride.—Howard and Wilson (*217*) have considered the prismatic $SbCl_3(g)$ molecule and have obtained 134(2), 165(1), 320(2), and 360(1) as the vibration frequencies, the numbers in parentheses being the degrees of freedom. The Sb–Cl distance was given as 2.30×10^{-8} cm. and the valence angle as 94°. A slightly different set of frequencies was reported by Hemptinne, Wouters, and Fayt (*209*), 130(2), 155(1), 320(2), and 360(1). From Howard and Wilson's figures the moments of inertia are $I_1=660\times10^{-40}$ and $I_2=I_3=470\times10^{-40}$. These, with the Sackur-Tetrode equation and the symmetry number 3, yield $S^\circ_{t+r,298.16}=68.77$. The vibrational entropy is $S^\circ_{v,298.16}=12.00$, making $S^\circ_{298,16}=80.8\pm1.0$ for $SbCl_3(g)$.

The free energy and heat of sublimation of $SbCl_3(c)$ have been reported (*270*) as $\Delta F^\circ_{298.16}=5{,}111$ and $\Delta H_{298.16}=15{,}855$, corresponding to an entropy of sublimation of $\Delta S_{298.16}=36.03$. This figure and the entropy of the gas yield $S^\circ_{298.16}=44.7\pm2$ for $SbCl_3(c)$.

ARGON

Element.—Clusius (*79*) (10°–89°) and Eucken (*146*) (17°–94°) have made heat-capacity measurements of solid and liquid argon. Eucken and Hauck (*147*) determined the melting point and heat of fusion, and Frank and Clusius (*162*) the boiling point and heat of vaporization. The data of Clusius and Frank and of Eucken differ appreciably. Two independent calculations of the third law value of the entropy will be given for comparison with the more reliable result obtainable from the Sackur equation.

Clusius and Frank (*98*) have summarized their data in an entropy calculation for 87.29°, the normal boiling point. Their results are: $S^\circ_{10}=0.303$ (extrapolation), $S^\circ_{83.78}-S^\circ_{10}=8.815$ (crystals), $\Delta S^\circ_{83.78}=280.8/83.78=3.352$ (fusion), $S^\circ_{87.29}-S^\circ_{83.78}=0.413$ (liquid), $\Delta S_{87.29}=1{,}557.5/87.29=17.843$ (vaporization), and $\Delta S_{87.29}=0.125$ (correction to ideal gas state). These values add to give $S^\circ_{87.29}=30.85$. To bring the gas to 298.16° there must be added 6.104 (calculated from a constant heat capacity of $C_p=5/2R=4.969$ cal. per deg.). The resulting third-law value is $S^\circ_{298.16}=36.95\pm0.2$.

Similar calculations from the data of Eucken and Eucken and Hauck yield: $S^\circ_{17.8}=1.133$ (extrapolation), $S^\circ_{83.6}-S^\circ_{17.8}=8.062$ (crystals); $\Delta S^\circ_{83.6}=265.2/83.6=3.172$ (fusion), and $S^\circ_{87.3}-S^\circ_{83.6}=0.453$ (liquid). These items add to give $S^\circ_{87.3}=12.82$ for the entropy of liquid argon. These investigators did not measure the heat of vaporization, and the value from the work of Frank and Clusius will be adopted together with their correction to the ideal gas state. The result is $S^\circ_{87.3}=30.79$, which, in turn, leads to $S^\circ_{298.16}=36.89\pm0.2$ for argon gas.

The most reliable value for argon gas is that computed from the Sackur equation, $S^\circ_{298,16}=36.99\pm0.01$. The two third-law values are seen to be in substantial agreement with this result.

ARSENIC

Element.—Anderson (*8*) (57°–291°) measured the heat capacity of As(*c*). His data give $S^\circ_{56.23}=1.20$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{56.23}=7.16$ (measured), making $S^\circ_{298.16}=8.4\pm0.2$.

Spectroscopic energy-level data for As(*g*), listed by Moore (*364*), show that only the lowest level, with a quantum weight of 4, is effective at 298.16°. Addition of $R\ ln\ 4$ to the Sackur equation yields $S^\circ_{298.16}=41.62\pm0.01$.

The vibration frequency, 429.4 cm.$^{-1}$, and the interatomic distance, 1.95×10^{-8} cm., of the $As_2(g)$ molecule were reported by Almy (*6*). From the latter figure, $I=236\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=56.38$ and $S^\circ_{v.298.16}=0.86$, making a total of $S^\circ_{298.16}=57.2\pm0.3$.

From vapor-pressure data the value $\Delta S_{298.16}=35.1$ was estimated as the entropy of sublimation of arsenic in forming $As_4(g)$ (*270*). This result and the entropy of the solid yield $S^\circ_{298.16}=35.1+4\times8.4=69$ for $As_4(g)$. The error in this value may be several units.

Oxides.—Anderson (*8*) (As_2O_3, 60°–297°; and As_2O_5, 63°–297°) measured heat capacities of two arsenic oxides.

The data for $As_2O_3(c)$ give $S^\circ_{56.23}=3.54$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.23}=22.04$ (measured), and $S^\circ_{298.16}=25.6\pm0.5$.

The entropy of sublimation of orthorhombic As_2O_3 to form $As_4O_6(g)$ was computed as $\Delta S^\circ_{298.16}=49.5$ from vapor-pressure data (*270*). This value and the entropy of the solid give $S^\circ_{298.16}=49.5+2\times25.6=101$ for $As_4O_6(g)$. The error in this value may be several units.

The data for $As_2O_5(c)$ give $S^\circ_{63.1}=1.94$ (extrapolation), $S_{298.16}-S^\circ_{63.1}=23.30$ (measured) and $S^\circ_{298.16}=25.2\pm0.4$.

Arsenious and Arsenic Acids and Ions.—The National Bureau of Standards Tables (*371*) record $S^\circ_{298.16}=30.3$ for $HAsO_2(aq.)$, $S^\circ_{298.16}=47.0$ for $H_3AsO_3(aq.)$, $S^\circ_{298.16}=49.3$ for $H_3AsO_4(aq.)$, $S^\circ_{298.16}=0.9$ for $HAsO_4^{--}(aq.)$, and $S^\circ_{298.16}=-34.6$ for $AsO_4^{--}(aq.)$. Stephenson (*454*) reported $S^\circ_{298.16}=28.0\pm1.0$ for $H_2AsO_4^{--}(aq.)$.

Trichloride.—Brodskii and Sack (*56*), Howard and Wilson (*217*), Paramasivan (*382*), Yost (*505*), and Yost and Anderson (*506*) have considered the vibration frequencies of the $AsCl_3(g)$ molecule. These frequencies are 159(2), 193(1), 370(2), and 410(1) cm.$^{-1}$. Yost and Anderson also report the moments of inertia, $I_1=661.8\times10^{-40}$ and $I_2=I_3=402.0\times10^{-40}$. The symmetry number is 3, as the molecule is pyramidal.

There are calculated $S^\circ_{t+r,298.16}=67.78$, $S^\circ_{v,298.16}=10.41$, and $S^\circ_{298.16}=78.2\pm1.0$. The last value agrees with the calculations of Yost and Anderson. The older calculation of Yost and Sherborne (*510*) is in error.

The heat and free energy of vaporization of $AsCl_3(l)$ have been calculated as $\Delta H_{298.16}=8{,}692$ and $\Delta F^\circ_{298.16}=2{,}009$, from vapor-pressure data (*270*). These figures correspond to an entropy of vaporization of $\Delta S^\circ_{298.16}=22.4$ which, when combined with the result for the gas, gives $S^\circ_{298.16}=55.8\pm2$ for $AsCl_3(l)$.

Trifluoride.—Russell, Rundle, and Yost (*407*) (13°–288°) have measured the heat capacity of AsF_3 and have obtained the entropy of AsF_3 (*g*) at 298.16° and 1 atm. pressure. The entropy terms are as follows: $S^\circ_{13.34}=0.454$ (extrapolation), $S^\circ_{267.21}-S^\circ_{13.34}=30.272$ (crystals), $\Delta S^\circ_{267.21}=\frac{2{,}486}{267.21}=9.304$ (fusion), $S^\circ_{292.50}-S^\circ_{267.21}=2.713$ (liquid), $\Delta S_{292.50}=\frac{8{,}566}{292.50}=29.285$ (vaporization at 141.6 mm. pressure), and $\Delta S_{292.50}=0.06$ (correction for gas imperfection). These terms add to give $S^\circ_{292.50}=72.09$ for $AsF_3(g)$ under 141.6 mm. pressure. The correction to 1 atm. pressure is -3.34 and the entropy increment for increasing the temperature from 292.50° to 298.16° is 0.30. The final result is $S^\circ_{298.16}=69.05\pm0.15$.

Russell, Rundle, and Yost also obtained $S^\circ_{298.16}=69.08\pm0.10$ from molecular constant data for $AsF_3(g)$. This calculation was checked by the present author to within 0.02 unit. The agreement with the third-law value is excellent.

The data of Russell, Rundle, and Yost also serve to obtain the entropy of $AsF_3(l)$. From terms listed above, the entropy of $AsF_3(l)$ at 292.50° is $S^\circ_{292.50}=42.74$. The entropy increment for heating the liquid to 298.16° is 0.58, making $S^\circ_{298.16}=43.3\pm0.1$.

BARIUM

Element.—The entropy of Ba(*g*) calculated from the Sackur equation is $S^\circ_{298.16}=40.67\pm0.01$. In this instance only one energy level of unit quantum weight is effective.

Kelley (*290*) estimated the entropy of Ba(*c*) as $S^\circ_{298.16}=16.0\pm0.5$.

Barium Ion.—Latimer, Pitzer, and Smith (*325*) have obtained $S^\circ_{298.16}=2.3\pm0.3$ for the entropy of Ba^{++} (*aq.*) from data for the reaction $BaCl_2\cdot2H_2O(c)=Ba^{++}(aq.)+2Cl^-(aq.)+2H_2O\ (l)$.

Oxide.—Anderson (*17*) 56°–299°) investigated the heat capacity of BaO (*c*). From his data, $S^\circ_{298.16}=16.8\pm0.3$, of which the extrapolation below 56.2° is 2.56.

From band spectra, Mahanti (*342*) has obtained $I=76.0\times10^{-40}$ and $\omega=671.5$ for BaO(*g*). These figures yield $S^\circ_{t+r,298.16}=55.58$ and $S^\circ_{v,298.16}=0.34$. The sum is $S^\circ_{298.16}=55.9\pm0.5$ for BaO (*g*).

Bromate.—Greensfelder and Latimer (*202*) (16°–296°) measured the heat capacity of $Ba(BrO_3)_2\cdot H_2O\cdot$ Their entropy calculation is in error, as was indicated by Latimer, Schutz, and Hicks (*328*). Recalculation gives 0.80 unit as the extrapolated portion between 0° and 15.85° and 67.97 as the measured portion between 15.85° and 298.16°. The total is $S^\circ_{298.16}=68.8\pm1.5$.

Carbonate.—The heat capacity of $BaCO_3$ (witherite) was measured by Anderson (*15*) (54°–296°). Calculation gives $S^\circ_{298.16}=26.8\pm0.5$, of which 3.59 is extrapolation below 56.2°.

Chloride.—Brown, Smith, and Latimer (*61*) (14°–302°) studied the heat capacity of $BaCl_2\cdot2H_2O$ (*c*). The extrapolated portion of the entropy is 0.33 below 14.13° and the measured portion is $S^\circ_{298.16}-S^\circ_{14.13}=48.18$. Therefore, $S^\circ_{298.16}=48.5\pm0.2$.

Fluoride.—The heat capacity of BaF_2 (*c*) was measured by Pitzer, Smith, and Latimer (*391*) (13°–301°). Their data yield $S^\circ_{298.16}=23.03\pm0.10$, of which only 0.06 is extrapolation below 13.34.

Hydride.—Available molecular-constant data for BaH(*g*) (*212, 311*) yield $S^\circ_{298.16}=52.3\pm0.1$.

Nitrate.—The heat capacity of $Ba(NO_3)_2(c)$ was measured by Latimer and Ahlberg (*316*) (16°–296°) and Shomate and Kelley (*435*) (54°–297°). The two sets of data are in excellent agreement and yield $S^\circ_{298.16}=51.1\pm0.2$, of which 0.56 is extrapolation below 15.8°.

Sulfate.—Latimer, Hicks, and Schutz (*324*) (15°–299°) measured the heat capacity of $BaSO_4$(c). There are computed $S^\circ_{14.13}=0.16$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{14.13}=31.43$ (measured). The total is $S^\circ_{298.16}=31.6\pm0.2$.

BERYLLIUM

Element.—The heat capacity of Be(*c*) was measured by Cristescu and Simon (*117*) (10°–300°), Lewis (*329*) (97°–283°), and Simon and Ruhemann (*441*) (71°–80°). The entropy calculation is based upon the work of Cristescu and Simon, which is the most extensive. Their data yield $S^\circ_{298.16}=2.28\pm0.02$. The extrapolation below 10° is virtually negligible, about 0.0002 unit.

The entropy of Be(*g*) is given as $S^\circ_{298.16}=32.55\pm0.01$ by the Sackur equation.

Oxide.—Günther (*204*) (76°–85°) and Kelley (*277*) (55°–293°) have measured the heat capacity of BeO(*c*). Employing the data of the latter investigator, there is obtained $S^\circ_{298.16}=3.37\pm0.02$. The extrapolation below 53.1° is 0.037 unit.

The moment of inertia and vibration frequency of BeO(*g*) were determined by Herzberg (*214*) as $I=16.72\times10^{-40}$ and $\omega=1{,}475$. From the first figure $S^\circ_{t+r,298.16}=47.16$, and from the second, $S^\circ_{v,298.16}=0.01$, making $S^\circ_{298.16}=47.17\pm0.10$.

Chloride.—Molecular-constant data (*212, 311*) yield $S^\circ_{298.16}=51.81\pm0.10$ for BeCl(*g*).

Fluoride.—The value, $S^\circ_{298.16}=49.13\pm0.10$, for BeF(*g*) is computed from available molecular-constant data (*212, 311*).

Hydride.—For BeH(*g*), available molecular-constant data (*212, 311*) yield $S^\circ_{298.16}=42.20\pm0.10$.

Silicate.—Kelley (*277*) (54°–295°) measured the heat capacity of Be_2SiO_4 (phenacite). His data yield $S^\circ_{298.16}=15.37\pm0.08$, of which 0.30 is extrapolation below 53.1°.

BISMUTH

Element.—The low-temperature heat capacity of Bi(*c*) was investigated by Anderson (*11*) (60°–299°), Bronson and MacHattie (*57*) (193°–293°), and Keesom and van den Ende (*249, 250*) (3°–20°). Combining these data, there is calculated $S^\circ_{298.16}=13.6\pm0.6$. The extrapolated portion below 3.16° is 0.005. The estimated error is large because the data of Anderson and of Bronson and MacHattie cannot be connected to those of Keesom and van den Ende in a reasonable manner. It appears likely that a transition ("hump") may occur in the temperature range 20° to 60°, especially in view of the fact that the entropy value is so low compared with that of Pb(*c*). The computed result is a compromise.

The entropy of Bi(*g*) computed from the Sackur equation with $R \ln 4$ added because of the quantum weight 4 (*364*) of the lowest energy level is $S^\circ_{298.16}=44.68\pm0.01$.

Almy and Sparks (*7*) have obtained the internuclear distance of the $Bi_2(g)$ molecule as 2.85×10^{-8} cm., and the vibration frequency as $\omega=173$. The nuclear separation results in $I=1{,}409\times10^{-40}$, which, in turn, yields $S^\circ_{t+r,298.16}=62.99$. The vibrational entropy is $S^\circ_{v,298.16}=2.40$, and the sum is $S^\circ_{298.16}=65.4\pm0.2$.

Oxide.—Anderson's (*11*) (60°–290°) heat-capacity data for $Bi_2O_3(c)$ lead to the values, $S^\circ_{56.2}=6.22$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{56.2}=29.96$ (measured), making $S^\circ_{298.16}=36.2\pm0.6$.

Bromide.—Molecular-constant data estimated by Stevenson (*467*) lead to $S^\circ_{298.16}=63.6\pm0.5$ for BiBr(*g*).

Chlorides.—The $BiCl_3(g)$ molecule was considered by Howard and Wilson (*217*), who gave 96(2), 130(1), 242(2), and 288(1) as the vibration frequencies, 2.46×10^{-80} cm. as the Bi–Cl distance, and 93° as the bond angle in the pyramidal model. From the last two figures $I=740\times10^{-40}$ and $I_2=I_3=580\times10^{-40}$. The moments of inertia and the symmetry number 3 result in $S^\circ_{t+r,298.16}=70.27$. The vibrational entropy is $S^\circ_{v,298.16}=15.08$. For $BiCl_3(g)$, therefore, $S^\circ_{298.16}=85.3\pm1.0$.

The heat and free energy of vaporization of $BiCl_3(l)$ were obtained formally from vapor-pressure data as $\Delta H_{298.16}=23{,}177$ and $\Delta F^\circ_{298.16}=12{,}228$ (*270*). These correspond to $\Delta S_{298.16}=36.52$. The heat of fusion of $BiCl_3(c)$ at its melting point, 497°, was computed as $\Delta H_{497}=2{,}600$ from binary-system freezing-point data (*271*). If it is assumed that $\Delta C_p=4$ for the reaction $BiCl_3(c)=BiCl_3(l)$, then $\Delta S^\circ_{298.16}=3.16$ for the fusion process. The entropy of sublimation is, therefore, $\Delta S_{298.16}=39.7$. From this and the entropy of the gas there is obtained $S^\circ_{298.16}=45.6\pm2$ for $BiCl_3(c)$.

From molecular-constant data (*467*), there is computed $S^\circ_{298.16}=60.9\pm0.5$ for BiCl(*g*).

Sulfide.—Kelley (*273*) has obtained $S^\circ_{298.16}=33.8$ for $Bi_2S_3(c)$ from data for the reaction $Bi_2S_3(c)+3H_2(g)=2Bi(c)+3H_2S(g)$.

Hydrides.—Molecular-constant data (*212*, *311*) for BiH(*g*) and BiD(*g*) yield, respectively, $S^\circ_{298.16}=51.28\pm0.10$ and $S^\circ_{298.16}=52.69\pm0.10$.

Iodide.—Stevenson (*467*) has estimated molecular-constant data for BiI(*g*), which lead to $S^\circ_{298.16}=65.4\pm0.5$.

BORON

Element.—From heat-capacity measurements of $B_4C(c)$ (*281*) and a comparison of available entropy data for carbides with those of their constituent metals there is estimated $S^\circ_{298.16}=1.7\pm0.2$ for B(*c*).

Spectroscopic data for B(*g*) (*311*) show that, in obtaining the entropy at 298.16° K., only two energy levels, having a separation of

15.5 waves per cm., need be considered. These levels are designated $^2P_{1/2}$ and $^2P_{3/2}$, respectively, with quantum weights of 2 and 4. It is found that 3.562 is to be added to the translational entropy given by the Sackur equation, making $S^\circ_{298.16}=36.66\pm0.01$ for B(*g*).

Oxides.—Kelley (*281*) (52°–296°) measured the heat capacity of $B_2O_3(c)$. His data give $S^\circ_{298.16}=13.04\pm0.07$, of which 0.68 is extrapolation below 53.1°.

Molecular-constant data for BO(*g*) (*212, 311*) yield $S^\circ_{298.16}=48.60\pm 0.10$.

Carbide.—The heat capacity of $B_4C(c)$ also was investigated by Kelley (*281*) (54°–295°). The data yield $S^\circ_{298.16}=6.47\pm0.03$, the extrapolation below 53.1° being 0.047.

Tribromide.—Spencer (*452*) has computed the entropy of $BBr_3(g)$ from the moments of inertia, $I_1=1{,}392\times10^{-40}$ and $I_2=I_3=696\times10^{-40}$, and the vibration frequencies, 151.2(2), 279(1), 375.3(1), and 812(2). The molecule is planar and nonlinear, so the symmetry number is 6. The calculation gives $S^\circ_{t+r,298.16}=69.19$ and $S^\circ_{v,298.16}=8.30$, making a total of $S^\circ_{298.16}=77.5\pm0.5$.

Trichloride.—The entropy of $BCl_3(g)$ was calculated by Spencer (*452*) from the moments of inertia, $I_1=528.6\times10^{-40}$ and $I_2=I_3=264.3\times10^{-40}$, the vibration frequencies, 243.2(2), 465.8(1), 471(1), and 965.2(2), and the symmetry number 6. These molecular constants yield $S^\circ_{t+r,298.16}=64.04$, $S^\circ_{v,298.16}=5.25$, and $S^\circ_{298.16}=69.3\pm0.5$.

Trifluoride.—Eucken and Schröder (*150*) (12°–173°) have measured the heat capacity and heats of transition and fusion of BF_3 and have used the data in computing $S^\circ_{298.16}=61.17$ for $BF_3(g)$. Spencer (*452*) has called attention to several errors in their calculations and has obtained $S^\circ_{298.16}=60.80$ from essentially the same basic data. He computes $S^\circ_{12.6}=0.55$ (extrapolation), $S^\circ_{142.15}-S^\circ_{12.6}=18.42$ (crystals II), $S^\circ_{144.46}-S^\circ_{142.15}=0.74$ (transition and crystals *I*), $\Delta S^\circ_{144.46}=\frac{1{,}014}{144.46}=7.02$ (fusion), $S^\circ_{154.5}-S^\circ_{144.46}=1.65$ (liquid), $\Delta S_{154.5}=\frac{4{,}411}{154.5}=28.55$ (vaporization at 0.2185 atm.), $\Delta S_{154.5}=0.04$ (correction to ideal gas state), $\Delta S^\circ_{154.5}=-3.02$ (compression to 1 atm.), and $S^\circ_{298.16}-S^\circ_{154.5}=6.85$ (gas). The total is $S^\circ_{298.16}=60.80\pm0.5$.

Spencer (*452*) also has computed the entropy of $BF_3(g)$ from molecular-constant data. The moments of inertia are $I_1=157.7\times10^{-40}$ and $I_2=I_3=78.84\times10^{-40}$. According to data presented by Gage and Barker (*164*) the vibration frequencies for the normal isotopic BF_3 mixture are 481(2), 697(1), 888(1), and 1,456(2). These figures and symmetry number 6 yield $S^\circ_{t+r,298.16}=58.80$, $S^\circ_{v298.16}=1.90$, and $S^\circ_{298.16}=60.7\pm0.5$. This value is in good agreement with the third-law result and is the value adopted.

Hydrides.—Molecular-constant data are available for BH(*g*) and BD(*g*) (*212*). Calculation gives $S^\circ_{298.16}=41.01\pm0.10$ for BH(*g*) and $S^\circ_{298.16}=42.46\pm0.10$ for BD(*g*).

BROMINE

Element.—The heat capacity of solid bromine was measured by Latimer and Hoenshel (*321*) (14°–253°) and Suhrmann and von Lüde (*478*) (20°–155°). The results of the former investigators are used in the entropy calculation, as the data of the latter are very erratic. Weber (*498*) has given the melting point as 265.9° and Regnault (*396*), the heat of fusion as 2,580 cal. per mole. A mean heat capacity of $Br_2(l)$, $C_p=17.0$, was measured near room temperature by Andrews (*28*).

The data of Latimer and Hoenshel lead to the values $S^\circ_{14.1}=0.68$ (extrapolation) and $S^\circ_{265.9}-S^\circ_{14.1}=24.32$ (crystals), making the value for $Br_2(c)$ at the melting point $S^\circ_{265.9}=25.00$. The entropy of fusion is $\Delta S^\circ=\frac{2,580}{265.9}=9.70$, and the entropy increment in heating the liquid from 265.9° to 298.16° is 1.94. Therefore, $S^\circ_{298.16}=36.6\pm0.5$.

Woitinek (*503*) has obtained $\Delta S^\circ_{298.16}=-3.00$ for the reaction $Ag(c)+1/2Br_2(l)=AgBr(c)$. Employing the value $S^\circ_{298.16}=10.20\pm0.05$ for $Ag(c)$ and $S^\circ_{298.16}=25.60\pm0.1$ for $AgBr(c)$, there is obtained $S^\circ_{298.16}=36.8\pm0.4$ for $Br_2(l)$, in agreement with the result from heat-capacity data.

The mean value, $S^\circ_{298.16}=36.7\pm0.4$ is adopted.

Brown (*66*) has computed the following values for $Br_2(g)$ from spectroscopic data: $S^\circ_{298.16}=58.56$ for $Br_2^{79,79}$, $S^\circ_{298.16}=60.01$ for $Br_2^{79,81}$, and $S^\circ_{298.16}=58.70$ for $Br_2^{81,81}$. For the usual isotopic mixture he obtained $S^\circ_{298.16}=58.63$. The latter value was checked by Gordon and Barnes (*201*) who obtained $S^\circ_{298.16}=58.67$. Using available molecular-constant data (*212*), $I=342.5\times10^{-40}$ and $\omega=322$, there is obtained $S^\circ_{t+r,298.16}=57.31$ and $S^\circ_{v298.16}=1.30$, making $S^\circ_{298.16}=58.61$. The value given by Brown, $S^\circ_{298.16}=58.63$, is adopted. The error should not exceed 0.03 unit.

The spectroscopic data for monatomic, Br (*g*), gas show that at 298.16° all but a negligible portion of the molecules are in the lowest energy state, which is a $^2P_{3/2}$ state with quantum weight 4. The Sackur equation with $R\ ln\ 4$ added yields $S^\circ_{298.16}=41.81\pm0.01$ for Br (*g*).

Bromide Ion.—Latimer, Pitzer, and Smith (*325*) have obtained the entropy of $Br^-(aq.)$ from data for three reactions, $AgBr(c)+Cl^-(aq.)=AgCl(c)+Br^-(aq.)$, $AgBr(c)+\frac{1}{2}H_2(g)=H^+(aq.)+Br^-(aq.)+Ag(c)$, and $\frac{1}{2}\ Br_2(l)+Cl^-(aq.)=\frac{1}{2}\ Cl_2(g)+Br^-(aq.)$. The results are, respectively, 19.8 ± 0.2, 19.6 ± 0.3, and 19.5 ± 0.4. Their selected result, $S^\circ_{298.16}=19.7\pm0.2$, is adopted here.

Bromate Ion.—The entropy of $BrO_3^-(aq.)$ has been obtained by Latimer, Pitzer, and Smith (*325*) from data for the reactions $KBrO_3(c)=K^+(aq.)+BrO_3^-(aq.)$ and $Ba(BrO_3)_2.H_2O(c)=Ba^{++}(aq.)+2BrO_3^-(aq.)+H_2O(l)$. The values are, respectively, 38.7 ± 1 and 38.1 ± 2. Their selection, $S^\circ_{298.16}=38.5\pm1.0$, is adopted.

Chloride.—From thermal measurements in CCl_4 solutions Blair and Yost (*45*) have obtained $S^\circ_{298.16}=57.1$ for $BrCl(g)$. The later paper of Beeson and Yost (*41*) gives $\Delta S^\circ_{298.16}=2.83$ for the reaction $Br_2(g)+Cl_2(g)=2BrCl\,(g)$. This result and the entropies of $Br_2(g)$ and $Cl_2(g)$ lead to $S^\circ_{298.16}=57.4$ for $BrCl(g)$. Available molecular-constant data (*212*) give $S^\circ_{t+r,298.16}=56.47$ and $S^\circ_{v,298.16}=0.89$, making $S^\circ_{298.16}=57.36\pm0.10$. The last figure is adopted.

Fluoride.—The entropy of $BrF(g)$ may be calculated from the relationship, $S^\circ_{298.16}(BrF(g))=\frac{1}{2}\ S^\circ_{298.16}(Br_2(g))+\frac{1}{2}\ S^\circ_{298.16}(F_2(g))+Rln\ 2$. The result is $S^\circ_{298.16}=54.98\pm0.10$.

CADMIUM

Element.—The low-temperature heat capacity of Cd(c) was measured by Bronson and Wilson (*58*) (193°–283°), Lange and Simon (*313*) (10°–300°), and Rodebush (*398*) (69°–298°). The most weight has been given to the data of Lange and Simon in obtaining $S^\circ_{298.16}=12.34\pm0.10$ for Cd(c). The extrapolation below 10° amounts to only 0.07.

From the Sackur equation, the entropy of Cd(g) is $S^\circ_{298.16}=40.07\pm0.01$. The lowest-energy state only is effective at 298.16°, and its quantum weight is 1.

Cadmium Ion.—Latimer, Pitzer, and Smith (*325*), from data for the reaction $Cd(c)+2H^+(aq.)=Cd^{++}(aq.)+H_2(g)$, have obtained $S^\circ_{298.16}=-16.4\pm1.5$ for $Cd^{++}(aq.)$. This value agrees within the limits of error with the figure given by Bates (*39*), $S^\circ_{298.16}=-14.8\pm1.0$. The mean, $S^\circ_{298.16}=-15.6\pm1.2$ is adopted.

Oxide.—Millar (*360*) (71°–291°) measured the heat capacity of CdO(c). His data lead to $S^\circ_{70.8}=2.16$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{70.8}=10.94$ measured; therefore, $S^\circ_{298.16}=13.1\pm0.3$.

The entropy of CdO(g) was computed from that of the solid and vapor-pressure data as $S^\circ_{298.16}=46.9$ (*270*). The error in this value may be several units.

Bromides.—Bates (*40*) has reported $S^\circ_{298.16}=32.0$ for $CdBr_2(c)$. This value is adopted, and the error is taken as ±2.0. Reasonable agreement is shown by the result obtainable from the heat and free energy of formation of $CdBr_2(c)$, found by Ishikawa and Ueda (*221*, *223*), namely, $S^\circ_{298.16}=34.4$.

Using molecular-constant data listed by Stevenson (*467*), there is computed $S^\circ_{298.16}=63.1\pm0.5$ for CdBr(g).

Carbonate.—The entropy of dissociation of $CdCO_3(c)$ to CdO(c) and $CO_2(g)$ was estimated previously (*290*) as $\Delta S^\circ_{298.16}=39.0$. From this there is obtained $S^\circ_{298.16}=25.2$ for $CdCO_3(c)$. This result may be in error by a few units.

Chlorides.—The entropy of $CdCl_2(c)$ was reported by Bates (*40*) as $S^\circ_{298.16}=31.2$. The reaction $Cd(c)+Cl_2(g)=CdCl_2(c)$ was studied by Ishikawa, Kimura, and Murooka (*225*), who adopted $\Delta H^\circ_{298.16}=-92{,}149$ and $\Delta F^\circ_{298.16}=-81{,}878$,making $\Delta S^\circ_{298.16}=-34.5$. The last figure corresponds to $S^\circ_{298.16}=31.5$ for $CdCl_2(c)$, in good agreement with Bates' value. Garner, Green, and Yost (*166*) have obtained data leading to a higher result, $S^\circ_{298.16}=34.0$ (corrected). The value given by Bates is adopted, $S^\circ_{298.16}=31.2\pm2.0$.

Molecular-constant data given by Stevenson (*467*) lead to $S^\circ_{298.16}=60.4\pm0.5$ for CdCl(g).

Hydride.—Available molecular-constant data (*212*, *311*) lead to $S^\circ_{298.16}=50.69\pm0.10$ for CdH(g). This value is based on $I=5.20\times10^{-40}$, $\omega=1{,}384$, and quantum weight=2 for the ground state.

Hydroxide.—Ishikawa and Shibata (*219*) have obtained $\Delta F^\circ_{298.16}=-42{,}100$ for the reaction $Cd(c)+HgO(c)+H_2O(l)=Cd(OH)_2(c)+Hg(l)$. The heat of this reaction may be approximated from existing data as $\Delta H^\circ_{298.16}=-44{,}200$, leading to $\Delta S^\circ_{298.16}=-7.0$ as the entropy change. As the other entropies are known, $S^\circ_{298.16}=21$ is calculated for $Cd(OH)_2(c)$. This result is one of low accuracy, and the error may be a few units.

Iodides.—The only available value for $CdI_2(c)$ is that given by Bates (*40*), $S^\circ_{298,16}=39.5$, in which the error is estimated as ± 2.0.

Molecular-constant data estimated by Stevenson (*467*) yield $S^\circ_{298,16}=65.0\pm 0.5$ for $CdI(g)$.

Sulfates.—From consideration of the thermodynamic properties of $CdSO_4(c)$, Kelley (*273*) has computed $S^\circ_{298,16}=31.3$, in which the error may be a few units. He also estimated $S^\circ_{298,16}=39.7$ for $CdSO_4 \cdot H_2O(c)$ and $S^\circ_{298,16}=57.5$ for $CdSO_4 \cdot 8/3H_2O(c)$.

Sulfide.—Kelley (*273*), in considering the thermodynamic properties of $CdS(c)$, has estimated $S^\circ_{298,16}=17\pm 1$.

Telluride.—McAteer and Seltz (*347*) have obtained $\Delta S^\circ_{298,16}=-2.0$ for the formation of $CdTe(c)$ from the elements. This result leads to $S^\circ_{298,16}=22.2\pm 1.0$ for $CdTe(c)$.

Antimonides.—The reaction $Cd(l)+Sb(c)=CdSb(c)$ was studied by Seltz and De Haven (*415*). They obtained $\Delta H=-4{,}730$ (ΔC_p assumed zero) and $\Delta F^\circ_{687}=-2{,}559$. From these figures, $\Delta F^\circ=-4{,}730+3.16T$, which at the melting point of Cd, 594°, yields $\Delta F^\circ_{594}=-2{,}853$. Taking the heat of fusion of Cd as $\Delta H_{594}=1{,}450$ (*288*), there is obtained $\Delta F^\circ=-3{,}280+0.72T$ for the reaction $Cd(c)+Sb(c)=CdSb(c)$. The entropy of reaction is therefore -0.72, which results in $S^\circ_{298,16}=22.1\pm 1.0$ for $CdSb(c)$.

Seltz and DeWitt (*416*) have obtained $\Delta S^\circ_{298,16}=21.0$ for the reaction $3Cd(c)+2Sb(c)=Cd_3Sb_2(c)$. This figure leads to $S^\circ_{298,16}=79.0\pm 5$ for $Cd_3Sb_2(c)$.

CALCIUM

Element.—The low-temperature heat capacity of $Ca(c)$ was measured by Clusius and Vaughen (*105*) (10°–201°), Eastman and Rodebush (*139*) (67°–294°), and Günther (*204*) (22°–62°). Relying almost entirely on the data of Clusius and Vaughen, there are obtained $S^\circ_{10.0}=0.013$ (extrapolation), $S^\circ_{298.16}-S^\circ_{10.0}=9.94$, and $S^\circ_{298.16}=9.95\pm 0.10$.

Spectroscopic data for $Ca(g)$ (*364*) show that only the lowest energy level, of unit quantum weight, need be considered in obtaining $S^\circ_{298.16}=37.00\pm 0.01$ from the Sackur equation.

Calcium Ion.—Latimer, Pitzer, and Smith (*325*) have obtained $S^\circ_{298.16}=-11.4\pm 0.3$ for $Ca^{++}(aq.)$ from thermal data for the reaction $CaCO_3(c)+2H^+(aq.)=Ca^{++}(aq.)+H_2O(l)+CO_2(g)$.

Oxide.—Nernst and Schwers (*377*) (28°–90°) and Parks and Kelley (*383*) (87°–293°) have measured the heat capacity of $CaO(c)$. The resulting entropy values are $S^\circ_{28.0}=0.04$ (extrapolation), $S^\circ_{298.16}-S^\circ_{28.0}=9.46$ (measured), and $S^\circ_{298.16}=9.5\pm 0.2$.

The values, $I=57.2\times 10^{-40}$ (*311*) and $\omega=837$ (*212*), are available for $CaO(g)$. There are computed $S^\circ_{t+r,298.16}=52.11$ and $S^\circ_{v,298.16}=0.18$, making $S^\circ_{298.16}=52.3\pm 0.3$.

Borates.—Low-temperature heat-capacity measurements of four crystalline calcium borates were reported by Kelley, Todd, and Shomate (*299*) ($3CaO \cdot B_2O_3$, 52°–297°; $2CaO \cdot B_2O_3$, 53°–297°; $CaO \cdot B_2O_3$, 54°–297°; and $CaO \cdot 2B_2O_3$, 54°–297°).

For $3CaO \cdot B_2O_3$ (*c*), the entropy extrapolation below 52.00° is 2.16, and the measured portion from 52.00° to 298.16° is 41.73, making $S^\circ_{298.16}=43.9\pm 0.3$.

The values for $2CaO\cdot B_2O_3$ (*c*) are 1.84 (extrapolation below 52.00°) and 32.84 (measured between 52.00° and 298.16°). These add to give $S^\circ_{298.16}=34.7\pm0.2$.

The entropy of $CaO\cdot B_2O_3(c)$ is $S^\circ_{298.16}=25.1\pm0.2$, of which 1.65 is extrapolation below 52.00° and 23.41 is measured.

For $CaO\cdot 2B_2O_3$, the extrapolated portion of the entropy, below 52.00°, is 1.59, and the measured portion is 30.61, making $S^\circ_{298.16}=32.2\pm0.3$.

Carbide.—Kelley (*283*) (53°–295°) measured the low-temperature heat capacity of CaC_2 (*c*). The entropy values are $S^\circ_{50.12}=1.02$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=15.82$ (measured), and $S^\circ_{298.16}=16.8\pm0.4$. The uncertainty is made large to allow for possible error in correcting for impurities in the calcium carbide.

Carbonates.—The heat capacity of $CaCO_3$ (calcite) was measured by Anderson (*15*) (57°–297°), Nernst and Schwers (*377*) (22°–89°), and Simon and Swain (*443*) (15°–80°). The entropy calculation, using all the data, gives $S^\circ_{298.16}=22.2\pm0.2$. The extrapolation, below 14.12°, is 0.05, and the measured portion is 22.10.

Anderson (*15*) (54°–293°) and Günther (*204*) (23°–57°) have measured the heat capacity of $CaCO_3$ (aragonite). Anderson's results, which differ considerably from the older values of Günther, are used. The entropy is $S^\circ_{298.16}=21.2\pm0.3$, of which 1.51 is extrapolation below 56.2° and 19.67 is measured.

The difference in entropy between the two varieties of $CaCO_3$ is 1.0 ± 0.4. This agrees with the value determined by Backström (*31*), 0.74 ± 0.2, by a different method.

Chlorides.—Kelley and Moore (*292*) (52°–296°) have measured the heat capacity of $CaCl_2(c)$. Their data yield $S^\circ_{50.12}=4.59$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{50.12}=22.57$ (measured), making $S^\circ_{298.16}=27.2\pm0.3$.

Data are available (*212, 311*) for computing the entropy of CaCl(*g*). The moment of inertia is 106×10^{-40}, the vibration frequency is 364, and two energy levels, separated by 75 cm^{-1}, and each having a quantum weight of 2, must be considered. There is obtained $S^\circ_{t+r,298.16}=54.12$, $S^\circ_{v,298.16}=1.10$, and $S^\circ_{e,298.16}=2.73$. The total is $S^\circ_{298.16}=58.0\pm0.3$.

Fluoride.—Eucken and Schwers (*151*) (17°–86°) and Todd (*486*) (53°–297°) have measured the heat capacity of $CaF_2(c)$. The more recent and better data of Todd are used in obtaining $S^\circ_{298.16}=16.46\pm0.08$. The extrapolation below 51.00° is 0.64, and the measured portion is 15.82.

From rather uncertain molecular-constant data (*212, 311*), there is estimated $S^\circ_{298.16}=54.8\pm1.0$ for CaF(*g*).

Hydrides.—Günther (*204*) (69°–87°) made heat-capacity measurements of $CaH_2(c)$. The investigated temperature range is much too small for a good entropy calculation, but there is estimated $S^\circ_{298.16}=9.9\pm1.0$.

Available molecular-constant data (*212, 311*), $I=6.54\times10^{-40}$, $\omega=1{,}280$, and quantum weight=2 for the ground state, result in $S^\circ_{298.16}=48.18\pm0.10$ for CaH(*g*).

Hydroxide.—The heat capacity of $Ca(OH)_2(c)$ was measured by Nernst and Schwers (*377*) (21°–86°). These measurements suffice only for a rough entropy calculation, $S^\circ_{298.16}=17.4\pm1.0$.

Nitrate.—The heat capacity of $Ca(NO_3)_2(c)$ was measured by Shomate and Kelley (*435*) (53°–314°). Their data yield $S^\circ_{53.09}=5.90$

(extrapolation) and $S^\circ_{298.16}-S^\circ_{53.09}=40.27$ (measured), making $S^\circ_{298.16}=46.2\pm0.5$.

Oxalate.—Latimer, Schutz, and Hicks (*326*) (19°–300°) have studied the heat capacity of $CaC_2O_4 \cdot H_2O(c)$. From their data $S^\circ_{298.16}-S^\circ_{17.78}=37.23$ is computed and $S^\circ_{17.78}=0.20$ is extrapolated, making $S^\circ_{298.16}=37.4\pm0.2$.

Phosphates.—Southard and Milner (*450*) (15°–298°) have investigated the heat capacities of α– and β–$Ca_3(PO_4)_2$. The entropy values are, respectively, $S^\circ_{298.16}=57.6\pm0.2$ and $S^\circ_{298.16}=56.4\pm0.4$. The extrapolation for the α–form is 0.09 below 14.13°, while for the β–modification 0.20 is the extrapolation below 17.78°.

Sulfide.—The heat capacity of $CaS(c)$ was measured by Anderson (*12*) (58°–295°). The data yield $S^\circ_{298.16}=13.5\pm0.3$, of which $S^\circ_{56.2}=1.32$ is extrapolation below 56.2°.

Sulfite.—Kelley and Moore (*294*) (53°–296°) measured the heat capacity of $CaSO_3(c)$. The extrapolated portion of the entropy below 50.12°, is 1.68, and the measured portion is 22.55. The total is $S^\circ_{298.16}=24.2\pm0.2$.

Sulfates.—Anhydrous or nearly anhydrous $CaSO_4$ exists in three forms having different but definite thermal properties. The variety obtained by heating gypsum or hemihydrate to temperatures around 900° C. is distinguishable by its low solubility in water and is identical with the naturally occurring anhydrite. It is designated here by the symbol $CaSO_4$ (insol.). The other two varieties are obtained by low-temperature dehydration of the two forms of the hemihydrate mentioned below. Both are several times as soluble in water as $CaSO_4$ (*insol.*) and they have different heats of solution and hydration. These forms are symbolized by $CaSO_4$ (sol. α) and $CaSO_4$ (sol. β), the α and β corresponding to the hemihydrates from which they are formed.

Anderson (*298*) (53°–296°) has studied the low-temperature heat capacity of $CaSO_4$ (*insol.*). His data yield $S^\circ_{298.16}=25.5\pm0.4$, of which 1.51 is extrapolation below 50.1° and 23.95 is measured between 50.1° and 298.16°. The entropy of this substance may be approximated from the data of Kamiike (*237*), who obtained $\Delta S^\circ_{298.16}=11.1$ for the reaction $CaSO_4 \cdot 2H_2O(c)=CaSO_4$ (*insol.*)$+2H_2O(l)$. This figure corresponds to $S^\circ_{298.16}=24.0\pm2.0$ for $CaSO_4$ (*insol.*). No weight is given this result in comparison with the value from Anderson's work.

Kelley (*298*) (54°–295°) has measured the heat capacities of the two soluble varieties of $CaSO_4$. Although appreciable differences are apparent in their heat capacities, compensation occurs and the two forms, $CaSO_4$ (sol. α) and $CaSO_4$ (sol. β), have virtually the same entropy. The results obtained are $S^\circ_{298.16}=25.9\pm0.3$ for $CaSO_4$ (sol. α), of which 1.76 is extrapolation below 53.1°, and $S^\circ_{298.16}=25.9\pm0.3$ for $CaSO_4$ (sol. β), of which 1.57 is extrapolation below 53.1°.

Calcium sulfate hemihydrate, $CaSO_4 \cdot 1/2H_2O$, exists in two forms having different but definite thermal properties. For the present purpose, macrocrystalline hemihydrate, obtained by dehydrating gypsum in the presence of liquid water, is designated as $CaSO_4 \cdot 1/2H_2O$ (α). The ordinary variety, prepared by dehydrating under conditions where the water is gaseous, is microcrystalline and is designated as $CaSO_4 \cdot 1/2H_2O(\beta)$.

The heat capacities of the two varieties of $CaSO_4 \cdot 1/2H_2O$ were measured by Kelley (*298*) (54°–295°). The entropy values obtained for $CaSO_4 \cdot 1/2H_2O(\alpha)$ are $S^\circ_{53.1}=2.62$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{53.1}=28.61$ (measured), making $S^\circ_{298.16}=31.2\pm0.4$. For $CaSO_4 \cdot 1/2H_2O(\beta)$, $S^\circ_{53.1}=2.82$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.1}=29.26$ (measured), and $S^\circ_{298.16}=32.1\pm0.4$.

Anderson (*298*) (53°–298°) and Latimer, Hicks, and Schutz (*324*) (18°–303°) have measured the heat capacity of $CaSO_4 \cdot 2H_2O$ (selenite). The results are in good agreement and yield $S^\circ_{298.16}=46.4\pm0.3$, the extrapolation below 17.78° being 0.20 and the measured portion between 17.78° and 298.16° being 46.15.

Silicates.—The heat capacity of $CaSiO_3$ (wollastonite) was measured by Cristescu and Simon (*117*) (10°–210°) and Wagner (*496*) (9°–304°). The combined data yield $S^\circ_{298.16}=19.6\pm0.2$, of which only 0.016 is extrapolation below 10°.

Parks and Kelley (*384*) (88°–299°) and Wagner (*496*) (10°–296°) have measured the heat capacity of $CaSiO_3$ (pseudowollastonite). The results of the two investigations are in fair agreement. Calculation gives $S^\circ_{298.16}=20.9\pm0.2$, with only 0.013 extrapolation below 10°.

Wagner (*496*) (20°–40°), in addition, has made a few heat-capacity determinations of $CaMg(SiO_3)_2$ (diopside). The temperature range covered is too small to permit a reasonable entropy calculation.

Titanate.—Shomate (*430*) (52°–297°) measured the heat capacity of $CaTiO_3$ (perovskite). His data yield $S^\circ_{52.00}=1.08$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=21.30$ (measured), and $S^\circ_{298.16}=22.4\pm0.1$

CARBON

Element.—The heat capacity of graphite was measured by Jacobs and Parks (*227*) (93°–294°) and Nernst (*373*) (28°–284°). Relying on the work of Jacobs and Parks, there is obtained $S^\circ_{298.16}=1.36\pm0.02$ for C (graphite). The extrapolation below 89.12° is 0.168.

Nernst (*373, 376*) (23°–220°), Pitzer (*387*) (70°–288°), and Robertson, Fox, and Martin (*397*) have measured the heat capacity of diamond. Pitzer's data yield $S^\circ_{298.16}=0.585\pm0.005$. The extrapolation below 70.8° is 0.008.

In obtaining the entropy of $C(g)$ at 298.16°, three states must be considered—${}^3P^\circ$, ${}^3P_1$, and ${}^3P_2$ (*364*). These states have the term values 0, 14.8, and 42.3 and quantum weights 1, 3, and 5. They result in the addition of 4.357 to the Sackur equation to obtain $S^\circ_{298.16}=37.76\pm0.01$ for $C(g)$.

Available molecular-constant data (*212*) for $C_2(g)$, $\omega=1{,}630$ and interatomic distance$=1.312\times10^{-8}$ cm. ($I=17.2\times10^{-40}$), lead to $S^\circ_{298.16}=47.91\pm0.10$. The quantum weight of the ground state is taken as 3.

Monoxide.—The heat capacity of solid and liquid CO was measured by Clayton and Giauque (*73, 74*) (14°–85°), Clusius (*75*) (11°–82°), Eucken (*146*) (17°–78°), and Kaischew (*235*) (54°–76°). Clayton and Giauque have calculated the entropy from spectroscopic data as well as from the thermal data. Their results are adopted; namely, $S^\circ_{11.70}=0.46$ (extrapolation), $S^\circ_{61.55}-S^\circ_{11.70}=9.63$ (crystals II), $\Delta S^\circ_{61.55}=$

$\frac{151.3}{61.55}=2.46$ (transition), $S^\circ_{68.09}-S^\circ_{61.55}=1.23$ (crystals I), $\Delta S^\circ_{68.09}=\frac{199.7}{68.09}=2.93$ (fusion), $S^\circ_{81.61}-S^\circ_{68.09}=2.61$ (liquid), $\Delta S^\circ_{68.61}=\frac{1443.6}{81.61}=17.69$ (vaporization at 1 atm.), $\Delta S_{81.61}=0.21$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{81.61}=9.00$ (gas). These figures add to give $S^\circ_{298.16}=46.22$. The result from spectroscopic data is $S^\circ_{298.16}=47.31\pm 0.01$. The difference of 1.1 units, which is of the order of $R\ ln\ 2$, was attributed by Clayton and Giauque to random orientation of molecules in the crystal lattice of solid CO. The value from spectroscopic data is adopted, as it can be in error by only a negligible amount.

The spectroscopic value may be checked by utilizing molecular-constant data (*212*, *311*), $I=15.0\times10^{-40}$ and $\omega=2155$. The result is $S^\circ_{298.16}=47.28$, the vibrational contribution being negligible.

Dioxide.—The low-temperature heat capacity of CO_2 was measured by Eucken (*146*) (19°–201°), Eucken and Hauck (*147*) (80°–320°), and Giauque and Egan (*178*) (15°–190°). Giauque and Egan determined accurately the heat of sublimation; the results of their entropy calculation are adopted. The computed terms are $S^\circ_{15}=0.19$ (extrapolation), $S^\circ_{194.67}-S^\circ_{15}=16.33$ (crystals), $\Delta S^\circ_{194.67}=\frac{6.030}{194.67}=30.98$ (sublimation at 1 atm. pressure), $\Delta S^\circ_{194.67}=0.09$ (correction to ideal gas state) and $S^\circ_{298.16}-S^\circ_{194.67}=3.52$ (gas). The sum is $S^\circ_{298.16}=51.11\pm0.10$.

Dennison (*124*) has reported $I=71.30\times10^{-40}$ and $\omega_1=1{,}351.2(1)$, $\omega_2=672.3(2)$, and $\omega_3=2396.4$ for the $CO_2(g)$ molecule. These figures lead to $S^\circ_{t+r,298.16}=50.35$, $S^\circ_{v,298.16}=0.70$, and $S^\circ_{298.16}=51.05\pm0.05$. The agreement between the third-law value and that from molecular constants is excellent. The latter is adopted, as it is subject to less uncertainty. Gordon (*195*), using somewhat different molecular constants, has obtained a satisfactory agreeing value.

Suboxide.—Molecular-constant data listed by Thompson (*482*), $I=395.2\times10^{-40}$ and $\omega=200(2)$, $550(2)$, $586(2)$, $843(1)$, $1{,}570(1)$, $2{,}200(1)$, and $2{,}290(1)$, enable the calculation of the entropy of $C_3O_2(g)$. There results $S^\circ_{t+r,298.16}=55.05$ and $S^\circ_{v,298.16}=6.49$, making $S^\circ_{298.16}=61.5\pm0.5$.

Monosulfide.—From molecular-constant data (*212*, *311*), $I=33.88\times 10^{-40}$ and $\omega=1{,}279$, there are calculated $S^\circ_{t+r,298.16}=50.25$ and $S^\circ_{v,298.16}=0.03$, making $S^\circ_{298,16}=50.28\pm0.10$ for $CS(g)$.

Disulfide.—Brown and Manov (*60*) (15°–298°) measured the heat capacity of CS_2. Calculation yields $S^\circ_{14.96}=0.64$ (extrapolation), $S^\circ_{161.1}-S^\circ_{14.96}=17.92$ (crystals), $\Delta S^\circ_{161.1}=\frac{1{,}049}{161.1}=6.51$ (fusion), and $S^\circ_{298.16}-S^\circ_{161.1}=11.09$ (liquid). The sum is $S^\circ_{298.16}=36.2\pm0.2$ for $CS_2(l)$.

The heat and free energy of vaporization of $CS_2(l)$ are $\Delta H_{298.16}=6{,}682$ and $\Delta F^\circ_{2981.6}=441$ (*270*), giving $\Delta S^\circ_{298.16}=20.93$. Addition of this entropy increment to the value for $CS_2(l)$ yields $S^\circ_{298.16}=57.1\pm0.4$ for $CS_2(g)$. A more reliable value for $CS_2(g)$ is obtained from molecular-constant data (*311*), which are $I=260\times10^{-40}$, $\omega_1=655(1)$, $\omega_2=397(2)$, and $\omega_3=1{,}523(1)$. These data yield $S^{\circ}_{t+r,298.16}=54.54$ and $S^{\circ}_{v,298.16}=2.32$. The total, $S^{\circ}_{298.16}=56.86\pm0.10$ is adopted for $CS_2(g)$.

Carbonyl Sulfide.—Kemp and Giauque (*300*) (15°–223°) have investigated the heat capacity of solid and liquid COS and have determined the heat of vaporization. Their calculations give $S^{\circ}_{15.0}=0.55$ (extrapolation), $S^{\circ}_{134.31}-S^{\circ}_{15.0}=14.96$ (crystals), $\Delta S^{\circ}_{134.31}=\frac{1{,}129.8}{134.31}=8.41$ (fusion), $S^{\circ}_{222.87}-S^{\circ}_{134.31}=8.66$ (liquid), $\Delta S_{222.87}=\frac{4{,}423}{222.87}=19.85$ (vaporization at 1 atm. pressure), $\Delta S_{222.87}=0.13$ (correction to ideal gas state), and $S^{\circ}_{298.16}-S^{\circ}_{222.87}=2.71$ (gas). These figures add to give $S^{\circ}_{298.16}=55.27\pm0.10$. All calculations have been checked by the author.

A somewhat more accurate value is obtainable from available molecular-constant data. The values selected by Giauque and Kemp are adopted here, $I=137\times10^{-40}$, $\omega_1=859.2$ (1), $\omega_2=521.5$ (2), and $\omega_2=2{,}050.5$. These figures give $S^{\circ}_{t+r,298.16}=53.95$ and $S^{\circ}_{v,298.16}=1.37$. The sum is $S^{\circ}_{298.16}=55.32\pm0.10$, with which the third-law value is in excellent agreement. Calculations of Cross and Brockway (*120*) and Cross (*119*), using slightly different molecular constants, yield $S^{\circ}_{298.16}=55.34$, which also is in agreement. The value, $S^{\circ}_{298.16}=55.32\pm0.10$, is adopted for $COS(g)$.

Tetrabromide.—Stevenson and Beach (*468*, *469*) reported 123 (2), 265 (1), 183 (3), and 667 (3) as the vibration frequencies of the $CBr_4(g)$ molecule and 1.91×10^{-8} cm. as the C–Br distance. The last figure yields $I_1=I_2=I_3=1{,}325\times10^{-40}$. There are computed $S^{\circ}_{t+r,298.16}=69.88$ and $S^{\circ}_{v,289.16}=15.67$, making $S^{\circ}_{298.16}=85.6\pm1.0$.

Tetrachloride.—The low-temperature heat capacity of CCl_4 was investigated by Hicks, Hooley, and Stephenson (*216*) (17°–299°), Latimer (*314*) (39°–290°), Lord and Blanchard (*341*) (10°–330°, data of Blanchard and Blue and of Stull), and Stull (*477*) (90°–320°). Johnston and Long (*232*) have measured the temperatures and heats of transition and fusion. These several sets of data show much disagreement. The most recent, and also most extensive, results of Hicks, Hooley, and Stephenson are adopted. Their calculations give $S^{\circ}_{18}=1.39$ (extrapolation), $S^{\circ}_{225.35}-S^{\circ}_{18}=34.12$ (crystals II), $\Delta S^{\circ}_{225.35}=\frac{1{,}095}{225.35}=4.86$ (transition), $S^{\circ}_{250.3}-S^{\circ}_{225.35}=3.01$ (crystals I), $\Delta S^{\circ}_{250.3}=\frac{601}{225.3}=2.40$ (fusion), and $S^{\circ}_{298.16}-S^{\circ}_{250.3}=5.48$ (liquid). The sum is $S^{\circ}_{298.16}=51.3\pm0.2$ for $CCl_4(l)$.

The entropy of vaporization of $CCl_4(l)$ at 298.16° is $\Delta S^{\circ}_{298.16}=22.4$, according to the survey by Hicks, Hooley, and Stephenson (*216*) and 22.5 according to the heat and free-energy-of-vaporization values of Kelley (*270*). Adopting the mean value and adding it to the entropy of $CCl_4(l)$ results in $S^{\circ}_{298.16}=73.7\pm0.3$ for $CCl_4(g)$.

Yost (*505*) gives 214 (2), 311 (3), 450 (1), and 775 (3) as the vibration frequencies of the $CCl_4(g)$ molecule, and 1.755×10^{-8} cm. as the C–Cl distance. The last value yields $I_1=I_2=I_3=499\times10^{-40}$. There are calculated $S^{\circ}_{t+r,298.16}=64.68$ and $S^{\circ}_{v,298.16}=9.63$. The total, $S^{\circ}_{298.16}=74.3\pm0.5$, agrees with the third-law value within the limits of the assigned uncertainties.

For the present, the mean value, $S^\circ_{298.16}=74.0\pm0.4$, is adopted for $CCl_4(g)$.

Tetrafluoride.—The heat capacity of CF_4 was measured by Eucken and Schröder (*150*) (12°–145°), who also determined the heats of transition, fusion, and vaporization. Recalculation of their results yields $S^\circ_{11.9}=0.70$ (extrapolation), $S^\circ_{76.23}-S^\circ_{11.9}=15.62$ (crystals II), $\Delta S^\circ_{76.23}=\frac{353.2}{76.23}=4.63$ (transition), $S^\circ_{89.47}-S^\circ_{76.23}=2.59$ (crystals I), $\Delta S^\circ_{89.47}=\frac{167.4}{89.47}=1.87$ (fusion), $S^\circ_{122.0}-S^\circ_{89.47}=5.76$ (liquid) $\Delta S^\circ_{122.0}=\frac{3{,}120}{122}=25.57$ (vaporization at 0.1365 atm.), and $\Delta S^\circ_{122.0}=-3.96$ (compression from 0.1365 to 1 atm.). From vibration frequencies given below, $C_p(g)$ was computed at several temperatures and $S^\circ_{298.16}-S^\circ_{122}=10.02$ (gas) obtained by graphical integration. The total is $S^\circ_{298.16}=62.8\pm0.5$ for $CF_4(g)$.

Yost (*505*) has listed 1.36×10^{-8} cm. as the C–F distance and 437 (2), 635 (3), 904 (1), and 1,350 (3) as the vibration frequencies of the $CF_4(g)$ molecule. From the first figure $I_1=I_2=I_3=156\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=59.55$ and $S^\circ_{v,298.16}=3.08$, making $S^\circ_{298.16}=62.6\pm0.3$, with which the third-law value is in excellent agreement.

Carbonyl Chloride.—Giauque and Jones (*180*) have measured the low-temperature heat capacity and heats of fusion and vaporization of $COCl_2$. Their entropy calculations are as follows: $S_{15}=0.64$ (extrapolation), $S_{145.34}-S_{15}=19.78$ (crystals), $\Delta S_{145.34}=\frac{1{,}371}{145.34}=9.43$ (fusion), $S_{280.66}-S_{145.34}=15.87$ (liquid), $\Delta S_{280.66}=\frac{5{,}832}{280.66}=20.78$ (vaporization at 1 atm. pressure), $\Delta S_{280.66}=0.13$ (correction to ideal gas state), and $S_{298.16}-S_{280.66}=0.87$ (gas). The sum is $S^\circ_{298.16}=67.50$ for $COCl_2(g)$.

Giauque and Jones also have considered the available molecular-constant data for $COCl_2(g)$ and have adopted $I_1=105.4\times10^{-40}$, $I_2=240.1\times10^{-40}$, $I_3=345.5\times10^{-40}$, and the vibration frequencies, 230 (1), 302 (1), 444 (1), 570 (1), 845 (1), and 1,827 (1). These data lead to $S^\circ_{t+r,298.16}=64.29$ and $S^\circ_{v,298.16}=4.78$, making $S^\circ_{298.16}=69.1\pm0.3$. The deviation between this and the value from heat-capacity data, 1.6 units, is attributed by Giauque and Jones to random orientation of the $COCl_2$ molecules in the crystal lattice; in other words, the heat-capacity measurements were made on a material in which complete internal equilibrium was not established and which could not be established in any reasonable length of time. The value $S^\circ_{298.16}=69.1\pm0.3$, therefore, is adopted for $COCl_2(g)$.

Thiocarbonyl Chloride.—Thompson (*483*) has computed the entropy of $CSCl_2(g)$ from the moments of inertia, $I_1=74.1\times10^{-40}$, $I_2=244.5\times10^{-40}$, and $I_3=318.6\times10^{-40}$, and the vibration frequencies, 200(1), 290(1), 365(1), 500(1), 660(1), and 1,140(1). Repetition of his calculation, using the natural constants adopted in this publication, yields $S^\circ_{t+r,298.16}=64.32$ and $S^\circ_{v,298.16}=5.78$. The sum is $S^\circ_{298.16}=70.1\pm0.3$ for $CSCl_2(g)$.

Cyanogen.—Ruehrwein and Giauque (*406*) (14°—252°) have measured the heat capacity of C_2N_2. Their calculations, the sum of which has been checked to 0.05 unit, are as follows: $S^\circ_{15}=0.31$ (extrapolation), $S^\circ_{245.27}-S^\circ_{15}=24.30$ (crystals), $\Delta S^\circ_{245.27}=\frac{1{,}938}{245.27}=7.90$(fusion), $S^\circ_{251.95}-S^\circ_{245.27}=0.68$ (liquid), $\Delta S_{251.95}=\frac{5{,}576}{251.95}=22.13$ (vaporization at 1 atm. pressure), $\Delta S_{251.95}=0.11$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{251.95}=2.21$ (gas). The sum is $S^\circ_{298.16}=57.64\pm0.1$ for $C_2N_2(g)$.

The $C_2N_2(g)$ molecule is linear, and the following molecular constants are listed by Ruehrwein and Giauque: $I=176\times10^{-40}$, $\omega_1=230(2)$, $\omega_2=512(2)$, $\omega_3=860(1)$, $\omega_4=2{,}150(1)$, and $\omega_5=2{,}336(1)$. These data, in conjunction with the presently adopted natural constants, lead to $S^\circ_{t+r,298.16}=52.65$ and $S^\circ_{v,298.16}=5.18$. The sum, $S^\circ_{298.16}=57.83\pm0.10$, is in good agreement with the value from heat-capacity data. Stevenson (*466*) and McMorris and Badger (*351*) have computed closely agreeing values. The result from the molecular-constant data is adopted.

Neutral CN.—Zeise (*513*) has computed $S^\circ_{298.16}=48.42\pm0.01$ for neutral $CN(g)$ from spectroscopic data. This value may be checked, using the molecular constants (*212, 311*), $I=14.63\times10^{-40}$ and $\omega=2{,}055$. A virtually identical result, $S^\circ_{298.16}=48.39$, is obtained.

Cyanide Ion.—The National Bureau of Standards tables (*370*) list $S^\circ_{298.16}=28.2$ for $CN^-(aq.)$. Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=25\pm5$ from data for the reaction $HCN(g)=H^+(aq.)+CN^-(aq.)$.

Cyanogen Bromide.—Stevenson (*466*) has listed molecular-constant data for $CNBr(g)$: $I=201\times10^{-40}$ and $\omega=368(2)$, $580(1)$, and $2{,}187(1)$. These values give $S^\circ_{t+r,298.16}=56.40$, $S^\circ_{v,298.16}=2.66$, and $S^\circ_{298.16}=59.1\pm0.5$. The last value may be checked by means of the approximate relationship, $S^\circ_{298.16}(CNBr(g))=1/2\ S^\circ_{298.16}(C_2N_2(g))+1/2\ S^\circ_{298.16}(Br_2(g))+R\ ln\ 2$, which yields $S^\circ_{298.16}=59.6$ for $CNBr(g)$.

Cyanogen Chloride.—Molecular-constant data of Stevenson (*466*), $I=143\times10^{-40}$, and $\omega=397(2)$, $729(1)$, and $2{,}201(1)$, yield $S^\circ_{t+r,298.16}=54.11$, $S^\circ_{v,298.16}=2.22$, and $S^\circ_{298.16}=56.3\pm0.5$. The relationship analogous to that given under "cyanogen bromide" leads to $S^\circ_{298.16}=56.9$.

Cyanogen Fluoride.—The entropy of $CNF(g)$ is given approximately by the relationship, $S^\circ_{298.16}(CNF(g))=1/2\ S^\circ_{298.16}(C_2N_2(g))+1/2\ S^\circ_{298.16}(F_2(g))+R\ ln\ 2$, which yields $S^\circ_{298.16}=54.6\pm0.5$.

Cyanogen Iodide.—The molecular-constant data of Stevenson (*466*), $I=251\times10^{-40}$ and $\omega=321(2)$, $470(1)$, and $2{,}158(1)$, give $S^\circ_{t+r,298.16}=57.94$, $S^\circ_{v,298.16}=3.35$, and $S^\circ_{298.16}=61.3\pm0.5$. The previously mentioned approximation method leads to $S^\circ_{298.16}=61.4$.

Phosphide.—Molecular-constant data are available for $CP(g)$ (*212*), $I=34.74\times10^{-40}$, $\omega=1{,}233$, and quantum weight of the ground state=2. From these data, $S^\circ_{t+r,\ 298.16}=50.23$, $S^\circ_{v,\ 298.16}=0.04$, $S^\circ_{e,\ 298.16}=1.38$, and $S^\circ_{298.16}=51.6\pm0.3$.

Methane.—Heat-capacity data for CH_4 have been reported by Clusius (*75*) (10°–106°), Clusius and Perlick (*102*) (10°–80°), Eucken and Karwat (*149*) (28°–109°), Eucken and Veith (*152*) (10°–80°), and Frank and Clusius (*161, 162*) (15°–26°). Additional information concerning the transition and fusion was given by Clusius, Popp, and Frank (*108*) and Kruis, Popp, and Clusius (*306*).

Previous calculations of the author (*269*) gave $S^\circ_{10}=0.31$ (extrapolation), $\Delta S^\circ_{20.4}=0.89$ (for the extra heat capacity at the "hump"), $S^\circ_{90.6}-S_{10}=12.43$ (crystals less extra heat capacity at the "hump"), $\Delta S^\circ_{90.6}=\frac{224.0}{90.6}=2.47$ (fusion), $S^\circ_{111.7}-S^\circ_{90.6}=2.70$ (liquid), $\Delta S^\circ_{111.7}=\frac{1,988}{111.7}=17.80$ (vaporization at 1 atm. pressure, from the vapor-pressure data of Stock, Henning, and Kuss (*471*)), and $S^\circ_{298.16}-S^\circ_{111.7}=7.91$ (gas). The sum is $S^\circ_{298.16}=44.51\pm0.2$.

A later calculation by Frank and Clusius (*161*) yields $S^\circ_{90.6}=13.66$ (crystals), $\Delta S^\circ_{90.6}=2.47$ (fusion), $S^\circ_{99.54}-S^\circ_{90.6}=1.21$ (liquid), $\Delta S_{99.54}=20.45$ (vaporization at 246.13 mm. pressure), $\Delta S^\circ_{99.54}=-2.24$ (compression from 246.13 mm. to 1 atm. pressure), and $\Delta S_{99.54}=0.08$ (correction to ideal gas state). To bring the gas to 298.16° requires an entropy increment of $S^\circ_{298.16}-S^\circ_{99.54}=8.83$ (gas). The sum is $S^\circ_{298.16}=44.46\pm0.2$, virtually identical with the other calculation.

From molecular constants (*311*) $I_1=I_2=I_3=5.27\times10^{-40}$, $\omega_1=1,305$ (3), $\omega_2=1,520$ (2), $\omega_3=2,915$ (1), $\omega_4=3,020$ (3), and symmetry number=12, there are computed $S^\circ_{t+r,\ 298.16}=44.37$, $S^\circ_{v,\ 298.16}=0.10$, and $S^\circ_{298.16}=44.47\pm0.10$. This last value is adopted.

Carbonic Acid and Its Ions.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=45.1\pm0.7$ for H_2CO_3 (*aq.*) from data for the reaction $CO_2(g)+H_2O(l)=H_2CO_3(aq.)$.

The same authors find $S^\circ_{298.16}=22.2\pm0.8$ for $HCO_3^-(aq.)$ from data for the reaction $H_2CO_3(aq.)=H^+(aq.)+HCO_3^-(aq.)$.

They also give $S^\circ_{298.16}=-13.0\pm1.0$ for $CO_3^{--}(aq.)$, computed from thermal data for the reaction $HCO_3^-(aq.)=H^+(aq.)+CO_3^{--}(aq.)$.

Cyanate Ion.—The National Bureau of Standards tables (*370*) list $S^\circ_{298.16}=31.1$ for $CNO^-(aq.)$.

Oxalate Ion.—From data for the reaction $CaC_2O_4\cdot H_2O(c)=Ca^{++}(aq.)+C_2O_4^{--}(aq.)+H_2O(l)$, Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=9.6\pm1$ for $C_2O_4^{--}(aq.)$.

CERIUM

Element.—Lewis and Gibson (*331*) have computed the entropy of Ce(*c*) from Dewar's (*126*) value of the mean heat capacity between 20° and 77°. Their method consisted essentially of correcting Dewar's reported value by the factor 1.085 and then computing θ_D for a Debye function. They obtained $S^\circ_{298.16}=13.8$, in which the error may be as much as ±0.8. No other low-temperature heat-capacity values of Ce(*c*) are available except those of Simon and Ruhemann (*441*) (71°–72°) on an impure sample. The heat capacity at this temperature is too high (6.14) for obtaining θ_D.

Available energy-level data for Ce(*g*) (*364*) add 7.36 to the entropy given by the Sackur equation, to make $S^\circ_{298.16}=48.09\pm0.05$.

CESIUM

Element.—The entropy of Cs(*g*), calculated from the Sackur equation with *R ln* 2 added, is $S^\circ_{298.16}=41.95\pm0.01$.

The entropy of sublimation of Cs(*c*) has been computed from vapor-pressure and heat-capacity data (*270*) as $\Delta S^\circ_{298.16}=22.13$. This value and the entropy of Cs(*g*) leads to the estimate $S^\circ_{298.16}=19.8\pm1.0$ for Cs(*c*).

The entropy of $Cs_2(g)$ is estimated here as $S^\circ_{298.16}=66.6\pm1.5$.

Cesium Ion.—From thermal data for the reaction $CsClO_4(c)=Cs^+(aq.)+ClO_4^-(aq.)$, Latimer, Pitzer, and Smith (*325*) computed $S^\circ_{298.16}=31.8\pm0.6$ for $Cs^+(aq.)$

Bromide.—Molecular-constant data estimated by Stevenson (*467*) give $S^\circ_{298.16}=63.5\pm0.5$ for $CsBr(g)$. Niwa (*380*) estimated $S^\circ_{298.16}=63.8\pm1.7$ from vapor-pressure data and an assumed entropy of $CsBr(c)$. The former value is adopted.

Chloride.—From molecular-constant data listed by Stevenson (*467*), $S^\circ_{298.16}=61.3\pm0.5$ for $CsCl(g)$. Niwa (*380*) estimated a lower and less-certain value, $S^\circ_{298.16}=58.9\pm2.0$, from vapor-pressure data and an assumed entropy for $CsCl(c)$.

Hydride.—Available molecular-constant data (*212*) lead to $S^\circ_{t+r,298.16}=51.20$, $S^\circ_{v,298.16}=0.15$, and $S^\circ_{298.16}=51.35\pm0.10$ for $CsH(g)$.

Iodide.—Stevenson's (*467*) suggested molecular-constant data for $CsI(g)$ give $S^\circ_{298.16}=65.2\pm0.5$.

Perchlorate.—Pitzer, Smith, and Latimer (*391*) (15°–293°) measured the heat capacity of $CsClO_4(c)$. There are computed $S^\circ_{15.0}=0.82$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{15.0}=41.07$, making $S^\circ_{298.16}=41.9\pm0.2$.

Cesium–Aluminum Sulfate.—The heat capacity of $CsAl(SO_4)_2\cdot12H_2O$ was measured by Latimer and Greensfelder (*320*) (18°–298°). The entropy calculation results in $S^\circ_{298.16}=163\pm5$. The extrapolation below 17.78° is 3.00.

CHLORINE

Element.—The low-temperature heat capacity of Cl_2 was measured by Eucken and Karwat (*149*) (21°–197°) and Giauque and Powell (*184*) (14°–237°). Relying on the work of the latter investigators, whose calculations have been checked and are repeated here, there are obtained $S^\circ_{15.0}=0.33$ (extrapolation), $S^\circ_{172.12}-S^\circ_{15.0}=16.57$ (crystals), $\Delta S^\circ_{172.12}=1{,}531/172.12=8.89$ (fusion), $S^\circ_{239.05}-S^\circ_{172.12}=5.23$ (liquid), $\Delta S_{239.05}=4{,}878/239.05=20.41$ (vaporization at 1 atm. pressure), $\Delta S_{239.05}=0.12$ (correction to ideal gas state), $S^\circ_{298.16}-S^\circ_{239.05}=1.76$ (gas). The sum is $S^\circ_{298.16}=53.31\pm0.10$.

Giauque and Overstreet (*183*) have computed the entropy of Cl_2 (g) from spectroscopic data. They find $S^\circ_{298.16}=53.24$ for $Cl_2^{35,35}(g)$, $S^\circ_{298.16}=53.39$ for $Cl_2^{35,37}(g)$, $S^\circ_{298.16}=53.54$ for $Cl_2^{37,37}(g)$, and $S^\circ_{298.16}=53.31$ for the ordinary isotopic mixture.

Molecular-constant data (*212*, *311*), $I=113.9\times10^{-40}$ and $\omega=651$ (1), for $Cl_2^{35,35}(g)$ yield $S^\circ_{t+r,298.16}=52.70$, $S^\circ_{v,298.16}=0.52$, and $S^\circ_{298.16}=53.22$, which is in good agreement with Giauque and Overstreet's more accurately calculated value.

An independent method of obtaining the entropy of ordinary $Cl_2(g)$ is offered by the data of Gerke (*169*), who, by means of measurements on cells, obtained $\Delta S^\circ_{298.16}=-13.7$ for the reaction $Ag(c)+\frac{1}{2}\,Cl_2(g)=AgCl(c)$. This result and the entropies of $Ag(c)$ (10.20 ± 0.05) and $AgCl(c)$ (23.0 ± 0.10) lead to $S^\circ_{298.16}=53.0\pm0.4$ for $Cl_2(g)$.

The value adopted for the ordinary isotopic mixture is Giauque and Overstreet's calculated value, $S^\circ_{298.16}=53.31\pm0.01$ for $Cl_2(g)$.

The entropy of monatomic $Cl(g)$ may be obtained from the Sackur equation and spectroscopic data. At 298.16° only two energy levels need be considered, the $^2P^\circ_{3/2}$ and $^2P^\circ_{1/2}$, having a separation of 881 cm.$^{-1}$

(*364*) and quantum weights of 4 and 2, respectively. The entropy associated with these states is 2.830 units, and the translational entropy is 36.634. The sum is $S^\circ_{298.16}=39.46\pm0.01$ for Cl(*g*).

Chloride Ion.—From thermal data for the reactions $HCl(g)=H^+(aq.)+Cl^-\ (aq.)$ and $AgCl(c)+\frac{1}{2}H_2(g)=H^+(aq.)+Cl^-(aq.)+Ag(c)$, Latimer, Pitzer, and Smith (*325*) obtained, respectively, 13.52 ± 0.15 and 13.49 ± 0.15 as values of the entropy of $Cl^-(aq.)$. The value $S^\circ_{298.16}=13.5\pm0.1$ is adopted. This figure has been checked by Rossini (*402*), who obtained $S^\circ_{298.16}=13.40\pm0.15$ for HCl(*aq.*) at hypothetical 1 molal concentration. Since by convention $S^\circ_{298.16}=0$ for $H^+(aq.)$, it follows that 13.40 ± 0.15 is also the entropy of $Cl^-(aq.)$.

Monoxide.—Sutherland and Penney (*479*) have reported Cl–O distance$=1.71\times10^{-8}$ cm., Cl–O–Cl angle$=110°$, $\omega_1=680(1)$, $\omega_2=320(1)$, and $\omega_3=973(1)$ for $Cl_2O(g)$. There are computed $I_1=252\times10^{-40}$, $I_2=231\times10^{-40}$, and $I_3=20.8\times10^{-40}$, which in turn give $S^\circ_{t+r,298.16}=61.94$. The vibrational entropy is $S^\circ_{v,298.16}=1.74$. The sum is $S^\circ_{298.16}=63.7\pm0.3$.

Yost and Felt (*509*) obtained heat and free-energy-of-formation values for $Cl_2O(g)$ which yield $\Delta S^\circ_{298.16}=-9.9$ as the entropy of formation. This value leads to $S^\circ_{298.16}=67.9$, which can be given no weight in comparison with the figure from the molecular constants.

Dioxide.—Brockway (*55*) has reported 1.53×10^{-8} cm. as the Cl–O distance and 137° as the O–Cl–O angle in the $ClO_2(g)$ molecule. These figures lead to $I=116.5\times10^{-40}$, $I_2=107.7\times10^{-40}$, and $I_3=8.8\times10^{-40}$ and to $S^\circ_{t+r,298.16}=58.79$. According to Ku (*307*) the vibration frequencies are 529(1), 954(1), and 1,105(1), giving $S^\circ_{v,298.16}=0.76$. The sum is $S^\circ_{298.16}=59.6\pm0.5$ for $ClO_2(g)$.

Fluoride.—The entropy of ClF(*g*) is estimated from the relationship $S^\circ_{298.16}\ (ClF(g))=\frac{1}{2}\ S^\circ_{298.16}\ (Cl_2(g))+\frac{1}{2}\ S^\circ_{298.16}\ (F_2(g))+R\ ln\ 2$ to be $S^\circ_{298.16}=52.3\pm0.5$.

Hypochlorite Ion.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=10.0\pm2.0$ for $ClO^-(aq.)$ from thermal data for the reaction $Cl_2(g)+2OH^-(aq.)=H_2O(l)+Cl^-(aq.)+ClO^-(aq.)$.

Chlorite Ion.—Latimer, Pitzer, and Smith (*325*) also reported $S^\circ_{298.16}=24.1\pm0.5$ for $Cl_2O_2^-(aq.)$, from thermal data for the reaction $AgClO_2(c)=Ag^+(aq.)+ClO_2^-(aq.)$.

Chlorate Ion.—The value $S^\circ_{298.16}=39.4\pm0.5$ for $ClO_3^-(aq.)$ was obtained by Latimer, Pitzer, and Smith (*325*) from thermal data for the reaction $KClO_3(c)=K^-(aq.)+ClO_3^-(aq.)$.

Perchlorate Ion.—In addition, Latimer, Pitzer, and Smith (*325*) have given $S^\circ_{298.16}=43.6\pm0.5$ for $ClO_4^-(aq.)$, based upon thermal data for the reaction $KClO_4(c)=K^+(aq.)+ClO_4^-(aq.)$.

CHROMIUM

Element.—The heat capacity of Cr(*c*) was measured by Anderson (*22*) (56°–292°) and Simon and Ruhemann (*441*) (71°–79°). The data of the former give $S^\circ_{298.16}=5.68\pm0.07$, of which 0.22 is extrapolation below 56.2°.

The spectroscopic data on Cr(*g*) show that only the lowest energy state, ${}^7S_3$, must be considered at 298.16° in deriving the entropy. This state adds *R ln* 7 to the Sackur equation to give $S^\circ_{298.16}=41.64\pm0.01$ for Cr(*g*).

Oxide.—Anderson (*22*) (56°–336°) measured the heat capacity of $Cr_2O_3(c)$. His data yield $S^\circ_{56.2}=0.53$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=18.88$ (measured), and $S^\circ_{298.16}=19.4\pm0.3$.

Carbides.—Kelley, Boericke, Moore, Huffman, and Bangert (*295*) have reported low-temperature heat-capacity data from three chromium carbides (Cr_4C, 54°–295°; Cr_3C_2, 53°–296°; and Cr_7C_3, 54°–296°).

The entropy values for $Cr_4C(c)$ are $S^\circ_{50.12}=0.84$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=24.46$ (measured), and $S^\circ_{298.16}=25.3\pm0.2$.

For $Cr_3C_2(c)$ there are obtained $S^\circ_{50.12}=0.56$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=19.79$ (measured), and $S^\circ_{298.16}=20.35\pm0.10$.

The corresponding values for $Cr_7C_3(c)$ are $S^\circ_{50.12}=1.70$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=46.32$ (measured), and $S^\circ_{298.16}=48.0\pm0.3$.

Dichloride.—The heat capacity of $CrCl_2(c)$ was measured by Anderson (*22*) (43°–297°). Recalculation of his data gives $S^\circ_{298.16}=27.7\pm0.7$, of which 5.05 is extrapolation below 44.7°. Doerner (*131*), from equilibrium studies at high temperatures of the reaction $CrCl_2(c)+H_2(g)=Cr(c)+2HCl(g)$, obtained $S^\circ_{298.16}=29.7$. More recently, Maier (*343*) has recalculated Doerner's data and obtained $S^\circ_{298.16}=27.3$. The value from the heat-capacity data, $S^\circ_{298.16}=27.7\pm0.7$ is adopted for $CrCl_2(c)$.

Trichloride.—Anderson (*22*) (54°–297°) and Trapeznikova, Shubnikov, and Miljutin (*492*) (12°–130°) have measured the heat capacity of $CrCl_3(c)$. Unfortunately, the two sets of data are in bad disagreement over their common temperature range. As data of the latter authors for other substances also are in disagreement with values that are considered good, reliance must be placed largely on the data of Anderson. This creates a difficult situation, as Trapeznikova and his coworkers found an anomalous region just below 20°.

Anderson's data alone give $S^\circ_{298.16}=27.3$, of which 3.19 is extrapolation below 56.2°. If allowance is made for a heat-capacity maximum below 20°, by constructing a curve resembling that of Trapeznikova and his coworkers, then about 1.3 must be added to both the extrapolated portion and the entropy at 298.16°, making $S^\circ_{298.16}=28.6$. However, the procedure that will be followed here is to accept the value from Anderson's measurements without this allowance and add $R\ ln\ 4=2.76$, corresponding to the splitting of the lowest energy level of Cr^{+++}, which is designated $^4F_{3/2}$ by Bowen (*52*). This procedure leads to $S^\circ_{298.16}=30.0\pm1.5$, in which the large allowance for error appears necessary.

Doerner (*131*), from rather meager indirect equilibrium data for the reaction $2CrCl_3(c)=2CrCl_2(c)+Cl_2(g)$, computed $S^\circ_{298.16}=31.0$ for $CrCl_3(c)$. However, Maier's (*343*) recalculations indicate that values in the range 28.2 to 31.0 may be obtained from these data.

The value adopted for $CrCl_3(c)$ is $S^\circ_{298.16}=30.0\pm1.5$.

Chromate Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=10.5\pm1.0$ for $CrO_4^{--}(aq.)$ from thermal data for the reaction $Ag_2CrO_4(c)=2Ag^+(aq.)+CrO_4^{--}(aq.)$.

COBALT

Element.—The heat capacity of $Co(c)$ was measured by Aoyama and Kanda (*29*) (79°–274°), Duyckaerts (*135*) (2°–18°), and Simon and Ruhemann (*441*) (71°–72°). The data lead to $S^\circ_{298.16}=6.86\pm0.10$, of which only ca. 8×10^{-4} is extrapolation below 2°.

Moore (*364*) has compiled spectroscopic-energy-level data for Co(g). At 298.16°, four energy levels are effective, $^4F_{9/2}$, $^4F_{7/2}$, $^4F_{5/2}$, and $^4F_{3/2}$. The quantum weights are 10, 8, 6, and 4, respectively, and the term values are 0, 816.0, 1,406.8, and 1,809.3 cm^{-1}. These states add 4.739 to the Sackur equation to make $S^\circ_{298,16}=42.89\pm0.01$ for Co(g).

Chloride.—The heat capacity of $CoCl_2(c)$ was measured by Miljutin and Parfenowa (*357*) (11°–19°) and Trapeznikova, Shubnikov, and Miljutin (*491*) (13°–131°). Their data yield $S^\circ_{298,16}=25.4\pm1.5$, of which 0.10 is extrapolation below 11.2°.

Iodide.—Miljutin, Parfenowa, and Esselson (*358*) (16°–129°) have reported heat-capacity data for $CoI_2(c)$. These data are inadequate for calculation of the entropy.

Ammoniated Cobalt Halides.—Ziegler (*515*) (107°–321°) has measured the heat capacities of $CoCl_3\cdot6NH_3$, $CoI_2\cdot6NH_3$, and $CoI_3\cdot6NH_3$. The data are insufficient for entropy calculations.

COLUMBIUM

Element.—Data are not available for obtaining the entropy of Cb(c). However, the entropy of Cb(g) may be obtained from spectroscopic data compiled by Moore (*364*). The states to be considered are $^6D_{1/2}$, $^6D_{3/2}$, $^6D_{5/2}$, $^6D_{7/2}$, and $^6D_{9/2}$, with quantum wieghts of 2, 4, 6, 8, and 10 and term values of 0, 154.1, 391.9, 695.3, and 1,050.3 cm.$^{-1}$, respectively. The result is that 4.949 must be added to the value given by the Sackur equation, making $S^\circ_{298.16}=44.46\pm0.01$ for Cb(g).

COPPER

Element.—Several investigators have measured the heat capacity of Cu(c): Aoyama and Kanda (*29*) (82°–274°), Dockerty (*129, 130*) (28°–299°), Eucken and Werth (*154*) (83°–216°), Giauque and Meads (*182*) (14°–301°), Keesom and Onnes (*265, 266*) (14°–90°), Kok and Keesom (*303*) (1°–20°), Maier and Anderson (*344*) (53°–295°), and Nernst (*373, 376*) (23°–88°). Using all the data, the entropy is $S^\circ_{298.16}=7.97\pm0.02$. The extrapolation is negligible (<0.0001 below 1°).

The entropy of Cu(g) may be obtained from the Sackur equation with *R ln* 2 added to account for the quantum weight of the lowest energy level. The result is $S^\circ_{298.16}=39.75\pm0.01$.

The entropy of $Cu_2(g)$ is estimated as $S^\circ_{298.16}=58.0\pm1.0$. This result probably is more reliable than the estimate of Randall, Nielsen, and West (*395*), $S^\circ_{298.16}=58.9$.

Cupric Ion.—Latimer, Pitzer, and Smith (*325*) have obtained -25.9 ± 3 and -26.6 ± 1, respectively, as values of the entropy of $Cu^{++}(aq.)$ from data for the reactions $Cu(c)+2H^+(aq.)=Cu^{++}(aq.)+H_2(g)$ and $Cu(c)+2Ag^+(aq.)=Cu^{++}(aq.)+2Ag(c)$. Their selected value, $S^\circ_{298.16}=-26.5\pm1.0$, also is adopted here.

Oxides.—Millar (*362*) (75°–291°) measured the heat capacity of $Cu_2Q(c)$. The heat-capacity curve for this substance is abnormally flat, making extrapolation quite uncertain. There is calculated $S^\circ_{298.16}=24.1\pm1.5$, of which 7.85 is extrapolation below 70.8°.

Clusius and Harteck (*100*) (30°–200°) and Millar (*362*) (71°–302°) have measured the heat capacity of CuO(c). The latter found a curious, nonreversible region centered around 220° on which more information would be desirable. From these data, $S^\circ_{298.16}=10.4\pm0.2$, of which 0.13 is extrapolation below 28.2°.

Carbonate.—From thermal data, the value $S^\circ_{298.16}=17.7$ was estimated for $CuCO_3$ (*c*) by Kelley and Anderson (*290*). The error in this value is uncertain and may be relatively large.

Cuprous Bromide.—Ishikawa, Yamazaki, and Murooka (*226*) gave $\Delta F^\circ_{298.16}=-23{,}812$ and $\Delta H^\circ_{298.16}=-24{,}872$ for the reaction $Cu(c)+\frac{1}{2}Br_2(l)=CuBr(c)$ making $\Delta S^\circ_{298.16}=-3.56$. From the last figure and the entropies of $Cu(c)$ and $Br_2(l)$, $S^\circ_{298.16}=22.8\pm1.0$ is computed for $CuBr(c)$.

The vibration frequency of CuBr (*g*) is $\omega=313$ (*212*), and Stevenson (*467*) has estimated the interatomic distance as 2.14×10^{-8} cm., which corresponds with $I=269\times10^{-40}$. These quantities give $S^\circ_{t+r,298.16}=57.89$, $S^\circ_{v,298.16}=1.34$, and $S^\circ_{298.16}=59.2\pm0.5$ for CuBr (*g*).

Cuprous Chloride.—Watanabe (*497*) has considered the reaction $Cu\ (c)+\frac{1}{2}Cl_2(g)=CuCl(c)$ and reported $\Delta H^\circ_{298.16}=-32{,}605$ and $\Delta F^\circ_{298.16}=-28{,}487$. These figures make $\Delta S^\circ_{298.16}=-13.81$, which, with the entropies of $Cu(c)$ and $Cl_2(g)$, leads to $S^\circ_{298.16}=20.8\pm1.0$ for CuCl (*c*).

Stevenson's (*467*) estimate of the interatomic distance in the $CuCl(g)$ molecule corresponds with $I=151\times10^{-40}$. The vibration frequency has been reported as $\omega=415$ (*212*). These figures yield $S^\circ_{t+r,298.16}=55.63$, $S^\circ_{v,298.16}=0.91$, and $S^\circ_{298.16}=56.5\pm0.5$.

Cuprous Fluoride.—The vibration frequency of the CuF (*g*) molecule has been reported as $\omega=616$ (*212*). The interatomic distance is estimated here as 1.9×10^{-8} cm., leading to $I=88\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=54.02$ and $S^\circ_{v,298.16}=0.44$, making $S^\circ_{298.16}=54.5\pm0.5$ for CuF (*g*).

Cuprous Hydrides.—Interatomic distances and vibration frequencies are available (*212*) for the CuH (*g*) and CuD (*g*) molecules. The requisite data for entropy calculations are $I=3.53\times10^{-40}$ and $\omega=1{,}903$ for CuH (*g*) and $I=6.94\times10^{-40}$ and $=1{,}365$ for CuD (*g*).

For $CuH(g)$, there are computed $S^\circ_{t+r,298.16}=46.894$, $S^\circ_{v,298.16}=0.002$, and $S^\circ_{298.16}=46.90\pm0.10$.

The corresponding values for $CuD(g)$ are $S^\circ_{t+r,298.16}=48.283$, $S^\circ_{v,298.16}=0.018$, and $S^\circ_{298.16}=48.30\pm0.10$.

Cuprous Iodide.—Simon (*437*) (16°–286°) measured the heat capacity of $CuI(c)$. The entropy extrapolation below 15.8° is 0.50; and the measured portion, $S^\circ_{298.16}-S^\circ_{15.8}$, is 22.56, making $S^\circ_{298.16}=23.1\pm0.3$.

Ishikawa, Yamazaki, and Murooka (*226*) gave $\Delta F^\circ_{298.16}=-16{,}658$ and $\Delta H_{298.16}=-16{,}065$, or $\Delta S^\circ_{298.16}=1.99$, for the reaction $Cu\ (c)+\frac{1}{2}\ I_2\ (c)=CuI\ (c)$. This value leads to $S^\circ_{298.16}=24.0\pm1.0$, in agreement with the more reliable result from heat-capacity measurements.

From the vibration frequency, $\omega=264$ cm.$^{-1}$ (*212*) and Stevenson's (*467*) estimate of the interatomic distance, 2.33×10^{-8} cm. ($I=382\times10^{-40}$), the following results are calculated for CuI (*g*): $S^\circ_{t+r,298.16}=59.43$, $S^\circ_{v,298.16}=1.63$, and $S^\circ_{298.16}=61.1\pm0.5$.

Sulfides.—The heat capacity of $Cu_2S(c)$ was measured by Anderson (*13*) (58°–293°). His data give $S^\circ_{298.16}=28.9\pm0.8$, of which 6.06 is extrapolation below 56.2°.

Anderson (*13*) (59°–295°) also measured the heat capacity of $CuS(c)$, covellite. The entropy is computed to be $S^\circ_{298.16}=15.9\pm0.4$, of which 2.56 is extrapolation below 56.2°.

Sulfates.—From calculations of the author (*273*), the following values were suggested: $S^\circ_{298.16}=25.3$ for $CuSO_4(c)$, $S^\circ_{298.16}=34.1$ for $CuO{\cdot}CuSO_4(c)$, $S^\circ_{298.16}=33.0$ for $CuSO_4{\cdot}H_2O(c)$, $S^\circ_{298.16}=52.4$ for $CuSO_4{\cdot}3H_2O(c)$, and $S^\circ_{298.16}=70.2$ for $CuSO_4{\cdot}5H_2O$ (c). No attempt is made to estimate the uncertainties in these figures.

EUROPIUM

Sulfate.—Long and Degraff (*338*) measured the heat capacity of Eu_2 $(SO_4)_3{\cdot}8H_2O(c)$. At the lowest point of the measured temperature range the heat capacity is 36.44 cal. per deg. per mole, which makes the calculation of the entropy difficult and somewhat uncertain. However, there is estimated $S^\circ_{60.0}=19.2$ as the extrapolated portion of the entropy, not considering unextracted magnetic entropy. The measured portion is $S^\circ_{298.16}-S^\circ_{60.0}=133.7$. To these quantities must be added $2R\ ln\ 7$ to account for splitting of the ground state of Eu^{+++}. The total is $S^\circ_{298.16}=160.6\pm1.6$ for Eu_2 $(SO_4)_3{\cdot}8H_2O(c)$.

FLUORINE

Element.—Murphy and Vance (*368*) have computed the entropy of $F_2(g)$ from molecular constants. They give $\omega=856$, and the nuclear separation as 1.45×10^{-8} cm. The latter corresponds to $I=33.2\times10^{-40}$. There are computed $S^\circ_{t+r,\,298.16}=48.39$, $S^\circ_{v,\,298.16}=0.17$, and $S^\circ_{298.16}=48.56\pm0.10$. The difference of 0.02 between the last value and that reported by Murphy and Vance is attributable to differences in the natural constants employed. A virtually identical result also was calculated by Garner and Yost (*165*), $S^\circ_{298.16}=48.6$.

Kanda (*238*) (14°84°) measured the heat capacities of solid and liquid F_2 and the heat of fusion. His data lead to $S^\circ_{85.2}=17.70$ for $F_2(l)$ at the normal boiling point. Combination of this result and the entropy increment for heating the gas from 85.2° to 298.16°, 8.90 units, would yield $\Delta S^\circ_{85.2}=22.0$ as the entropy of vaporization to form ideal gas at 1 atmosphere pressure. The last result is much higher than is indicated by vapor-pressure data for liquid fluorine. It is evident that some discrepancy exists in these thermal data.

The value, $S^\circ_{298.16}=48.56\pm0.10$, is adopted for $F_2(g)$.

In obtaining the entropy of monatomic $F(g)$, two energy states are concerned at 298.16°, $^2P^\circ_{3/2}$ and $^2P^\circ_{1/2}$. These states are separated by 407 $cm.^{-1}$ (*364*) and have quantum weights of 4 and 2, respectively. Calculation gives 3.146 to be added to the Sackur equation. The result is $S^\circ_{298.16}=37.92\pm0.01$.

Fluoride Ion.—Latimer, Pitzer, and Smith (*325*) have obtained the entropy of $F^-(aq.)$ from thermal data for three reactions, $HF\ (g)=H^+(aq.)+F^-(aq.)$, $BaF_2(c)=Ba^{++}(aq.)+2F^-(aq.)$, and $CaF_2(c)=Ca^{++}(aq.)+2F^-(aq.)$. The results, -2.4 ± 2, -0.4 ± 2, and -4.2 ± 2, respectively, are not in good agreement. The mean is $S^\circ_{298.16}=-2.3\pm2$.

Monoxide.—Stuart (*476*) has given 1.4×10^{-8} cm. and 2.22×10^{-8} cm., respectively, as the F–O and F–F distances in the $F_2O(g)$ molecule and 105°±5° as the valence angle. From these figures, $I_1=91.2\times10^{-40}$, $I_2=77.7\times10^{-40}$, and $I_3=13.5\times10^{-40}$. There is computed $S^\circ_{t+r,\,298.16}=58.00$. The vibration frequencies reported by Sutherland and Penney (*479*) are 492 (1), 833 (1), and 1,110 (1), which make $S^\circ_{v,\,298.16}=0.92$. Therefore, $S^\circ_{298.16}=58.9\pm0.3$ for F_2O (*g*).

GADOLINIUM

Gadolinium Ion.—Coulter and Latimer (*111*) have reported $S^\circ_{298.16}=-32.5\pm4$ for Gd^{+++}(*aq.*).

Sulfate.—The heat capacity of $Gd_2(SO_4)_3{\cdot}8H_2O$(*c*) was measured by Ahlberg and Clark (*2*) (16°–297°), Clark and Keesom (*72*) (1°–21°), Giauque and Clark (*176*) (15°–289°), and Kürti (*308*) (1°–20°). The heat capacity of this substance decreases in a normal manner to about 7°, then begins to rise, and near 1.6° reaches some 500 times the value that would correspond to a Debye extrapolation of the data for the region above 7°. This behavior is attributed to the splitting of the ground state, $^8S_{7/2}$, of the gadolinium ion. Such splitting involves an entropy change of *R ln* 8 per gram-ion. Consequently, in computing the entropy, 2 *R ln* 8 per gram-formula mass of $Gd_2(SO_4)_3{\cdot}8H_2O$ has been added to the usual type of extrapolation below 7.08°. Thus, at 7.08 the entropy is $2\,R\,ln\,8+0.07=8.34$. Between 7.08° and 298.16° the entropy increment is 147.44. The entropy at 298.16° is therefore $S^\circ_{298.16}=155.8\pm0.4$.

Phosphomolybdate.—Giauque, Stout, Egan, and Clark (*192*) (0.18°–4.20°) have measured the heat capacity of $GdPO_4{\cdot}12MoO_3{\cdot}30H_2O$(*c*) at very low temperatures. An entropy calculation is, or course, not possible from data for this narrow temperature range. The data are interesting in that they show the beginning of a "hump" in the heat-capacity curve, analogous to the behavior of $Gd_2(SO_4)_3{\cdot}8H_2O$(*c*).

GALLIUM

Element.—The heat capacity of Ga(*c*) was measured by Clusius and Harteck (*100*) (15°–200°). The entropy is $S^\circ_{298.16}=10.2\pm0.3$, of which 0.13 is extrapolation below 14.1°. The allowance for error is made large to account for uncertainty connected with the abnormally large heat interchange corrections in the heat-capacity data. These were caused by poor thermal contact in the calorimeter, resulting from shrinking and flaking of the metal.

The entropy of Ga(*g*) may be obtained from the Sackur equation and available spectroscopic data (*364*). Two energy states, $^2P^\circ_{1/2}$ and $^2P^\circ_{3/2}$, are to be considered. These states are separated by 826.0 $cm.^{-1}$ and have quantum weights of 2 and 4, respectively. The addition to the Sackur equation is 1.734, making $S^\circ_{298.16}=40.38\pm0.01$ for Ga(*g*)

GERMANIUM

Element.—Cristescu and Simon (*117*) (10°–200°) measured the heat capacity of Ge(*c*). The entropy at 10° obtained by extrapolation is 0.03, and that between 10° and 298.16° is 10.05. Thus, $S^\circ_{298.16}=10.1\pm0.2$.

In obtaining the entropy of Ge(*g*) at 298.16° three energy levels must be considered. These have term values of 0, 557.1, and 1,410.0 (*364*) and quantum weights of 1, 3, and 5, respectively. The amount to be added to the Sackur equation is 1.342, making $S^\circ_{298.16}=40.11\pm 0.01$ for Ge(g).

Oxide.—Molecular-constant data (*212*) for the GeO(g) molecule, $\omega=981$ and $I=59.3\times 10^{-40}$, yield $S^\circ_{t+r,\,298.16}=53.45$, $S^\circ_{v,\,298.16}=0.10$, and $S^\circ_{298.16}=53.55\pm 0.10$.

Monogermane.—Clusius and Faber(*94*), Schäfer and Barredo (*411*), and Straley, Tindal, and Nielsen (*475*) have listed molecular-constant data for GeH_4(g). The values adopted for the present entropy calculation are $I_1=I_2=I_3=9.7\times 10^{-40}$, $\omega_1=819(2)$, $\omega_2=931(3)$, $\omega_3=2{,}090(1)$, and $\omega_4=2{,}114(3)$. There are computed $S^\circ_{t+r,\,298.16}=50.86$, $S^\circ_{v,298.16}=0.75$, and $S^\circ_{298.16}=50.6\pm 0.3$.

Clusius and Faber (*94*) (12°–166°) have measured the heat capacity and heats of transition, fusion, and vaporization of GeH_4. Their data are rather crude and do not permit an accurate entropy calculation. However, an approximate check of the value from molecular-constant data is possible. There are obtained $S^\circ_{10.0}=0.36$ (extrapolation), $S^\circ_{73.2}-S^\circ_{10.0}=11.49$ (crystals III), $\Delta S^\circ_{73.2}=50/73.2=0.68$ (transition), $S^\circ_{76.5}-S^\circ_{73.2}=0.61$ (crystals II), $\Delta S^\circ_{76.5}=85/76.5=1.11$ (transition), $S^\circ_{107.3}-S^\circ_{76.5}=4.02$ (crystals I), $\Delta S^\circ_{107.3}=199.5/107.3=1.86$ (fusion), $S^\circ_{184.8}-S^\circ_{107.3}=7.96$ (liquid), $\Delta S^\circ_{184.8}=3{,}361/184.8=18.19$ (vaporization at 1 atm. pressure), and $\Delta S^\circ_{184.8}=0.15$ (correction to ideal gas state). These values add to give $S^\circ_{184.8}=46.43$ for GeH_4(g) at the normal boiling point, which is in fair agreement with the result calculated by Clusius and Faber, 46.56, although details of the two calculations differ appreciably. Heating the gas from 184.8° to 298.16° involves an entropy increase of 4.48. Therefore, $S^\circ_{298.16}=50.9\pm 0.5$. This agrees within the limits of error with the molecular-constant result, but it is worthy of no weight in comparison.

GOLD

Element.—Clusius and Harteck (*100*) (14°–213°) measured the heat capacity of Au(c). The extrapolated portion of the entropy below 14.1° is 0.11 and the measured portion is 11.28, making $S^\circ_{298.16}=11.39\pm 0.10$.

The entropy of Au(g) may be obtained from the Sackur equation with *R ln* 2 added to account for the quantum weight of the lowest energy state. The result is $S^\circ_{298.16}=43.13\pm 0.01$.

Hydrides.—Molecular-constant data are available for AuH(g) and AuD(g) (*212*). For the former, $I=3.87\times 10^{-40}$, and $\omega=2{,}262$, while for the latter, $I=7.69\times 10^{-40}$, and $\omega=1{,}613$. These data yield $S^\circ_{298.16}=50.42\pm 0.10$ for AuH(g) and $S^\circ_{298.16}=51.81\pm 0.10$ for AuD (g). The vibrational contribution to the entropy is less than 0.01 in each instance.

HAFNIUM

Element.—The heat capacity of Hf(c) was measured by Cristescu and Simon (*117*) (13°–210°). The results of the entropy calculations are $S^\circ_{12.59}=0.013$ (extrapolation), $S^\circ_{298.16}-S^\circ_{12.59}=13.06$, and $S^\circ_{298.16}=13.1\pm 0.2$.

Available spectroscopic data (*364*) for Hf(g) show that its entropy may be obtained by adding *R ln* 5 to the Sackur equation. The result is $S^\circ_{298.16}=44.65\pm 0.01$.

HELIUM

Element.—Thermal data on solid and liquid He have been reported by Kaischew and Simon (*236*) (heat of fusion), Keesom and Clusius (*247*) (heat capacity, 1°–22°), Keesom (*243*) (heat of fusion), Keesom and Keesom (*252, 253, 254*) (heat capacity, 1°–5°), and Simon and Steckel (*442*) (heat of vaporization). No calculation of the entropy will be made from these data as a more reliable value may be obtained from the Sackur equation.

For He(g), the Sackur equation results in $S^\circ_{298.16}=30.13\pm0.01$.

Molecular-constant data are available for $He_2(g)$ (*212*), $I=3.64\times10^{-40}$, $\omega=1{,}732$, and quantum weight=3 for the ground state. There are computed $S^\circ_{t+r298.16}=39.355$, $S^\circ_{v,298.16}=0.003$, $S^\circ_{e,298.16}=2.183$, and $S^\circ_{298.16}=41.54\pm0.10$.

HYDROGEN

Element.—The heat capacity of H_2 has been measured by Bartholomé and Eucken (*37*) (11°–24°), Clusius and Hiller (*101*) (11°–19° and 83°–162°), Cornish and Eastman (*110*) (81°–373°), Eucken (*145, 146*) (17°–22° and 35°–274°), Eucken and Hiller (*148*) (89°–151°), Keesom and Onnes (*268*) (11°–21°), Mendelssohn, Ruhemann, and Simon (*355*) (4°–12°), and Simon and Lange (*439*) (10°–19°).

Most of the pertinent data were reviewed by Giauque (*171*), who also calculated the total entropy of $H_2(g)$ from spectroscopic data as $S^\circ_{298.16}=33.98\pm0.01$, which agrees with the values $S^\circ_{298.16}=34.0$, similarly calculated by Rodebush (*399*), and $S^\circ_{300}=34.00$, calculated by Gordon and Barnes (*199*). These values include the entropy contribution of nuclear spin and are not to be used in combination with other values in this bulletin.

Ordinary hydrogen is a mixture of symmetrical and antisymmetrical molecules between which the rate of transition at low temperatures is so slow that heat-capacity measurements, as ordinarily made, do not give the correct entropy when the third law is applied in the usual manner. Giauque has evaluated the entropy of mixing from the relationship, $\Delta S=-\sum_{i=1}^{n}N_iR\ ln\ N_i$, as $\Delta S=-1/4\,R\ ln\ 1/4-9/12\,R\ ln\ 1/12=4.39$ units. Subtracting this value from 33.98 gives 29.59, which is the figure that should result from ordinary thermal data for H_2. This was shown to be true by Giauque, who obtained 29.74 or 29.64, depending on whether a Berthelot or van der Waal gas was assumed in correcting to the ideal state. The several items of entropy concerned are $S_{13.95}=0.52$ (crystals), $\Delta S_{13.95}=28.0/13.95=2.01$ (fusion), $\Delta S_{13.95}=217.8/13.95=15.61$ (vaporization at 5.38 cm. pressure), $\Delta S_{13.95}=-5.26$ (compression from 5.38 cm. to 1 atm. pressure), $\Delta S_{13.95}=0.13$ (correction to ideal state, Berthelot) or $\Delta S_{13.95}=0.03$ (correction to ideal state, van der Waal), and $S_{298.16}-S_{13.95}=16.73$ (gas).

The entropy value for $H_2(g)$ to be used in thermodynamic calculations in conjunction with other values in this bulletin is obtained by subtracting $R\ ln\ 4=2.76$, the nuclear-spin contribution, from 33.98, the total spectroscopic entropy, which gives $S^\circ_{298.16}=31.22\pm0.01$. The corresponding corrected value from thermal data is $S^\circ_{298.16}=31.3\pm0.1$. The value given by molecular constants, $I=0.466\times10^{-40}$ and $\omega=4{,}280$, is $S^\circ_{298.16}=31.16\pm0.10$.

Data pertaining to the entropy of HD(g) have been reported by Clusius (*80*), Clusius and Bartholomé (*83, 86, 89, 93*), Clusius, Popp, and Frank (*108*), and Johnston and Long (*233, 234*). Symmetrical and antisymmetrical molecules are not possible in HD(g).

Clusius, Popp, and Frank (*108*) have computed the entropy from available thermal data. They find $S^\circ_{16.60}=0.84$ (crystals), $\Delta S^\circ_{16.60}=38/16.60=2.29$ (fusion), $\Delta S_{16.60}=265/16.60=15.96$ (vaporization at 95 mm. pressure), $\Delta S_{16.60}=-4.13$ (compression from 95 mm. to 1 atm. pressure), $\Delta S_{16.60}=0.10$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{16.60}=19.39$ (gas). The sum of these quantities is $S^\circ_{298.16}=34.45\pm0.15$. Johnston and Long reported $S^\circ_{298.16}=37.95-3.56=34.39$, the first figure including nuclear spin, for which correction is made in the subtraction. From molecular-constant data, $I=0.621\times10^{-40}$ and $\omega=3{,}722$, there is obtained $S^\circ_{298.16}=34.31$. The value $S^\circ_{298.16}=34.35\pm 0.10$ is adopted here for HD(g).

Data pertaining to the entropy of $D_2(g)$ were reported by Bartholomé and Eucken (*37*), Clusius (*80*), Clusius and Bartholomé (*83, 84, 85, 86, 87, 88, 89, 90, 91, 92*), Johnston and Long (*233, 234*), and Lewis and Hanson (*333*). Symmetrical and antisymmetrical molecules again are encountered in $D_2(g)$.

Clusius and Bartholomé (*91*) have considered the available thermal data and have computed the entropy. They find $S_{12.0}=0.36$ (extrapolation), $S_{18.65}-S_{12.0}=0.75$ (crystals), $\Delta S_{18.65}=47.0/18.65=2.52$ (fusion), $S_{19.65}-S_{18.65}=0.26$ (liquid), $\Delta S_{19.65}=302.3/19.65=15.38$ (vaporization at 194.5 mm. pressure), $\Delta S_{19.65}=-2.71$ (compression from 194.5 mm. to 1 atm. pressure), $\Delta S_{19.65}=0.11$ (correction to ideal gas state, and $S_{298.16}-S_{19.65}=17.23$ (gas). The sum is $S_{298.16}=33.90$, which, however, is not the value to be used in thermodynamic calculations, for the same reason as was mentioned in the case of $H_2(g)$. The correction involved in the present instance is $\Delta S=1/3\ R ln 3=0.72$, making finally $S^\circ_{298.16}=34.63\pm0.10$. Another way of obtaining virtually the same result is by subtracting the nuclear-spin term, $R\ ln\ 9=4.366$ from Clusius and Bartholomé's (*91*) spectroscopic calculation of the total entropy, $S^\circ_{298.16}=38.984$. This procedure yields $S^\circ_{298.16}=34.62$, in excellent agreement with the value from thermal data. Molecular-constant data, $I=0.931\times10^{-40}$ and $\omega=3{,}055$, give $S^\circ_{298.16}=34.60$. The value $S^\circ_{298.16}=34.62\pm0.10$ is adopted for $D_2(g)$.

The entropy of monatomic H(g) is obtained from the Sackur equation with $R\ ln\ 2$ added. The result is $S^\circ_{298.16}=27.40\pm0.01$.

Likewise, the entropy of D(g) is calculated from the Sackur equation to be $S^\circ_{298.16}=29.46\pm0.01$.

Hydrogen Ion.—All the ionic entropies recorded are relative values based upon the definition $S^\circ_{298.16}=0$ for $H^+(aq.)$ in hypothetical 1 molal solution.

Water.—Low-temperature heat-capacity measurements of H_2O were made by Barnes and Maass (*36*) (194°–271°), Cockett and Ferguson (*109*) (289°–322°), Giauque and Stout (*187*) (16°–268°), Nernst (*373*) (83°–266°), Pollitzer (*393*) (22°–263°), and Simon (*208*) (10°–373°). The results from the work of Giauque and Stout are adopted. They find $S_{10.0}=0.02$ (extrapolation), $S_{273.16}-S_{10.0}=9.08$

(crystals), $\Delta S_{273.16}=1{,}435.7/273.16=5.26$ (fusion), and $S_{298.16}-S_{273.16}=1.58$ (liquid). The sum is $S_{298.16}=15.94$. This value is not the quantity to be used in thermodynamic calculations, however, but it must be corrected by adding $R\ ln\ 6/4=0.81$, according to Pauling (*385*) (see below). This makes $S^\circ_{298.16}=16.75\pm0.03$ for $H_2O(l)$.

For $H_2O(g)$, Gordon (*196*) has computed $S^\circ_{298.16}=45.10$ from spectroscopic data and Giauque and Archibald (*173*) have made a small correction to this value, raising it to $S^\circ_{298.16}=45.13$. The latter also obtained $S^\circ_{298.16}=45.10$ from their study of the reaction $Mg(OH)_2(c)=MgO(c)+H_2O(g)$. Other reported values are $S^\circ_{298.16}=45.19$, from thermal data for the reaction $H_2(g)+HgO(c)=Hg(l)+H_2O(g)$, and $S^\circ_{298.16}=45.1$, from thermal data for the reaction $2HCl(g)+1/2\,O_2(g)=H_2O(g)+Cl_2(g)$, both obtained by Giauque and Ashley (*174*). The values of the molecular constants assigned by Dennison (*124*), $I_1=1.023\times10^{-40}$, $I_2=1.921\times10^{-40}$, $I_3=2.944\times10^{-40}$, $\omega_1=3{,}825$, $\omega_2=1{,}654$, and $\omega_3=3{,}936$, lead to $S^\circ_{298.16}=45.08$. The value adopted for $H_2O(g)$ is $S^\circ_{298.16}=45.13\pm0.03$.

The adopted value of $H_2O(g)$ may be used to obtain an independent result for the entropy of $H_2O(l)$. First, there must be added the entropy of expansion, $\Delta S^\circ_{298.16}=6.886$, from 1 atm. pressure to 2.3756 cm. pressure, that is, the vapor pressure of $H_2O(l)$ at 298.16°. Second there must be subtracted the small entropy correction, $\Delta S_{298.16}=0.002$, for the difference between the ideal and actual gas. Third, there must be subtracted the entropy of vaporization at 2.3756 cm. pressure at 298.16°, $\Delta S_{298.16}=10{,}514/298.16=35.263$. The net result is $S_{298.16}=16.75$ for $H_2O(l)$, which is in exact agreement with the third-law value and constitutes excellent proof of Pauling's (*385*) correction for randomness of the hydrogen bonds in ice crystals.

Heat-capacity measurements of D_2O at low temperatures were made by Brown, Barnes, and Maass (*64, 65*) (203°–273°), Cockett and Ferguson (*109*) (284°–326°), and Long and Kemp (*339*) (14°–296°). The results of the last investigators will be employed. There are computed $S_{15.0}=0.09$ (extrapolation), $S_{276.98}-S_{15.0}=10.29$ (crystals), $\Delta S_{276.98}=1{,}501/276.98=5.42$ (fusion), and $S_{298.16}-S_{276.98}=1.47$ (liquid). The sum is $S_{298.16}=17.27$, to which must be added Pauling's (*385*) correction 0.81, making $S^\circ_{298.16}=18.08\pm0.10$ for $D_2O(l)$.

The entropy of $D_2O(g)$ may be obtained from molecular-constant data as listed by Long and Kemp, $I_1=5.752\times10^{-40}$, $I_2=3.812\times10^{-40}$, $I_3=1.790\times10^{-40}$, $\omega_1=2{,}784$, $\omega_2=2{,}666$, and $\omega_3=1{,}179$. These values give $S^\circ_{t+r,298.15}=47.288$, $S^\circ_{v,298.16}=0.045$ and $S^\circ_{298.16}=47.33\pm0.10$. This value is adopted.

Returning now to Long and Kemp's heat-capacity measurements, calculation gives $S^\circ_{273.16}=11.04$ for $D_2O(c)$, after applying the Pauling correction. Long and Kemp have computed the entropy of sublimation (3.65 mm. pressure) as $\Delta S_{273.16}=12{,}636/273.16=46.26$ and the entropy of compression to 1 atm. pressure as $\Delta S_{273.16}=-10.61$. These figures result in $S^\circ_{273.16}=46.69$ for $D_2O(g)$. Heating the gas from 273.16° to 298.16° requires $\Delta S=0.71$, so that $S^\circ_{298.16}=47.40$. The excellent agreement with the calculation from molecular-constant data again substantiates the Pauling correction.

The entropy of $HDO(g)$ may be approximated by adding $R\ ln\ 2$ to the mean of the entropies of $H_2O(g)$ and $D_2O(g)$. The result is $S^\circ_{298.16}=47.6\pm0.2$.

Peroxide. Zeise (*514*) has obtained the entropy of $H_2O_2(g)$ from molecular-constant data as $S^\circ_{298.16}=55.3$. The uncertainty in this value is estimated tentatively here as ± 1.0.

Bromide.—Eucken and Karwat (*149*) (21°–199°) and Giauque and Wiebe (*189*) (15°–206°) have measured the heat capacity of HBr. Relying on the latter work, there are repeated $S^\circ_{14.5}=0.55$ (extrapolation), $S^\circ_{186.24}-S^\circ_{14.5}=17.27$ (crystalline forms less transition entropies), $\Delta S^\circ_{89.2}=63.4/89.2=0.71$ (transition), $\Delta S^\circ_{113.2}=78.8/113.2=0.70$ (transition), $\Delta S^\circ_{116.8}=85.7/116.8=0.73$ (transition), $\Delta S^\circ_{186.24}=575.1/186.24=3.10$ (fusion), $S^\circ_{206.38}-S^\circ_{186,24}=1.46$ (liquid), $\Delta S_{206.38}=4{,}210/206.38=20.40$ (vaporization at 1 atm. pressure), $\Delta S_{206.38}=0.10$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{206.38}=2.61$ (gas). These add to give $S^\circ_{298.16}=47.63\pm 0.15$.

From spectroscopic data, Giauque and Wiebe (*189*) and Gordon and Barnes (*201*) have computed $S^\circ_{298.16}=47.48\pm 0.05$, which is adopted.

The entropy of DBr (g) is estimated here as $S^\circ_{298.16}=48.9\pm 0.2$.

Chloride.—Clusius (*75*) (10°–174°), Eucken and Karwat (*149*) (22°–189°), and Giauque and Wiebe (*189*) (17°–189°) have measured the heat capacity of HCl. The calculations that follow are in accordance with the data of the last-named investigators. They find $S^\circ_{16.0}=0.30$ (extrapolation), $S^\circ_{98.36}-S^\circ_{16.0}=7.06$ (crystals II), $\Delta S^\circ_{98.36}=284.3/98.36=2.89$ (transition), $S^\circ_{158.91}-S^\circ_{98.36}=5.05$ (crystals I), $\Delta S^\circ_{168.91}=476.0/158.91=3.00$ (fusion), $S^\circ_{188.07}-S^\circ_{158.91}=2.36$ (liquid), $\Delta S_{188.07}=3{,}860/188.07=20.52$ (vaporization at 1 atm. pressure), $\Delta S_{188.07}=0.10$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{188.07}=3.19$ (gas). The sum is $S^\circ_{298.16}=44.47\pm 0.15$.

Giauque and Wiebe (*188*) and Giauque and Overstreet (*183*) have calculated the entropy from spectroscopic data as $S^\circ_{298.16}=44.66\pm 0.05$. Gordon and Barnes (*200*) computed a slightly lower result, $S^\circ_{300}=44.65$, corresponding to $S^\circ_{298.16}=44.61$. The value calculated by Giauque and coworkers is adopted.

The entropy of DCl (g) is calculated from molecular-constant data: $I=5.14\times 10^{-40}$, and $\omega=2{,}090$, as $S^\circ_{298.16}=46.02\pm 0.10$.

Fluoride.—Clusius, Hiller, and Vaughen (*106*) (11°–78°) have measured the heat capacity of HF, and Dahmlos and Jung (*121*) have obtained 1,094 cal. per mole as the heat of fusion at 190.09°. These data are insufficient for an entropy calculation.

Murphy and Vance (*368*) have computed the entropy of HF (g) from molecular-constant data corresponding to $I=1.35\times 10^{-40}$ and $\omega=4{,}050$. The vibrational contribution is negligible. The result, corrected to accord with values of natural constants used here, is $S^\circ_{298.16}=41.49\pm 0.05$.

The entropy of DF (g) is estimated here as $S^\circ_{298.16}=42.9\pm 0.2$.

Iodide.—Eucken and Karwat (*149*) (58°–238°) and Giauque and Wiebe (*190*) (17°–238°) have measured the heat capacity of HI. Again, the data of the latter are used in obtaining $S^\circ_{15.3}=1.08$ (extrapolation), $S^\circ_{222.31}-S^\circ_{15.3}=20.99$ (crystalline forms less transition entropies), $\Delta S^\circ_{70.1}=18.6/70.1=0.26$ (transition), $\Delta S^\circ_{125.6}=192.4/125.6=1.53$ (transition), $\Delta S^\circ_{222.31}=686.3/222.31=3.09$ (fusion), $S^\circ_{237.75}-S^\circ_{222.31}=0.96$ (liquid), $\Delta S^\circ_{237.75}=4{,}724/237.75=19.87$ (vaporization at 1 atm. pressure), $\Delta S^\circ_{237.75}=0.10$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{237.75}=1.60$ (gas). The sum is $S^\circ_{298.16}=49.48\pm 0.15$.

From spectroscopic data, Giauque and Wiebe compute $S^\circ_{298.16}=49.4$, in agreement with their third-law value. Murphy (*367*) more recently has calculated the entropy from molecular-constant data, $I=4.30\times10^{-40}$ and $\omega=2{,}270$. Their result, which has been corrected for differences in natural constants, is $S^\circ_{298.16}=49.33\pm0.05$. This value is adopted.

Blagg and Murphy (*44*) computed the entropy of DI (*g*) from molecular-constant data corresponding to $I=8.4\times10^{-40}$ and $\omega=1{,}620$. Evidently some mistake was made, as they obtain an impossibly low value in comparison with that for HI (*g*). Repetition of the calculation yields $S^\circ_{298.16}=50.69\pm0.05$, which is higher than the value for HI (*g*) by the anticipated amount.

Azide.—Eyster and Gillette (*157*) have computed the entropy of HN_3 (*g*) from the moments of inertia, $I_1=70.75\times10^{-40}$, $I_2=69.38\times10^{-40}$, and $I_3=1.376\times10^{-40}$, and the vibration frequencies, 658, 739, 1,152, 1,269, 2,140, and 3,336 cm.$^{-1}$ Repetition of the calculation leads to $S^\circ_{t+r,298.16}=56.06$, $S^\circ_{v,298.16}=0.70$, and $S^\circ_{298.16}=56.8\pm0.3$.

Cyanide.—The heat capacity of HCN was measured by Giauque and Ruehrwein (*185*) (14°–300°). Their calculations, which have been checked, are $S^\circ_{15.0}=0.13$ (extrapolation), $S^\circ_{259.86}-S^\circ_{15.0}=16.77$ (crystals, less abnormal heat absorption near 170.37°), $\Delta S^\circ_{170.37}=3.8/170.37=0.02$ (abnormal heat absorption), $\Delta S^\circ_{259.86}=2{,}009/259.86=7.73$ (fusion), $S^\circ_{298.80}-S^\circ_{259.86}=2.36$ (liquid), $\Delta S_{298.80}=6{,}027/298.80=20.17$ (vaporization at 1 atm. pressure), $\Delta S_{298.80}=0.03$ (correction to ideal gas state), and $\Delta S_{298.80}=0.73$ (correction for polymerization). The sum is $S^\circ_{298.80}=47.94$ for HCN (*g*). The value for 298.16° is 0.02 less, or $S^\circ_{298.16}=47.92\pm0.2$. It also is evident that $S^\circ_{298.80}=27.01$ for HCN (*l*), which corresponds to $S^\circ_{298.16}=26.97\pm0.10$. The values for HCN (*l*) apply to the equilibrium mixture of polymers.

From molecular-constant values, $I=18.72\times10^{-40}$, $\omega_1=2{,}089$ (1), $\omega_2=712$ (2), and $\omega_3=3{,}313$ (1), which were reported by Bartunek and Barker (*38*) and used by Giauque and Ruehrwein (*185*), there are computed $S^\circ_{t+r,\ 298.16}=47.615$, $S^\circ_{v,\ 298.16}=0.586$, and $S^\circ_{298.16}=48.20\pm0.10$ for HCN (*g*). This value from molecular-constant data is adopted. Giauque and Ruehrwein obtained $S^\circ_{298.1}=48.23$; Badger and Woo (*34*) obtained $S^\circ_{298.2}=48.23$; and Gordon (*198*) obtained $S^\circ_{298.16}=48.29$.

From molecular-constant values given by Bartunek and Barker (*38*) and Crawford and Brinkley (*113*), $I=22.92\times10^{-40}$, $\omega_1=1{,}906$ (1), $\omega_2=569$ (2), and $\omega_3=2{,}630$ (1), there are obtained $S^\circ_{t+r,298.16}=48.126$, $S^\circ_{v,\ 298.16}=1.010$, and $S^\circ_{298.16}=49.14\pm0.10$ for DCN (*g*).

The National Bureau of Standards tables (*370*) list $S^\circ_{298.16}=30.8$ for HCN (*aq*).

Cyanic Acid.—The value, $S^\circ_{298.16}=43.6$, for HCNO (*aq.*) is given in the National Bureau of Standards tables (*370*).

Sulfide.—Heat-capacity measurements of H_2S at low temperatures were made by Clusius and Frank (*95, 97, 162*) (11°–209°) and Giauque and Blue (*175*) (16°–213°). The calculations of the latter investigators are repeated here. They find $S^\circ_{16.0}=0.26$ (extrapolation), $S^\circ_{103.52}-S^\circ_{16.0}=7.65$ (crystals III), $\Delta S^\circ_{103.52}=368.0/103.52=3.55$ (transition), $S^\circ_{126.0}-S^\circ_{103.52}=2.48$ (crystals II), $S^\circ_{127.0}-S^\circ_{126.0}=121.3/126.22=0.96$ (transition), $S^\circ_{187.61}-S^\circ_{127.0}=5.32$ (crystals I), $\Delta S^\circ_{187.61}=568.1/187.61=3.03$ (fusion), $S^\circ_{212.77}-S^\circ_{187.61}=2.05$ (liquid), $\Delta S_{212.77}=4{,}463/212.77$

$=20.98$ (vaporization at 1 atm. pressure), and $\Delta S^\circ_{212.77}=0.10$ (correction to ideal gas state). The sum is $S^\circ_{212.77}=46.38\pm0.10$. This differs but little from the result calculated by Clusius and Frank (*95*) from their own data, $S^\circ_{212.7}=46.31\pm0.10$. An entropy increment of 2.72 is required for warming the gas from 212.77° to 298.16°, which leads to $S^\circ_{298.16}=49.10\pm0.10$ from Giauque and Blue's data.

Avdeeva (*30*), Cross (*118*), and Giauque and Blue (*175*) have computed the entropy from molecular constants, $I_1=5.845\times10^{-40}$, $I_2=3.076\times10^{-40}$, and $I_3=2.667\times10^{-40}$, $\omega_1=1{,}260$ (1) and $\omega_2=2{,}620$ (2). Repetition of the calculation, using presently accepted values of natural constants, gives $S^\circ_{t+r,298.16}=49.072$, $S^\circ_{v,298.16}=0.032$, and $S^\circ_{298.16}=49.10\pm0.10$. The last figure is identical with the value from Giauque and Blue's heat-capacity data.

Kruis and Clusius (*305*) (91°–203°) made heat-capacity measurements of D_2S, but the data are insufficient for calculation of the entropy.

Selenide.—The heat capacities of H_2Se and D_2Se were measured by Kruis and Clusius (*305*) (61°–233°). The data are insufficient for entropy calculations.

Cameron, Sears, and Nielsen (*67*) have reported 1.6×10^{-8} cm. as the H–Se distance and 2.3×10^{-8} cm. as the H–H distance in the H_2Se (*g*) molecule and also $\omega_1=1{,}074$, $\omega_2=2{,}260$, and $\omega_3=2{,}350$. The interatomic distances correspond to $I_1=8.4\times10^{-40}$, $I_2=4.4\times10^{-40}$, and $I_3=4.0\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=52.77$, $S^\circ_{v,298.16}=0.07$, and $S^\circ_{298.16}=52.8\pm0.5$.

Likewise, the entropy of D_2Se (*g*) is calculated from $I_1\doteq16.6\times10^{-40}$, $I_2=8.8\times10^{-40}$, $I_3=7.8\times10^{-40}$, $\omega_1=745$, $\omega_2=1{,}630$, and $\omega_3=1{,}696$. The results are $S^\circ_{t+r,298.16}=54.87$, $S^\circ_{v,298.16}=0.27$, and $S^\circ_{298.16}=55.1\pm0.5$.

The entropy of HDSe (*g*) is obtained from $I_1=12.4\times10^{-40}$, $I_2=6.5\times10^{-40}$, $I_3=5.9\times10^{-40}$, $\omega_1=905$, $\omega_2=1{,}691$, and $\omega_3=2{,}352$. There are computed $S^\circ_{t+r,298.16}=55.35$, $S^\circ_{v,298.16}=0.14$, and $S^\circ_{298.16}=55.5\pm0.5$.

Telluride.—The National Bureau of Standards tables (*371*) list $S^\circ_{298.16}=56$ for H_2Te (*g*).

INDIUM

Element.—Clusius (*82*) has reported $S^\circ_{298.16}=13.88$ as the entropy of In (*c*), but the heat-capacity data upon which the value is based have not been available to the author for inspection. For the present, we shall employ the rounded figure $S^\circ_{298.16}=13.9\pm0.2$.

The entropy of In(*g*) may be obtained by adding R l*n* 2 to the Sackur equation, in accordance with spectroscopic energy-level data listed by Moors (*364*). The result is $S^\circ_{298.16}=41.51\pm0.01$.

Bromide.—From molecular-constant data listed by Stevenson (*467*), $I=501\times10^{-40}$ and $\omega=220$ for InBr (*g*), there are computed $S^\circ_{t+r,298.16}=60.03$, $S^\circ_{v,298.16}=1.96$, and $S^\circ_{298.16}=62.0\pm0.5$.

Chloride.—From $I=257\times10^{-40}$ and $\omega=316$ (*467*), there are obtained $S^\circ_{t+r,298.16}=57.93$, $S^\circ_{v,298.16}=1.33$, and $S^\circ_{298.16}=59.3\pm0.5$ for InCl (*g*).

Hydride.—Stevenson's (*467*) molecular-constant data, $I=5.69\times10^{-40}$ and $\omega=1{,}420$ lead to $S^\circ_{t+r,298.16}=49.58$, $S^\circ_{v,298.16}=0.02$, and $S^\circ_{298.16}=49.60\pm0.10$ for InH(*g*).

Iodide.—For InI(*g*), there are computed $S^\circ_{t+r,298.16}=61.45$, $S^\circ_{v,298.16}=2.36$, and $S^\circ_{298.16}=63.8\pm0.5$, based upon Stevenson's (*467*) data, $I=740\times10^{-40}$ and $\omega=177$.

IODINE

Element.—The heat capacity of I_2 was measured by Günther (*204*) (21°–73°), Lange (*312*) (9°–52°), and Nernst (*373*) (28°–298°). There are computed $S^\circ_{10.0}=0.33$ (extrapolation), $S^\circ_{298.16}-S^\circ_{10,0}=27.57$ (measured), and $S^\circ_{298.16}=27.90\pm0.10$ for I_2 (*c*). Giauque (*172*) has made the same calculation, obtaining an identical result, and has shown that this value for the solid is in agreement with that of the gas, obtained from spectroscopic data to within ±0.1 unit.

Giauque (*172*) and Murphy (*367*) have computed the entropy of I_2 (*g*) from spectroscopic data and have found $S^\circ_{298.16}=62.29$. This value should be reduced to $S^\circ_{298.16}=62.25$ to accord with changes in the values of natural constants. Available molecular-constant data (*212*), $I=749\times10^{-40}$ and $\omega=213.8$, yield $S^\circ_{t+r,298.16}=60.246$, $S^\circ_{v,298.16}=2.007$, and $S^\circ_{298.16}=62.25$. The value $S^\circ_{298.16}=62.25\pm0.05$ is adopted.

At 298.16° the entropy of monatomic $I(g)$ is $S^\circ_{298.16}=43.19\pm0.01$. $R\ ln\ 4$ has been added to the Sackur equation.

Iodide Ion.—Latimer, Pitzer, and Smith (*325*) obtained the entropy of $I^-(aq.)$ from thermal data on the reactions $AgI(c)+\frac{1}{2}H_2(g)=H^+(aq.)+I^-(aq.)+Ag(c)$ and $\frac{1}{2}I_2(c)+\frac{1}{2}H_2(g)=H^+(aq.)+I^-(aq.)$. The respective values are $S^\circ_{298.16}=25.4\pm0.5$ and $S^\circ_{298.16}=25.2\pm0.7$. The mean is $S^\circ_{298.16}=25.3\pm0.5$.

Bromide.—Available molecular-constant data (*212*, *311*), $I=493\times10^{-40}$ and $\omega=268$, yield $S^\circ_{t+r,298.16}=60.18$, $S^\circ_{v,298.16}=1.61$ and $S^\circ_{298.16}=61.8\pm0.2$ for $IBr(g)$. McMorris and Yost (*352*) obtained $S^\circ_{298.16}=60.6$ from thermal data for the reaction $CuBr_2(c)+\frac{1}{2}I_2(g)=CuBr(c)+IBr(g)$, and, more recently, Blair and Yost (*45*) obtained $S^\circ_{298.16}=62.0$ from thermal measurements in CCl_4—solutions. The value $S^\circ_{298.16}=61.8\pm0.2$ is adopted. This result is virtually identical with that given by the relationship, $S^\circ_{298.16}(IBr(g))=\frac{1}{2}S^\circ_{298.16}(I_2(g))+\frac{1}{2}S^\circ_{298.16}(Br_2(g))+R\ ln\ 2$.

If the difference in entropy between $IBr(g)$ and $IBr(c)$ employed by McMorris and Yost is applied, then $S^\circ_{298.16}=33.0\pm1.5$ for $IBr(c)$.

Chlorides.—Molecular-constant data (*212*), $I=248\times10^{-40}$ and $\omega=383$, yield $S^\circ_{t+r,298.16}=58.095$, $S^\circ_{v,298.16}=1{,}026$, and $S^\circ_{298.16}=59.12\pm0.10$ for $ICl(g)$. Blair and Yost (*45*) reported $S^\circ_{298.16}=59.15$ from their own thermal data. McMorris and Yost (*353*) computed $S^\circ_{298.16}=59.15$ from molecular constants and obtained $S^\circ_{298.16}=56.9$ from thermal data. The value $S^\circ_{298.16}=59.12\pm0.10$ is adopted.

Nies and Yost (*378*) obtained $\Delta H^\circ_{298.16}=-21{,}150$ and $\Delta F^\circ_{298.16}=-5{,}410$ for the reaction $\frac{1}{2}I_2(c)+\frac{3}{2}Cl_2(g)=ICl_3(c)$.. The entropy of reaction is $\Delta S^\circ_{298.16}=-52.8$; consequently $S^\circ_{298.16}=41.1\pm0.5$ for $ICl_3(c)$.

Fluoride.—The entropy of $IF(g)$ may be obtained from the relationship, $S^\circ_{298.16}(IF(g))=\frac{1}{2}S^\circ_{298.16}(I_2(g))+\frac{1}{2}S^\circ_{298.16}(F_2(g))+R\ ln\ 2$. The result is $S^\circ_{298.16}=56.8\pm0.2$.

Iodate Ion.—From thermal data for the reactions $KIO_3(c)=K^+(aq.)+IO_3^-(aq.)$ and $AgIO_3(c)=Ag^+(aq.)+IO_3^-(aq.)$, Latimer, Pitzer, and Smith (*325*) obtained, respectively, $S^\circ_{298.16}=27.9\pm1$ and $S^\circ_{298.16}=28.3\pm3$ for $IO_3^-(aq.)$. They selected $S^\circ_{298.16}=28.0\pm1.0$, which is also adopted here.

IRIDIUM

Element.—The entropy of Ir(c), calculated by Lewis and Gibson (*331*) from Dewar's (*126*) mean heat-capacity value, is adopted, the uncertainty being estimated as ±0.5. Therefore, $S^\circ_{298.16}=8.7\pm0.5$ for Ir(c).

Spectroscopic data for Ir(g) (*364*) show that $R\ ln$ 10 should be added to the Sackur equation in evaluating the entropy. The result is $S^\circ_{298.16}=46.26\pm0.01$.

IRON

Element.—The heat capacity of Fe(α) was measured by Duyckaerts (*133*, *134*) (1.5°–20°), Eucken and Werth (*154*) (16°–206°), Günther (*204*) 32°–95°), Keesom and Kurrelmeyer (*261*) (1°–21°), Kelley (*284*) (54°–296°), Rodebush and Michalek (*401*) (72°–199°), and Simon and Swain (*443*) (30°–220°). The entropy obtained from these data is $S^\circ_{298.16}=6.49\pm0.03$. The extrapolated portion is negligible, ca 4×10^{-4} below 1°.

The entropy of Fe(g) may be obtained from spectroscopic data and the Sackur equation. The lowest five energy levels, $^5D_4$, $^5D_3$, $^5D_2$, $^5D_1$, and $^5D_0$, need be considered at 298.16°. Moore (*364*) has listed the term values for these levels as 0, 415.93, 704.00, 888.13, and 978.07 cm.$^{-1}$, respectively. The quantum weights are 9, 7, 5, 3, and 1. These states add 5.125 to the Sackur equation, so that $S^\circ_{298.16}=43.11\pm0.01$ for Fe(g).

Ferrous Ion.—Latimer, Pitzer, and Smith (*325*) calculated $S^\circ_{298.16}=-25.9\pm1.0$ for $Fe^{++}(aq.)$ from thermal data for the reaction $Fe(c)+2H^+(aq.)=Fe^{++}(aq.)+H_2(g)$.

Ferric Ion.—Similarly, from thermal data for the reaction $Fe^{++}(aq.)+H^+(aq.)=Fe^{+++}(aq.)+1/2H_2(g)$, Latimer, Pitzer, and Smith (*325*) found $S^\circ_{298.16}=-61\pm5$ for $Fe^{+++}(aq.)$.

Ferrous Oxide.—Millar (*362*) (70°–302°) measured the heat capacity of a sample of "ferrous oxide" of 83 percent purity. The entropy calculation gives $S^\circ_{298.16}=14.2\pm2.0$, of which 1.34 is extrapolation below 70.8°.

A value that probably is better was calculated by Kelley (*273*) from equilibrium data for the reaction $FeO(c)+H_2(g)=Fe(\alpha)+H_2O(g)$. The result is $S^\circ_{298.16}=13.4\pm1.0$. This value should be more certain than the figure 12.6 calculated by Kielland (*301*) from data for the reaction $Fe_2O_3(l)=2FeO(l)+1/2O_2$. More recently, Chipman and Marshall (*70*) have obtained $S_{298.16}=14.1$ for FeO (or rather wüstite) from a combination of their own and Emmett and Schultz's (*144*) equilibrium data. The value $S^\circ_{298.16}=13.4\pm1.0$ is adopted for FeO(c).

Ferric Oxide.—The heat capacity of $Fe_2O_3(c)$ was measured by Parks and Kelley (*383*) (88°–292°). Two materials were employed, specular hematite and the ignition product of ferrous oxalate. From data for the specular hematite, $S^\circ_{298.16}=21.5\pm0.5$, of which 3.30 is extrapolation below 89.2°.

Magnetite.—Millar (*362*) (60°–300°) and Parks and Kelley (*383*) (90°–295°) measured the heat dapacity of similar samples of Fe_3O_4 (magnetite) of 99 percent purity. From the combined data, $S^\circ_{298.16}=35.0\pm0.6$. The extrapolation below 56.2° is 2.17.

Ferrous Bromide.—Miljutin and Nachimowitsch (*356*) (12°–110°) have made some rather uncertain-appearing heat-capacity measurements of $FeBr_2(c)$. The data hardly warrant an entropy calculation, but there is estimated $S^\circ_{298.16}=34.2\pm2.0$, of which 0.81 is extrapolation below 11.9°.

Carbide.—Andes (*27*) (102°–324°) measured the heat capacity of carburized iron, extrapolated his results to the composition Fe_3C, and calculated $S^\circ_{298.16}=23.55$. More recently, Seltz, McDonald, and Wells (*419*) (68°–298°) measured the heat capacity of iron containing 1.354 weight-percent carbon which showed no signs of graphite. They computed the heat capacity of $Fe_3C(c)$ from their results by subtracting that of the contained iron in excess of the composition Fe_3C. The entropy of $Fe_3C(c)$ was evaluated as $S^\circ_{298.16}=25.7\pm1.0$, of which 2.57 is extrapolation below 68°. In addition, Naeser (*369*) (85°–298°) has measured the heat content of $Fe_3C(c)$. His data were considered by Schwarz and Ulich (*414*), who attempted to extract true heat capacities and calculated $S^\circ_{298.16}=23.9$.

The author (*274*) calculated $\Delta S^\circ_{298.16}=2.99$ as the entropy of formation of $Fe_3C(c)$ from equilibrium data for the reactions $3Fe(\alpha)+CH_4(g)=Fe_3C(\alpha)+2H_2(g)$ and $3Fe(\alpha)+2CO(g)=Fe_3C(\alpha)+CO_2(g)$. This figure leads to $S^\circ_{298.16}=23.8$ for $Fe_3C\ (\alpha)$, in fortuitous agreement with Schwarz and Ulich's calculation.

The mean of these several results, $S^\circ_{298.16}=24.2\pm1.0$, is adopted.

Ferrous Carbonate.—The heat capacity of $FeCO_3$ (siderite) was measured by Anderson (*16*) (54°–297°). Calculation gives $S^\circ_{298.16}=22.2\pm0.4$, of which 2.33 is extrapolation below 56.2°.

Ferrous Chloride.—Kelley and Moore (292) (53°–295°) and Trapeznikova and Shubnikov (*491*) (16°–127°) have measured the heat capacity of $FeCl_2(c)$. The data of the latter are erratic and are given little weight. There are obtained $S^\circ_{50.12}=5.19$ (extrapolation), $S^\circ_{298.16}=23.46$ (measured), and $S^\circ_{298.16}=28.7\pm0.5$.

Ferrous Chromite.—Shomate (*425*) measured the heat capacity of $FeCr_2O_4(c)$. The data yield $S^\circ_{53.09}=4.38$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=30.52$ (measured), and $S^\circ_{298.16}=34.9\pm0.4$.

Ferrous Iodide.—Some rather inadequate heat-capacity measurements of $FeI_2(c)$ were made by Miljutin and Parfenowa (*357*) (11°–130°). The data probably do not warrant an entropy calculation, but there is estimated $S^\circ_{298.16}=36.8\pm2.0$, of which 0.35 is extrapolation below 11.2°.

Nitride.—Kelley (*274*), from data for the reaction $2Fe_4N(c)+3H_2(g)=8Fe(\alpha)+2NH_3$, has estimated $S^\circ_{298.16}=37.4$ for $Fe_4N(c)$. This value may be in error, probably high, by a few units.

Ferrous Silicate.—The heat capacity of Fe_2SiO_4 (fayalite) was measured by Kelley (*282*) (52°–296°). This substance has a "hump" in its heat-capacity curve at 65.0° which makes extrapolation difficult; and, as indicated by Shomate (*430*), the original entropy calculation probably is too high. Recalculation gives $S^\circ_{50.12}=3.05$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=31.69$ (measured), and $S^\circ_{298.16}=34.7\pm0.4$.

Ferrous Sulfide.—Anderson (*12*) (57°–296°) measured the heat capacity of $FeS(c)$. Calculation gives $S^\circ_{56.2}=1.43$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=14.68$ (measured), and $S^\circ_{298.16}=16.1\pm0.3$.

Pyrite.—The heat capacity of FeS_2 (pyrite) was measured by Anderson (*21*) (55°–297°) and Eucken and Schwers (*151*) (21°–84°). The data of the former are the more certain. There are computed $S^\circ_{56.2}=0.35$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=12.39$ (measured), and $S^\circ_{298.16}=12.7\pm0.2$.

Ferrous Sulfate.—The heat capacity of $FeSO_4$ (*c*) was measured by Moore and Kelley (*365*) (53°–295°). The data yield $S^\circ_{50.12}=2.10$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=23.60$ (measured), and $S^\circ_{298.16}=25.7\pm 0.2$.

Ferrous Titanate.—Shomate (*430*) (51°–297°) measured the heat capacity of $FeTiO_3$ (ilmenite). Calculation gives $S^\circ_{50.42}$ (extrapolation) $=2.01$, $S^\circ_{298.16}-S^\circ_{50.42}=23.31$ (measured), and $S^\circ_{298.16}=25.3\pm0.3$.

KRYPTON

Element.—Clusius (*79*) (10°–121°) and Clusius, Kruis, and Konnertz (*107*) (63°–124°) have measured the heat capacity of Kr. Calculations from these data give $S^\circ_{10}=0.57$ (extrapolation), $S^\circ_{115.95}-S^\circ_{10}=12.18$ (crystals), $\Delta S^\circ_{115.95}=390.7/115.95=3.37$ (fusion), $S^\circ_{119.93}-S^\circ_{115.95}=0.35$ (liquid), $\Delta S_{119.93}=2{,}158/119.93=18.00$ (vaporization at 1 atm. pressure), $\Delta S_{119.93}=0.17$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{119.93}=4.53$ (gas). The sum is $S^\circ_{298.16}=39.17\pm0.10$ for Kr (*g*). A somewhat better value is that obtained from the Sackur equation, $S^\circ_{298.16}=39.20\pm0.01$.

LANTHANUM

Element.—In accordance with Lewis and Gibson (*331*) the entropy of La(*c*), to which is assigned the uncertainty ±0.8, is taken as $S^\circ_{298.16}=13.7\pm0.8$.

The entropy of La(*g*) may be obtained from spectroscopic data listed by Moore (*364*). At 298.16°, four energy levels, ${}^2D_{3/2}$, ${}^2D_{5/2}$, ${}^4F_{3/2}$, and ${}^4F_{5/2}$, must be considered. The term values are 0, 1,053.2, 2,668.2, and 3,010.0, respectively, and the quantum weights are 4, 6, 4, and 6. These states add 2.867 to the Sackur equation to make $S^\circ_{298.16}=43.57\pm0.01$.

Lanthanum–Magnesium Nitrate.—The heat capacity of $La_2Mg_3(NO_3)_{12}\cdot24H_2O(c)$ was measured by Fornoff, Pitzer, and Latimer (*159*) (15°–301°). They obtained $S^\circ_{15.55}=2.8$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.55}=522.4$ (measured), and $S^\circ_{298.16}=525.2\pm2.6$.

LEAD

Element.—The heat capacity of Pb(*c*) was measured by Bronson and Wilson (*58*) (203°–303°), Eucken and Schwers (*151*) (15°–276°), Keesom and Andrews (*244*) (2°–20°), Keesom and van den Ende (*249, 250*) (2°–20°), Keesom and Onnes (*265*) (14°–81°), Meads, Forsythe, and Giauque (*354*) (15°–300°), and Nernst (*372, 376*), (23°–273°). There is computed $S^\circ_{298.16}=15.49\pm0.05$, of which 0.007 is extrapolation below 3°.

The entropy of Pb (*g*), obtained from the Sackur equation, is $S^\circ_{298,16}=41.90\pm0.01$.

For $Pb_2(g)$, there is estimated here $S^\circ_{298.16}=65.5\pm0.5$.

Lead Ion.—From thermal data for the reaction $PbCl_2(c)=Pb^{++}(aq.)+2Cl^-(aq.)$, Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=3.9\pm0.9$ for $Pb^{++}(aq.)$.

Oxides.—The heat capacity of $PbO(c)$, presumably the yellow variety, was measured by Nernst and Schwers (*377*) (21°–93°). There is obtained $S^\circ_{298.16}=16.6\pm0.5$, of which 0.55 is extrapolation below 20°. The entropy may be calculated independently from the cell measurements of Fried (*163*) for the reaction $PbO(c)+H_2=Pb(c)+H_2O(l)$. From the e. m. f. measurements and their temperature coefficient, the value $\Delta S^\circ_{298.16}=-16.80$ is obtained, which in turn leads to $S^\circ_{298.16}=17.8\pm1.0$ for PbO. The third-law value, $S^\circ_{298.16}=16.6\pm05$, is adopted.

From molecular constants (*212*), $I=91.2\times10^{-40}$ and $\omega=718$, there are computed $S^\circ_{t+r,\ 298.16}=57.06$, $S^\circ_{v,\ 298.16}=0.29$, and $S^\circ_{298.16}=57.34\pm0.10$ for $PbO(g)$. A rough check on this value is afforded by the heat and free energy of sublimation (*269*), which correspond to $\Delta S^\circ_{298.16}=39.3$. Adding the entropy of the solid gives $S^\circ_{298.16}=55.9$ for $PbO(g)$, which merits no weight in comparison with the value from molecular constants.

Millar (*361*) (69°–298°) measured the heat capacity of $PbO_2(c)$. There is computed $S^\circ_{298.16}=18.3\pm0.5$, of which 3.50 is extrapolation below 70.8°.

Millar (*361*) (71°–239°) also measured the heat capacity of $Pb_3O_4(c)$. The calculated results are $S^\circ_{70.8}=12.67$ (extrapolation), $S^\circ_{298.16}-S^\circ_{70.8}=37.83$ (measured), and $S^\circ_{298.16}=50.5\pm1.6$.

Bromides.—The heat capacity of $PbBr_2(c)$ was measured by Latimer and Hoenshel (*321*) (18°–297°). The data yield $S^\circ_{298.16}=38.6\pm0.5$, of which 1.64 is extrapolation below 17.8°. Cann and Sumner (*68*) have obtained $\Delta S^\circ_{298.16}=-12.60$ for the reaction $Pb(c)+2AgBr(c)=PbBr_2(c)+2Ag(c)$. Corresponding to this result, $S^\circ_{298.16}=33.7$ may be calculated for $PbBr_2(c)$, which disagrees with the third-law value and also appears out of line with the entropies of $PbCl_2(c)$ and $PbI_2(c)$.

From values of $I=603\times10^{-40}$ and $\omega=207$, and quantum weight of 2 for the lowest energy level, there are computed $S^\circ_{t+r,\ 298.16}=61.56$, $S^\circ_{v,\ 298.16}=2.24$, $S^\circ_{e,\ 298.16}=1.38$, and $S^\circ_{298.16}=65.2\pm0.5$ for $PbBr(g)$.

Carbonate.—The heat capacity of $PbCO_3$ (cerussite) was measured by Anderson (*16*) (53°–294°). The data give $S^\circ_{56.2}=6.45$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=24.82$ (measured), and $S^\circ_{298.16}=31.3\pm0.8$.

Basic Carbonate.—From dissociation pressure and thermal data, the value $S^\circ_{298.16}=48.5\pm1.5$ was obtained for $PbO{\cdot}PbCO_3(c)$ by Kelley and Anderson (*290*).

Chlorides.—The heat capacity of $PbCl_2(c)$ was measured by Nernst (*373*) (15°–206°). There is calculated $S^\circ_{298.16}=34.0\pm1.0$, with an extrapolation of 0.91 below 15.8°.

Gerke's (*169*) cell measurements permit two independent calculations. He gave $\Delta S^\circ_{298.16}=-8.6$ for the reaction $Pb(c)+2AgCl(c)=PbCl_2(c)+2Ag(c)$ and $\Delta S^\circ_{298.16}=6.7$ for the reaction $Pb(c)+2HgCl(c)=PbCl_2(c)+2\ Hg(l)$. The corresponding calculated entropies of $PbCl_2(c)$ are $S^\circ_{298.16}=32.5\pm.05$ and $S^\circ_{298.16}=32.2\pm1.0$. The value $S^\circ_{298.16}=32.5\pm0.5$ is adopted.

From molecular-constant data (*467*), $I=282\times10^{-40}$ and $\omega=303$, and quantum weight of 2 for the lowest energy level, there are obtained

$S^{\circ}_{t+r,298.16}=59{,}55$, $S^{\circ}_{v,298.16}=1.40$, $S^{\circ}_{e,298.16}=1.38$, and $S^{\circ}_{298.16}=62.3\pm0.5$ for PbCl(*g*).

Fluoride.—The vibration frequency of the PbF(*g*) molecule is 505 cm.$^{-1}$ (*212*) and the quantum weight of the lowest energy level is 2. The interatomic distance is estimated here as 2.3×10^{-8} cm., leading to $I=153\times10^{-40}$. There are computed $S^{\circ}_{t+r,298.16}=58.12$, $S^{\circ}_{v,298.16}=0.64$, $S^{\circ}_{e,298.16}=1.38$, and $S^{\circ}_{298.16}=60.1\pm0.5$ for PbF(*g*).

Hydride.—Molecular-constant data are available for PbH(*g*) (*212*), $I=5.63\times10^{-40}$ and $\omega=1{,}535$. Calculation yields $S^{\circ}_{t+r,298.16}=51.314$, $S^{\circ}_{v,298.16}=0.009$, $S^{\circ}_{e,298.16}=1.378$, and $S^{\circ}_{298.16}=52.70\pm0.10$.

Iodides.—From the heat-capacity data of Nernst and Schwers (*377*) (22°–96°), Lewis and Gibson (*331*) have calculated the entropy of $PbI_2(c)$ as $S^{\circ}_{298.16}=41.3$ by means of their *N*-formula. As the data are meager and the extrapolation is large, C_p being 7.05 at 22.3°, it is not possible to improve much on this calculation. The uncertainty may easily be as much as ±1.5 units.

A much more reliable value may be obtained from the cell measurements of Gerke (*169*), which give $\Delta S^{\circ}_{298.16}=-1.2$ for the reaction $Pb(c)+I_2(c)=PbI_2(c)$. This figure leads to $S^{\circ}_{298.16}=42.2\pm0.5$ for $PbI_2(c)$.

For PbI(*g*), there are computed $S^{\circ}_{t+r,298.16}=62.88$, $S^{\circ}_{v,298.16}=2.50$, $S^{\circ}_{e,298.16}=1.38$, and $S^{\circ}_{298.16}=66.8\pm0.5$ from molecular-constant data listed by Stevenson (*467*), $I=932\times10^{-40}$ and $\omega=164$.

Phosphate.—Pitzer, Smith, and Latimer (*391*) (15°—292°) measured the heat capacity of $Pb_3(PO_4)_2$ (*c*). There is computed $S^{\circ}_{298.16}=84.5\pm0.4$ of which 1.10 is extrapolation below 15°.

Selenide.—The entropy of PbSe(*g*) is estimated here as $S^{\circ}_{298.16}=67.9\pm0.5$.

Silicate.—Kelley (*289*) (52°–296°) has measured the heat capacity of $PbSiO_3(c)$. There are computed $S^{\circ}_{50.12}=4.39$ (extrapolation), $S^{\circ}_{298.16}-S^{\circ}_{50.12}=24.33$ (measured), and $S^{\circ}_{298.16}=28.7\pm0.3$.

Sulfide.—The heat capacity of PbS (galena) was measured by Anderson (*13*) (53°–290°) and Eastman and Rodebush (*139*) (63°–283°). The data of Anderson are used in obtaining $S^{\circ}_{298.16}=21.8\pm0.5$, of which 4.50 is extrapolation below 50.1°.

Molecular-constant data (*212*), $I=264\times10^{-40}$ and $\omega=427$, give $S^{\circ}_{t+r,298.16}=59.375$, $S^{\circ}_{v,298.16}=0.803$, and $S^{\circ}_{298.16}=60.18\pm0.10$ for PbS(*g*).

Sulfate.—Anderson (*19*) (53°–294°) and Haas and Stegeman (*207*) (83°–298°) measured the heat capacity of $PbSO_4(c)$. There is obtained $S^{\circ}_{298.16}=35.2\pm0.9$, of which 6.75 is extrapolation below 56.2°.

Basic Sulfates.—From consideration of various equilibrium data, the author (*273*) has calculated $\Delta S^{\circ}_{298.16}=-3.5$ for the reaction $PbSO_4(c)+PbO(c)=PbSO_4{\cdot}PbO(c)$, $\Delta S^{\circ}_{298.16}=-4.3$ for the reaction $PbSO_4(c)+2PbO(c)=PbSO_4{\cdot}2PbO(c)$, and $\Delta S^{\circ}_{298.16}=-5.8$ for the reaction $PbSO_4(c)+3PbO(c)=PbSO_4{\cdot}3PbO(c)$. These values lead to $S^{\circ}_{298.16}=48\pm2$ for $PbSO_4{\cdot}PbO(c)$, $S^{\circ}_{298.16}=64\pm2.5$ for $PbSO_4{\cdot}2PbO(c)$, and $S^{\circ}_{298.16}=79\pm3$ for $PbSO_4{\cdot}3PbO$.

Telluride.—McAteer and Seltz (*347*) reported $\Delta S^{\circ}_{298.16}=-1.0$ for the reaction $Pb(c)+Te(c)=PbTe(c)$. This leads to $S^{\circ}_{298.16}=26.4\pm0.7$ for PbTe(*c*).

For PbTe(*g*), there is estimated here $S^{\circ}_{298.16}=68.6\pm0.5$.

LITHIUM

Element.—Simon and Swain (*443*) (15°–300°) measured the heat capacity of Li(*c*). Their data give $S^\circ_{15.0}=0.015$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.0}=6.68$, and $S^\circ_{298.16}=6.70\pm0.06$.

For Li(*g*), the Sackur equation, to which must be added *R ln* 2 in this instance, yields $S^\circ_{298.16}=33.15\pm0.01$.

Molecular constants of Li_2(*g*), $I=41.1\times10^{-40}$ and $\omega=348.8$, yield $S^\circ_{t+r,298.16}=45.813$, $S^\circ_{v,298.16}=1.170$, and $S^\circ_{298.16}=46.98\pm0.10$.

Lithium Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=4.7\pm1.0$ for Li^+(*aq.*) from thermal data for the reaction $Li_2CO_3(c)=2Li^+(aq.)+CO_3^{--}(aq.)$.

Bromide.—Stevenson (*467*) estimated 2.27×10^{-8} cm. as the interatomic distance in the LiBr(*g*) molecule, corresponding to $I=54.6\times10^{-40}$, and lists the vibration frequency as 540 cm.$^{-1}$. These values yield $S^\circ_{t+r,298.16}=53.22$, $S^\circ_{v,298.16}=0.56$, and $S^\circ_{298.16}=53.8\pm0.5$ for LiBr(*g*).

Carbonate.—The heat capacity of Li_2CO_3(*c*) was measured by Brown and Latimer (*59*) (16°–301°). The data yield $S^\circ_{16.8}=0.05$ (extrapolation), $S^\circ_{298.16}-S^\circ_{16.8}=21.55$, and $S^\circ_{298.16}=21.60\pm0.10$.

Chloride.—Ueda (*493*, *494*) reported $\Delta F^\circ_{298.16}=-91{,}612$ and $\Delta H^\circ_{298.16}=-97{,}420$, corresponding to $\Delta S^\circ_{298.16}=-19.5$, for the reaction $Li(c)+\frac{1}{2}\,Cl_2(g)=LiCl(c)$. There is computed $S^\circ_{298.16}=13.9\pm0.5$ for LiCl(*c*).

The entropy of LiCl(*g*) is computed from molecular constants listed by Stevenson (*467*), which correspond to $I=43.7\times10^{-40}$ and $\omega=650$. There are obtained $S^\circ_{t+r,298.16}=50.64$, $S^\circ_{v,298.16}=0.37$, and $S^\circ_{298.16}=51.0\pm0.5$. Niwa (*380*) estimated $S^\circ_{298.16}=49.9\pm1.4$, which is given no weight in comparison with the value just calculated.

Fluoride.—Clusius (*81*) (18°–273°) measured the heat capacity of LiF(*c*). There is calculated $S^\circ_{298.16}=8.32\pm0.08$, of which only 0.004 is extrapolation below 18°.

For LiF(*g*), there is estimated here $S^\circ_{298.16}=49.2\pm0.5$.

Hydrides.—A few heat-capacity measurements of LiH(*c*) were made by Günther (*205*) (74°–293°). There is obtained $S^\circ_{298.16}=5.9\pm0.5$, of which 0.21 is extrapolation below 70.8°.

Available molecular-constant data for LiH(*g*) (*212*), $I=3.72\times10^{-40}$ and $\omega=1{,}382$, lead to $S^\circ_{t+r,298.16}=40.754$, $S^\circ_{v,298.16}=0.018$, and $S^\circ_{298.16}=40.77\pm0.10$.

Similar data for LiD(*g*) (*212*), $I=6.59\times10^{-40}$ and $\omega=1{,}042$, give $S^\circ_{t+r,298.16}=42.246$, $S^\circ_{v,298.16}=0.078$, and $S^\circ_{298.16}=42.32\pm0.10$.

Hydroxide.—The heat and free energy of formation from the elements of LiOH(*c*) were obtained by Ueda (*493*, *494*) as $\Delta H^\circ_{298.16}=-115{,}253$ and $\Delta F^\circ_{298.16}=-105{,}128$. These figures correspond to $\Delta S^\circ_{298.16}=-34.0$ and to $S^\circ_{298.16}=12.8\pm1.0$, for LiOH(*c*).

Iodide.—From Stevenson's (*467*) suggested molecular constants for LiI(*g*), $I=66.1\times10^{-40}$ and $\omega=448$, there are computed $S^\circ_{t+r,298.16}=54.89$, $S^\circ_{v,298.16}=0.80$, and $S^\circ_{298.16}=55.7\pm0.5$.

Intermetallic Compounds.—There are estimated here $S^\circ_{298.16}=52.3\pm0.5$ for LiNa(*g*), $S^\circ_{298.16}=54.6\pm0.5$ for LiK(*g*), $S^\circ_{298.16}=56.4\pm1.0$ for LiRb(*g*), and $S^\circ_{298.16}=58.2\pm1.0$ for LiCs(*g*).

MAGNESIUM

Element.—The heat capacity of Mg(*c*) was measured by Clusius and Vaughen (*105*) (11°–229°), Eastman and Rodebush (*139*) (74°–289°), and Nernst and Schwers (*377*) (27°–94°). Relying largely on the data of the first-named investigators, there is calculated $S^\circ_{298.16}=7.77\pm0.05$. The extrapolation is 0.004 below 11.3°.

The Sackur equation gives $S^\circ_{298.16}=35.51\pm0.01$ for Mg(*g*). Clusius and Vaughen reported $S^\circ_{298.16}=35.3$ from the entropy of the solid, high-temperature heat-capacity data, and vapor-pressure data. The agreement is good but the latter value is worthy of no weight in comparison with the former.

Magnesium Ion.—Stephenson (*456*) has reported $S^\circ_{298.16}=-32.7\pm1.0$ for $Mg^{++}(aq.)$ from a consideration of thermal data for magnesium nitrate solutions. This value is adopted. It agrees within the limits of uncertainty with the result, $S^\circ_{298.16}=-31.6\pm3$, obtained by Latimer, Pitzer, and Smith (*325*) from thermal data for the reaction $Mg(OH)_2(c)+2H^+(aq.)=Mg^{++}(aq.)+2H_2O(l)$.

Oxide.—Giauque and Archibald (*173*) (20°–301°), Günther (*204*) (21°–84°), and Parks and Kelley (*383*) (94°–291°) measured the heat capacity of MgO(*c*). The measurements of Parks and Kelley were made on a virtually perfectly crystallized sample, while those of Giauque and Archibald were made on finely powdered material obtained by dehydrating $Mg(OH)_2$ at 573°–623°. This probably is the reason for the difference in the two sets of results which lead to the entropy values $S^\circ_{298.16}=6.4\pm0.1$ and $S^\circ_{298.16}=6.66\pm0.02$, respectively. This difference in entropy is not large enough to be of importance in most thermodynamic calculations and an intermediate value, $S^\circ_{298.16}=6.55\pm0.15$, may be employed without consideration of the physical characteristics of the material.

From molecular-constant data (*212*), $I=40.6\times10^{-40}$ and $\omega=662$, there are computed $S^\circ_{t+r,298.16}=50.34$, $S^\circ_{v,298.16}=0.36$, and $S^\circ_{298.16}=50.7\pm0.2$ for MgO(*g*).

Bromide.—It is estimated here that the entropy of MgBr(*g*) is $S^\circ_{298.16}=57.8\pm0.5$. This is obtained from the vibration frequency, 372, quantum weight of the lowest energy state, 2, and an assumed value for the moment of inertia, 124×10^{-40}.

Carbonate.—The heat capacity of $MgCO_3$ (magnesite) was measured by Anderson (*16*) (56°–292°). There are computed $S^\circ_{56.2}=0.57$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=15.17$ (measured), and $S^\circ_{298.16}=15.7\pm0.2$.

Chlorides.—Kelley and Moore (*292*) (53°–296°) measured the heat capacity of $MgCl_2(c)$. There are obtained $S^\circ_{50.12}=1.74$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=19.68$ (measured), and $S^\circ_{298.16}=21.4\pm0.2$.

The heat capacity of $MgCl_2{\cdot}H_2O(c)$ was measured by Kelley and Moore (*293*) (53°–299°). The entropy values are $S^\circ_{50.12}=2.80$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=30.05$ (measured), and $S^\circ_{298.16}=32.8\pm0.5$.

The heat capacity of $MgCl_2{\cdot}2H_2O(c)$ also was measured by Kelley and Moore (*293*) (54°–295°). Their results yield $S^\circ_{50.12}=3.75$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=39.27$ (measured), and $S^\circ_{296.16}=43.0\pm0.5$.

Kelley and Moore (*293*) (54°–296°) measured the heat capacity of

$MgCl_2{\cdot}4H_2O(c)$. There are calculated $S^\circ_{50.12}=5.73$ (extrapolated), $S^\circ_{298.16}-S^\circ_{50.12}=57.35$ (measured), and $S^\circ_{298.16}=63.1\pm0.7$.

In addition, Kelley and Moore (*293*) (54°–296°) measured the heat capacity of $MgCl_2{\cdot}6H_2O(c)$. There are obtained $S^\circ_{50.12}=8.76$ (extrapolated), $S^\circ_{298.16}-S^\circ_{50.12}=78.75$ (measured), and $S^\circ_{298.16}=87.5\pm1.0$.

For $MgCl(g)$, there is estimated $S^\circ_{298.16}=55.0\pm0.5$. This is based upon $\omega=464$ (*212*), quantum weight of the ground state=2, and an assumed $I=82\times10^{-40}$.

Chromite.—Shomate (*425*) (54°–296°) measured the heat capacity of $MgCr_2O_4(c)$. The data yield $S^\circ_{53.09}=1.63$ (extrapolated), $S^\circ_{298.16}-S^\circ_{53.09}=23.71$ (measured), and $S^\circ_{298.16}=25.3\pm0.2$.

Fluoride.—The heat capacity of $MgF_2(c)$ was measured by Todd (*486*) (54°–297°). The data yield $S^\circ_{51.0}=0.54$ (extrapolated), $S^\circ_{298.16}-S^\circ_{51.0}=13.14$ (measured), and $S^\circ_{298.16}=13.68\pm0.07$.

Molecular-constant data (*212*), $I=54.2\times10^{-40}$, $\omega=687$, and quantum weight=2 for the ground state, lead to $S^\circ_{t+r,298.16}=51.13$, $S^\circ_{v,298.16}=0.32$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=52.8\pm0.5$ for $Mg\ F(g)$.

Hydrides.—Molecular-constant data (*212*) are available for $MgH(g)$ and $MgD(g)$. For the former, $I=4.8\times10^{-40}$ and $\omega=1{,}463$; for the latter, $I=9.24\times10^{-40}$ and $\omega=1{,}062$. Both have a quantum weight of 2 for the ground state.

For $MgH(g)$, $S^\circ_{t+r,298.16}=44.720$, $S^\circ_{v,298.16}=0.011$, $S^\circ_{e,296.16}=1{,}378$, and $S^\circ_{298.16}=46.11\pm0.10$.

The corresponding values for $MgD(g)$ are $S^\circ_{t+r,298.16}=46.133$, $S^\circ_{v,298.16}=0.072$, $S^\circ_{e,298.16}=1.378$, and $S^\circ_{298.16}=47.58\pm0.10$.

Hydroxide.—Giauque and Archibald (*173*) (22°–321°) measured the heat capacity of $Mg(OH)_2(c)$. Their caluclations give $S^\circ_{298.16}=15.09$, of which 0.033 is extrapolation below 21.10. The uncertainty should not exceed ±0.05 unit.

Iodide.—The vibration frequency of the $MgI(g)$ molecule has been reported (*212*) as 312 $cm.^{-1}$. This value, quantum weight of 2 for the ground state, and an estimated value of the moment of inertia, $I=172\times10^{-40}$, lead to $S^\circ_{298.16}=59.9\pm0.5$.

Nitrate.—Shomate and Kelley (*435*) (54°–297°) measured the heat capacity of $Mg(NO_3)_2(c)$. There are computed, $S^\circ_{53.09}=4.09$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=35.06$ (measured), and $S^\circ_{298.16}=39.2\pm0.4$.

Silicates.—The heat capacity of $MgSiO_3$ (clinoenstatite) was measured by Kelley (*285*) (52°–296°) and Wagner (*496*) (21°–36°). The data of Wagner appear to be too high and only those of Kelley are used in obtaining $S^\circ_{50.12}=0.49$ (extapolation), $S^\circ_{298.16}-S^\circ_{50.12}=15.73$ (measured), and $S^\circ_{298.16}=16.22\pm0.10$.

Kelley (*285*) (53°–295°) also measured the heat capacity of $Mg_2SiO_4(c)$. There are computed $S^\circ_{50.12}=0.60$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=22.15$ (measured), and $S^\circ_{298.16}=22.75\pm0.2$.

Sulfate.—The heat capacity of $MgSO_4(c)$ was measured by Moore and Kelley (*365*) (53°–296°). There are obtained $S^\circ_{50.12}=1.10$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=20.78$ (measured), and $S^\circ_{298.16}=21.9\pm0.2$.

Titanate.—Shomate (*430*) (52°–297°) measured the heat capacity of $MgTiO_3(c)$. His data yield $S^\circ_{52.00}=0.45$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=17.37$ (measured), and $S^\circ_{298.16}=17.82\pm0.10$.

MANGANESE

Element.—Elson, Smith, and Wilhelm (*143*) (15°–23°), Kelley (*275*) (53°–290°), and Shomate (*296*, *426*) (54°–297°) measured the heat capacity of Mn(α). The data of the latter two investigators give $S^\circ_{52.0}=0.48$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.0}=7.11$ (measured), and $S^\circ_{298.16}=7.59\pm0.04$. This value is adopted.

Shomate (*296*, *426*) (53°–297°) also measured the heat capacity of Mn(γ). His data yield $S^\circ_{52.0}=0.49$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.0}=7.23$ (measured), and $S^\circ_{298.16}=7.72\pm0.04$.

Kelley (*296*) computed $S^\circ_{298.16}=41.50\pm0.01$ for Mn(g) by means of the Sackur equation, with $R\ ln\ 6$ added to account for the quantum weight of the one state effective at 298.16°.

Manganous Ion.—Kapustinsky (*239*) has reported $S^\circ_{298.16}=-19.1\pm0.6$ for $Mn^{++}(aq.)$ from thermal data for manganese carbonate.

Oxides.—Millar (*359*) (70°–301°) measured the heat capacity of MnO(c). The data yield $S^\circ_{50.8}=2.22$ (extrapolation) and $S^\circ_{298.16}=14.4\pm0.6$.

The entropy of MnO(g) is estimated roughly from the vibration frequency (*212*), 836 cm.$^{-1}$, and an assumed value of the moment of inertia, 60×10^{-40}. The result is $S^\circ_{298.16}=53.0\pm1.5$.

The heat capacity of $MnO_2(c)$ was measured by Kelley and Moore (*291*) (53°–295°) and Millar (*359*) (72°–294°). The results of the two investigations are not in agreement, and Kelley and Moore (*291*) have shown that this is attributable largely to an error in Millar's calculations of his data. From Kelley and Moore's data, there are obtained $S^\circ_{50.12}=0.60$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=12.08$ (measured), and $S^\circ_{298.16}=12.68\pm0.10$.

Kapustinsky and Bayuskina (*240*) have suggested $S^\circ_{298.16}=22.9$ for $Mn_2O_3(c)$, calculated from dissociation-pressure measurements of $MnO_2(c)$. No attempt is made to estimate the uncertainty in this result.

In addition, Millar (*359*) (72°–306°) measured the heat capacity of $Mn_3O_4(c)$. The data yield $S^\circ_{298.16}=35.5\pm0.7$, the extrapolation being 4.67 below 70.8°.

Carbide.—Kelley and Moore (*291*) (52°–296°) measured the heat capacity of $Mn_3C(c)$. The data yield $S^\circ_{50.12}=1.24$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=22.38$ (measured), and $S^\circ_{298.16}=23.6\pm0.2$.

Carbonate.—Anderson (*16*) (55°–297°) measured the heat capacity of $MnCO_3$ (rhodochrosite). His results give $S^\circ_{56.2}=1.65$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=18.87$ (measured), and $S^\circ_{298.16}=20.5\pm0.3$.

Chloride.—The heat capacity of $MnCl_2(c)$ was measured by Kelley and Moore (*292*) (53°–295°) and Trapeznikova and Miljutin (*489*, *490*) (14°–131°). The results of the two investigations disagree by 3 to 4 percent over the common temperature range and those of Kelley and Moore are adopted. There are obtained $S^\circ_{50.12}=6.02$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=21.97$ (measured), and $S^\circ_{298.16}=28.0\pm0.5$. There have been added 3.27 units to the extrapolated portion, to take account of unextracted magnetic entropy. The uncertainty figure has been increased to allow for error in this procedure.

Fluoride.—Stout and Adams (*473*) (13°–311°) measured the heat capacity of $MnF_2(c)$. They obtained $S^\circ_{15.0}=0.22$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.0}=22.03$ (measured), and $S^\circ_{298.16}=22.25\pm0.10$.

Selenide.—Kelley (*275*) (54°–287°) measured the heat capacity of $MnSe(c)$. The data yield $S^\circ_{53.1}=2.78$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.1}=18.95$ (measured), and $S^\circ_{298.16}=21.7\pm0.4$.

Silicate.—The heat capacity of $MnSiO_3(c)$ was measured by Kelley (*282*) (52°–295°). There are computed $S^\circ_{50.12}=1.69$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=19.61$ (measured), and $S^\circ_{298.16}=21.3\pm0.2$.

Sulfide.—Anderson (*12*) (59°–297°) measured the heat capacity of $MnS(c)$. There is obtained $S^\circ_{298.16}=18.7\pm0.4$, of which 2.14 is extrapolation below 56.2°.

Sulfate.—Moore and Kelley (*365*) (53°–295°) measured the heat capacity of $MnSO_4(c)$. The data yield $S^\circ_{50.12}=2.72$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=24.07$ (measured), and $S^\circ_{298.16}=26.8\pm0.2$.

Telluride.—Kelley (*275*) (54°–327°) measured the heat capacity of $MnTe(c)$. There are obtained $S^\circ_{53.1}=3.35$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.1}=19.07$ (measured), and $S^\circ_{298.16}=22.4\pm0.4$.

Dithionate.—The heat capacity of $MnS_2O_6\cdot 2H_2O(c)$ was measured by Kelley and Moore (*294*) (53°–295°). Their data yield $S^\circ_{50.12}=7.15$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=59.51$ (measured), and $S^\circ_{298.16}=66.7\pm0.8$. These workers also estimated $S^\circ_{298.16}=45$ for $MnS_2O_6(c)$ and $S^\circ_{298.16}=110$ for $MnS_2O_6\cdot 6H_2O(c)$.

Permanganate Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=46.7\pm0.4$ for $MnO_4^-(aq.)$ from thermal data for the reaction $KMnO_4(c)=K^+(aq.)+MnO_4^-(aq.)$.

MERCURY

Element.—The heat capacity of Hg at low temperatures was measured by Carpenter and Stoodley (*69*) (197°–234°), Pollitzer (*392*, *393*) (31°–243°), and Simon (*437*, *438*) (3°–232°). Pollitzer measured the heat of fusion as 554.5 cal. per mole, while Bridgeman (*54*) obtained 560 cal. per mole. The mean value, 557.2, is adopted. Henning (*210*) gave 234.2° as the melting point. The entropy calculations are $S^\circ_{3.16}=0.03$ (extrapolation), $S^\circ_{234.2}-S^\circ_{3.16}=14.47$ (crystals), $\Delta S^\circ_{234.2}=557.2/234.2=2.38$ (fusion), and $S^\circ_{298.16}-S^\circ_{234.2}=1.65$ (liquid). The sum is $S^\circ_{298.16}=18.53\pm0.10$.

The Sackur equation gives $S^\circ_{298.16}=41.80\pm0.01$ for $Hg(g)$. Only the lowest energy state, whose quantum weight is 1, is effective at 298.16°K.

There is estimated here $S^\circ_{298.16}=66.0\pm1.0$ for $Hg_2(g)$.

Hg_2^{++}(aq.) Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=17.7\pm3$ for $Hg_2^{++}(aq.)$ from thermal data for the reaction $2Hg(l)+2H^+(aq.)=Hg_2^{++}(aq.)+H_2(g)$.

Oxides.—Günther (*204*) (25°–75°) measured the heat capacity of HgO (*red*). His data lead to $S^\circ_{298.16}=16.6\pm1.0$, the extrapolation below 25.1° being 0.83.

The cell measurements of Fried (*163*) give $\Delta S^\circ_{298.16}=-14.0$ for the reaction HgO (*yellow*) $+H_2(g)=H_2O(l)+Hg(l)$. As the other entropies are known, there results $S^\circ_{298.16}=18.1$ for HgO (*yellow*). The same reaction was studied by Shibata and Murata (*423*) and Shibata, Kobayashi, and Furukawa (*424*). Their results yield $\Delta S^\circ_{298.16}=$

-13.25, which corresponds to $S^\circ_{298.16}=17.3$ for HgO (*yellow*). The mean value, $S^\circ_{298.16}=17.7\pm0.5$, is adopted.

Bromides.—From cell measurements, Ishikawa and Ueda (*222*) give $\Delta F^\circ_{298.16}=-21{,}350$ and $\Delta H^\circ_{298.16}=-24{,}470$ for the formation of $HgBr(c)$ from the elements. These figures result in $\Delta S^\circ_{298.16}=-10.5$, which, with the values for the constituent elements, yields $S_{298.16}=26.4$ for $HgBr(c)$. More recently, Dakin and Ewing (*122*) have obtained $\Delta S^\circ_{298.16}=7.19$ for the reaction $Ag(c)+HgBr(c)=AgBr(c)+Hg(l)$. This, in turn, leads to $S^\circ_{298.16}=26.7$ for $HgBr(c)$. The mean, $S^\circ_{298.16}=26.6\pm0.5$ is adopted.

Molecular-constant data for $HgBr(g)$ (*212*, *467*), $I=551\times10^{-40}$, $\omega=185$, and quantum weight=2 for the ground state, lead to $S^\circ_{t+r,\,298.16}=61.27$, $S^\circ_{v,\,298.16}=2.28$, $S^\circ_{e,\,298.16}=1.38$, and $S^\circ_{298.16}=64.9\pm0.5$.

Molecular-constant data are available for $HgBr_2(g)$, $I=1{,}500\times10^{-40}$, $\omega_1=64(2)$, $\omega_2=220(1)$, and $\omega_3=297(1)$. There are calculated $S^\circ_{t+r,298.16}=62.67$, $S^\circ_{v,298.16}=12.04$, and $S^\circ_{298.16}=74.7\pm1.0$. This value for $HgBr_2(g)$, in conjunction with heat and free energy of sublimation values (*270*), gives $S^\circ_{298.16}=38.9$ for $HgBr_2(c)$.

Chlorides.—Pollitzer (*392*, *393*) (22°–199°) measured the heat capacity of $HgCl(c)$. His data give $S^\circ_{298.16}=23.0\pm0.7$, of which 1.35 is extrapolation below 22.4°. Better values are obtainable from the cell measurements of Gerke (*169*), who reported $\Delta S^\circ_{298.16}=-21.8$ for the reaction $Hg(l)+\frac{1}{2}\ Cl_2(g)=HgCl(c)$ and $\Delta S^\circ_{298.16}=7.8$ for the reaction $Ag(c)+HgCl(c)=AgCl(c)+Hg(l)$. The corresponding entropy values for $HgCl(c)$ are $S^\circ_{298.16}=23.4\pm0.5$ and $S^\circ_{298.16}=23.5\pm0.5$. Still another value may be obtained from the residual-ray data of Rubens (*403*), which is $S^\circ_{298.16}=24.7$. The value $S^\circ_{298.16}=23.5\pm0.5$ is adopted for $HgCl(c)$.

Molecular-constant data for $HgCl(g)$ (*212*, *467*), $I=260\times10^{-40}$, $\omega=291$, and quantum weight=2 for the ground state, give $S^\circ_{t+r,298.16}=59.30$, $S^\circ_{v,298.16}=1.47$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=62.2\pm0.5$.

Available molecular-constant data for $HgCl_2(g)$ (*55*, *311*) are $I=612\times10^{-40}$, $\omega_1=71(2)$, $\omega_2=355(1)$, and $\omega_3=413(1)$. There are computed $S^\circ_{t+r,298.16}=60.04$, $S^\circ_{v,298.16}=10.30$, and $S^\circ_{298.16}=70.3\pm1.0$.

The value for $HgCl_2$ (g) and heat and free-energy-of-sublimation data (*271*) give $S^\circ_{298.16}=34.5$ for $HgCl_2(c)$.

Fluoride.—There is estimated here $S^\circ_{298.16}=58.6\pm1.0$ for $HgF(g)$.

Hydrides.—Molecular-constant data are available for $HgH(g)$ and $HgD(g)$ (*212*). For $HgH(g)$, $I=5.05\times10^{-40}$ and $\omega=1{,}304$; for $HgD(g)$, $I=10.00\times10^{-40}$ and $\omega=945$. The ground state of each has the quantum weight 2.

Calculation gives $S^\circ_{t+r,298.16}=51.002$, $S^\circ_{v,298.16}=0.026$, $S^\circ_{e,298.16}=1.378$, and $S^\circ_{298.16}=52.41\pm0.10$ for $HgH(g)$.

Corresponding values for $HgD(g)$ are $S^\circ_{t+r,298.16}=52.373$, $S^\circ_{v,298.16}=0.116$, $S^\circ_{e,298.16}=1.378$, and $S^\circ_{298.16}=53.87\pm0.10$.

Iodides.—Molecular-constant data for $HgI(g)$ (*212*, *467*), $I=873\times10^{-40}$, $\omega=124$, and quantum weight=2 for the ground state, yield $S^\circ_{t+r,298.16}=62.69$, $S^\circ_{v,298.16}=3.04$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=67.1\pm0.5$.

Molecular-constant data for $HgI_2(g)$ (*55*, *311*) are $I=2{,}740\times10^{-40}$, $\omega_1=50(2)$, $\omega_2=153(1)$, and $\omega_3=233(1)$. There are computed $S^\circ_{t+r,298.16}=64.56$, $S^\circ_{v298.16}=14.13$, and $S^\circ_{298.16}=78.7\pm1.0$.

The value for $HgI_2(g)$ and heat and free-energy-of-sublimation data (*270*) give $S^\circ_{298.16}=40.8$ for $HgI_2(c)$.

Sulfate.—The heat capacity of $Hg_2SO_4(c)$ was measured by Pollitzer (*392*, *393*) (23°–203°) and Schutz (*413*) (14°–295°). The data of the former are erratic, and only those of Schutz will be used. His heat-capacity curve breaks quite sharply and peculiarly at the lower end, making extrapolation uncertain; results with a spread of 0.4 unit may be obtained, depending on the judgment of the calculator. The values given by Schutz are adopted, $S^\circ_{15.90}=1.23$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.90}=46.78$ (measured), and $S^\circ_{298.16}=48.0\pm0.5$. Independently, the author (*272*, *273*) computed $S^\circ_{298.16}=47.9$ from heat and free-energy data for $Hg_2SO_4(c)$.

MOLYBDENUM

Element.—Simon and Zeidler (*444*) (15°–275°) measured the heat capacity of Mo(*c*). The results yield $S^\circ_{298.16}=6.83\pm0.05$, of which 0.013 is extrapolation below 15.8°.

The lowest energy state of Mo(*g*), which is the only one effective at 298.16°, has the quantum weight 7 (*364*). The entropy is computed to be $S^\circ_{298.16}=43.47\pm0.01$.

Oxide.—Seltz, Dunkerley, and DeWitt (*418*) (70°–299°) measured the heat capacity of $MoO_3(c)$. Their calculations, which have been checked here to within 0.04 unit, give $S^\circ_{70.05}=2.97$ (extrapolation), $S^\circ_{298.16}-S^\circ_{70.05}=15.71$ (measured), and $S^\circ_{298.16}=18.7\pm0.3$.

Sulfides.—The heat capacity of MoS_2(molybdenite) was measured by Anderson (*21*) (56°–293°). There are calculated $S^\circ_{56.2}=1.04$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=14.00$ (measured), and $S^\circ_{298.16}=15.0\pm0.2$.

Kelley (*273*) has computed $\Delta S^\circ_{298.16}=-13.8$ for the reaction $Mo(c)+3S\ (rh)=MoS_3(c)$. This value leads to $S^\circ_{298.16}=15.9\pm1.0$ for $MoS_3(c)$.

NEON

Element.—The Sackur equation gives $S^\circ_{298.16}=34.95\pm0.01$ for Ne(*g*), which is adopted.

The heat capacity of Ne at low temperatures was measured by Clusius (*76*, *79*) (11°–53°). He has also determined the vapor pressure from which the heat of sublimation at the melting point, 24.57°, was calculated to be 511 cal. per mole. The entropy calculations give $S^\circ_{11.20}=0.74$ (extrapolation), $S^\circ_{24.57}-S^\circ_{11.20}=2.76$ (crystals), $\Delta S^\circ_{24.57}=20.80$ (sublimation at 324 mm. pressure), $\Delta S^\circ_{24.57}=-1.69$ (compression from 324 mm. to 1 atm. pressure), and $S^\circ_{298.16}-S^\circ_{24.57}=12.40$ (gas). The sum, $S^\circ_{298.16}=35.01\pm0.10$, is in good agreement with the value from the Sackur equation.

NICKEL

Element.—The heat capacity of Ni(*c*) at low temperatures was measured by Aoyama and Kanda (*29*) (81°–274°), Bronson and Wilson (*58*) (203°–303°), Clusius and Goldmann (*99*) (10°–26°), Eucken and Werth (*154*) (15°–205°), Keesom and Clark (*245*) (1°–20°), Rodebush and Michalek (*401*) (67°–204°), and Simon and Ruhemann (*441*) (71°–83°). Calculation yields $S^\circ_{298.16}=7.12\pm0.05$, of which the extrapolation below 1.1° is about 6×10^{-4}.

In obtaining the entropy of Ni(g) at 298.16°, the following energy states are to be considered, $^3F_4$, $^3D_3$, $^3D_2$, $^3F_3$, $^3D_1$, and $^3F_2$. The term values have been listed by Moore (*364*) as 0, 204.82, 879.82, 1,332.15, 1,713.11, and 2.216.55 cm.$^{-1}$, respectively, and the quantum weights are 9, 7, 5, 7, 3, and 5. These states add 5.390 to the translational entropy given by the Sackur equation, making $S^\circ_{298.16}=43.53\pm0.01$.

Oxide.—Seltz, DeWitt, and McDonald (*417*) (68°–297°) measured the heat capacity of NiO(c). The data yield $S^\circ_{66.8}=0.62$ (extrapolation), $S^\circ_{298.16}-S^\circ_{66.8}=8.62$ (measured), and $S^\circ_{298.16}=9.24\pm0.10$.

Carbonyl.—Crawford and Cross (*114*) and Crawford and Horwitz (*115*) have considered the $Ni(CO)_4$(g) molecule. They give 1.82×10^{-8} cm. as the Ni–C distance and 1.15×10^{-8} cm. as the C–O distance, the molecule being tetrahedral (symmetry number$=$12). These distances yield $I_1=I_2=I_3=795\times10^{-40}$. The vibration frequencies are taken as 80 (5), 300 (3), 380 (1), 420 (3), 460 (2), 540 (3), and 2,040 (4) cm.$^{-1}$. There are computed $S^\circ_{t+r,298.16}=66.38$, $S^\circ_{v,298.16}=30.64$, and $S^\circ_{298.16}=97.0\pm2$, in agreement with the calculations of Crawford and Cross.

Chloride.—The heat capacity of $NiCl_2$(c) was measured by Trapeznikova, Shubnikov, and Miljutin (*492*) (12°–129°). Calculation gives $S^\circ_{12.6}=0.16$ (extrapolation), $S^\circ_{298.16}-S^\circ_{12.6}=25.42$ (measured), and $S^\circ_{298.16}=25.6\pm1.0$.

Nitrate Hexammoniate.—Long and Toettcher (*340*) (54°–296°) measured the heat capacity of $Ni(NO_3)_3\cdot6NH_3$(c). No attempt will be made to evaluate the entropy.

Sulfate.—Stout and Giauque (*474*) (1°–17°) measured the heat capacity of $NiSO_4\cdot7H_2O$(c) and showed that the entropy at 10° is $S^\circ_{10}=2.26$. The thermal portion is 0.06, leaving 2.20 as the magnetic entropy, which is to be compared with the expected value $R\ ln\ 3=2.18$.

NITROGEN

Element.—The heat capacity of N_2 at low temperatures was measured by Clusius (*75*) (10°–74°), Eucken (*146*) (16°–73°), Giauque and Clayton (*178*) (15°–78°), Keesom and Onnes (*267*) (15°–77°), and Wiebe and Brevoort (*501*) (79°–117°). The calculations of Giauque and Clayton, which have been checked, are adopted. They find $S^\circ_{10.00}=0.46$ (extrapolation), $S^\circ_{35.61}-S^\circ_{10.00}=6.03$ (crystals II), $\Delta S^\circ_{35.61}=54.71/35.61=1.54$ (transition), $S^\circ_{63.14}-S^\circ_{35.61}=5.59$ (crystals I), $\Delta S^\circ_{63.14}=172.3/63.14=2.73$ (fusion), $S^\circ_{77.32}-S^\circ_{63.14}=2.73$ (liquid), $\Delta S_{77.32}=1{,}332.9/77.32=17.24$ (vaporization at 1 atm. pressure), $\Delta S_{77.32}=0.22$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{77.32}=9.39$ (gas). The sum is $S^\circ_{298.16}=45.93\pm0.15$.

Clayton and Giauque also have calculated the entropy from spectroscopic data as $S^\circ_{298.16}=45.79$, which becomes $S^\circ_{298.16}=45.77$ when corrected to conform with values of the natural constants used here. From molecular-constant data (*212*), $I=13.94\times10^{-40}$ and $\omega=2{,}345$, there is obtained $S^\circ_{298.16}=45.76$, the vibrational portion being negligible. The value $S^\circ_{298.16}=45.77\pm0.01$ is adopted.

The entropy of N(g), calculated from the Sackur equation with $R\ ln\ 4$ added to account for the quantum weight of the ground state, is $S^\circ_{298.16}=36.62\pm0.01$.

Nitrous Oxide.—The heat capacity of N_2O at low temperatures was measured by Blue and Giauque (*47*) (15°–188°), Clusius, Hiller, and

Vaughen (*106*) (10°–61°), Eucken and Hauck (*147*) (90°–170°), and Eucken and Veith (*153*) (heat of fusion). The data and calculations of Giauque and Blue are adopted. They find $S_{14.00}=0.21$ (extrapolation), $S_{182.26}-S_{14.00}=16.79$ (crystals), $\Delta S_{182.26}=1{,}563/182.26=8.58$ (fusion), $S_{184.59}-S_{182.26}=0.22$ (liquid), $\Delta S_{184.59}=3{,}958/184.59=21.44$ (vaporization at 1 atm. pressure), $\Delta S_{184.59}=0.11$ (correction to ideal gas state), and $S_{298.16}-S_{184.59}=4.08$ (gas). The sum is $S_{298.16}=51.43\pm0.10$.

Schomaker and Spurr's (*412*) interatomic dimensions lead to $I=66.4\times10^{-40}$ for the $N_2O(g)$ molecule. The vibration frequencies (*311*) are 589(2), 1,285(1), and 2,224 cm.$^{-1}$. These figures give $S^\circ_{t+r,298.16}=51.585$, $S^\circ_{v,298.16}=0.967$, and $S^\circ_{298.16}=52.55\pm0.03$. Similarly calculated results have been reported by Badger and Woo (*34*), 52.58; Blue and Giauque (*47*), 52.58; Kassel (*242*), 52.58; and Rodebush (*400*), 52.4. Rodebush employed a value of the moment of inertia now considered as erroneous. The remaining results differ from the present calculation only because of differences in natural constants. The value $S^\circ_{298.16}=52.55\pm0.03$ is adopted.

The value from the heat-capacity data is low by 1.12 units, which is of the order of *R ln* 2. Blue and Giauque (*47*) attribute this to random orientation of the N_2O molecules in the crystal lattice of the solid. In other words, the heat-capacity measurements apply to a system not in thermodynamic equilibrium.

Nitric Oxide.—Eucken and Karwat (*149*) (22°–117°) and Johnston and Giauque (*233*) (15°–121°) measured the heat capacity of NO at low temperatures. The entropy calculations of Johnston and Giauque are repeated here. They find $S_{14.35}=0.27$ (extrapolation), $S_{109.49}-S_{14.35}=8.79$ (crystals), $\Delta S_{109.49}=549.5/109.49=5.02$ (fusion), $S_{121.36}-S_{109.49}=1.73$ (liquid), $\Delta S_{121.36}=3{,}292.6/121.36=27.13$ (vaporization at 1 atm. pressure), $\Delta S_{121.36}=0.09$ (correction to ideal gas state), and $S_{298.16}-S_{121.36}=6.68$ (gas). The sum is $S_{298.16}=49.71\pm0.10$.

Johnston and Giauque (*231*) have computed $S^\circ_{298.16}=50.43$ from spectroscopic data. Johnston and Chapman (*229*) corrected this value to $S^\circ_{298.16}=50.35$, and Witmer (*502*) made an additional small correction to $S^\circ_{298.16}=50.34$. Available molecular-constant data (*212*, *311*), $I=16.40\times10^{-40}$, and $\omega=1{,}892$, the term values of the two effective electronic states, 0 and 120 cm.$^{-1}$, and their quantum weights of 2, yield $S^\circ_{t+r,298.16}=47.664$, $S^\circ_{v,298.16}=0.002$, $S^\circ_{e,298.16}=2.667$, and $S^\circ_{298.16}=50.33$. The value $S^\circ_{298.16}=50.34\pm0.01$ is adopted.

The value from heat-capacity data is 0.63 unit low, which is of the order of 1/2 *R ln* 2. Giauque and Johnston attribute this to random orientation of $(NO)_2$ polymers in the crystal lattice of the solid.

Dioxide.—Claesson, Donohoe, and Schomaker (*71*) have reported $I_1I_2I_3=1.50\times10^{-116}$ for the NO_2 (*g*) molecule, and Sutherland and Penney (*479*) have given 648, 1,321, and 1,621 cm.$^{-1}$ as the vibration frequencies. The quantum weight of the ground state is 2. There are computed $S^\circ_{t+r,298.16}=55.677$, $S^\circ_{v,298.16}=0.403$, $S^\circ_{e,298.16}=1.378$, and $S^\circ_{298.16}=57.46\pm0.03$.

Tetroxide.—Giauque and Kemp (*181*) (16°—295°) have measured the heat capacity of N_2O_4 (that is, the equilibrium mixture of N_2O_4 and NO_2). Their calculations are repeated here. They give $S_{15.00}=0.34$ (extrapolation), $S_{261.90}-S_{15.00}=31.98$ (crystals), $\Delta S_{261.90}=3{,}502/261.90=13.37$ (fusion), $S_{294.25}-S_{261.90}=3.87$ (liquid), $\Delta S_{294.25}=9{,}110/294.25=30.96$ (vaporization), and $\Delta S^\circ_{294.25}=0.10$ (correction to ideal gas state). The sum is $S_{294.25}=80.62\pm0.15$ for the equilibrium mixture of $NO_2(g)$ and $N_2O_4(g)$.

At 294.25°, the boiling point, $S^\circ_{294.25}=57.34$ for $NO_2(g)$ is calculated from the data given previously. Giauque and Kemp find the degree of dissociation to be $\alpha=0.161$, from a careful study of available equilibrium data for the reaction $N_2O_4=2NO_2$. By substituting this value in the relationship,

$$S^\circ_{N_2O_4}=\frac{1}{1-\alpha}\,S\,\text{mix}-\frac{2\alpha}{1-\alpha}\,S^\circ_{NO_2}+R\,ln\,\frac{1-\alpha}{1+\alpha}+\frac{2\alpha R}{1-\alpha}\,ln\,\frac{2\alpha}{1+\alpha},$$

there is obtained $S^\circ_{294.25}=72.5\pm0.2$ for $N_2O_4(g)$. This value corresponds to $S^\circ_{298.16}=72.7\pm0.2$.

Pentoxide.—An approximate value of the entropy of $N_2O_5(c)$ may be obtained from the heat-capacity data of McGraw (*350*) (95°—245°). The extrapolation is large, as $C_p=14.27$ at 95°, and is subject to a large uncertainty. There is calculated $S^\circ_{298.16}=36.6\pm2$, of which 8.68 is extrapolation below 89.1°.

An estimate of the entropy of $N_2O_5(g)$ may be made by adding the above result to the entropy of sublimation, $\Delta S^\circ_{298.16}=45.2$ (*270*). The result is $S^\circ_{298.16}=82$, which can be considered merely an order-of-magnitude calculation.

Nitric Acid.—Forsythe and Giauque (*160*) (13°—303°) measured the heat capacities of HNO_3, $HNO_3{\cdot}H_2O$, and $HNO_3{\cdot}3H_2O$. Their entropy calculations are adopted here.

For HNO_3, there are obtained $S^\circ_{15.00}=0.24$ (extrapolation), $S^\circ_{231.51}-S^\circ_{15.00}=19.45$ (crystals), $\Delta S^\circ_{231.51}=2{,}503/231.51=10.81$ (fusion), and $S^\circ_{298.16}-S^\circ_{231.51}=6.69$ (liquid). The sum is $S^\circ_{298.16}=37.19\pm0.10$ for $HNO_3(l)$. To obtain the entropy of $HNO_3(g)$, there are added $\Delta S^\circ_{298.16}=9{,}355/298.16=31.38$ (vaporization at 0.0828 atm. pressure) and $\Delta S^\circ_{298.16}=-4.95$ (compression form 0.0828 to 1 atm. pressure). The result is $S^\circ_{298.16}=63.62\pm0.2$ for $HNO_3(g)$.

Similarly for $HNO_3{\cdot}H_2O$, there are obtained $S^\circ_{15.00}=0.22$ (extrapolation), $S^\circ_{235.48}-S^\circ_{15.00}=23.64$ (crystals), $\Delta S^\circ_{235.48}=4{,}184/235.48=17.77$ (fusion), and $S^\circ_{298.16}-S^\circ_{235.48}=10.21$ (liquid). The sum is $S^\circ_{298.16}=51.84\pm0.1$ for $HNO_3{\cdot}H_2O$ (l).

Also, for $HNO_3{\cdot}3H_2O$ there are computed $S^\circ_{15.00}=0.37$ (extrapolation), $S^\circ_{254.63}-S^\circ_{15.00}=43.23$ (crystals), $\Delta S^\circ_{254.63}=6{,}954/254.63=27.31$ (fusion), and $S^\circ_{298.16}-S^\circ_{254.63}=12.02$ (liquid). The sum is $S^\circ_{298.16}=82.93\pm0.2$ for $HNO_3{\cdot}3H_2O$ (l).

Hyponitrous Acid.—Latimer and Zimmermann (*322*) estimated $S^\circ_{298.16}=52$ for $H_2N_2O_2(aq.)$.

Ions.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=35.0\pm0.2$ for $NO_3^-(aq.)$ from thermal data for each of the following reactions: $KNO_3(c)=K^+(aq.)+NO_3-(aq.)$ and $Ba(NO_3)_2(c)=Ba^{++}(aq.)+2NO_3^-(aq.)$.

The same authors report $S^\circ_{298.16}=29.9\pm1.0$ for NO_2^- ($aq.$) from thermal data for the reaction $AgNO_2(c)=Ag^+(aq.)+NO_2-(aq.)$.

Latimer and Zimmermann (*322*) estimated $S^\circ_{298.16}=34$ for $H_2NO_2^-$ ($aq.$) and $S^\circ_{298.16}=6.6$ for $N_2O_2^{--}(aq.)$.

Nitrosyl Bromide.—Blair, Brass, and Yost (*46*) determined the heat and free energy of the reaction $2NO(g)+Br_2(g)=2NOBr(g)$. Their figures give $\Delta S^\circ_{298.16}=-28.98\pm0.3$ from which $S^\circ_{298.16}=65.2\pm0.2$ for $NOBr(g)$.

Nitrosyl Chloride.—The heat and free energy of the reaction $2NO(g)+Cl_2(g)=2NOCl(g)$ were determined by Beesom and Yost (*42*) and Dixon (*128*). Their values correspond to $\Delta S^\circ_{298.16}=28.0\pm0.5$ and $\Delta S^\circ_{298.16}=33.6$, respectively. Beesom and Yost's value is adopted in obtaining $S^\circ_{298.16}=63.0\pm0.3$ for $NOCl(g)$.

Jahn (*228*) has calculated $S^\circ_{298.16}=64.0$ from $I_1I_2I_3=2.06\times10^{-115}$, $\omega_1=1{,}832(1)$, $\omega_2=633(1)$, $\omega_3=923(1)$ and the assumption of 4 as the quantum weight of the ground state. Beesom and Yost suggest $\omega_2=346$ instead of 633. The entropy value from Beesom and Yost's data appears to be the more reliable at this point.

Ammonia.—The heat capacity of NH_3 at low temperatures was determined by Clusius, Hiller, and Vaughen (*106*) (10°–135°), Eucken and Karwat (*149*) (24°–222°), and Overstreet and Giauque (*381*) (15°–240°). The results obtained by the last-named workers are adopted. They give $S^\circ_{15.00}=0.06$ (extrapolation), $S^\circ_{195.36}-S^\circ_{15.00}=10.16$ (crystals), $\Delta S^\circ_{195.36}=1.351.6/195.36=6.92$ (fusion), $S^\circ_{239.68}-S^\circ_{195.36}=3.65$ (liquid), $\Delta S_{239.68}=5{,}581/239.68=23.29$ (vaporization at 1 atm. pressure), $\Delta S_{239.68}=0.07$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{239.68}=1.81$ (gas). The sum is $S^\circ_{298.16}=45.96\pm0.10$.

Dennison (*124*) has reported $I_1=I_2=2.814\times10^{-40}$, $I_3=4.452\times10^{-40}$, $\omega_1=3{,}539(1)$, $\omega_2=3{,}622(2)$ $\omega_3=1{,}055(1)$, and $\omega_4=1{,}685.4(2)$ for the NH_3 (g) molecule. The symmetry number is 3. There are computed $S^\circ_{t+r,298.16}=45.893$, $S^\circ_{v,298.16}=0.084$, and $S^\circ_{298.16}=45.98\pm0.03$, with which the third-law value is in almost exact agreement. This result is adopted. Similar calculations from slightly different molecular constant data have been made by Giauque, Blue, and Overstreet (*191*), Overstreet and Giauque (*380*), and Stephenson and McMahon (*461*).

Ammonium Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=26.4\pm0.5$ for $NH_4^+(aq)$. from thermal data for the reaction $NH_4OH(aq.)=NH_4^+(aq.)+OH^-(aq.)$. A virtually identical value, $S^\circ_{298.16}=26.6\pm0.5$, was reported by Stephenson (*454*).

Neutral NH(g).—From molecular-constant data (*212*), $I=1.682\times10^{-40}$, $\omega=3{,}300$, and quantum weight=3 for the ground state, there are computed $S^\circ_{t+r,298.16}=41.073$, $S^\circ_{v,298.16}=0.000$, $S^\circ_{e,298.16}=2.183$, and $S^\circ_{298.16}=43.26\pm0.10$ for NH (g).

Ammonium Halides.—Simon (*437*) (20°–291°) measured the heat capacity of $NH_4Cl(c)$ and Simon, Simson, and Ruhemann (*445*) measured the heat capacities of $NH_4Br(c)$ (201°–227°), $NH_4Cl(c)$ (205°–276°), $NH_4F(c)$ (203°–284°), and $NH_4I(c)$ (199°–276°). In addition, Extermann and Weigle (*154*) have covered a short temperature interval (228°–248°) for $NH_4Cl(c)$, and Zlunitsyn (*516*) (230°–263°) has made some measurements of $NH_3I(c)$. All these substances have temperature ranges in which the heat capacity rises to very large values and then decreases abruptly on the high-temperature side. In no instance has the total energy under the "hump" been measured; consequently, it is virtually impossible to make use of the data satisfactorily in entropy calculations. Moreover, only in the case of NH_4Cl have data been obtained to temperatures low enough to permit reasonably certain extrapolation.

A graphic calculation of the entropy of $NH_4Cl(c)$, including that under the "hump," gives $S^\circ_{298.16}=23.6\pm1.0$, the extrapolation below 20° being 0.11.

Stephenson (*455*) has reviewed data for the reaction $NH_3(g)+HCl(g)=NH_4Cl(c)$. His mean values of the heat and free energy of reaction lead to $S^\circ_{298.16}=23.9\pm2.0$ for $NH_4Cl(c)$, substantiating the third-law result.

Ammonium Bicarbonate.—From decomposition-pressure data, $S^\circ_{298.16}=28.3$ was estimated for NH_4HCO_3 (*c*) by Kelley and Anderson (*290*). The error in this value is estimated as ±2.0.

The Bureau of Standards tables (*370*) list $S^\circ_{298.16}=49.7$ for $NH_4HCO_3(aq.)$.

Ammonium Carbonate.—The entropy of $(NH_4)_2CO_3$ (*aq.*) is given as $S^\circ_{298.16}=41.2$ in the Bureau of Standards tables (*370*).

Hydroxide.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=42.8\pm0.4$ for NH_4OH (*aq.*) from thermal data for the reaction NH_3 $(g)+H_2O$ $(l)=NH_4OH$ (*aq.*).

Ammonium Bisulfide.—The value $S^\circ_{298.16}=27.1$ for NH_4HS (*c*) was suggested by Kelley (*273*) from consideration of thermodynamic properties. The error in this value is estimated as ±2.0.

Ammonium-Dihydrogen Arsenate.—Stephenson and Adams (*457*) (15°–296°) measured the heat capacity of $NH_4H_2AsO_4(c)$. Their data yield $S^\circ_{15.00}=0.28$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{15.00}=40.84$, making $S^\circ_{298.16}=41.12\pm0.10$.

Ammonium-Dihydrogen Phosphate.—The heat capacity of $NH_4H_2PO_4(c)$ was measured by Stephenson and Zettlemoyer (*463*) (18°–300°). The entropy is $S^\circ_{298.16}=36.32\pm0.10$, of which 0.14 is extrapolation below 15.00°.

Ammonium Sulfate.—The heat capacity of $(NH_4)_2SO_4$ (*c*) at low temperatures has been investigated by Crenshaw and Ritter (*116*) (183°–283°), Kelley, Shomate, Young, Naylor, Salo, and Huffman (*297*) (52°–311°), Nitta and Suenaga (*379*) (93°–293°), and Shomate (*428*) (52°–311°). Only the data reported by Kelley and coworkers and by Shomate are accurate enough for use in entropy calculations. There are obtained $S^\circ_{50.12}=4.55$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=48.10$ (measured), and $S^\circ_{298.16}=52.6\pm0.3$.

Ammonium Vanadate.—Todd (*486*) (53°–297°) measured the heat capacity of $NH_4VO_3(c)$. The data yield $S^\circ_{51.00}=3.61$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{53.00}=30.00$ (measured), making $S^\circ_{298.16}=33.6\pm0.3$.

Ammonium Alums.—Kelley, Shomate, Young, Naylor, Salo, and Huffman (*297*) (54°–297°) and Shomate (*428*) (54°–297°) have reported low-temperature heat-capacity data for $NH_4Al\ (SO_4)_2(c)$ and $NH_4Al(SO_4)_2\cdot12H_2O(c)$.

For the anhydrous compound, $S^\circ_{53.09}=3.37$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=48.33$ (measured), and $S^\circ_{298.16}=51.7\pm0.3$.

Similarly, for the hydrated compound, $S^\circ_{53.09}=18.44$ (extrapolation), $S^\circ_{71.0}-S^\circ_{53.09}=10.73$ (crystals II), $\Delta S^\circ_{71.0}=193.5/71.0=2.73$ (transition), and $S^\circ_{298.16}-S^\circ_{71.0}=134.72$ (crystals I). The sum is $S^\circ_{298.16}=166.6\pm1.0$ for $NH_4Al(SO_4)_2\cdot12H_2O$.

Ammonium Analog of Alunite.—Kelley, Shomate, Young, Naylor, Salo, and Huffman (*297*) (53°–297°) reported heat-capacity measurements of $(NH_4)_2O\cdot3Al_2O_3\cdot4SO_2\cdot6H_2O(c)$. There are computed $S^\circ_{53.09}=$

10.68 (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=153.48$ (measured), and $S^\circ_{298.16}=164.2\pm1.0$.

Other Ammonium Compounds.—Crenshaw and Ritter (*116*) have obtained heat-capacity data for $NH_4CN(c)$ (203°–283°) and $NH_4NO_3(c)$ (183°–273°), and Nitta and Suenaga (*379*) have reported values for $(ND_4)_2SO_4(c)$ (93°–298°). These data are insufficient for entropy calculations because of the large extrapolations involved, the difficulties being enhanced by transitions of the NH_4Cl-type that occur in all three cases.

OSMIUM

Element.—The value computed by Lewis and Gibson (*331*) $S^\circ_{298.16}=7.8\pm0.5$, from Dewar's (*126*) heat-capacity determination of $Os(c)$ is adopted.

The entropy of $Os(g)$ is calculated from the Sackur equation with $R\ ln\ 9$ added for the quantum weight of the ground state. The result is $S^\circ_{298.16}=46.01\pm0.01$.

Oxide.—Anderson and Yost (*25*) report 971 (1), 568 (2), 1,187 (3), and 688 (3) as the vibration frequencies of the $OsO_4(g)$ molecule. Their value of the interatomic distance (Os–O) is $1.66\pm0.05\times10^{-8}$ cm., corresponding to $I_1=I_2=I_3=195\times10^{-40}$. Calculation yields $S^\circ_{t+r,298.16}=63.38$, $S^\circ_{v,298.16}=2.21$, and $S^\circ_{298.16}=65.6\pm0.3$ for $OsO_4(g)$.

Anderson and Yost (*25*) also report $\Delta F^\circ_{298.16}=-70{,}900$ and $\Delta H_{298.16}=-93{,}600$ for the reaction $Os(c)+2O_2(g)=OsO_4(c)$, corresponding to $\Delta S^\circ_{298.16}=-76.1$. This figure leads to $S^\circ_{298.16}=29.7$ for $OsO_4(c)$. Another value may be obtained by subtracting the entropy of sublimation given by Kelley (*270*), $\Delta S^\circ_{298.16}=35.8$, from the entropy of the gas. The result is $S^\circ_{298.16}=29.8$ for $OsO_4(c)$ (*yellow* variety). The value $S^\circ_{298.16}=29.7\pm1.0$ is adopted.

Kelley (*270*) found $\Delta S^\circ_{298.16}=30.9$ as the entropy of sublimation of the white variety, which corresponds to $S^\circ_{298.16}=34.7\pm2.0$ for $OsO_4(c)$ (*white*).

OXYGEN

Element.—Low-temperature heat-capacity measurements of O_2 were made by Clusius (*75*) (10°–73°), Eucken (*146*) (17°–73°), and Giauque and Johnston (*179*) (12°–91°). The heat of vaporization was determined by Frank and Clusius (*162*). The calculations of Giauque and Johnston, which have been checked, are repeated here. They find $S^\circ_{11.75}=0.32$ (extrapolation), $S^\circ_{23.66}-S^\circ_{11.75}=1.70$ (crystals III), $\Delta S^\circ_{23.66}=22.42/23.66=0.95$ (transition), $S^\circ_{43.76}-S^\circ_{23.66}=4.66$ (crystals II), $\Delta S^\circ_{43.76}=177.6/43.76=4.06$ (transition), $S^\circ_{54.39}-S^\circ_{43.76}=2.40$ (crystals I), $\Delta S^\circ_{54.39}=106.3/54.39=1.95$ (fusion), $S^\circ_{90.13}-S^\circ_{54.39}=6.46$ (liquid), $\Delta S_{90.13}=1{,}628.8/90.13=18.07$ (vaporization at 1 atm. pressure), $\Delta S_{90.13}=0.17$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{90.13}=8.35$ (gas). The sum is $S^\circ_{298.16}=49.10\pm0.10$.

Giauque and Johnston also have calculated the entropy from spectroscopic data, obtaining $S^\circ_{298.16}=49.03$. Gordon and Barnes (*199*) obtained $S^\circ_{293.16}=49.00$ and, just recently, Woolley (*504*) computed $S^\circ_{298.16}=49.01$.

Molecular-constant data (*212*), $I=19.38\times10^{-40}$, $\omega=1{,}568$, and quantum weight$=3$ for the ground state, yield $S^\circ_{t+r,298.16}=46.808$, $S^\circ_{v,298.16}=0.008$, $S^\circ_{e,298.16}=2.183$, and $S^\circ_{298.16}=49.00$.

The value $S^\circ_{298.16}=49.01\pm0.01$ is adopted for $O_2(g)$.

The entropy of monatomic $O(g)$ is obtainable from the Sackur equation and spectroscopic data (*364*). At 298.16°, the only states to be considered are $^3P_2$, $^3P_1$, and $^3P_0$, which have term values 0, 158.17, and 226.78 cm.$^{-1}$, and quantum weights 5, 3, and 1, respectively. These states contribute 4.214 and the translational entropy is 34.262, making $S^\circ_{298.16}=38.48\pm0.01$ for $O(g)$.

Ozone.—Shand and Spurr (*420*) have reported dimensions of the $O_3(g)$ molecule that yield the moments of inertia $I_1=67.6\times10^{-40}$, $I_2=5.60\times10^{-40}$, and $I_2=73.2\times10^{-40}$. The vibration frequencies are $\omega_1=1{,}110(1)$, $\omega_2=705(1)$, and $\omega_3=1{,}043(1)$. These values result in $S^\circ_{t+r,298.16}=56.413$, $S^\circ_{v,298.16}=0.437$, and $S^\circ_{298.16}=56.85\pm0.10$.

Neutral Hydroxyl.—Johnston and Dawson (*230*) computed $S^\circ_{298.16}=43.90\pm0.02$ for neutral $OH(g)$ from spectroscopic data. From molecular constants (*212*), $I=1.484\times10^{-40}$ and $\omega=3{,}650$, and the term values 0 and 140 cm.$^{-1}$ for the two energy states (both of quantum weight 2) involved at 298.16°, there are computed $S^\circ_{t+r,298.16}=41.196$, $S^\circ_{v,298.16}=0.000$, $S^\circ_{e,298.16}=2.653$, and $S^\circ_{298.16}=43.85$. Johnston and Dawson's result is selected.

Hydroxyl Ion.—Latimer, Pitzer, and Smith (*325*) report $S^\circ_{298.16}=-2.49\pm0.06$ for $OH^-(aq.)$ from thermal data for the reaction $H_2O(l)=H^+(aq.)+OH^-(aq.)$.

PALLADIUM

Element.—The heat capacity of Pd (*c*) was measured by Clusius and Schachinger (*104*) (13°–269°) and Pickard (*386*) (2.5°–22°). The entropy is computed to be $S^\circ_{298.16}=9.03\pm0.05$, of which only 0.003 is extrapolation below 2.5°.

The entropy of Pd(*g*), obtained from the Sackur equation, is $S^\circ_{298.16}=39.92\pm0.01$.

PHOSPHORUS

Element.—The entropy of $P_2(g)$ is obtainable from molecular-constant data, $I=92.5\times10^{-40}$ (*213*) and $\omega=777.6$ (*212*). There are computed $S^\circ_{t+r,298.16}=51.885$, $S^\circ_{v,298.16}=0.226$, and $S^\circ_{298.16}=52.11\pm0.10$. Yost and Anderson (*506*) calculated a virtually identical value, $S^\circ_{198.16}=52.0$, and Stevenson and Yost (*470*) reported $S^\circ_{298.16}=52.15$.

Anderson and Yost (*26*) have given 2.21×10^{-8} cm as the interatomic distance in the tetrahedral $P_4(g)$ molecule and 372 (2), 463 (3), and 607 (1) as the vibration frequencies. The dimensional value corresponds to $I_1=I_2=I_3=251\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=61.987$, $S^\circ_{v,298.16}=4.863$, and $S^\circ_{298.16}=66.85\pm0.5$.

The entropy of P(*g*) is calculated from the Sackur equation with $R\ ln\ 4$ added to account for the quantum weight of the ground state The result is $S^\circ_{298.16}=38.99\pm0.01$.

The entropy of sublimation of P(*c*) (*white*) to $P_4(g)$ was given as $\Delta S^\circ_{298.16}=24.59$ by Kelley (*270*). Combination of this result and the value for $P_4(g)$ leads to $S^\circ_{298.16}=10.6\pm0.5$ for P(*c*) (*white*), in agreement with the value, 10.55, calculated by Anderson and Yost (*26*).

Latimer (*315*) has estimated $S^\circ_{298.16}=7.0$ for P(*c*) (*violet*). This value is checked by combining the entropy of sublimation of P(*c*) (*violet*), $\Delta S^\circ_{298.16}=37.11$ (*270*) and the entropy of $P_4(g)$. The result is $S^\circ_{298.16}=7.4\pm0.5$.

The entropy of sublimation of P(c) (*black*), $\Delta S^\circ_{298.16}=45.58$ (*270*) and the entropy of $P_4(g)$ lead to $S^\circ_{298.16}=5.3\pm0.5$ for P(c) (*black*)

Oxide.—The entropy of PO(g) is obtainable from molecular-constant data (*212*), $I=36.7\times10^{-40}$ and $\omega=1{,}224$, and the term values of the two lowest electronic states (each of quantum weight 2), 0 and 221 cm.$^{-1}$ There are computed $S^\circ_{t+r,298.16}=50.601$, $S^\circ_{v,298.16}=0.037$, and $S^\circ_{e,298.16}=2.510$. The sum is $S^\circ_{298.16}=53.15\pm0.10$ for PO(g).

Tribromide.—Howard and Wilson (*217*) have given dimensions of the $PBr_3(g)$ molecule that correspond to $I_1=1{,}650\times10^{-40}$ and $I_2=I_3=865\times10^{-40}$, and have reported the vibration frequencies as 116 (2), 162 (1), 380 (2), and 400 (1) cm.$^{-1}$ There are calculated $S^\circ_{t+r,298.16}=71.40$, $S^\circ_{v,298.16}=11.87$, and $S^\circ_{298.13}=83.3\pm1.0$. A similar result, 83.1, was calculated by Stevenson and Yost (*470*).

Chlorides.—From dimensional data given by Howard and Wilson (*217*), the moments of inertia of the $PCl_3(g)$ molecule are $I_1=585\times10^{-40}$ and $I_2=I_3=325\times10^{-40}$. The vibrational frequencies are 190 (2), 257 (1), 480 (2), and 510 (1). These values lead to $S^\circ_{t+r,298.16}=66.40$, $S^\circ_{v,298.16}=8.18$, and $S^\circ_{298.16}=74.6\pm1.0$. The last value is in substantial agreement with the calculations of Anderson and Yost (*26*) and Stevenson and Yost (*470*).

From heat and free-energy-of-vaporization values given by Kelley (*270*), the entropy of vaporization of $PCl_3(l)$ is $\Delta S^\circ_{298.16}=22.50$. This leads to $S^\circ_{298.16}=52.1\pm2.0$ for $PCl_3(l)$, which also is in substantial agreement with the result calculated by Anderson and Yost (*26*).

Stevenson and Yost (*470*) have estimated $S^\circ{}_{298.16}=84.3$ for $PC_5(g)$. The uncertainty is estimated here as ±2.0. This value supersedes the earlier result reported by Anderson and Yost (*26*).

Trifluoride.—Howard and Wilson (*217*) have reported dimensional data for the $PF_3(g)$ molecule which correspond to $I_1=178\times10^{-40}$ and $I_2=I_3=106\times10^{-40}$. The vibration frequencies are 486 (2), 531 (1), 840 (2), and 890 (1) cm.$^{-1}$ There are computed $S^\circ_{t+r,298.16}=61.67$ and $S^\circ_{v,298.16}=2.48$. The sum is $S^\circ_{298.16}=64.1\pm0.3$, in virtually exact agreement with the value calculated by Stevenson and Yost (*470*).

Hydrides.—Clusius and Frank (*96*) (11°–186°) and Stephenson and Giauque (*459*) (15°–186°) have measured the heat capacity of phosphine, PH_3, at low temperatures. This substance undergoes transitions in the solid state at 49.43° and 88.10°, and it is possible to supercool the form stable between these temperatures. When this is done, however, the supercooled form itself undergoes a transition at 30.29°. Stephenson and Giauque have straightened out very satisfactorily the energy relationships among these crystalline species. The data of Clusius and Frank are somewhat lacking in this respect.

The calculations of Stephenson and Giauque have been checked and are repeated here. For $PH_3(c)$, supercooled below 49.43°, they find $S_{15.00}=0.495$ (extrapolation), $S^\circ_{30.29}-S^\circ_{15.00}=2.185$ (crystals III′), $\Delta S^\circ_{30.29}=19.6/30.29=0.647$ (transition), and $S^\circ_{49.43}-S^\circ_{30.29}=4.800$ (crystals II). The sum is $S^\circ_{49.43}=8.13$. For the variety stable below 49.43°, $S^\circ_{15.00}=0.338$ (extrapolation), $S^\circ_{49.43}-S^\circ_{15.00}=4.041$ (crystals III), and $\Delta S^\circ_{49.43}=185.7/49.43=3.757$ (transition). The sum for this path is $S^\circ_{49.43}=8.14$. The agreement between these two values of $S^\circ_{49.43}$ constitutes a good test of the third law of thermodynamics. The remaining calculations are $S^\circ_{88.10}-S^\circ_{49.43}=6.71$ (crystals II), $\Delta S^\circ_{88.10}=115.8/88.10=1.31$ (transition), $S^\circ_{139.35}-S^\circ_{88.10}=5.19$ (crystals I), $\Delta S^\circ_{139.35}=270.4/139.35=1.94$ (fusion), $S^\circ_{185.38}-S^\circ_{139.35}=4.14$ (liquid), $\Delta S_{185.38}=3{,}489/185.38=18.82$ (vaporization at 1 atm. pressure), $\Delta S_{185.38}=0.14$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{185.38}=3.96$ (gas). The total is $S^\circ_{298.16}=50.35\pm0.10$.

Yost and Anderson (*506*) and Stephenson and Giauque (*459*) have employed $I_1=8.26\times10^{-40}$ and $I_2=I_3=6.22\times10^{-40}$ in computing the entropy of $PH_3(g)$. The vibration frequencies are 1,118 (2), 970 (1), 2,430 (2), and 2,300 (1) $cm.^{-1}$, according to Stevenson and Yost (*470*). There are computed $S^\circ_{t+r,298.16}=50.145$, $S^\circ_{v,298.16}=0.221$, and $S^\circ_{298.16}=50.37\pm0.2$. The agreement with the third-law value is virtually exact. Stevenson and Yost (*470*) computed a slightly lower value, $S^\circ_{298.16}=50.20$.

Herzberg (*212*) gives $\omega=2{,}380$ for the $PH(g)$ molecule and 1.433×10^{-8} cm. for the interatomic distance. The latter corresponds to $I=3.33\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=44.69$, $S^\circ_{v.298.16}=0.00$, $S^\circ_{e,298.16}=R\ ln\ 3=2.18$, and $S^\circ_{298.16}=46.9\pm0.2$.

Nitride.—From molecular-constant data listed by Herzberg (*212*), $I=35.6\times10^{-40}$ and $\omega=1{,}330$. There are obtained $S^\circ_{t+r,298.16}=50.411$, $S^\circ_{v,298.16}=0.023$, and $S^\circ_{298.16}=50.43\pm0.10$.

Oxychloride.—Stevenson and Yost (*470*) have computed $S^\circ_{298.16}=77.6$ for $POCl_3(g)$ from molecular-constant data. The uncertainty is estimated here as ±1.0.

Thiochloride.—Stevenson and Yost (*470*) reported $S^\circ_{298.16}=79.3$ for $PSCl_3(g)$, from molecular-constant data. Again, the uncertainty is estimated as ±1.0.

Phosphonium Iodide.—Crenshaw and Ritter (*116*) (93°—283°) measured the heat capacity of $PH_4I(c)$. At 93° the heat capacity is 11.97 cal. per deg. per mole, making extrapolation both difficult and uncertain. There is estimated $S^\circ_{89.1}=10.92$ as the extrapolation, and $S^\circ_{298.16}-S^\circ_{89.1}=21.14$ is the measured entropy. The sum is $S^\circ_{298.16}=32.1\pm2$.

Phosphoric Acid and Its Ions.—Stephenson (*454*) has obtained the following entropy values: $S^\circ_{298.16}=37.6\pm1.0$ for $H_3PO_4(aq.)$, from thermal data for the reaction $H_3PO_4(aq.)=H^+(aq.)+H_2PO_4^-(aq.)$; $S^\circ_{298.16}=21.6\pm0.3$ for $H_2PO_4^-(aq.)$, from thermal data for the reaction $KH_2PO_4\ (c)=K^+(aq.)+H_2PO_4^-(aq.)$; $S^\circ_{298.16}=-8.7\pm1.0$ for $HPO_4^{--}(aq.)$, from thermal data for the reaction $H_2PO_4^-(aq.)=H^+(aq.)+HPO_4^{--}(aq.)$; and $S^\circ_{298.16}=-52\pm2$ for $PO_4^{---}(aq.)$, from thermal data for the reaction $HPO_4^{--}(aq.)=H^+(aq.)+PO_4^{---}(aq.)$.

PLATINUM

Element.—Kok and Keesom (*303*) (1°–21°) and Simon and Zeidler (*444*) (17°–209°) have measured the heat capacity of $Pt(c)$. Calculation gives $S^\circ_{298.16}=10.00\pm0.05$. The extrapolation is about 6×10^{-4} below 1.1°.

Spectroscopic data for $Pt(g)$ are listed by Moore (*364*). At 298.16°, three energy states having term values of 0, 775.9, and 823.7 $cm.^{-1}$ must be considered. The quantum weights are 7, 5, and 9, respectively. It is computed that 4.252 is to be added to the Sackur value, 41.720, making $S^\circ_{298.16}=45.97\pm0.01$.

Sulfides.—From equilibrium data, Kelley (*273*) computed $\Delta S_{298.16}=50.1$ for the reaction $2PtS(c)=2Pt(c)+S_2(g)$ and $\Delta S_{298.16}=44.0$ for the reaction $2PtS_2(c)=2PtS(c)+S_2(g)$. These values yield $S^\circ_{298.16}=12.2$ for $PtS(c)$ and $S^\circ_{298.16}=17.4$ for $PtS_2(c)$. The uncertainties in these results are not readily determinable.

Chloroplatinate Ion.—Coulter, Pitzer, and Latimer (*112*) report $S^\circ_{298.16}=53.2\pm2$ for $PtCl_6^{--}(aq.)$.

POTASSIUM

Element.—Eastman and Rodebush (*139*) (68°–287°) and Simon and Zeidler (*444*) (14°–277°) have measured the heat capacity of $K(c)$ at low temperatures. Relying entirely on the data of the latter investigators, there are obtained $S^\circ_{14.1}=0.45$ (exrapolation), $S^\circ_{298.16}-S^\circ_{14.1}=14.77$ (measured), and $S^\circ_{298.16}=15.2\pm0.2$.

For $K(g)$, the Sackur equation, with $R\ ln\ 2$ added, gives $S^\circ_{298.16}=38.30\pm0.01$.

The moment of inertia amd vibration frequency of $K_2(g)$ are $I=499 \text{ x } 10^{-40}$ and $\omega=92.3$, from data compiled by Herzberg (*212*). There are computed $S^\circ_{t+r,298.16}=55.929$, $S^\circ_{v.298.16}=3.617$, and $S^\circ_{298.16}=59.55\pm0.10$.

Potassium Ion.—Latimer, Pitzer, and Smith (*325*) report $S^\circ_{298.16}=24.2\pm0.2$ for $K^+(aq.)$. Data for two reactions, $KCl(c)=K^+(aq.)+Cl^-(aq.)$ and $KBr(c)=K^+(aq.)+Br^-(aq.)$, were employed, and the individual results obtained are 24.2 ± 0.2 and 24.3 ± 0.8, respectively.

Bromide.—Nernst (*373*, *376*) (78°–90°) made a few heat-capacity measurements of $KBr(c)$. The heat capacity at 78.7° is 9.48 cal. per deg. per mole, so that only a rough entropy calculation is possible. The result is $S^\circ_{298.16}=22.4\pm1.0$. Residual-ray data of Rubens (*403*) and Rubens and von Wartenberg (*405*) give $S^\circ_{298.16}=22.6\pm0.5$. The latter value is adopted.

From data listed by Herzberg (*212*), the moment of inertia of $KBr(g)$ is 377×10^{-40}, and the vibration frequency is 230. These figures yield $S^\circ_{t+r,298.16}=54.00$, $S^\circ_{298.16}=1.88$ and $S^\circ_{298.16}=59.9\pm0.5$. Correction of Stevenson's (*467*) calculation gives an identical result, while Niwa's (*380*) estimate is low, 58.2 ± 1.5.

Chloride.—Feodosiev (*158*) (86°–298°), Keesom and Clark (*246*) (3°–18°), Lindemann and Schwers (*336*) (22°–90°), Nernst (*373*, *376*) (22°–235°), and Southard and Nelson (*451*) (16°–288°) have measured the heat capacity of $KCl(c)$. There is obtained $S^\circ_{298,16}=19.76\pm0.07$, of which 7×10^{-4} is extrapolation below 3°.

The residual-ray data of Rubens (*403*) and Rubens and Hollnagel (*404*) give $S^\circ_{298.16}=19.5\pm0.5$, in good agreement with the more reliable value given above.

For $KCl(g)$, $I=240\times10^{-40}$ and $\omega=279$, from data listed by Herzberg (*212*). There are computed $S^\circ_{t+r,298.16}=55.71$, $S^\circ_{v,298.16}=1.54$, and $S^\circ_{298.16}=57.2\pm0.5$. The last value is adopted for $KCl(g)$. A virtually identical result is obtained by correction of Stevenson's (*467*) calculation. In addition, an independent check on the entropy of $KCl(g)$ is afforded by combining vapor-pressure data and the entropy of $KCl(c)$. In this manner, the author (*270*) obtained $S^\circ_{298.16}=57.6$. Niwa (*380*) has reported a too low value, 56.0 ± 1.4.

Fluoride.—The entropy of KF(g) is estimated from the relationship, $S^\circ_{KF}=\frac{1}{2}\ (S^\circ_{K_2}+S^\circ_{F_2})+R\ ln\ 2$, to be $S^\circ_{298.16}=55.4\pm1.0$. A probably less reliable value, 56.7 ± 1.8 was estimated by Niwa (*380*).

Hydride.—Herzberg (*212*) listed molecular-constant data for KH(g) corresponding to $I=8.22\times10^{-40}$ and $\omega=969$. These figures yield $S^\circ_{t+r,298.16}=47.155$, $S^\circ_{v,298.16}=0.106$, and $S^\circ_{298.16}=47.26\pm0.10$.

Iodide.—From Rubens and von Wartenberg's (*405*) residual-ray data, $S^\circ_{298.16}=24.1\pm0.5$ is computed for KI(c).

Molecular-constant data listed by Herzberg (*212*) correspond to $I=518\times10^{-40}$ and $\omega=211$ for KI(g). There are computed $S^\circ_{t+r,298.16}=59.63$, $S^\circ_{v,298.16}=2.03$ and $S^\circ_{298.16}=61.7\pm0.5$. Correction of Stevenson's (*467*) calculation leads to an agreeing value, 61.5, while Niwa (*380*) has estimated a too low value, 60.7 ± 2.1.

Bromate.—The heat capacity of $KBrO_3(c)$ was measured by Ahlberg and Latimer (*4*) (15°–297°). Their data yield $S^\circ_{298.16}=35.7\pm0.2$, of which 0.23 is extrapolation below 14.13° and 35.44 is measured between 14.13° and 298.16°.

Chlorate.—Latimer, Schutz, and Hicks (*327*) (13°–294°) measured the heat capacity of $KClO_3(c)$. There is computed $S^\circ_{298.16}=34.2\pm0.2$, with an extrapolation below 12.59° of 0.14.

Perchlorate.—Latimer and Ahlberg (*317*) (12°–299°) measured the heat capacity of $KClO_4(c)$. Calculation gives $S^\circ_{298.16}=36.1\pm0.2$. The extrapolation is 0.29 below 12.6°.

Iodate.—The heat capacity of $KIO_3(c)$ was measured by Ahlberg and Latimer (*4*) (17°–295°). The results of the entropy calculation are $S^\circ_{15.85}=0.36$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.85}=35.87$ (measured), and $S^\circ_{298.16}=36.2\pm0.2$.

Nitrate.—Southard and Nelson (*451*) (15°–296°) measured the heat capacity of $KNO_3(c)$. There are obtained $S^\circ_{14.13}=0.22$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.13}=31.59$ (measured), and $S^\circ_{298.16}=31.81\pm0.15$.

Permanganate.—The heat capacity of $KMnO_4(c)$ was measured by Brown, Smith, and Latimer (*62*) (14°–296°). Their results yield $S^\circ_{14.79}=0.53$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{14.79}=40.51$ (measured), making $S^\circ_{298.16}=41.0\pm0.2$.

Sulfate.—Moore and Kelley (*365*) (52°–296°) measured the heat capacity of $K_2SO_4(c)$. There are computed $S^\circ_{50.12}=4.82$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=37.21$ (measured), and $S^\circ_{298.16}=42.0\pm0.4$.

Potassium-Aluminum Sulfates.—Shomate (*427*) and Kelley, Shomate, Young, Naylor, Salo, and Huffman (*297*) have reported low-temperature heat-capacity data for $KAl(SO_4)_2(c)$ (54°–297°) and $KAl(SO_4)_2\cdot12H_2O(c)$ (52°–297°). The latter substance also was studied by Eucken and Schwers (*151*) (25°–91°).

For $KAl(SO_4)_2(c)$, the data yield $S^\circ_{53.09}=4.97$ (extrapolation), $S^\circ_{298.16}-S_{53.09}=43.91$ (measured), and $S^\circ_{298.16}=48.9\pm0.4$.

Similarly, for $KAl(SO_4)_2\cdot H_2O(c)$, $S^\circ_{53.09}=20.94$ (extrapolation,) $S^\circ_{59.7}-S^\circ_{53.09}=4.22$ (crystals II), $\Delta S^\circ_{59.7}=46.9/59.7=0.79$ (transition), and $S^\circ_{298.16}-S^\circ_{59.7}=138.33$ (crystals I). The sum is $S^\circ_{298.16}=164.3\pm2.0$.

Potassium Basic Alum.—Kelley, Shomate, Young, Naylor, Salo, and Huffman (*297*) (54°–297°) reported heat-capacity measurements of $K_2O\cdot3Al_2O_3\cdot5SO_3\cdot9H_2O(c)$. There are obtained $S^\circ_{53.09}=17.95$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=204.82$ (measured), and $S^\circ_{298.16}=222.8\pm1.6$.

Alunite.—Kelley, Shomate, Young, Naylor, Salo, and Huffman (*297*) (54°–297°) also measured the heat capacity of natural and synthetic alunite, $K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O(c)$.

For natural alunite, there are obtained $S^\circ_{53.09}=7.79$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=144.40$ (measured), and $S^\circ_{298.16}=152.2\pm0.9$.

For synthetic alunite, there are computed $S^\circ_{53.09}=8.64$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.09}=148.12$ (measured), and $S^\circ_{298.16}=156.8\pm0.9$.

Potassium-Dihydrogen Arsenate.—The heat capacity of KH_2AsO_4 (*c*) was measured by Stephenson and Zettlemoyer (*462*) (16°–297°). There are obtained $S^\circ_{15.00}=0.21$ (extrapolation) and $S^\circ_{298.16}-S^\circ_{15.00}=36.87$ (measured), making $S^\circ_{298.16}=37.08\pm0.10$.

Potassium-Dihydrogen Phosphate.—Stephenson and Hooley (*460*) (16°–300°) determined the heat capacity of $KH_2PO_4(c)$. There are computed $S^\circ_{15.00}=0.11$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.00}=32.12$ (measured), and $S^\circ_{298.16}=32.23\pm0.10$.

Potassium Chloroplatinate.—The heat capacity of $K_2PtCl_6(c)$ was measured by Coulter, Pitzer, and Latimer (*112*) (13°–300°). The entropy calculation gives $S^\circ_{14.00}=1.05$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.00}=78.73$ (measured), and $S^\circ_{298.16}=79.8\pm0.4$.

Intermetallic Compounds.—There are estimated here $S^\circ_{298.16}=62.7\pm1.0$ for KRb(*g*) and $S^\circ_{298.16}=64.5\pm1.0$ for KCs(*g*).

RADIUM

Element.—The Sackur equation gives $S^\circ_{298.16}=42.16\pm0.01$ for Ra(*g*).

RADON

Element.—The Sackur equation gives $S^\circ_{298.16}=42.10\pm0.01$ for Rn(*g*).

RHENIUM

Element.—The entropy of Re(*g*) is calculated from the Sackur equation, with *R ln* 6 added to account for the quantum weight of the ground state. The result is $S^\circ_{298.16}=45.14\pm0.01$.

RHODIUM

Element.—Revision of the entropy of Rh(*c*) is not possible, as no new pertinent data have appeared. The result of Lewis and Gibson (*331*), $S^\circ_{298.16}=7.6\pm0.5$, is therefore retained.

Spectroscopic data assembled by Moore (*364*) show that three energy levels need be considered in deriving the entropy of Rh(*g*) at 298.16°. These states have term values of 0, 1,530.0, and 2,598.1 cm.$^{-1}$ and quantum weights of 10, 8, and 6, respectively. It is calculated that 4.585 is to be added to the entropy computed from the Sackur equation, to give $S^\circ_{298.16}=44.40\pm0.01$ for Rh(*g*.)

RUBIDIUM

Element.—The Sackur equation, with *R ln* 2 added, gives $S^\circ_{298.16}=40.64\pm0.01$ for Rb(*g*).

From vapor-pressure data and the above entropy value of the gas, $S^\circ_{298.16}=16.6\pm1.0$ was computed for Rb(*c*) by Kelley (*270*).

For $Rb_2(g)$, there is estimated here $S^\circ_{298.16}=63.1\pm1.5$.

Rubidium Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=28.7\pm0.7$ for $Rb^+(aq.)$ from thermal data for the reactions $RbClO_3(c)=Rb^+(aq.)+ClO_3^-(aq.)$ and $RbClO_4(c)=Rb^+(aq.)+ClO_4-(aq.)$. The individual values obtained are, respectively, 28.9 ± 0.8 and 28.5 ± 1.0.

Bromide.—Stevenson (*467*) has suggested molecular constants for $RbBr(g)$ corresponding to $I=634\times10^{-40}$ and $\omega=210$. These lead to $S^\circ_{t+r,298.16}=60.02$, $S^\circ_{v,298.16}=2.04$, and $S^\circ_{298.16}=62.1\pm0.5$.

Chloride.—Using data suggested by Stevenson (*467*), which correspond to $I=350\times10^{-40}$ and $\omega=253$, there are computed $S^\circ_{t+r,298.16}=57.90$, $S^\circ_{v,298.16}=1.71$, and $S^\circ_{298.16}=59.6\pm0.5$. Niwa (*380*) has estimated a too low value, $S^\circ_{298.16}=57.9\pm2.0$.

Chlorate.—Aulberg (*1*) (16°–291°) measured the heat capacity of $RbClO_3(c)$. Calculation from his data yields $S^\circ_{16.8}=0.48$ (extrapolation), $S^\circ_{298.16}-S^\circ_{16.8}=35.83$ (measured), and $S^\circ_{298.16}=36.3\pm0.4$.

Fluoride.—There is estimated here $S^\circ_{298.16}=57.2\pm1.0$ for $RbF(g)$.

Hydride.—Herzberg (*212*) has listed data for the $RbH(g)$ molecule corresponding to $I=9.28\times10^{-40}$ and $\omega=922$. There are calculated $S^\circ_{t+r,298.16}=49.687$, $S^\circ_{v,298.16}=0.127$, and $S^\circ_{298.16}=49.81\pm0.10$.

Iodide.—Data listed by Stevenson (*467*), $I=885\times10^{-40}$ and $\omega=179$, yield $S^\circ_{t+r,298.16}=61.42$, $S^\circ_{v,298.16}=2.34$, and $S^\circ_{298.16}=63.8\pm0.5$. Niwa's estimated value, 62.2 ± 2.0, is low.

RUTHENIUM

Element.—The only available entropy value for $Ru(c)$ is that given by Lewis and Gibson (*331*), $S^\circ_{298.16}=6.9\pm0.5$.

Spectroscopic data compiled by Moore (*364*) show that at 298.16° five energy levels need be considered in deriving the entropy of $Ru(g)$. The term values are 0, 1,190.8, 2,091.7, 2,713.4, and 3,105.6, and the quantum weights are 11, 9, 7, 5, and 3, respectively. These states add 4.802 to the translational entropy given by the Sackur equation, making $S^\circ_{298.16}=44.58\pm0.01$ for $Ru(g)$.

Sulfide.—Kelley (*273*) has given values for the heat and free energy of decomposition of $RuS_2(c)$ which correspond to $S^\circ_{298.16}=12.5$ for this substance. The uncertainty is at least ± 1.0.

SAMARIUM

Sulfate.—The heat capacity of $Sm_2(SO_4)_3\cdot8H_2O(c)$ was measured by Ahlberg and Freed (*3*) (17°–279°) and Ahlberg, Blanchard, and Lundberg (*5*) (2°–41°). The lowest energy level of Sm^{+++} is $^6H_{5/2}$, with quantum weight 6. In computing the entropy, $2R\ ln\ 6$ per gram-formula mass is added to the value calculated in the usual manner from the heat-capacity data. There are obtained $S^\circ_{2.51}=0.09$ (ordinary extrapolation), $S^\circ_{298.16}-S^\circ_{2.51}=153.67$ (measured), and $2R\ ln\ 6=7.12$. The sum is $S^\circ_{298.16}=160.9\pm0.5$.

SCANDIUM

Element.—Avaliable spectroscopic data (*364*) show that in calculating the entropy of $Sc(g)$ at 298.16° two energy levels must be considered. The term values are 0 and 168.34 cm.$^{-1}$ and the quantum weights are 4 and 6, respectively. These levels add 4.415 to the Sackur equation, making $S^\circ_{298.16}=41.77\pm0.01$ for $Sc(g)$.

SELENIUM

Element.—Anderson (*23*) (54°–297°) and DeVries and Dobry (*125*) (98°–279°) measured the heat capacity of Se(*c*). Relying entirely on Anderson's data there is computed $S^\circ_{298,16}=10.0\pm0.3$, of which 1.95 is extrapolation below 53.1°. This is 0.5 unit lower than the value reported by Anderson but it agrees with the findings of Slansky and Coulter (*446*), who have intercompared the available data for S(*c*), Se(*c*), and Te(*c*).

The compilation of spectroscopic data by Moore (*364*) shows that three energy levels must be considered in obtaining the entropy of Se(*g*) at 298.16°. The term values are 0, 1,989, and 2,534 cm.$^{-1}$ and the quantum weights are 5, 3, and 1, respectively. The translational entropy from the Sackur equation is 39.021 and the electronic contribution is 3.200, making $S^\circ_{298.16}=42.22\pm0.01$ for Se(*g*).

Maxwell and Mosley (*346*) report $2.19\pm0.03\times10^{-8}$ cm. as the interatomic distance in the $Se_2(g)$ molecule, corresponding to $I=314\times10^{-40}$. The vibration frequency is 391 cm.$^{-1}$ according to Herzberg (*212*). There are computed $S^\circ_{t+r,298.16}=57.10$, $S^\circ_{v,298.16}=1.00$, and $S^\circ_{e,298.16}=2.18$. The sum is $S^\circ_{298.16}=60.3\pm0.3$.

Selenium Ion.—The National Bureau of Standards tables (*370*) list $S^\circ_{298.16}=41.5$ for $Se^{--}(aq.)$.

Oxide.—The entropy of SeO(*g*) is estimated here as $S^\circ_{298.16}=56.0\pm1.0$.

Hexafluoride.—From data given by Yost, Steffens, and Gross (*512*), Yost (*505*), Yost and Claussen (*508*), and Sachsse and Bartholomé (*409*), the following molecular constants are available: $I_1=I_2=I_3=365\times10^{-40}$, $\omega_1=708(1)$, $\omega_2=662(2)$, $\omega_3=405(3)$, $\omega_4=245(3)$, $\omega_5=461(3)$, $\omega_6=787(3)$, and symmetry number=24. There are computed $S^\circ_{t+r,298.16}=63.05$, $S^\circ_{v,298.16}=12.08$, and $S^\circ_{298.16}=75.1\pm1.0$.

Acids and Ions.—The National Bureau of Standards tables (*370*) list the following values: $H_2SeO_4(aq.)$, $S^\circ_{298.16}=5.7$; $HSeO_4^-(aq.)$, $S^\circ_{298.16}=22.0$; $SeO_4^{--}(aq.)$, $S^\circ_{298.16}=5.7$; $H_2SeO_3(aq.)$, $S^\circ_{298.16}=45.7$; $HSeO_3^-(aq.)$, $S^\circ_{298.16}=30.4$; $SeO_3^{--}(aq.)$, $S^\circ_{298.16}=3.9$; $H_2Se(aq.)$, $S^\circ_{298.16}=39.9$; and $HSe^-(aq.)$, $S^\circ_{298.16}=50.6$.

SILICON

Element.—Anderson (*9*) (61°–297°) and Nernst and Schwers (*377*) (20°–90°) have measured the heat capacity of Si(*c*). The two sets of data yield $S^\circ_{298.16}=4.50\pm0.05$. The extrapolation is 0.007 below 20°.

Spectroscopic data compiled by Moore (*364*) shows that three energy levels are involved in deriving the entropy of Si(*g*) at 298.16°. The term values are 0, 77.06, and 223.14 cm.$^{-1}$ and the quantum weights are 1, 3, and 5, respectively. These states add 4.191 to the Sackur equation to make $S^\circ_{298.16}=40.13\pm0.01$.

Oxides.—The heat capacity of SiO_2 (quartz) was measured by Anderson (*20*) (53°–297°), Günther (*206*) (71°–89°), and Nernst (*373*) (25°–233°). Employing all the data, there is obtained $S^\circ_{298.16}=10.00\pm0.10$, of which 0.19 is extrapolation below 28.2°. This result is identical with the calculation of Mosesman and Pitzer (*366*).

Anderson (*20*) (54°298°) and Simon (*437*) (28°–117°) measured the heat capacity of SiO_2 (cristobalite). There is obtained $S^\circ_{298.16}=10.20\pm0.10$, of which 0.23 is extrapolation below 28.2°. A virtually identical result was obtained by Mosesman and Pitzer (*366*).

Anderson (*20*) (54°–295°) also measured the heat capacity of SiO_2 (tridymite). For this substance $S^\circ_{298.16}=10.4\pm0.2$, the extrapolation below 50.1° being 0.92.

The heat capacity of SiO_2 (glass) was measured by Nernst (*373*) (26°–233°), Simon (*437*) (18°–288°), and Simon and Lange (*440*) (10°–13°). From the data of the two latter investigations, $S_{298.16}-S_0=10.35\pm0.10$ is calculated, with an extrapolation below 10° of only 0.02. Simon and Lange have estimated $S^\circ=0.9\pm0.3$ for the entropy of SiO_2 (glass) at 0°. Adding this quantity, $S^\circ_{298.16}=11.2\pm0.4$.

Data listed by Herzberg (*212*) for the $SiO(g)$ molecule correspond to $I=38.6\times10^{-40}$ and $\omega=1{,}236$. There are calculated $S^\circ_{t+r,298.16}=50.510$, $S^\circ_{v,298.16}=0.035$, and $S^\circ_{298.16}=50.55\pm0.10$.

Tetrabromide.—Spitzer, Howell, and Schomaker (*453*) obtained 3.51×10^{-8} cm. as the Br–Br distance in the $SiBr_4(g)$ molecule. This corresponds to $I_1=I_2=I_3=1{,}635\times10^{-40}$. The vibration frequencies (*311*) are 90(2), 137(3), 249(1), and 487(3) cm.$^{-1}$ There are calculated $S^\circ_{t+r,298.16}=70.65$, $S^\circ_{v,298.16}=19.65$, and $S^\circ_{298.16}=90.3\pm1.0$ for $SiBr_4(g)$.

Carbide.—The heat capacity of $SiC(c)$ was measured by Nernst and Schwers (*377*) (52°–97°), Günther (*204*) (53°–76°), and Kelley (*281*) (54°–295°). Relying wholly on the last investigation, there is computed $S^\circ_{298.16}=3.95\pm0.02$. The extrapolation below 53.1° is only 0.043.

Tetrachloride.—Yost (*505*) and Yost and Blair (*507*) computed the entropy of $SiCl_4(g)$ from molecular-constant data. This calculation has been checked, using $I_1=I_2=I_3=640\times10^{-40}$ and the vibration frequencies, 148(2), 220(3), 422(1), and 608(3). There are obtained $S^\circ_{t+r,298.16}=65.72$, $S^\circ_{v,298.16}=13.46$, and $S^\circ_{298.16}=79.2\pm1.0$.

From vapor-pressure data, the entropy of vaporization at 298.16° is $\Delta S^\circ_{298.16}=21.8$ (*270*). This value and the above result for the gas yield $S^\circ_{298.16}=57.4\pm2.0$ for $SiCl_4(l)$. Latimer (*314*) obtained $S^\circ_{298.16}=56.4$ for this substance from heat-capacity data (77°–295°). However, recalculation from his data yields the following: $S^\circ_{70.8}=10.30$ (extrapolation), $S^\circ_{203.3}-S^\circ_{70.8}=24.75$ (crystals), $\Delta S^\circ_{203.3}=1{,}845/203.3=9.08$ (fusion), and $S^\circ_{298.16}-S^\circ_{203.3}=13.11$ (liquid). The sum is $S^\circ_{298.16}=57.2\pm2.0$. The value $S^\circ_{298.16}=57.3\pm2.0$ is adopted for $SiCl_4(l)$.

Fluorides.—Brockway (*55*) reported 1.54×10^{-8} cm. as the Si–F distance in the $SiF_4(g)$ molecule. This corresponds to $I_1=I_2=I_3=200\times10^{-40}$. The vibration frequencies were listed by Ryss (*408*) as 260(2), 420(3), 800(1), and 1,022(3). There are computed $S^\circ_{t+r,298.16}=60.79$, $S^\circ_{v,298.16}=6.45$, and $S^\circ_{298.16}=67.2\pm0.5$ for $SiF_4(g)$. Yost (*505*) and Ryss (*408*) have calculated agreeing results, 67.0 and 67.4, respectively.

From molecular-constant data (*212*), $I=48.3\times10^{-40}$ and $\omega=852$, and an assumed quantum weight of 2 for the ground state, there are calculated $S^\circ_{t+r,298.16}=51.15$, $S^\circ_{v,298.16}=0.17$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=52.7\pm1.5$ for $SiF(g)$.

Hydrides.—Clusius (*77*) (11°–160°) measured the heat capacity of monosilane, SiH_4. The heat of vaporization was computed by Kelley (*270*) from vapor-pressure data as 2,955 cal. per mole at the boiling point, 161.5°. In warming the gas from 161.5° to 298.16°, the entropy increment was computed from the molecular-constant data given below. There are obtained $S^\circ_{11.22}=0.26$ (extrapolation), $S^\circ_{63.45}-S^\circ_{11.22}=7.77$ (crystals II), $\Delta S^\circ_{63.45}=147.1/63.45=2.32$ (transition), $S^\circ_{88.48}-S^\circ_{63.45}=4.00$ (crystals *I*), $\Delta S^\circ_{88.48}=159.5/88.48=1.80$ (fusion), $S^\circ_{161.5}-S^\circ_{88.48}=8.77$ (liquid), $\Delta S^\circ_{161.5}=2{,}955/161.5=18.30$ (vaporization at 1 atm. pressure), and $S^\circ_{298.16}-S^\circ_{161.5}=5.48$ (gas). The sum is $S^\circ_{298.16}=48.7\pm0.2$.

The entropy of $SiH_4(g)$ also may be calculated from the molecular-constant data given by Tindal, Straley, and Nielsen (*485*), $I_1=I_2=I_3=9.33\times10^{-40}$, $\omega_1=2{,}187(1)$, $\omega_2=975(2)$, $\omega_3=2{,}191(3)$, and $\omega_4=914(3)$. There are calculated $S^\circ_{t+r,298.16}=48.14$, $S^\circ_{v,298.16}=0.60$, and $S^\circ_{298.16}=48.7\pm0.2$, in virtually exact agreement with the third-law value.

The entropy of $SiH(g)$ is obtainable from data listed by Herzberg (*212*), which correspond to $I=3.74\times10^{-40}$ and $\omega=2{,}080$. Two electronic states are involved at 298.16°. Both have quantum weight=2, and the term values are 0 and 141.9 cm.$^{-1}$ There are calculated $S^\circ_{t+r,298.16}=45.631$, $S^\circ_{v,298.16}=0.001$, and $S^\circ_{e,298.16}=2.645$. The sum is $S^\circ_{298.16}=48.28\pm0.10$.

Nitrides.—Kelley (*274*) estimated $S^\circ_{298.16}=22.8$ for $Si_3N_4(c)$ from equilibrium data for the reaction $3Si(c)+2N_2(g)=Si_3N_4(c)$. The uncertainty in this value may be a few units.

Molecular-constant data for the $SiN(g)$ molecule, corresponding to $I=38.3\times10^{-40}$ and $\omega=1{,}145$, were listed by Herzberg (*212*). The quantum weight of the ground state is 2. There are obtained $S^\circ_{t+r,298.16}=50.463$, $S^\circ_{v,298.16}=0.051$, and $S^\circ_{e,298.16}=1.378$. The sum is $S^\circ_{298.16}=51.89\pm0.10$.

SILVER

Element.—Bronson and Wilson (*58*) (193°–303°), Eucken, Clusius, and Woitinek (*155*) (11°–206°), Keesom and Kok (*255, 260*) (1.3°–21°), Meads, Forsythe, and Giauque (*354*) (14°–298), and Nernst (*373, 376*) (35°–273°) measured the heat capacity of $Ag(c)$. The entropy is computed as $S^\circ_{298.16}=10.20\pm0.05$. The extrapolation below 1.35 is negligible, ca. 8×10^{-5}.

The entropy of $Ag(g)$ may be obtained from the Sackur equation with *R ln* 2 added to account for the quantum weight of the ground state. The result is $S^\circ_{298.16}=41.33\pm0.01$.

Silver Ion.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=17.54\pm0.15$ for $Ag^+(aq.)$. Thermal data for two reactions were considered, $Ag_2O(c)+2H^+(aq.)=2Ag^+(aq.)+H_2O(l)$ and $AgCl(c)=Ag^+(aq.)+Cl^-(aq.)$, which give, respectively, 17.46 ± 0.2 and 17.62 ± 0.2. The result of Lingane and Larson (*337*), $S^\circ_{298.16}=16.7$, is fair agreement.

Oxide.—Pitzer and Smith (*390*) (12°–286°) measured the heat capacity of $Ag_2O(c)$. They found a region between liquid-hydrogen and liquid-air temperatures in which the heat capacity was not reproducible. Calculation gives $S^\circ_{298.16}=29.1\pm0.2$, with an extrapolation below 12.59° of 0.72. This value is adopted.

Two other values for $Ag_2O(c)$ may be mentioned. The free-energy equation of Lewis and Randall (*335*) results in $\Delta S^\circ_{298.16}=-17.3$ for the action $2Ag(c)+\frac{1}{2}O_2(g)=Ag_2O(c)$, which makes $S^\circ_{298.16}=27.6$ for

$Ag_2O(c)$. Also, in a discussion of the properties of $Ag_2CO_3(c)$, Kelley and Anderson (*290*) derived $S^\circ_{298.16}=29.7$ for $Ag_2O(c)$.

Sulfide.—Kelley (*273*), from a consideration of available equilibrium data, has obtained $S^\circ_{298.16}=35.0\pm1.0$ for $Ag_2S(\alpha)$. This value is checked by e. m. f. measurements of Kimura (*302*), which yield $\Delta S^\circ_{298.16}=-3.83$ for the reaction $2Ag(c)+H_2S(g)=H_2(g)+Ag_2S(\alpha)$. This value, in turn, leads to $S^\circ_{298.16}=34.5$ for $Ag_2S(\alpha)$.

Bromide.—Eastman and Milner (*138*) (24°–290°) and Eucken, Clusius, and Woitinek (*155*) (11°–274°) measured the heat capacity of $AgBr(c)$. Using both sets of data, $S^\circ_{11.22}=0.27$ (extrapolation), $S^\circ_{298.16}-S^\circ_{11.22}=25.33$ (measured), and $S^\circ_{298.16}=25.60\pm0.10$. The residual-ray data of Rubens (*403*) lead to $S^\circ_{298.16}=26.1\pm0.5$.

Molecular-constant data suggested by Stevenson (*467*), $I=400\times10^{-40}$ and $\omega=248$, lead to $S^\circ_{t+r,298.16}=59.48$, $S^\circ_{v,298.16}=1.74$, and $S^\circ_{298.16}=61.2\pm0.5$ for $AgBr(g)$.

Chloride.—The heat capacity of $AgCl(c)$ was measured by Clusius and Harteck (*100*) (10°–126°), Eastman and Milner (*138*) (15°–293°), Nernst and Schwers (*377*) (22°–92°), and Nernst (*373*) (23°–208°). From the data of Clusius and Harteck and of Eastman and Milner there are obtained $S^\circ_{10.00}=0.14$ (extrapolation), $S^\circ_{298.16}-S^\circ_{10.00}=22.86$ (measured), and $S^\circ_{298.16}=23.00\pm0.10$. The residual-ray data of Rubens (*403*) permit calculation of $S^\circ_{298.16}=22.5\pm0.5$.

Molecular-constant values for $AgCl(g)$ listed by Stevenson (*467*) correspond to $I=205\times10^{-40}$ and $\omega=343$. There are calculated $S^\circ_{t+r,298.16}=57.34$, $S^\circ_{v,298.16}=1.20$, and $S^\circ_{298.16}=58.5\pm0.5$ for $AgCl(g)$. This value is adopted. The entropy of the solid and vaporization data (*270*) combine to give an approximately agreeing value, $S^\circ_{298.16}=59.7\pm1.5$.

Fluoride.—There is estimated here $S^\circ_{298.16}=56.1\pm0.5$ for $AgF(g)$.

Hydrides.—Herzberg (*212*) has listed molecular constants for $AgH(g)$, corresponding to $I=4.34\times10^{-40}$ and $\omega=1,726$. There are computed $S^\circ_{t+r,298.16}=48.863$, $S^\circ_{v,298.16}=0.004$, and $S^\circ_{298.16}=48.87\pm0.10$.

For $AgD(g)$, the nuclear separation listed by Herzberg (*212*) yields 8.59×10^{-40} as the moment of inertia. There is computed $S^\circ_{t+r,298.16}=50.25$. The vibration frequency is not known and the vibrational contribution to the entropy is estimated here as 0.05. The sum is $S^\circ_{298.16}=50.3\pm0.1$.

Iodide.—Nernst and Schwers (*377*) (17°–117°), Nernst (*373*) (29°–137°), and Pitzer (*388*) (15°–302°) measured the heat capacity of AgI (*c*). The entropy calculation of the last-named investigator has been checked and will be adopted. There are obtained $S^\circ_{15.00}=1.5\pm0.3$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.00}=26.09\pm0.1$ (measured), and $S^\circ_{298.16}=27.6\pm0.4$.

An identical value is obtainable from Gerke's (*169*) cell measurements, which give $\Delta S^\circ_{298.16}=-8.0$ for the reaction $Pb(c)+2AgI(c)=PbI_2(c)+2Ag(c)$. This value results in $S^\circ_{298.16}=27.6\pm0.4$ for $AgI(c)$.

From data listed by Stevenson (*467*), $I=595\times10^{-40}$ and $\omega=206$ for $AgI(g)$. There are calculated $S^\circ_{t+r,298.16}=60.93$, $S^\circ_{v,298.16}=2.08$, and $S^\circ_{298.16}=63.0\pm0.5$.

Carbonate.—Anderson (*14*) (53°–291°) measured the heat capacity of $Ag_2CO_3(c)$. His data yield $S^\circ_{298.16}=40.0\pm0.9$. The extrapolation is 7.86 below 56.2°.

Chlorite.—The heat capacity of $AgClO_2(c)$ was measured by Smith, Pitzer, and Latimer (*448*) (14°–298°). There are obtained $S^\circ_{14.13}=0.43$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.13}=31.73$ (measured), and $S^\circ_{298.16}=32.2\pm0.2$.

Chromate.—Smith, Pitzer, and Latimer (*449*) (15°–295°) measured the heat capacity of $Ag_2CrO_4(c)$. Recalculation of their data gives $S^\circ_{298.16}=52.0\pm0.3$, of which 1.29 is extrapolation below 15.85° and 50.67 is measured.

Iodate.—Greensfelder and Latimer (*203*) (16°–298°) measured the heat capacity of $AgIO_3(c)$. The entropy calculation yields $S^\circ_{15.85}=0.56$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.85}=35.10$ (measured), and $S^\circ_{298.16}=35.7\pm1.0$.

Nitrate.—The heat capacity of $AgNO_3(c)$ was measured by Smith, Brown, and Pitzer (*447*) (13°–297°). There are computed $S^\circ_{12.59}=0.38$ (extrapolation), $S^\circ_{298.16}-S^\circ_{12.59}=33.30$ (measured), and $S^\circ_{298.16}=33.68\pm0.15$.

Nitrite.—Brown, Smith, and Latimer (*63*) (14°–295°) measured the heat capacity of $AgNO_2(c)$. There are obtained $S^\circ_{14.10}=0.58$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.10}=30.06$ (measured), and $S^\circ_{298.16}=30.64\pm0.15$.

Silicate.—Kelley (*289*) (53°–296°) measured the heat capacity of $Ag_2SiO_3(c)$. There are calculated $S^\circ_{50.12}=8.10$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=34.32$ (measured), and $S^\circ_{298.16}=42.4\pm0.6$.

Sulfate.—The heat capacity of $Ag_2SO_4(c)$ was measured by Latimer, Hicks, and Schutz (*323*) (14°–297°). There is computed $S^\circ_{298.16}=47.9\pm0.2$, of which 0.79 is extrapolation below 14.13° and 47.13 is measured.

Silver-Trihydrogen Paraperiodate.—Stephenson and Adams (*458*) (15°–296°) measured the heat capacity of $Ag_2H_3IO_6(c)$. The sample employed contained about 0.053 percent nitric acid, an impurity for which correction of 0.22 was made in the entropy. The corrected entropy values are $S^\circ_{15.00}=0.71$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.00}=58.73$, and $S^\circ_{298.16}=59.4\pm0.3$.

$Ag(NH_3)_2{}^+$aq.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=57.8\pm1.0$ for $Ag(NH_3)_2{}^+$ (*aq.*) from thermal data for the reaction Ag^+ (*aq.*)$+2NH_3$ (*aq.*)$=Ag(NH_3)_2{}^+$ (*aq.*).

SODIUM

Element.—The heat capacity of Na(*c*) at low temperatures was measured by Eastman and Rodebush (*139*) (64°–294°), Günther (*205*) (87°–124°), and Simon and Zeidler (*444*) (16°–118°). Relying largely on the data of the last-mentioned investigators, $S^\circ_{298.16}=12.23\pm0.10$, of which 0.09 is extrapolation below 12.6°.

For Na(*g*) at 298.16°, the Sackur equation with *R ln* 2 added gives $S^\circ_{298.16}=36.72\pm0.01$.

Molecular-constant data for $Na_2(g)$ listed by Herzberg (*212*) correspond to $I=181\times10^{-40}$ and $\omega=158.5$ There are computed $S^\circ_{t+r,298.16}=52.331$, $S^\circ_{v,298.26}=2.567$, and $S^\circ_{298.16}=54.90\pm0.10$.

Sodium ion.—Latimer, Pitzer, and Smith (*325*) report $S^\circ_{298.16}=14.0\pm0.4$ for $Na^+(aq.)$. This value is based on thermal data for three reactions, $NaCl(c)=Na^+(aq.)+Cl^-(aq.)$, $NaNO_3(c)=Na^+(aq.)+NO_3{}^-(aq.)$, and $Na(c)+H^+(aq.)=Na^+(aq.)+\frac{1}{2}H_2(g)$. The individual values are 14.1 ± 0.5, 14.3 ± 0.5, and 13.7 ± 0.5, respectively.

Oxide.—From low-temperature heat-capacity data for three sodium silicates and the approximately additive properties of silicates, Kelley (*276*) has suggested $S^\circ_{298.16}=17$ for $Na_2O(c)$. Shomate (*431*) similarly has indicated this value from his measurements of three sodium titanates. The uncertainty in this value is taken as ± 1.0.

Bromide.—For the $NaBr(g)$ molecule, $I=207\times 10^{-40}$ and $\omega=314$, according to data listed by Herzberg (*212*). Calculation yields $S^\circ_{t+r,298.16}=56.38$, $S^\circ_{v,298.16}=1.34$, and $S^\circ_{298.16}=57.7\pm 0.5$. Niwa (*380*) has estimated an agreeing value, 57.8 ± 2.0.

The entropy of $NaBr(c)$ is estimated here as $S^\circ_{298.16}=20.0\pm 0.5$.

Chloride.—The heat capacity of $NaCl(c)$ was measured by McGraw (*350*) (95°–245°) and Nernst (*373, 376*) (25°–84°). Relying largely on Nernst's work, there is obtained $S^\circ_{25.10}=0.20$ (extrapolation), $S^\circ_{298.16}-S^\circ 25.10=17.09$ (measured), and $S^\circ_{298.16}=17.3\pm 0.3$. The residual-ray data of Rubens (*403*) and Rubens and Hollnagel (*404*) lead to $S^\circ_{298.16}=17.2\pm 0.5$. a good agreement.

According to the data listed by Herzberg (*212*), $I=146\times 10^{-40}$ and $\omega=379$ for the $NaCl(g)$ molecule. There are calculated $S^\circ_{t+r,298.16}=54.00$, $S^\circ_{v,298.16}=1.04$, and $S^\circ_{298.16}=55.0\pm 0.5$. Niwa (*380*) obtained an agreeing value, 55.5 ± 1.4. From the entropy of sublimation and the entropy of the solid, Kelley (*270*) obtained $S^\circ_{298.16}=56.4$, which was reported as 46.4, owing to a typographical error.

Fluoride.—From residual-ray data (*310*), $S^\circ_{298.16}=13.1\pm 0.5$ is calculated for $NaF(c)$.

For $NaF(g)$, there is estimated here $S^\circ_{298.16}=53.1\pm 0.5$, in satisfactory agreement with Niwa's (*380*) estimate of 53.8 ± 1.8.

Hydrides.—Data listed by Herzberg (*212*) yield $I=5.71\times 10^{-40}$ and $\omega=1{,}152$ for the $NaH(g)$ molecule and $I=10.94\times 10^{-44}$ and $\omega=826$ for the $Na(g)$ molecule. For $NaH(g)$, there are computed $S^\circ_{t+r,298.16}=44.901$, $S^\circ_{v,298.16}=0.050$, and $S^\circ_{298.16}=44.95\pm 0.10$. Similarly, $S^\circ_{t+r,298.16}=46.316$, $S^\circ_{v,298.16}=0.187$, and $S^\circ_{298.16}=46.50\pm 0.10$ are obtained for $NaD(g)$.

Iodide.—For $NaI(g)$, $I=272\times 10^{-40}$ and $\omega=285$, according to data listed by Herzberg (*212*). The entropy calculation gives $S^\circ_{t+r,298.16}=58.04$, $S^\circ_{v,298.16}=1.50$, and $S^\circ_{298.16}=59.5\pm 0.5$.

The entropy of $NaI(c)$ is estimated here as $S^\circ_{298.16}=21.8\pm 0.5$.

Carbonate.—Anderson (*14*) (54°–290°) measured the heat capacity of $Na_2CO_3(c)$. There are obtained $S^\circ_{56.2}=4.10$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=28.40$ (measured), and $S^\circ_{298.16}=32.5\pm 0.6$.

Bicarbonate.—Anderson (*14*) (54°–296°) also measured the heat capacity of $NaHCO_3(c)$. The data yield $S^\circ_{56.2}=2.19$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=22.20$ (measured), and $S^\circ_{298.16}=24.4\pm 0.4$.

Hydroxide.—Shibata (*421, 422*) obtained $\Delta F^\circ_{298.16}=-111{,}155$ and $\Delta H_{298.16}=-114{,}932$ for the reaction $2Na(c)+HgO(c)+H_2O(l)=2NaOH(c)+Hg(l)$. The entropy of reaction is $S^\circ_{298.16}=-12.7$, which leads to $S^\circ_{298.16}=13.8\pm 1.5$ for $NaOH$ (c).

Nitrate.—The heat capacity of $NaNO_3(c)$ was measured by Southard and Nelson (*451*) (16°–287°). There are calculated $S^\circ_{15.85}=0.15$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.85}=27.70$ (measured), and $S^\circ_{298.16}=27.85\pm 0.10$.

Silicates.—Kelley (*276*) (53°–299°) measured the heat capacities of $Na_4SiO_4(c)$, $Na_2SiO_3(c)$, and $Na_2Si_2O_5(c)$. For $Na_4SiO_4(c)$, there are obtained $S^\circ_{53.10}=2.48$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.10}=44.30$ (measured), and $S^\circ_{298.16}=46.8\pm0.4$. For $Na_2SiO_3(c)$, the results are $S^\circ_{53.10}=1.39$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.10}=25.80$ (measured), and $S^\circ_{298.16}=27.2\pm0.2$. Similarly, for $Na_2Si_2O_5(c)$, $S^\circ_{53.10}=3.43$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.10}=35.93$ (measured), and $S^\circ_{298.16}=39.4\pm0.3$.

Sulfates.—The heat capacities of $Na_2SO_4(c)$ (13°–314°) and $Na_2SO_4\cdot10H_2O(c)$ (14°–299°) were measured by Pitzer and Coulter (*389*). For $Na_2SO_4(c)$, there are computed $S^\circ_{14.00}=0.06$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.00}=35.67$ (measured), and $S^\circ_{298.16}=35.73\pm0.10$. Likewise, for $Na_2SO_4\cdot10H_2O(c)$, $S^\circ_{14.00}=0.5$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.00}=140.0$ (measured), and $S^\circ_{298.16}=140.5\pm0.4$.

Sulfite.—Kelley and Moore (*294*) (53°–296°) measured the heat capacity of $Na_2SO_3(c)$. There are computed $S^\circ_{50.12}=2.65$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=32.23$ (measured), and $S^\circ_{298.16}=34.9\pm0.3$.

Titanates.—Shomate (*431*) (52°–297°) measured the heat capacities of $Na_2TiO_3(c)$, $Na_2Ti_2O_5(c)$, and $Na_2Ti_3O_7(c)$. For $Na_2TiO_3(c)$, calculation yields $S^\circ_{52.00}=1.42$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=27.64$ (measured), and $S^\circ_{298.16}=29.1\pm0.2$. For $Na_2Ti_2O_5(c)$, there are obtained $S^\circ_{52.00}=2.52$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=39.02$ (measured), and $S^\circ_{298.16}=41.5\pm0.3$. Likewise, for $Na_2Ti_3O_7(c)$, $S^\circ_{52.00}=3.98$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=51.93$ (measured), and $S^\circ_{298.16}=55.9\pm0.4$.

Sodium-Aluminum Silicates.—Todd (*486*) (53°–297°) has measured the heat capacities of $NaAlSi_3O_8$ (albite) and $NaAlSi_2O_6$ (jadeite). For albite, there are obtained $S^\circ_{51.00}=3.85$ (extrapolation), $S^\circ_{298.16}-S^\circ_{51.00}=45.37$ (measured), and $S^\circ_{298.16}=49.2\pm0.3$; for jadeite, $S^\circ_{51.00}=0.96$ (extrapolation), $S^\circ_{298.16}-S^\circ_{51.00}=30.87$ (measured), and $S^\circ_{298.16}=31.8\pm0.2$.

Intermetallic Compounds.—The following entropies are estimated here: $S^\circ_{298.16}=62.1\pm1.0$ for $NaCs(g)$; $S^\circ_{298.16}=58.6\pm0.5$ for $NaK(g)$; and $S^\circ_{298.16}=60.4\pm1.0$ for $NaRb(g)$.

STRONTIUM

Element.—The entropy of $Sr(g)$ may be obtained directly from the Sackur equation. The result is $S^\circ_{298.16}=39.33\pm0.01$.

The entropy of $Sr(c)$ is estimated here as $S^\circ_{298.16}=12.5\pm0.5$.

Strontium Ion.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=-7.3\pm1.5$ for $Sr^{++}(aq.)$, from thermal data for the reaction $SrCO_3(c)+2H^+(aq.)=Sr^{++}(aq.)+H_2O(l)+CO_2(g)$. The more recent value of Kapustinsky and Dezideryeva (*241*), $S^\circ_{298.16}=-6.3$, is in agreement within the limits of uncertainty assigned.

Oxide.—The heat capacity of $SrO(c)$ was measured by Anderson (*17*) (57°–299°). The data yield $S^\circ_{56.2}=1.17$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=11.84$ (measured), and $S^\circ_{298.16}=13.0\pm0.2$.

From data listed by Herzberg (*212*), $I=74.9\times10^{-40}$ and $\omega=631$ for $SrO(g)$. There are calculated $S^\circ_{t+r,\ 298.16}=54.377$, $S^\circ_{v,\ 298.16}=0.412$, and $S^\circ_{298.16}=54.79\pm0.10$.

Hydride.—Herzberg (*212*) listed molecular constants of the $SrH(g)$ molecule which correspond to $I=7.62\times10^{-40}$ and $\omega=1{,}189$. The quantum weight of the ground state is 2. There are computed $S^\circ_{t+r,298.16}=49.369$, $S^\circ_{v,\ 298.16}=0.043$, $S^\circ_{e,\ 298.16}=1.378$, and $S^\circ_{298.16}=50.79\pm0.10$.

Carbonate.—The heat capacity of $SrCO_3(c)$ (strontianite) was measured by Anderson (*15*) (54°–292°). There are calculated $S^\circ_{56.2}=$

2.11 (extrapolation), $S^\circ_{298.16}-S^\circ_{56.2}=21.10$ (measured), and $S^\circ_{298.16}=23.2\pm0.4$.

Sulfate.—The thermodynamic properties of $SrSO_4(c)$ were considered by Kelley (*273*), $S^\circ_{298.16}=28.2$ being estimated. No attempt will be made to estimate the uncertainty in this value, which, however, appears reasonable in comparison with the entropies of $CaSO_4(c)$ and $BaSO_4(c)$.

SULFUR

Element.—The heat capacity of rhombic sulfur, S(*rh*), was measured by Eastman and McGavock (*137*) (12°–366°) and Nernst (*373*) (22°–202°). The more recent and more extensive data of the former investigators are adopted. There are obtained $S^\circ_{15.00}=0.12$ (extrapolation), $S^\circ_{298.13}-S^\circ_{15.00}=7.50$ (measured), and $S^\circ_{298.16}=7.62\pm0.04$.

Eastman and McGavock (*137*) (64°–378°) and Nernst (*373*) (83°–201°) also measured the heat capacity of monoclinic sulfur, S(*mon*). Again the values from Eastman and McGavock's work are adopted. They compute 0.16 as the difference in entropy between the monoclinic and rhombic modifications, making $S^\circ_{298.16}=7.78\pm0.06$.

In calculating the entropy of S(*g*) at 298.16°, three energy levels must be considered. The compilation of Moore (*364*) gives the term values as 0, 398, and 573 $cm.^{-1}$ and the quantum weights as 5, 3, and 1, respectively. These states add 3.757 to the translational entropy given by the Sackur equation, to make $S^\circ_{298.16}=40.09\pm0.01$.

Badger (*32*) has reinterpreted the spectroscopic data for $S_2(g)$ and has obtained 1.840×10^{-8} cm. as the S–S distance. This corresponds to $I=90.1\times10^{-40}$. According to Herzberg (*212*), the vibration frequency is 723. The quantum weight of the ground state is 3. These values yield $S^\circ_{t+r,298.16}=51.936$, $S^\circ_{v,298.16}=0.279$, and $S^\circ_{e,298.16}=2.183$. The sum is $S^\circ_{298.16}=54.40\pm0.10$ for $S_2(g)$. Cross (*118*) computed a virtually identical value, while a different but incorrect figure, 53.85, was reported by Godnev and Sverdlin (*194*). The result of Montgomery and Kassel (*363*) is based upon the older interpretation of the spectra which gave 1.60×10^{-8} cm. as the S–S distance.

From a recalculation (*273*) of the equilibrium data of Preuner and Schupp (*394*), values were obtained leading to $S^\circ_{298.16}=92$ for $S_6(g)$ and $S^\circ_{298.16}=109$ for $S_8(g)$. The uncertainties in these values undoubtedly are large but difficult to estimate.

Monoxide.—Herzberg (*212*) listed molecular-constant data for SO(*g*) which correspond to $I=39.5\times10^{-40}$ and $\omega=1{,}118$. The quantum weight of the ground state is 3. There are computed $S^\circ_{t+r,298.16}=50.815$, $S^\circ_{v,298.16}=0.057$, and $S^\circ_{e,298.16}=2.183$. The sum is $S^\circ_{298.16}=53.06\pm0.10$.

Dioxide.—Giauque and Stephenson (*186*) (15°–264°) measured the heat capacity of SO_2. Their entropy calculation has been checked to within 0.01 unit. The individual items are $S^\circ_{15.00}=0.30$ (extrapolation), $S^\circ_{197.64}-S^\circ_{15.00}=20.12$ (crystals), $\Delta S^\circ_{197.64}=1{,}769.1/197.64=8.95$ (fusion), $S^\circ_{263.08}-S^\circ_{197.64}=5.96$ (liquid), $\Delta S_{263.08}=5{,}960/263.08=22.65$ (vaporization at 1 atm. pressure), $\Delta S_{263.08}=0.09$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{263.08}=1.17$ (gas). The sum is $S^\circ_{298.16}=59.24\pm0.10$. This value is adopted.

Molecular dimensions listed by Brockway (*55*) lead to $I_1=12.4\times10^{-40}$, $I_2=87.0\times10^{-40}$, and $I_3=99.4\times10^{-40}$ as the moments of inertia of the $SO_2(g)$ molecule. The vibration frequencies were given by Badger and Bonner (*33*) as 525, 1,152, and 1,361. There are computed $S^\circ_{t+r,298.16}=58.618$ and $S^\circ_{v,298.16}=0.670$. The sum is $S^\circ_{298.16}=59.29\pm0.15$, which is in excellent agreement with the third-law value. Agreeing calculations have been made by Cross (*119*) and Giauque and Stephenson (*186*). In the older calculation of Gordon (*197*) erroneous moments of inertia were used.

Trioxide.—Stockmayer, Kavanagh, and Mickley (*472*) have listed molecular constants of the $SO_3(g)$ molecule and have calculated the entropy. The moments of inertia are $I_1=I_2=81.5\times10^{-40}$ and $I_3=163\times10^{-40}$, and the vibration frequencies are 530 (1), 560 (2), 1,068 (1), and 1,332 (2). The molecule is considered to be planar, with symmetry number 6. There are computed $S^\circ_{t,+r,298.16}=59.40$, $S^\circ_{v,298.16}=1.82$ (with allowance of 0.07 for anharmonicity, according to Stockmayer, Kavanagh, and Mickley), and $S^\circ_{298.16}=61.2\pm1.0$.

The entropy of vaporization of $SO_3(l)$ is $\Delta S^\circ_{298.16}=32.1$ (*270*). This and the value for the gas lead to $S^\circ_{298.16}=29.1\pm2.0$ for $SO_3(l)$.

Dichloride.—McDowell and Moelwyn-Hughes (*349*) have suggested molecular-constant data for the $SCl_2(g)$ molecule and have estimated the entropy. The moments of inertia are $I_1=60.6\times10^{-40}$, $I_2=286\times10^{-40}$, and $I_3=347\times10^{-40}$, according to their dimensional values, and the estimated vibration frequencies are 206, 404, and 461. These figures yield $S^\circ_{t+r,298.16}=64.04$, $S^\circ_{v,298.16}=3.79$, and $S^\circ_{298.16}=67.8\pm1.0$.

Sulfuryl Chloride.—Thompson (*484*) has considered the $SO_2Cl_2(g)$ molecule and has given the vibration frequencies as 214, 280, 365, 390, 408, 560, 576, 1,190, and 1,415. His dimensional values yield $I_1=I_2=I_3=383\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=66.99$, $S^\circ_{v,298.16}=7.64$, and $S^\circ_{298.16}=74.6\pm1.0$ for $SO_2Cl_2(g)$. Employing $\Delta S^\circ_{298.16}=22.7$ (*270*) as the entropy of vaporization, there is obtained $S^\circ_{298.16}=51.9\pm2$ for $SO_2Cl_2(l)$.

Hexafluoride.—Eucken and Schröder (*150*) (13°–230°) measured the heat capacity of SF_6. Calculations from their data yield $S^\circ_{12.6}=1.08$ (extrapolation), $S^\circ_{94.30}-S^\circ_{12.6}=18.13$ (crystals II), $\Delta S^\circ_{94.30}=384.2/94.30=4.07$ (transition), $S^\circ_{186.0}-S^\circ_{94.30}=11.47$ (crystals I), $\Delta S_{186.0}=5{,}615/186.0=30.19$ (sublimation at 0.161 atm. pressure), and $\Delta S_{186.0}=-3.63$ (compression from 0.161 to 1 atm.). The entropy increment for warming the gas from 186.0° to 298.16° is $S^\circ_{298.16}-S^\circ_{186.0}=8.96$ (gas), calculated from molecular-constant data given below. These quantities add to give $S^\circ_{298.16}=70.3\pm0.7$.

Yost (*505*) and Yost and Claussen (*508*) have reported 1.58×10^{-8} cm. as the S–F distance in the $SF_6(g)$ molecule and 775 (1), 645 (2), 525 (3), 363 (3), 617 (3), and 965 (3) as the vibration frequencies. From the dimensional value, $I_1=I_2=I_3=315\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=61.78$, $S^\circ_{v,298.16}=7.74$, and $S^\circ_{298.16}=69.5\pm0.5$ for $SF_6(g)$. This value is adopted.

Aqueous Hydrogen Sulfide and Ions.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=29.4\pm0.3$ for $H_2S(aq.)$, from data for the reaction $H_2S(g)=H_2S(aq.)$. The same authors also obtained $S^\circ_{298.16}=14.9\pm1.0$ for $HS^-(aq.)$, from data for the reaction $H_2S(aq.)=H^+(aq.)+HS^-(aq.)$. The National Bureau of Standards tables (*370*) list $S^\circ_{298.16}=5.3$ for $S^{--}(aq.)$.

Sulfuric Acid and Ions.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=30.6\pm2$ for $HSO_4^-(aq.)$, from data for the reaction $SO_4^{--}(aq.)+H^+(aq.)=HSO_4^-(aq.)$. They also obtained $S^\circ_{298.16}=4.4\pm1.0$ for $SO_4^{--}(aq.)$, using data on four reactions, $Na_2SO_4\cdot10H_2O(c)=2Na^+(aq.)+SO_4^{--}(aq.)+10H_2O(l)$, $Ag_2SO_4(c)=2Ag^+(aq.)+SO_4^{--}(aq.)$, $CaSO_4\cdot2H_2O(c)=Ca^{++}(aq.)+SO_4^{--}(aq.)+2H_2O(l)$, and $PbSO_4(c)+2H_2O(l)=H_2(g)+PbO_2(c)+SO_4^{--}(aq.)+2H^+(aq.)$. The value, $S^\circ_{298.16}=4.4\pm1.0$, is also the entropy of $H_2SO_4(aq.)$.

Sulfurous Acid and Ions.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=54.7\pm1.0$ for $H_2SO_3(aq.)$, from thermal data for the reaction $SO_2(g)+H_2O(l)=H_2SO_3(aq.)$. They also report $S^\circ_{298.16}=32.6\pm1.5$ for $HSO_3^-(aq.)$ from data for the reaction $H_2SO_3(aq.)=H^+(aq.)+HSO_3^-(aq.)$. The National Bureau of Standards tables (*370*) list $S^\circ_{298.16}=10.4$ for $SO_3^{--}(aq.)$.

Other Acids and Ions.—The National Bureau of Standards tables (*370*) list the following values of $S^\circ_{298.16}$: 35 for $H_2S_2O_8(aq.)$, 57.9 for $S_2O_3^{--}(aq.)$, 57 for $S_2O_4^{--}(aq.)$, 35 for $S_2O_8^{--}(aq.)$, and 120.5 for $S_4O_6^{--}(aq.)$.

TANTALIUM

Element.—The heat capacity of Ta(*c*) was measured by Keesom and Desirant (*248*) (1.3°–4.8°), Kelley (*278*) (53°–295°), and Simon and Ruhemann (*441*) (71°–78°). There is obtained $S^\circ_{298.16}=9.94\pm0.04$, of which only about 3×10^{-4} is extrapolation below 1.4°.

The entropy of Ta(*g*) is obtainable from the Sackur equation and spectroscopic data. For the latter, the tabulation of Moore (*364*) shows that only two states need be considered at 298.16°. These states have term values of 0 and 2,010.0 cm.$^{-1}$ and quantum weights of 4 and 6, respectively. They add 2.757 to the Sackur equation, making $S^\circ_{298.16}=44.25\pm0.01$.

Oxide.—Kelley (*279*) (53°–295°) measured the heat capacity of $Ta_2O_5(c)$. The data yield $S^\circ_{53.10}=2.83$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.10}=31.36$ (measured), and $S^\circ_{298.16}=34.2\pm0.3$.

Carbide.—Kelley (*279*) (54°–295°) measured the heat capacity of TaC(*c*). There are obtained $S^\circ_{53.10}=0.95$ (extrapolation), $S^\circ_{298.16}-S^\circ_{53.10}=9.16$ (measured), and $S^\circ_{298.16}=10.11\pm0.08$.

TELLURIUM

Element.—Anderson (*23*) (54°–292°) and Slansky and Coulter (*446*) (14°–302°) measured the heat capacity of Te(*c*). The data are in fair agreement, but Slansky and Coulter showed that Anderson's extrapolation of his results is in error. The calculations of Slansky and Coulter have been checked. There are obtained $S^\circ_{12.59}=0.14$ (extrapolation), $S^\circ_{298.16}-S^\circ_{12.59}=11.74$ (measured), and $S^\circ_{298.16}=11.88\pm0.10$.

In calculating the entropy of Te(*g*), *R ln* 5 is added to the Sackur equation to account for the quantum weight of the ground state. No other states are concerned at 298.16°. The result is $S^\circ_{298.16}=43.65\pm0.01$.

Herzberg (*212*) has listed molecular-constant data for $Te_2(g)$ corresponding to $I=711\times10^{-40}$ and $\omega=250.5$. The quantum weight of the ground state is 3. There are obtained $S^\circ_{t+r,298.16}=60.16$, $S^\circ_{v,298.16}=1.73$, $S^\circ_{e,298.16}=2.18$, and $S^\circ_{298.16}=64.1\pm0.3$.

Oxide.—Geblen and Gehlen-Keller (*167*) have reported values of the heat and free energy of formation of $TeO_2(c)$ which lead to $\Delta S^\circ_{298.16}=-44.1$ for the entropy of formation. This figure, in turn, results in $S^\circ_{298.16}=16.8\pm1.0$ for $TeO_2(c)$.

Hexafluoride.—Sachsse and Bartholomé (*409*), Yost (*505*), and Yost and Claussen (*508*) have listed 165(3), 313(3), 370(3), 674(2), 701(1), and 752(3) as the vibration frequencies of the $TeF_6(g)$ molecule. Yost also gives the Te–F distance as 1.84×10^{-8} cm., corresponding to $I=427\times10^{-40}$. The symmetry number is 24. There are computed $S^\circ_{t+r,298.16}=64.18$, $S^\circ_{v,298.16}=16.48$, and $S^\circ_{298.16}=80.7\pm1.0$.

THALLIUM

Element.—The heat capacity of $Tl(c)$ was measured by Clusius and Vaughen (*105*) (11°–249°), Hicks (*215*) (14°–299°), Nernst and Schwers (*377*) (22°–96°), and Keesom and Kok (*257, 258, 259*) (1.3°–4.2°). The entropy is $S^\circ_{298.16}=15.35\pm0.06$, of which the extrapolation below 1.3° is about 7×10^{-4}.

The entropy of $Tl(g)$ from the Sackur equation, with $R\ ln\ 2$ added to account for the quantum weight of the ground state, is $S^\circ_{298.16}=43.23\pm0.01$.

Thallous Ion.—The entropy of $Tl^+(aq.)$ was reported by Latimer, Pitzer, and Smith (*325*) as $S^\circ_{298.16}=30.5\pm0.4$. Data for two reactions were considered, $TlNO_3(c)=Tl^+(aq.)+NO_3^-(aq.)$ and $Tl(c)+AgCl(c)=Ag(c)+Tl^+(aq.)+Cl^-(aq.)$, from which the respective values are 31.0 ± 0.5 and 30.1 ± 0.5. The value given by Hicks (*215*), 30.2, is in excellent agreement.

Bromide.—The residual-ray data of Rubens and Hollnagel (*404*) yield $S^\circ_{298.16}=26.8\pm1.0$ for $TlBr(c)$. From thermal data of Ishikawa and Terui (*220*) for the reaction $Tl(c)+1/2\ Br_2(l)=TlBr(c)$, there is obtained $\Delta S^\circ_{298.16}=-5.9$ which, in turn, leads to $S^\circ_{298.16}=27.8$ for $TlBr(c)$. The former value is adopted.

Brockway (*55*) gave 2.68×10^{-8} cm. as the Tl–Br distance in the $TlBr(g)$ molecule, which corresponds to $I=685\times10^{-40}$. Herzberg (*212*) reported 192 $cm.^{-1}$ as the vibration frequency. These values yield $S^\circ_{t+r,298.16}=61.78$, $S^\circ_{v,198.16}=2.21$, and $S^\circ_{298.16}=64.0\pm0.5$. Kelley (*270*) reported $S^\circ_{298.16}=63.2$ from vapor-pressure data and the entropy of the solid, an agreeing but less-reliable result.

Chloride.—Pollitzer (*393*) (23°–94°) measured the heat capacity of $TlCl(c)$. The data yield $S^\circ_{22.4}=0.56$ (extrapolation), $S^\circ_{298.16}-S^\circ_{22.4}=25.31$, and $S^\circ_{298.16}=25.9\pm0.6$.

The cell measurements of Gerke (*169*) give $\Delta S^\circ_{298.16}=-1.1$ for the reaction $Tl(c)+AgCl(c)=TlCl(c)+Ag(c)$. This value leads to $S^\circ_{298.16}=27.0\pm0.5$, in disagreement with the third-law result.

Still another value for $TlCl(c)$ is obtainable from the residual-ray data of Rubens and Hollnagel (*404*), which yield $S^\circ_{298.16}=23.7\pm1.0$.

Finally, a fourth value is obtained from the entropy of $TlCl(g)$, given below, and the entropy of sublimation, $\Delta S^\circ_{298.16}=34.4$, from the heat and free-energy values of Kelley (*270*). The result is $S^\circ_{298.16}=26.9\pm1.0$.

The exact reason for the discrepancies in these values is not apparent. For the present purpose, the value $S^\circ_{298.16}=26.5\pm1.0$ is adopted.

Brockway (*55*) reported 2.55×10^{-8} cm. as the interatomic distance in the $TlCl(g)$ molecule and Herzberg (*212*) gave 286 $cm.^{-1}$ as the vibration frequency. The first figure corresponds to $I=326\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=59.80$, $S^\circ_{v,298.16}=1.50$, and $S^\circ_{298.16}=61.3\pm0.5$ for $TlCl(g)$.

Fluoride.—There is estimated here $S^\circ_{298.16}=59.0\pm0.5$ for $TlF(g)$.

Iodide.—Brockway's (*55*) value for the interatomic distance in the $TlI(g)$ molecule corresponds to $I=1{,}070\times10^{-40}$. The vibration frequency is 150, according to the compilation of Herzberg (*212*). There are obtained $S^\circ_{t+r,298.16}=63.13$, $S^\circ_{v,298.16}=2.67$, and $S^\circ_{298.16}=65.8\pm0.5$.

For $TlI(c)$, Rubens and Hollnagel's (*404*) residual-ray data lead to $S^\circ_{298.16}=29.9\pm1.0$. Another value, $S^\circ_{298.16}=31.8$, is derived from the heat and free energy of sublimation given by Kelley (*270*) and the above value for the gas. The latter result appears too high in comparison with those for the chloride and bromide.

Hydride.—Data listed by Herzberg (*212*) correspond to $I=5.82\times10^{-40}$ and $\omega=1{,}368$ for the $TlH(g)$ molecule. There are computed $S^\circ_{t+r,298.16}=51.339$, $S^\circ_{v,298.16}=0.020$, and $S^\circ_{298.16}=51.36\pm0.10$.

Nitrate.—Latimer and Ahlberg (*318*) (16°–291°) measured the heat capacity of $TlNO_3(c)$. Entropy calculations give $S^\circ_{15.85}=1.39$ (extrapolation), $S^\circ_{298.16}-S^\circ_{15.85}=37.01$ (measured), and $S^\circ_{298.16}=38.4\pm0.2$.

THORIUM

Element.—Lewis and Gibson's (*331*) value for $Th(c)$, with an estimate of the probable uncertainty, is listed, $S^\circ_{298.16}=13.6\pm0.8$. No other pertinent data are available.

TIN

Element.—The heat capacity of ordinary or white $Sn(c)$ was measured by Keesom and van den Ende (*251*) (1.3°–20.2°), Keesom and Kok (*256*) (3.5°–3.9°), Keesom and van Laer (*262*, *263*, *264*) (1°–4°). Lange (*312*) (9°–287°), and Rodebush (*398*) (69°–101°). The entropy is $S^\circ_{298.16}=12.29\pm0.06$. The extrapolation is negligible, about 8×10^{-5} below 1.1°.

Lange (*312*) (15°–284°) also measured the heat capacity of gray $Sn(c)$. There are calculated $S^\circ_{12.60}=0.25$ (extrapolation), $S^\circ_{298.16}-S^\circ_{12.60}=10.50$ (measured), and $S^\circ_{298.16}=10.75\pm0.06$.

Moore's (*364*) compilation of spectroscopic data shows that at 298.16° only two energy states need be considered in computing the entropy of $Sn(g)$. These states have term values of 0 and 1,691.81 cm^{-1} and quantum weights of 1 and 3, respectively. They add 0.016 to the Sackur equation, making $S^\circ_{298.16}=40.25\pm0.01$ for $Sn(g)$.

Stannous ion.—Latimer, Pitzer, and Smith (*325*) reported $S^\circ_{298.16}=-4.9\pm1.0$ for $Sn^{++}(aq.)$, based upon thermal data for the reaction $Sn(c)+2H^+(aq.)=Sn^{++}(aq.)+H_2(g)$.

Oxides.—Millar (*361*) (69°–293°) measured the heat capacity of $SnO(c)$. There are computed $S^\circ_{63.10}=2.07$ (extrapolation), $S^\circ_{298.16}-S^\circ_{63.10}=11.45$ (measured), and $S^\circ_{298.16}=13.5\pm0.3$.

Molecular-constant data for SnO(*g*) listed by Herzberg (*212*) correspond to $I=79.1\times10^{-40}$ and $\omega=819$. There are obtained $S^\circ_{t+r,298.16}=55.267$, $S^\circ_{v,298.16}=0.192$, and $S^\circ_{298.16}=55.46\pm0.10$.

Millar (*361*) (71°–290°) also measured the heat capacity of $SnO_2(c)$. The data yield $S^\circ_{70.80}=1.38$ (extrapolation), $S^\circ_{298.16}-S^\circ_{70.80}=11.11$ (measured) and $S^\circ_{298.16}=12.5\pm0.3$.

Sulfide.—From molecular-constant data listed by Herzberg (*212*), $I=178\times10^{-40}$ and $\omega=487$ for the SnS(*g*) molecule. Calculation gives $S^\circ_{t+r,298.16}=57.22$, $S^\circ_{v,298.16}=0.69$, and $S^\circ_{298.16}=57.9\pm0.3$.

Tetrabromide.—Landolt-Börnstein (*311*) records $I_1=I_2=I_3=2{,}160\times10^{-40}$ for the $SnBr_4(g)$ molecule and the vibration frequencies are 68 (2), 88 (3), 221 (1), and 280 (3), according to the work of Welsh, Crawford, and Scott (*500*). There are computed $S^\circ_{t+r,298.16}=72.17$, $S^\circ_{v,298.16}=26.07$, and $S^\circ_{298.16}=98.2\pm1.0$.

Tetrachloride.—Yost and Blair (*507*) give 3.81 ± 10^{-8} cm. as the Cl–Cl distance in the $SnCl_4(g)$ molecule, corresponding to $I_1=I_2=I_3=855\times10^{-40}$. From the work of Welsh, Crawford, and Scott (*500*), the vibration frequencies are 106 (2), 131 (3), 368 (1), and 403 (3). The calculations yield $S^\circ_{t+r,298.16}=67.86$, $S^\circ_{v,298.16}=19.40$, and $S^\circ_{298.16}=87.3\pm1.0$ for $SnCl_4(g)$. Yost and Blair (*507*) calculated a virtually identical value, 87.2.

From the above entropy value and the entropy of vaporization (*270*), $S^\circ_{298.16}=62.2\pm1.5$ is calculated for $SnCl_4(l)$. Latimer (*314*) obtained $S^\circ_{298.16}=61.8$ from heat-capacity measurements (89°–294°). The agreement is well within the limit of uncertainty of either result.

Telluride.—McAteer and Seltz (*347*) found $\Delta S^\circ_{298.16}=0.0$ for the reaction $Sn(c)+Te(c)=SnTe(c)$. This leads to $S^\circ_{298.16}=24.2\pm1.0$ for SnTe(*c*).

TITANIUM

Element.—The heat capacity of Ti(*c*) was measured by Kelley (*287*) (53°–296°). The entropy calculation yields $S^\circ_{50.12}=0.40$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=6.84$ (measured), and $S^\circ_{298.16}=7.24\pm0.05$.

For Ti(*g*), the compilation of Moore (*364*) shows that three energy levels must be considered in deriving the entropy at 298.16°. The term values are 0, 170.132, and 386.873 cm.$^{-1}$, and the quantum weights are 5, 7, and 9, respectively. These levels add 5.545 to the translational entropy, 37.531, to make $S^\circ_{298.16}=43.08\pm0.01$ for Ti(*g*).

Oxides.—Shomate (*429*) (52°–297°) measured the heat capacity of TiO(*c*). His data yield $S^\circ_{52.00}=0.25$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=8.06$ (measured), and $S^\circ_{298.16}=8.31\pm0.04$.

Molecular-constant (*212*) and spectroscopic (*311*) data for TiO(*g*) are used in obtaining the entropy. The moment of inertia is 52.3×10^{-40} and the vibration frequency is 1,004. Three electronic energy levels with term values 0, 66, and 140 cm.$^{-1}$ are concerned; the quantum weight is 2 in each instance. These figures yield $S^\circ_{t+r,298.16}=52.222$, $S^\circ_{v,298.16}=0.092$, and $S^\circ_{e,298.16}=3.489$. The sum is $S^\circ_{298.16}=55.80\pm0.10$ for TiO(*g*).

The heat capacity of $Ti_2O_3(c)$ was measured by Shomate (*429*) (53°–297°). There are obtained $S^\circ_{52.00}=0.50$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=18.33$ (measured), and $S^\circ_{298.16}=18.83\pm0.09$.

Shomate (*429*) (53°–297°) also measured the heat capacity of $Ti_3O_5(c)$. The data yield $S^\circ_{52.00}=0.97$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=29.95$ (measured), and $S^\circ_{298.16}=30.9\pm0.2$.

McDonald and Seltz (*348*) (68°–296°) and Shomate (*432*) measured the heat capacity of TiO_2 (rutile). There are obtained $S^\circ_{52.00}=0.60$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=11.41$ (measured), and $S^\circ_{298.16}=12.01\pm0.07$.

Shomate (*432*) (52°–296°) also measured the heat capacity of TiO_2 (anatase). His data give $S^\circ_{52.00}=0.50$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=11.43$ (measured), and $S^\circ_{298.16}=11.93\pm0.07$.

Sulfide.—The heat capacity of $TiS_2(c)$ was measured by Todd (*486*) (53°–297°). The data yield $S^\circ_{51.00}=1.38$ (extrapolation), $S^\circ_{298.16}-S^\circ_{51.00}=17.35$ (measured), and $S^\circ_{298.16}=18.73\pm0.15$.

Carbide.—Kelley (*287*) (55°–295°) measured the heat capacity of $TiC(c)$. There are computed $S^\circ_{50.12}=0.08$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=5.71$ (measured), and $S^\circ_{298.16}=5.79\pm0.05$.

Tetrachloride.—Brockway (*55*) and Yost and Blair (*507*) have given dimensions of the $TiCl_4(g)$ molecule that correspond to $I_1=I_2=I_3=767\times10^{-40}$. Herman (*211*), Paramasivan (*382*), and Yost and Blair (*507*) have employed substantially the same set of vibration frequencies, 119(2), 139(3), 386(1), and 491(3). These values yield $S^\circ_{t+r,298.16}=66.59$, $S^\circ_{v,298.16}=17.71$, and $S^\circ_{298.16}=84.3\pm1.0$ for $TiCl_4(g)$. A virtually identical value, 84.4, was calculated by Yost and Blair.

The entropy of vaporization of $TiCl_4(l)$, $\Delta S^\circ_{298.16}=24.0$, was obtained (*270*) from vapor-pressure data. From this and the entropy of the gas, $S^\circ_{298.16}=60.3\pm1.5$ is obtained for $TiCl_4(l)$. Latimer (*314*) found $S^\circ_{298.16}=59.5$ from heat-capacity data (86°–295°). Again, the agreement is within the limit of uncertainty of either value.

Nitride.—The heat capacity of $TiN(c)$ was measured by Shomate (*429*) (52°–297°). The data yield $S^\circ_{52.00}=0.17$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=7.07$ (measured), and $S^\circ_{298.16}=7.24\pm0.04$.

TUNGSTEN

Element.—Lange (*312*) (26°–92°) and Zwikker and Schmidt (*517*) (92°–290°) measured the heat capacity of W (*c*). From the data of the former, which are more reliable, $S^\circ_{25.10}=0.07$ (extrapolation), $S^\circ_{298.16}-S^\circ_{25.10}=7.97$ (measured), and $S^\circ_{298.1.}=8.04\pm0.10$.

Spectroscopic data for W(*g*) (*364*) show that only four energy levels need be considered in deriving the entropy at 298.16°K. The term values are 0, 1,670.27, 2,951.27, and 3,325.70, and the quantum weights are 1, 3, 7, and 5, respectively. These states add 0.017 to the translational entropy, 41.542, making $S^\circ_{298.16}=41.56\pm0.01$.

Oxide.—Seltz, Dunkerley, and DeWitt (*418*) (62°–300°) measured the heat capacity of $WO_3(c)$. Their entropy calculations have been checked to within 0.04 unit. The results are $S^\circ_{62.90}=2.44$ (extrapolation), $S^\circ_{298.16}-S^\circ_{62.90}=17.48$ (measured), and $S^\circ_{298.16}=19.9\pm0.4$.

URANIUM

Element.—Lewis and Gibson (*331*), from Dewar's (*126*) data, give $S^\circ_{298.16}=11.1\pm0.6$ for U(*c*).

Tetrafluoride.—The heat capacity of $UF_4(c)$ was measured by Brickwedde, Hoge, and Scott (*53*) (20°–350°). Their calculations correspond to $S^\circ_{20.00}=0.41$ (extrapolation), $S^\circ_{298.16}-S^\circ_{20.00}=35.71$ (measured), and $S^\circ_{298.16}=36.1\pm0.2$.

Hexafluoride.—Brickwedde, Hoge, and Scott (*53*) (14°–327°) measured the heat capacity of $UF_6(c)$. The data yield $S^\circ_{14.00}=0.99$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.00}=53.46$ (measured), and $S^\circ_{298.16}=54.5\pm0.3$.

Bigeleisen and Mayer (*43*) have listed 130(3), 200(3), 200(3), 511(2), 640(3), and 656(1) as the vibration frequencies of the $UF_6(g)$ molecule and have given 2.0×10^{-8} cm. as the U–F distance. The last-mentioned item corresponds to $I_1=I_2=I_3=505\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=65.79$, $S^\circ_{v,298.16}=24.41$, and $S^\circ_{298.16}=90.2\pm2.0$ for $UF_6(g)$. A virtually identical value, 90.3, was calcuated similarly by Bigeleisen and Mayer, while Weinstock and Crist (*499*) obtained 90.8 from the entropy of the solid and vapor-pressure data.

Uranyl Fluoride.—The heat capacity of $UO_2F_2(c)$ was measured by Wacker and Cheney (*495*) (*13°–300°*). The data give $S^\circ_{13.00}=0.21$ (extrapolation), $S^\circ_{298.16}-S^\circ_{13.00}=32.20$ (measured), and $S^\circ_{298.16}=32.4\pm0.2$.

Uranyl Nitrate.—Coulter, Pitzer, and Latimer (*112*) measured the heat capacity of $UO_2(NO_3)_2\cdot6H_2O(c)$ (13°–299°). The entropy calculations, which have been checked, give $S^\circ_{14.00}=1.89$ (extrapolation), $S^\circ_{298.16}-S^\circ_{14.00}=118.96$ (measured), and $S^\circ_{298.16}=120.8\pm0.5$.

Ions.—Coulter, Pitzer, and Latimer (*112*) obtained $S^\circ_{298.16}=-17\pm5$ for $UO_2^{++}(aq.)$ and $S^\circ_{298.16}=16\pm5$ for $U(OH)_4^{++}(aq)$.

VANADIUM

Element.—Anderson (*18*) (54°–297°) measured the heat capacity of $V(c)$. Calculation gives $S^\circ_{56.20}=0.48$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.20}=6.53$ (measured), and $S^\circ_{298.16}=7.01\pm0.10$.

The entropy of $V(g)$ may be calculated from spectroscopic data listed by Moore (*364*). Nine energy levels are to be considered for which the term values are 0, 137.38, 323.42, 553.02, 2,112.32, 2,153.20, 2,220.13, 2,311.37, and 2,424.89 cm.$^{-1}$. The quantum weights are 4, 6, 8, 10, 2, 4, 6, 8, and 10, respectively. The result is that 5.838 must be added to the Sackur entropy, making $S^\circ_{298.16}=43.55\pm0.01$.

Oxides.—Anderson (*18*) measured the heat capacities of $V_2O_3(c)$ (56°–288°), $V_2O_4(c)$ (61°–280°), and $V_2O_5(c)$ (56°–290°).

For $V_2O_3(c)$, there are obtained $S^\circ_{56.20}=1.03$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.20}=22.50$ (measured), and $S^\circ_{298.16}=23.5\pm0.3$.

Similarly, for $V_2O_4(c)$, $S^\circ_{56.20}=1.23$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.20}=23.29$ (measured), and $S^\circ_{298.16}=24.5\pm0.3$.

The results for $V_2O_5(c)$ are $S^\circ_{56.20}=2.47$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.20}=28.81$ (measured), and $S^\circ_{298.16}=31.3\pm0.5$.

Herzberg (*212*) has listed molecular-constant data for the $VO(g)$ molecule corresponding to $I=72.2\times10^{-40}$ and $\omega=1{,}008$. The quantum weight of the ground state is assumed to be 2. There are computed $S^\circ_{t+r,298.16}=53.091$, $S^\circ_{v,298.16}=0.090$, $S^\circ_{e,298.16}=1.378$, and $S^\circ_{298.16}=54.47\pm0.10$.

Carbide.—The heat capacity of $VC(c)$ was measured by Shomate and Kelley (*436*) (52°–297°). There are obtained $S^\circ_{52.00}=0.02$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=6.57$ (measured), and $S^\circ_{298.16}=6.77\pm0.03$.

Chlorides.—Shomate (*433*) (52°–297°) measured the heat capacity of $VCl_2(c)$. The entropy calculations give $S^\circ_{52.00}=2.93$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=20.30$ (measured), and $S^\circ_{298.16}=23.2\pm0.3$.

Shomate (*433*) (52°–297°) also measured the heat capacity of $VCl_3(c)$. His data yield $S^\circ_{52.00}=4.04$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=27.29$ (measured), and $S^\circ_{298.16}=31.3\pm0.4$.

Nitride.—The heat capacity of $VN(c)$ was measured by Shomate and Kelley (*436*) (52°–297°). Their data give $S^\circ_{52.00}=0.47$ (extrapolation), $S^\circ_{298.16}-S^\circ_{52.00}=8.44$ (measured), and $S^\circ_{298.16}=8.91\pm0.04$.

XENON

Element.—Clusius and Roccobini (*103*) (10°–166°) measured the heat capacity of Xe at low temperatures. The entropy calculation from their data is made somewhat uncertain by the large amount of premelting, indicating lack of purity. The results are $S^\circ_{10.00}=0.82$ (extrapolation), $S^\circ_{161.3}-S^\circ_{10.00}=14.82$ (crystals), $\Delta S^\circ_{161.3}=548.5/161.3=3.40$ (fusion), $S^\circ_{165.13}-S^\circ_{163.1}=0.25$ (liquid), $\Delta S^\circ_{165.13}=3{,}020/165.13=18.29$ (vaporization at 1 atm. pressure), $\Delta S^\circ_{165.13}=0.14$ (correction to ideal gas state), and $S^\circ_{298.16}-S^\circ_{165.13}=2.94$ (gas, $C_p=4.969$). The sum is $S^\circ_{298.16}=40.7\pm0.3$.

A better value for $Xe(g)$ is obtained from the Sackur equation, $S^\circ_{298.16}=40.54\pm0.01$.

YTTERBIUM

Element.—Spectroscopic data listed by Moore (*364*) show that only one energy level (quantum weight=1) need be considered in deriving the entropy of $Yb(g)$ at 298.16°. There is obtained $S^\circ_{298.16}=41.36\pm0.01$.

YTTRIUM

Element.—The entropy of $Y(g)$ is obtainable from the Sackur equation and spectroscopic data (*364*). At 298.16° two states having term values of 0 and 530.5 cm.^{-1} and quantum weights of 4 and 6, respectively, are to be considered. They add 3.502 to the Sackur-equation result, giving $S^\circ_{298.16}=42.88\pm0.01$.

ZINC

Element.—Bronson and Wilson (*58*) (193°–303°), Clusius and Harteck (*100*) (12°–202°), Keesom and van den Ende (*251*) (1.3°–22°), Nernst (*373*) (33°–274°), and Pollitzer (*392*) (76°–210°) measured the heat capacity of $Zn(c)$. Giving the most weight to the data of Clusius and Harteck and of Keesom and van den Ende, $S^\circ_{298.16}=9.95\pm0.05$ is computed. The extrapolation is negligible, about 8×10^{-5} below 1.3°.

At 298.16°, the Sackur equation yields $S^\circ_{298.16}=38.46\pm0.01$ for $Zn(g)$. Only one energy level, having unit quantum weight, is effective.

Zinc Ion.—Latimer, Pitzer, and Smith (*325*) obtained $S^\circ_{298.16}=-25.7\pm1.0$ for $Zn^{++}(aq.)$, from thermal data for the reaction $Zn(c)+2H^+(aq.)=Zn^{++}(aq.)+H_2(g)$. Excellent agreement exists between this value and that reported by Bates (*39*), $S^\circ_{298.16}=-25.9\pm0.5$. The mean, -25.8 ± 0.5, is adopted.

Oxide.—Heat capacity measurements of $ZnO(c)$ were made by Clusius and Harteck (*100*) (30°–200°), Maier, Parks, and Anderson (*345*) (88°–295°), and Millar (*360*) (81°–298°). The combined results yield $S^\circ_{28.20}=0.17$ (extrapolation), $S^\circ_{298.16}-S^\circ_{28.20}=10.26$, and $S^\circ_{298.16}=10.43\pm0.10$.

The vibration frequency of the ZnO(*g*) molecule is 818 (*212*). The interatomic distance is estimated here as 1.8×10^{-8} cm., corresponding to $I=69\times10^{-40}$. There are computed $S^\circ_{t+r,298.16}=53.49$, $S^\circ_{v,298.16}=0.19$, and $S^\circ_{298.16}=53.7\pm0.5$ for ZnO(*g*).

Sulfide.—Clusius and Harteck (*100*) (18°–197°) and Günther (*204*) (21°–59°) measured the heat capacity of ZnS(*c*). Employing only the data of the first-named investigators, there are calculated $S^\circ_{17.80}=0.09$ (extrapolation), $S^\circ_{298.16}-S^\circ_{17.80}=13.68$ (measured), and $S^\circ_{298.16}=13.8\pm0.2$.

Bromides.—Ishikawa and Yoshida (*224*) obtained $\Delta F^\circ_{298.16}=-31{,}442$ and $\Delta H^\circ_{298.16}=-29{,}530$ for the reaction $\mathrm{Zn}(c)+2\mathrm{HgBr}(c)=\mathrm{ZnBr_2}(c)+2\mathrm{Hg}(l)$. The entropy of reaction is $\Delta S^\circ_{298.16}=6.41$, which, in turn, leads to $S^\circ_{298.16}=32.5\pm1.0$ for $\mathrm{ZnBr_2}(c)$. More recently, Bates (*40*), from cell measurements and thermal data, reported $S^\circ_{298.16}=32.95$. The mean, $S^\circ_{298.16}=32.7\pm1.0$, is adopted.

Stevenson (*467*) has suggested molecular constants for the ZnBr(g) molecule, which correspond to $I=308\times10^{-40}$ and $\omega=330$. The quantum weight of the ground state is 2. There are computed $S^\circ_{t+r,298.16}=58.20$, $S^\circ_{v,298.16}=1.26$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=60.8\pm0.5$.

Chlorides.—Elliott and Yost (*142*) have given the heat and free energy of formation of $\mathrm{ZnCl_2}(c)$ as $\Delta H^\circ_{298.16}=-99{,}550$ and $\Delta F^\circ_{298.16}=-87{,}990$. The entropy of formation is $\Delta S^\circ_{298.16}=-38.8$, and the corresponding entropy of $\mathrm{ZnCl_2}(c)$ is $S^\circ_{298.16}=24.5$.

Ishikawa, Kimura, and Murooka (*225*) have studied the reaction $\mathrm{Zn}(c)+2\mathrm{HgCl}(c)=\mathrm{ZnCl_2}(c)+2\mathrm{Hg}(l)$. Their results yield $\Delta S^\circ_{298.16}=6.68$, corresponding to $S^\circ_{298.16}=26.5$ for $\mathrm{ZnCl_2}(c)$.

More recently, Bates (*40*) obtained $S^\circ_{298.16}=25.9$ for $\mathrm{ZnCl_2}(c)$ from cell measurements and thermal data. This value, which intermediates the two above-given results, is adopted and the uncertainty is estimated as ±1.0.

Data listed by Stevenson (*467*) for ZnCl(*g*) correspond to $I=173\times10^{-40}$ and $\omega=390$. There are obtained $S^\circ_{t+r,298.16}=55.96$, $S^\circ_{v,298.16}=1.00$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=58.3\pm0.5$.

Hydride.—Molecular-constant data for ZnH(*g*) listed by Herzberg (*212*) correspond to $I=4.19\times10^{-40}$, $\omega=1{,}552$, and quantum weight of the ground state=2. These values yield $S^\circ_{t+r,298.16}=47.318$, $S^\circ_{v,298.16}=0.008$, $S^\circ_{e,298.16}=1.378$, and $S^\circ_{298.16}=48.70\pm0.10$.

Iodides.—Bates (*40*) also reported $S^\circ_{298.16}=38.5$ for $\mathrm{ZnI_2}(c)$, from cell measurements and thermal data. Again, ±1.0 is estimated as the uncertainty.

The molecular-constant data listed by Stevenson (*467*) for the ZnI(*g*) molecule correspond to $I=434\times10^{-40}$ and $\omega=240$. There are computed $S^\circ_{t+r,298.16}=59.71$, $S^\circ_{v,298.16}=1.80$, $S^\circ_{e,298.16}=1.38$, and $S^\circ_{298.16}=62.9\pm0.5$.

Telluride.—McAteer and Seltz (*347*) obtained $\Delta S^\circ_{298.16}=-2.9$ for the reaction $\mathrm{Zn}(c)+\mathrm{Te}(c)=\mathrm{ZnTe}(c)$. This leads to $S^\circ_{298.16}=18.9\pm1.0$ for ZnTe(*c*).

Carbonate.—Anderson (*16*) (58°–299°) measured the heat capacity of $\mathrm{ZnCO_3}(c)$ (smithsonite). His data give $S^\circ_{56.20}=1.45$ (extrapolation), $S^\circ_{298.16}-S^\circ_{56.20}=18.25$ (measured), and $S^\circ_{298.16}=19.7\pm0.3$.

Sulfates.—Ishikawa and Murooka (*218*) obtained $\Delta H_{298.16}=-56{,}322$ and $\Delta F^\circ_{298.16}=-59{,}209$ for the reaction $Zn(c)+Hg_2SO_4(c)=ZnSO_4(c)+2Hg(l)$, making $\Delta S^\circ_{298.16}=9.68$. This leads to $S^\circ_{298.16}=30.6\pm2$ for $ZnSO_4(c)$.

Barieau (*35*) has measured the heat capacities of $ZnSO_4\cdot6H_2O(c)$ (16°–305°) and $ZnSO_4\cdot7H_2O(c)$ (15°–308°), and Pollitzer (*392*, *393*) (27°–208°) has measured $ZnSO_4\cdot7H_2O(c)$. From Barieau's work, $S^\circ_{298.16}=85.9\pm0.3$ for $ZnSO_4\cdot6H_2O(c)$ and $S^\circ_{298.16}=92.9\pm0.3$ for $ZnSO_4\cdot7H_2O(c)$.

Zinc-Antimony Compounds.—DeWitt and Seltz (*127*) reported $S^\circ_{298.16}=21.4$ for $ZnSb(c)$, $S^\circ_{298.16}=63.6$ for $Zn_3Sb_2(c)$, and $S^\circ_{298.16}=73.5$ for $Zn_4Sb_3(c)$. These values are based upon e. m. f. measurements. The uncertainties are estimated here as ±1.4, ±1.8, and ±2.1, respectively.

ZIRCONIUM

Element.—The heat capacity of $Zr(c)$ was measured by Todd (*486*) (53°–297°). The data yield $S^\circ_{51.00}=1.00$ (extrapolation), $S^\circ_{298.16}-S^\circ_{51.00}=8.28$ (measured), and $S^\circ_{298.16}=9.28\pm0.08$.

Moore's (*364*) compilation of spectroscopic data for $Zr(g)$ shows that at 298.16° three energy levels must be considered in deriving the entropy. The term values are 0, 570.41, and 1,240.84 $cm.^{-1}$, and the quantum weights are 5, 7, and 9, respectively. These states add 3.873 to the Sackur equation to make $S^\circ_{298.16}=43.32\pm0.01$ for $Zr(g)$.

Oxides.—Kelley (*286*) (54°–295°) measured the heat capacity of $ZrO_2(c)$. The data yield $S^\circ_{50.12}=0.44$ (extrapolation), $S^\circ_{298.16}-S^\circ_{50.12}=11.68$ (measured), and $S^\circ_{298.16}=12.12\pm0.08$.

The entropy of $ZrO(g)$ may be calculated from data listed by Herzberg (*212*), which correspond to $I=45.3\times10^{-40}$ and $\omega=933$. Three electronic energy levels are to be considered. They have term values of 0, 292.1, and 605.5 $cm.^{-1}$ and the quantum weight is 2 in each instance. There are computed $S^\circ_{t+r,298.16}=53.479$, $S^\circ_{v,298.16}=0.122$, $S^\circ_{e,298.16}=2.280$, and $S^\circ_{298.16}=55.88\pm0.10$.

Chloride.—The heat capacity of $ZrCl_4(c)$ was measured by Todd (*486*) (52°–297°). His data yield $S^\circ_{51.00}=8.12$ (extrapolation), $S^\circ_{298.16}-S^\circ_{51.00}=36.39$ (measured), and $S^\circ_{298.16}=44.5\pm0.5$.

From data given by Kelley (*270*), the entropy of sublimation of $ZrCl_4(c)$ is $\Delta S^\circ_{298.16}=49.1$. This and the value above result in $S^\circ_{298.16}=93.6\pm2$ for $ZrCl_4$ (g).

Nitride.—Todd (*486*) (53°–297°) measured the heat capacity of $ZrN(c)$. His data give $S^\circ_{51.00}=0.41$ (extrapolation), $S^\circ_{298.16}-S^\circ_{51.00}=8.88$ (measured), and $S^\circ_{298.16}=9.29\pm0.05$.

Silicate.—The heat capacity of $ZrSiO_4(c)$ (zircon) was measured by Kelley (*282*) (52°–259°). The data yield $S^\circ_{50.12}=0.56$ (extrapolation). $S^\circ_{298.16}-S^\circ_{50.12}=19.64$ (measured), and $S^\circ_{298.16}=20.2\pm0.2$.

ELECTRON GAS

The application of the Sackur equation, with *R ln* 2 added for electron spin, to electron gas gives $S^\circ_{298.16}=4.99\pm0.01$.

TABLES OF LOW-TEMPERATURE HEAT CAPACITIES, ENTROPIES, AT 298.16 K.°, AND DATA CONCERNING CHANGES IN STATE

The following tables summarize the available low-temperature heat-capacity data, and data concerning changes in state occurring in the temperature range 0° to 298.16° K. for the elements and inorganic compounds.

Table 7 lists values of the heat capacities read from the smooth curves used in calculating the third-law entropies. These values are given for 10°, 25°, 50°, 100°, 150°, 200°, and 298.16° K. Heat-capacity figures for gases are those obtained by calculation from spectroscopically determined energy levels or molecular constants. Values in parentheses are extrapolations below or above the temperature range of the actual measurements. The asterisk (*) is used to denote substances having "humps" in their heat-capacity curves in the range 0° to 298.16° K. The dagger marks substances undergoing one or more changes in state—sharp transition, fusion, sublimation, and vaporization. The letters *c*, *l*, and *g* denote respectively the crystalline, liquid, and gaseous states, and the symbol *aq.*, placed after chemical formulas of ions and a few other substances, refers to hypothetical, ideal solutions of 1 molal concentration. Table 7 also gives the entropy values at 298.16° obtained by the methods indicated.

Table 8 gives values of the temperatures of changes in state, together with the accompanying heat absorptions in calories per mole. This table includes all the substances marked by the dagger in table 7. The data given are those selected previously in computing the third-law entropies.

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Aluminum:											
Al (*c*)	0.01	0.11	0.91	3.12	4.43	5.16	5.82	6.77±0.02			6.77± 0.02
Al (*g*)									39.31±0.01		39.31± .01
Al^{+++} (*aq.*)										−76 ±10	−76 ±10
Al_2O_3 (*c*)	(.01)	(.05)	.45	3.21	8.00	12.40	18.90	12.5 ± .15			12.5 ± .15
AlO (*g*)									52.14± .10		52.14± .10
$Al_2O_3 \cdot H_2O$ (*c*)	(.02)	(.38)	1.95	7.29	13.91	20.56	31.37	23.15± .10			23.15± .10
$Al_2O_3 \cdot 3H_2O$ (*gibbsite*)	(.04)	(.62)	2.88	10.65	20.38	29.67	44.49	33.5 ± .2			33.5 ± .2
AlCl (*g*)									54.4 ± .5		54.4 ± .5
AlH (*g*)									44.84± .10		44.84± .10
AlD (*g*)									46.28± .10		46.28± .10
$Al(NO_3)_3 \cdot 6H_2O$ (*c*)	(1.69)	(7.57)	23.17	43.88	58.86	73.31	103.5	111.8 ±1.1			111.8 ± 1.1
Al_2SiO_5 (*kyanite*)	(.00)	(.11)	.84	5.64	12.69	19.38	29.10	20.02± .08			20.02± .08
Al_2SiO_5 (*sillimanite*)	(.02)	(.27)	1.79	7.69	14.43	20.48	29.31	22.97± .10			22.97± .10
Al_2SiO_5 (*andalusite*)	(.01)	(.23)	1.51	7.23	14.01	20.19	29.34	22.28± .10			22.28± .10
$Al_2(SO_4)_3$ (*c*)	(.12)	(1.58)	7.41	21.85	34.82	45.68	62.00	57.2 ± .3			57.2 ± .3
$Al_2(SO_4)_3 \cdot 6H_2O$ (*c*)	(.85)	(5.75)	17.15	41.50	63.96	84.10	117.8	112.1 ± .9			112.1 ± .9
Antimony;											
Sb (*c*)	(.06)	(.80)	(2.99)	4.92	5.55	5.82	6.03	10.5 ± .3			10.5 ± .3
Sb (*g*)									43.07± .01		43.07± .01
Sb_2 (*g*)									60.9 ± .2		60.9 ± .2
Sb_2O_3 (*c*)	(.23)	(2.16)	(5.50)	12.02	16.79	20.26	24.23	29.4 ± .6			29.4 ± .6
Sb_4O_6 (*g*)										102	102
Sb_2O_4 (*c*)	(.26)	(2.31)	(5.49)	11.16	17.27	21.75	27.39	30.4 ± .7			30.4 ± .7
Sb_2O_5 (*c*)	(.08)	(1.03)	(3.94)	12.67	18.48	22.73	28.11	29.9 ±1.0			29.9 ± 1.0
Sb_2S_3 (*c*)										39.6	39.6
$SbCl_3$ (*g*)									80.8 ±1.0		80.8 ± 1.0
$SbCl_3$ (*c*)										44.7 ± 2	44.7 ± 2
Argon: A (*g*)†	.90	3.70	5.93(*c*)	4.97(*g*)	4.97	4.97	4.97	36.95± .2	36.99± .01		36.99± .01
Arsenic:											
As (*c*)	(.03)	(.35)	(1.88)	3.99	4.94	5.43	5.89	8.4 ± .2			8.4 ± .2
As (*g*)									41.62± .01		41.62± .01
As_2 (*g*)									57.2 ± .3		57.2 ± .3
As_4(*g*)										69	69
As_2O_3(*c*)	(.25)	(2.16)	(4.77)	9.72	14.45	18.26	22.86	25.6 ± .5			25.6 ± .5
As_4O_6(*g*)										101	101
As_2O_5(*c*)	(.03)	(.50)	(2.62)	9.45	15.87	20.93	27.85	25.2 ± .4			25.2 ± .4
H_2AsO_2(*aq.*)										30.3	30.3
H_3AsO_3(*aq.*)										47.0	47.0
H_3AsO_4(*aq.*)										49.3	49.3
$H_2AsO_4^-$(*aq.*)										28.0 ± 1.0	28.0 ± 1.0

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Arsenic—Continued											
$HAsO_4^{--}$(*aq.*)										0.9	0.9
AsO_4^{---}(*aq.*)										−34.6	−34.6
$AsCl_3$(*g*)									78.2 ±1.0		78.2 ±1.0
$AsCl_3$(*l*)										55.8 ±2	55.8 ±2
AsF_3(*g*)								69.05± .15	69.08± .10		69.08± .10
AsF_3(*l*) †	(.59)	3.94	8.45	13.11	16.39	19.16(*c*)	30.25(*l*)	43.1 ± .1			43.1 ± .1
Barium:											
Ba(*c*)										16.0 ± .5	16.0 ± .5
Ba(*g*)									40.67± .01		40.67± .01
Ba^{++}(*aq.*)										2.3 ± .3	2.3 ± .3
BaO(*c*)	(.07)	(1.06)	(3.81)	7.63	9.55	10.47	11.34	16.8± .3			16.8 ± .3
BaO (*g*)									55.9 ± .5		55.9 ± .5
$Ba(BrO_3)_2 \cdot H_2O$(*c*)	(.65)	5.31	15.08	28.59	37.70	44.00	52.90	68.8±1 .5			68.8 ±1.5
$BaCO_3$ (*witherite*)	(.13)	(1.62)	(5.40)	12.02	15.32	17.41	20.40	26.8 ± .5			26.8 ± .5
$BaCl_2 \cdot 2H_2O$(*c*)	(.37)	3.18	10.19	21.13	27.30	31.64	37.10	48.5 ± .2			48.5 ± .2
BaF_2(*c*)	(.08)	1.09	4.31	10.56	13.97	15.78	17.02	23.03± .10			23.03± .10
BaH(*g*)									52.3 ± .1		52.3 ± .1
$Ba(NO_3)_2$(*c*)	(.45)	4.02	12.02	22.72	27.34	30.50	36.18	51.1 ± .2			51.1 ± .2
$BaSO_4$(*c*)	(.17)	1.98	7.16	13.75	17.30	20.12	24.32	31.6 ± .2			31.6 ± .2
Beryllium:											
Be(*c*)	.00	.01	.05	.41	1.26	2.38	4.26	2.28± .02			2.28± .02
Be(*g*)									32.55± .01		32.55± .01
BeO(*c*)	(.00)	(.02)	.09	.69	1.90	3.42	6.07	3.37 ± .02			3.37± .02
BeO(*g*)									47.17± .10		47.17± .10
BeCl(*g*)									51.81± .10		51.81± .10
BeF(*g*)									49.13± .10		49.13± .10
BeH(*g*)									42.20± .10		42.20± .10
Be_2SiO_4 (*phenacite*)	(.01)	(.10)	.75	4.47	9.55	14.48	22.84	15.37 ± .08			15.37± .08
Bismuth:											
Bi(*c*)	.52	2.43	4.27	5.46	5.83	5.98	6.10	13.6 ± .6			13.6 ± .61
Bi(*g*)									44.68± .01		44.68± .0
Bi_2(*g*)									65.4 ± .2		65.4 ± .2
Bi_2O_3(*c*)	(.49)	(2.95)	(7.33)	15.04	19.48	23.10	27.13	36.2 ± .6			36.2 ± .6
BiBr(*g*)									63.5 ± .5		63.5 ± .5
$BiCl_3$(*g*)									85.3 ±1.0		85.3 ±1.0
$BiCl_3$(*c*)										45.6 ±2	45.6 ±2
BiCl(*g*)									60.9 ± .5		60.9 ± .5
BiI(*g*)										65.4 ± .5	65.4 ± .5
Bi_2S_3										33.8	33.8
BiH(*g*)									51.28± .10		51.28± .10
BiD(*g*)									52.69± .10		52.69± .10

Boron:											
$B(c)$										1.7 ±0.2	1.7 ±0.2
$B(g)$									36.66± .01		36.66± .01
$B_2O_3(c)$	(.03)	(.24)	1.51	4.99	7.98	10.60	14.83	13.04 ± .07			13.04± .07
$BO(g)$									48.60± .10		48.60± .10
$B_4C(c)$	(.00)	(.00)	.10	1.22	3.51	6.57	12.56	6.47 ± .03			6.47± .03
$BBr_3(g)$									77.5 ± .5		77.5 ± .5
$BCl_3(g)$									69.3 ± .5		69.3 ± .5
$BF_3(g)$†	(.75)	3.95	8.52	12.75(*s*)	24.64(*l*)	10.03(*g*)	12.06	60.8 ± .5	60.7 ± .5		60.7 ± .5
$BH(g)$									41.01± .10		41.01± .10
$BI(g)$									42.46± .10		42.46± .10
Bromine:											
$Br_2(l)$†	(.74)	4.12	8.14	10.51	11.75	12.87(*c*)	17.0(*l*)	36.6 ± .5		36.8 ± .4	36.7 ± .4
$Br_2(g)$									58.63± .03		58.63± .03
$Br(g)$									41.81± .01		41.81± .01
$Br^-(aq.)$										19.7 ± .2	19.7 ± .02
$BrO_3^-(aq.)$										38.5 ±1.0	38.5 ±1.0
$BrCl(g)$									57.36± .10	57.4	57.36± .10
$BrF(g)$										54.98± .10	54.98± .10
Cadmium:											
$Cd(c)$	.22	1.71	3.90	5.32	5.73	5.93	6.19	12.34± .10			12.34± .10
$Cd(g)$									40.07± .01		40.07± .01
$Cd^{++}(aq.)$										−15.6 ±1.2	−15.6 ±1.2
$CdO(c)$	(.03)	(.51)	(2.38)	5.76	7.99	9.31	10.38	13.1 ± .3			13.1 ± .3
$CdO(g)$										46.9	46.9
$CdBr_2(c)$										32.0 ±2.0	32.0 ±2.0
$CdBr(g)$									63.1 ± .5		63.1 ± .5
$CdCO_3(c)$										25.2	25.2
$CdCl_2(c)$										31.2 ±2.0	31.2 ±2.0
$CdCl(g)$									60.4 ± .5		60.4 ± .5
$CdH(g)$									50.69± .10		50.69± .10
$Cd(OH)_2(c)$										21	21
$CdI_2(c)$										39.5 ±2.0	39.5 ±2.0
$CdI(g)$									65.0 ± .5		65.0 ± .5
$CdSO_4(c)$										31.3	31.3
$CdSO_4 \cdot H_2O(c)$										39.7	39.7
$CdSO_4 \cdot 8/3\ H_2O(c)$										57.5	57.5
$CdS(c)$										17 ±1	17 ±1
$CdTe(c)$										22.2 ±1.0	22.2 ±1.0
$CdSb(c)$										22.1 ±1.0	22.1 ±1.0
$Cd_3Sb_2(c)$										79.0 ±5	79.0 ±5
Calcium:											
$Ca(c)$	.04	.62	2.60	4.66	5.49	5.91	62.8	99.5 ± .10			9.95± .10
$Ca(g)$									37.00± .01		37.00± .01
$Ca^{++}(aq.)$										−11.4 ± .3	−11.4 ± .3
$CaO(c)$	(.00)	.08	.60	3.86	6.49	8.32	10.23	9.5 ± .2			9.5 ± .2
$CaO(g)$									52.3 ± .3		52.3 ± .3
$3CaO \cdot B_2O_3(c)$	(.05)	(.79)	5.37	17.85	28.15	35.33	44.90	43.9 ± .3			43.9 ± .3
$2CaO \cdot B_2O_3(c)$	(.04)	(.69)	4.38	14.22	21.97	27.50	35.16	34.7 ± .2			34.7 ± .2
$CaO \cdot B_2O_3(c)$	(.04)	(.65)	3.58	10.30	15.32	19.21	24.85	25.1 ± .2			25.1 ± .2
$CaO \cdot 2B_2O_3(c)$	(.04)	(.58)	3.86	11.93	19.55	26.35	37.75	32.2 ± .3			32.2 ± .3
$CaC_2(c)$	(.03)	(.46)	2.29	7.26	10.79	12.92	14.94	16.8 ± .4			16.8 ± .4
$CaCO_3$(*calcite*)	(.05)	.77	3.73	9.35	13.30	15.92	19.57	22.2 ± .2			22.2 ± .2

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Calcium—Continued											
$CaCO_3$(*aragonite*)	(.04)	(.63)	2.94	9.40	13.46	16.01	19.42	21.2 ±0.3			21.2 ± 0.3
$CaCl_2$(*c*)	(.44)	(2.99)	6.04	11.67	14.63	16.07	17.35	27.2 ± .3			27.2 ± .3
CaCl(*g*)									58.0 ± .3		58.0 ± .3
CaF_2(*c*)	(.02)	(.25)	1.62	6.85	11.06	13.60	16.02	16.46 ± .08			16.46± .08
CaF(*g*)									54.8 ±1.0		54.8 ± 1.0
CaH_2(*c*)	(1)							9.9 ±1.0			9.9 ± 1.0
CaH(*g*)									48.18± .10		48.18± .10
$Ca(OH)_2$(*c*)	(2)							17.4 ±1.0			17.4 ± 1.0
$Ca(NO_3)_2$(*c*)*	(.39)	(3.06)	9.26	20.08	25.84	29.89	35.70	46.2 ± .5			46.2 ± .5
$CaC_2O_4 \cdot H_2O$(*c*)	(.11)	1.45	6.04	15.35	22.30	27.66	36.52	37.4 ± .2			37.4 ± .2
$Ca_3(PO_4)_2$(α)	(.08)	1.83	8.62	20.95	35.15	43.55	55.35	57.6 ± .2			57.6 ± .2
$Ca_3(PO_4)_2$(β)	(.10)	1.57	8.14	20.63	34.55	43.00	54.45	56.4 ± .4			56.4 ± .4
CaS(*c*)	(.02)	(.34)	2.02	6.16	8.72	10.09	11.33	13.5 ± .3			13.5 ± .3
$CaSO_3$(*c*)	(.06)	(.82)	3.72	10.50	14.81	17.80	21.92	24.2 ± .2			24.2 ± .2
$CaSO_4$(*insol.*)	(.05)	(.62)	3.86	11.05	15.64	19.11	23.82	25.5 ± .4		24.0 ± 2.0	25.5 ± .4
$CaSO_4$(*sol.* α)	(.06)	(.66)	4.13	11.37	15.85	19.12	23.95	25.9 ± .3			25.9 ± .3
$CaSO_4$(*sol.* β)	(.03)	(.36)	3.87	11.55	15.97	19.18	23.67	25.9 ± .3			25.9 ± .3
$CaSO_4 \cdot \frac{1}{2}H_2O$(α)	(.09)	(1.08)	5.24	13.31	18.61	22.56	28.54	31.2 ± .4			31.2 ± .4
$CaSO_4 \cdot \frac{1}{2}H_2O$(β)	(.10)	(1.18)	5.53	13.57	19.01	23.10	29.69	32.1 ± .4			32.1 ± .4
$CaSO_4 \cdot 2H_2O$(*selenite*)	(.14)	1.60	7.60	19.10	27.52	34.36	44.46	46.4 ± .3			46.4 ± .3
$CaSiO_3$(*wollastonite*)	.04	.47	2.70	7.29	11.81	16.05	20.38	19.6 ± .2			19.6 ± .2
$CaSiO_3$(*pseudowollastonite*)	.04	.55	2.57	8.57	13.41	16.78	20.67	20.9 ± .2			20.9 ± .2
$CaTiO_3$(*perovskite*)	(.03)	(.43)	2.51	8.78	14.35	18.44	23.34	22.4 ± .1			22.4 ± .1
Carbon:											
C(*graphite*)	(.00)	(.04)	.11	.40	.77	1.20	2.06	1.36 ± .02			1.36 ± .02
C(*diamond*)	(.00)	(.00)	(.00)	.06	.25	.58	1.45	.585± .005			.585± .005
C(*g*)									37.76± .01		37.76 ± .01
C_2(*g*)									47.91± .10		47.91 ± .10
CO(*g*)†	(.78)	5.44	10.36(*c*)	6.96(*g*)	6.96	6.96	6.96	46.2	47.31± .01		47.31 ± .01
CO_2(*g*)†	(.18)	2.14	6.09	9.51	11.39(*c*)	7.74(*g*)	8.85	51.11 ± .10	51.05± .05		51.05 ± .05
C_3O_2(*g*)									61.5 ± .5		61.5 ± .5
CS(*g*)									50.28± .10		50.28 ± .10
CS_2(*l*)†	(.60)	4.01	7.77	11.05	13.33(*c*)	17.98(*l*)	18.06	36.2 ± .2			36.2 ± .2
CS_2(*g*)									56.86± .10	57.1 ± .4	56.86 ± .1
COS(*g*)†	(.51)	3.81	7.71	10.51(*c*)	17.26(*l*)	16.94	9.92(*g*)	55.27 ± .10	55.32± .10		55.32 ± .10
CBr_4(*g*)									85.6 ±1.0		85.6 ± 1.0
CCl_4(*l*)†	(.72)	6.81	11.07	16.00	20.29	24.70(*c*)	31.48(*l*)	51.3 ± .2			51.3 ± .2
CCl_4(*g*)								73.7 ± .3	74.3 ± .5		74.0 ± .4
CF_4(*g*)†	(1.19)	6.50	12.07(*c*)	18.64(*l*)	9.59(*g*)	11.24	14.51	62.8 ± .5	62.6 ± .3		62.6 ± .3
$COCl_2$(*g*)†	(.60)	4.79	9.33	13.18(*c*)	24.91(*l*)	23.81(*l*)	14.48(*g*)	67.5	69.1 ± .3		69.1 ± .3
$CSCl_2$(*g*)									70.1 ± .3		70.1 ± .3

$C_2N_2(g)$†	(.29)	2.82	7.02	11.41	14.47	17.45(*c*)	13.56(*g*)	57.64 ± 0.10	57.83 ± 0.10		57.83 ± 0.10
$CN(g)$									48.42 ± .01		48.42 ± .01
$CN^-(aq.)$										28.2	28.2
$CNBr(g)$									59.1 ± .5	59.6	59.1 ± .5
$CNCl(g)$									56.3 ± .5	56.9	56.3 ± .5
$CNF(g)$										54.6 ± .5	54.6 ± .5
$CNI(g)$									61.3 ± .5	61.4	61.3 ± .5
$CP(g)$									51.6 ± .3		51.6 ± .3
$CH_4(g)$†*	(.87)	4.99	7.81(*c*)	12.91(*l*)	7.95(*g*)	8.00	8.54	44.5 ± .2	44.47 ± .10		44.47 ± .10
$H_2CO_3(aq.)$										45.1 ± .7	45.1 ± .7
$HCO_3^-(aq.)$										22.2 ± .8	22.2 ± .8
$CO_3^{--}(aq.)$										−13.0 ± 1.0	−13.0 ± 1.0
$CNO^-(aq.)$										31.1	31.1
$C_2O_4^{--}(aq.)$										9.6 ± 1	9.6 ±1
Cerium:											
$Ce(c)$	(3)								13.8 ± 8		13.8 ± .8
$Ce(g)$										48.09 ± .05	48.09 ± .05
Cesium:											
$Cs(g)$									41.95 ± .01		41.95 ± .01
$Cs(c)$										19.8 ± 1.0	19.8 ± 1.0
$Cs_2(g)$										66.6 ± 1.5	66.6 ± 1.5
$Cs^+(aq.)$										31.8 ± .6	31.8 ± .6
$CsBr(g)$									63.5 ± .5		63.5 ± .5
$CsCl(g)$									61.3 ± .5		61.3 ± .5
$CsH(g)$									51.35 ± .10		51.35 ± .10
$CsI(g)$									65.2 ± .5		65.2 ± .5
$CsClO_4(c)$	(.87)	5.71	12.24	16.80	19.37	21.91	25.93	41.9 ± .2			41.9 ± .2
$CsAl(SO_4)_2{\cdot}12H_2O(c)$	(1.97)	11.96	32.2	62.6	87.0	110.7	148.1	163 ± 5			163 ± 5
Chlorine:											
$Cl_2(g)$†	(.30)	2.89	6.99	10.10	12.20(*c*)	12.95(*l*)	8.07(*g*)	53.31 ± .10	53.31 ± .01	53.0 ± .4	53.31 ± .01
$Cl(g)$									39.46 ± .01		39.46 ± .01
$Cl^-(aq.)$										13.5 ± .1	13.5 ± .1
$Cl_2O(g)$									63.7 ± .3	67.9	63.7 ± .3
$ClO_2(g)$									59.6 ± .5		59.6 ± .5
$ClF(g)$										52.3 ± .5	52.3 ± .5
$ClO^-(aq.)$										10.0 ± 2.0	10.0 ± 2.0
$ClO_2^-(aq.)$										24.5 ± .5	24.5 ± .5
$ClO_3^-(aq.)$										39.4 ± .5	39.4 ± .5
$ClO_4^-(aq.)$										43.6 ± 0.5	43.6 ± .5
Chromium:											
$Cr(c)$	(.01)	(.06)	.47	2.39	3.94	4.81	5.58	5.68 ± .07			5.68 ± .07
$Cr(g)$									41.64 ± .01		41.64 ± .01
$Cr_2O_3(c)$	(.02)	(.14)	1.10	5.78	12.20	18.00	28.38	19.4 ± .3			19.4 ± .3
$Cr_4C(c)$	(.02)	(.32)	2.41	10.38	16.88	21.12	25.89	25.3 ± .2			25.3 ± .2
$Cr_3C_2(c)$	(.01)	(.22)	1.59	7.48	13.36	17.88	23.38	20.35 ± .10			20.35 ± .10
$Cr_7C_3(c)$	(.04)	(.64)	4.81	19.20	31.47	40.10	49.92	48.0 ± .3			48.0 ± .3
$CrCl_2(c)$	(.77)	(3.73)	6.65	11.17	13.98	15.55	16.87	27.7 ± .7		27.3	27.7 ± .7
$CrCl_3(c)$*			4.93	11.98	16.52	19.22	21.53	30.0 ± 1.5		31.0	30.0 ± 1.5
$CrO_4^-(aq.)$										10.5 ± 1.0	10.5 ± 1.0

[1] Heat-capacity data exist only for the temperature range 69°–87°.

[2] Insufficient data. Entropy value based on heat-capacity measurements in the range 21°–86°.

[3] $\overline{C}_p$=4.27 at 48.5°; $\overline{C}_p$=6.14 at 71.6°.

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Cobalt:											
$Co(c)$	0.02	0.12	0.88	3.12	4.52	5.26	5.90	6.86±0.10			6.86±0.10
$Co(g)$									42.89± 0.01		42.89 .01
$CoCl_2(c)$*	(.18)	3.77	4.68	11.04	(14.39)	(16.42)	(18.76)	25.4 ±1.5			25.4 ±1.5
Columbium: $Cb(g)$									44.46± .01		44.46± .01
Copper:											
$Cu(c)$	.01	.24	1.50	3.86	4.91	5.42	5.86	7.97±.02			7.97± .02
$Cu(g)$									39.75± .01		39.75± .01
$Cu_2(g)$										58.0 ± 1.0	58.0 ±1.0
$Cu^{++}(aq.)$										26.5 ± 1.0	26.5 ±1.0
$Cu_2O(c)$	(.57)	(3.46)	(6.54)	9.50	11.32	12.80	14.69	24.1 ±1.5			24.1 ±1.5
$CuO(c)$	(.02)	(.28)	1.51	3.99	6.25	8.45	10.09	10.4 ± .2			10.4 ± .2
$CuCO_3(c)$									17.7		17.7
$CuBr(c)$										22.8 ± 1.0	22.8 ±1.0
$CuBr(g)$									59.2 ± .5		59.2 ± .5
$CuCl(c)$										20.8 ± 1.0	20.8 ±1.0
$CuCl(g)$									56.5 ± .5		56.5 ± .5
$CuF(g)$									54.5 ± .5		54.5 ± .5
$CuH(g)$									46.90± .10		46.90± .10
$CuD(g)$									48.30± .10		48.30± .10
$CuI(c)$	(.40)	2.90	6.54	9.99	11.26	11.89	12.92	23.1 ±.3		24.0 ± 1.0	23.1 ± .3
$CuI(g)$									61.1 ± .5		61.1 ± .5
$Cu_2S(c)$	(.55)	(3.05)	6.96	11.94	14.81	16.45	18.24	28.9 ± .8			28.9 ± .8
$CuS(c)$	(.09)	(1.26)	(3.63)	6.78	8.88	10.12	11.43	15.9 ± .4			15.9 ± .4
$CuSO_4(c)$										25.3	25.3
$CuO \cdot CuSO_4(c)$										34.1	34.1
$CuSO_4 \cdot H_2O(c)$										33.0	33.0
$CuSO_4 \cdot 3H_2O(c)$										52.4	52.4
$CuSO_4 \cdot 5H_2O(c)$										70.2	70.2
Europium: $Eu_2(SO_4)_3 \cdot 8H_2O(c)$	(.65)	(7.46)	(26.5)	60.3	88.4	111.6	146.0	160.6 ±1.6			160.6 ±1.6
Fluorine:											
$F_2(g)$									48.56± .10		48.56± .10
$F(g)$									37.92± .01		37.92± .01
$F^-(aq.)$										−2.3 ± 2	−2.3 ±2
$F_2O(g)$									58.9± 0.3		58.9 ± .3
Gadolinium:											
$Gd^{+++}(aq.)$										−32.5 ± 4	−32.5 ±4
$Gd_2(SO_4)_3 \cdot 8H_2O(c)$*	.60	7.24	25.6	58.9	84.6	107.0	140.5	155.8 ± .4			155.8 ± .4
Gallium:											
$Ga(c)$	(.15)	.84	2.50	4.66	5.48	5.87	(6.21)	10.2 ± .3			10.2 ± .3
$Ga(g)$									40.38± .01		40.38± .01

Germanium:											
Ge(c)*	(.09)	1.12	3.02	3.96	4.83	5.45	(6.24)	10.1 ±.2			10.1 ± .2
Ge(g)									40.11±.01		40.11± .01
GeO(g)									53.55±.10		53.55± .10
GeH_4(g)†*	(.98)	4.12	9.33	12.54(c)	14.64(l)	8.66(g)	10.60(g)	50.9 ±.5	50.6 ±.3		50.6 ± .3
Gold:											
Au(c)	(.12)	1.23	3.50	5.10	5.68	5.89	6.03	11.39±.10			11.39± .10
Au(g)									43.13±.01		43.13± .01
AuH(g)									50.42±.10		50.42± .10
AuD(g)									51.81±.10		51.81± .10
Hafnium:											
Hf(c)*	(.63)	.31	3.90	5.40	5.80	6.00	6.15	13.1 ±.2			13. 1± .2
Hf(g)									44.65±.01		44.65± .01
Helium:											
He(g)									30.13±.01		30.13± .01
He_2(g)									41.54±.10		41.54± .10
Hydrogen:											
H_2(g)								31.3 ±.1	31.22±.01		31.22± .01
HD(g)								34.45±.15	34.35±.10		34.35± .10
D_2(g)								34.63±.10	34.62±.10		34.62± .10
H(g)									27.40±.01		27.40± .01
D(g)									29.46±.01		29.46± .01
H^+(aq.)										0	0
H_2O(l)†	.07	.74	1.90	3.80	5.26	6.74(c)	18.04(l)	16.75±.03	16.75±.03		16.75± .03
H_2O(g)									45.13±.03		45.13± .03
D_2O(l)†	(.03)	.80	1.96	4.05	6.09	8.04(c)	19.70(l)	18.08±.10			18.08± .10
D_2O(g)								47.40	47.33±.10		47.33± .10
HDO(g)										47.6±.2	47.6 ± .2
H_2O_2(g)									55.3 ±1.0		55.3 ±1.0
HBr(g)†*	(.63)	3.39	5.63	10.39	11.24(c)	14.27(l)	6.96(g)	47.63±.15	47.48±.05		47.48± .05
DBr(g)										48.9±.2	48.9 ± .2
HCl(g)†	(.24)	2.13	4.57	9.47	11.42(c)	6.96(g)	6.96(g)	44.47±.15	44.66±.05		44.66± .05
DCl(g)									46.02±.10		46.02± .10
HF(g)									41.49±.05		41.49± .05
DF(g)										42.9±.2	42.9 ± .2
HI(g)†*	(1.00)	4.03	6.64	10.47	10.83	11.42(c)	6.96(g)	49.48±.15	49.33±.05		49.33± .05
DI(g)									50.69±.05		50.69± .05
HN_3(g)									56.8 ±.3		56.8 ± .3
HCN(l)†*	(.12)	1.34	4.21	8.01	10.11	11.90(c)	16.97(l)	26.97±.10			26.97± .10
HCN(g)								47.92±.2	48.20±.10		48.20± .10
DCN(g)									49.14±.10		49.14± .10
HCN(aq.)										30.8	30.8
HCNO(aq.)										43.6	43.6
H_2S(g)†	(.19)	1.88	4.58	9.37	13.46(c)	16.26(l)	8.12(g)	49.10±.10	49.10±.10		49.10± .10
H_2Se(g)									52.8 ±.5		52.8 ± .5
D_2Se(g)									55.1 ±.5		55.1 ± .5
HDSe(g)									55.5 ±.5		55.5 ± .5
H_2Te(g)										56	56
Indium:											
In(c)								13.9 ±.2			13.9 ± .2
In(g)									41.51±.01		41.51± .01
InBr(g)									62.0 ±.5		62.0 ± .5
InCl(g)									59.3 ±.5		59.3 ± .5

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Indium—Continued											
InH(*g*)									49.60±0.10		49.60± 0.10
InI(*g*)									63.8 ± .5		63.8 ± .5
Iodine:											
I_2(*c*)	0.93	5.12	8.79	10.96	11.86	12.42	13.14	27.90±0.10			27.90± .10
I_2(*g*)									62.25± .05		62.25± .05
I(*g*)									43.19± .01		43.19± .01
I^-(*aq.*)										25.3 ± .5	25.3 ± .5
IBr(*g*)									61.8 ± .2		61.8 ± .2
IBr(*c*)										33.0 ± 1.5	33.0 ± 1.5
ICl(*g*)									59.12± .10		59.12± .10
ICl_3(*c*)										41.1 ± .5	41.1 ± .5
IF(*g*)										56.8 ± .2	56.8 ± .2
IO_3^-(*aq.*)										28.0 ± 1.0	28.0 ± 1.0
Iridium:											
Ir(*c*)	(4)							8.7 ± .5			8.7 ± .5
Ir(*g*)									46.26± .01		46.26± .01
Iron:											
Fe(α)	.02	.10	.72	2.88	4.33	5.13	5.97	6.49± .03			6.49± .03
Fe(*g*)									43.11± .01		43.11± .01
Fe^{++}(*aq.*)										−25.9± 1.0	−25.9 ± 1.0
Fe^{+++}(*aq.*)										−61 ± 5	−61 ± 5
FeO(*c*)*	(.02)	(.24)	(1.45)	5.85	10.00	11.73	12.43	14.2 ±2.0		13.4± 1.0	13.4 ± 1.0
Fe_2O_3(*c*)	(.05)	(.77)	(2.86)	7.65	13.42	18.27	25.04	21.5 ± .5			21.5 ± .5
Fe_3O_4(*c*)*	(.06)	(.85)	(3.72)	13.53	22.17	27.85	34.28	35.0 ± .6			35.0 ± .6
$FeBr_2$(*c*)*	(1.42)	3.18	8.21	15.21	(17.48)	(18.69)	(20.07)	34.2 ±2.0			34.2 ± 2.0
Fe_3C(*c*)	(.04)	(.47)	(3.20)	10.42	15.92	21.04	25.33	25.7 ±1.0		23.8	24.2 ± 1.0
$FeCO_3$(siderite)	(.05)	(1.01)	3.66	9.57	13.33	16.08	19.63	22.2 ± .4			22.2 ± .4
$FeCl_2$(*c*)*			5.59	12.18	15.38	16.92	18.24	28.7 ± .5			28.7 ± .5
$FeCr_2O_4$(*c*)*	(.24)	(2.37)	6.46	13.31	18.49	24.16	31.94	34.9 ± .4			34.9 ± .4
FeI_2(*c*)	(.74)	4.22	10.50	16.21	(18.13)	(19.01)	(20.12)	36.8 ±2.0			36.8 ± 2.0
Fe_4N(*c*)										37.4	37.4
Fe_2SiO_4(fayalite)*	(.11)	(1.38)	7.85	13.08	19.43	24.57	31.76	34.7 ± .4			34.7 ± .4
FeS(*c*)	(.05)	(.73)	(2.82)	7.15	9.85	11.33	13.06	16.1 ± .3			16.1 ± .3
FeS_2(pyrite)	(.01)	.09	.72	4.50	8.77	11.77	14.84	12.7 ± .2			12.7 ± .2
Fe_2SO_4(*c*)	(.08)	(1.12)	4.16	10.53	15.22	18.86	24.04	25.7 ± .2			25.7 ± .2
$FeTiO_3$(ilmenite)*	(.05)	(.72)	6.39	9.64	14.77	18.74	23.78	25.3 ± .3			25.3 ± .3
Krypton: Kr(*g*)†	1.46	4.43	6.01	7.55(*c*)	4.97(*g*)	4.97	4.97	39.17± .10	39.20± .01		39.20± .01
Lanthanum:											
La(*c*)	(5)							13.7 ± .8			13.7 ± .8
La(*g*)									43.57± .01		43.57± .01
$La_2Mg_3(NO_3)_{12}\cdot 24H_2O$ (*c*)*	(2.31)	27.36	97.32	211.0	287.6	353.2	483.2	525.2 ±2.6			525.2 ± 2.6

Lead:										
Pb(c)	.66	3.36	5.11	5.83	6.06	6.20	6.39	15.49± .05			15.49 ± .05
Pb(g)									41.90± .01		41.90 ± .01
Pb_2(g)										65.5 ± .5	65. 5 ± .5
Pb^{++}(aq.)										3.9 ± .9	3.9 ± .9
PbO(c) (yellow)	(.23)	1.95	3.99	6.75	8.55	9.84	11.60	16.6 ± .5		17.8 ± 1.0	16.6 ± .5
PbO(g)									57.34± .10	55.9	57.34± .10
PbO_2(c)	(.08)	(1.04)	(3.64)	7.56	10.42	12.56	15.45	18.3 ± .5			18.3 ± .5
Pb_3O_4(c)				20.84	26.98	31.29	35.14	50.5 ±1.6			50.5 ±1.6
$PbBr_2$(c)	(1.11)	5.41	12.00	16.30	17.61	18.31	19.15	38.6 ± .5		33.7	38.6 ± .5
PbBr(g)									65.2 ± .5		65.2 ± .5
$PbCO_3$(cerussite)	(.59)	(3.43)	7.52	13.19	16.08	17.88	20.89	31.3 ± .8			31.3 ± .8
$PbO \cdot PbCO_3$(c)										48.5 ± 1.5	48.5 ±1.5
$PbCl_2$(c)	(.77)	4.37	10.09	14.32	16.24	17.29	18.35	34.0 ±1.0		32.5 ± .5	32.5 ± .5
PbCl(g)									62.3 ± .5		62.3 ± .5
PbF(g)									60.1 ± .5		60.1 ± .5
PbH(g)									52.70± .10		52.70± .10
PbI_2(c)	(6)							41.3		42.2 ± .5	42.2 ± .5
PbI(g)									66.8 ± .5		66.8 ± .5
$Pb_3(PO_4)_2$(c)	(1.20)	7.91	20.15	34.75	44.27	51.71	61.25	84.5 ± .4			84.5 ± .4
PbSe(g)										67.9 ± .5	67.9 ± .5
$PbSiO_3$(c)	(.34)	(2.72)	6.40	11.39	15.20	18.15	22.43	28.7 ± .3			28.7 ± .3
PbS(galena)	(.37)	(2.88)	6.18	9.41	10.65	11.25	11.83	21.8 ± .5			21.8 ± .5
PbS(g)									60.18± .10		60.18± .10
$PbSO_4$(c)	(.36)	(3.48)	8.82	14.62	18.02	20.70	24.93	35.2 ± .9			35.2 ± .9
$PbSO_4 \cdot PbO$(c)										48 ± 2	48 ±2
$PbSO_4 \cdot 2PbO$(c)										64 ± 2.5	64 ±2.5
$PbSO_4 \cdot 3PbO$(c)										79 ± 3	79 ±3
PbTe(c)										26.4 ± .7	26.4 ± .7
PbTe(g)										68.6 ± .5	68.6 ± .5
Lithium:											
Li(c)	(.03)	.17	1.00	3.05	4.26	4.92	5.65	6.70± .06			6.70± .06
Li(g)									33.15± .01		33.15± .01
Li_2(g)									46.98± .10		46.98± .10
Li^+(aq.)										4.7 ± 1.0	4.7 ±1.0
LiBr(g)									53.8 ± .5		53.8 ± .5
Li_2CO_3(c)	(.04)	.46	2.78	8.33	13.31	17.32	23.28	21.60± .10			21.60± .10
LiCl(c)										13.9 ± .5	13.9 ± .5
LiCl(g)									51.0 ± .5		51.0 ± .5
LiF(c)	(.00)	.05	.46	3.04	5.82	7.63	9.44	8.32± .08			8.32± .08
LiF(g)										49.2 ± .5	49.2 ± .5
LiH(c)	(.00)	(.03)	(.23)	1.66	4.03	5.79	8.28	5.9 ± .5			5.9 ± .5
LiH(g)									40.77± .10		40.77± .10
LiD(g)									42.32± .10		42.32± .10
LiOH(c)										12.8 ± 1.0	12.8 ±1.0
LiI(g)									55.7 ± .5		55.7 ± .5
LiNa(g)										52.3 ± .5	52.3 ± .5
LiK(g)										54.6 ± .5	54.6 ± .5

[4] $\bar{C}_p$=1.77 at 48.5°.

[5] $\bar{C}_p$=4.24 at 48.5°.

[6] Insufficient data; third-law entropy based on heat-capacity measurements in the range 22°-96°.

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Lithium—Continued:											
$LiRb(g)$										56.4 ±1.0	56.4 ±1.0
$LiCs(g)$										58.2 ±1.0	58.2 ±1.0
Magnesium:											
$Mg(c)$	0.01	0.19	1.41	3.77	4.90	5.38	5.71	7.77± .05			7.77± .05
$Mg(g)$									35.51± .01	35.3	35.51± .01
$Mg^{++}(aq.)$										−32.7 ±1.0	−32.7 ±1.0
$MgO(c)$	(.00)	.03	.22	2.04	4.48	6.52	9.03	6.55± .15			6.55± .15
$MgO(g)$									50.7 ± .2		50.7 ± .2
$MgBr(g)$									57.8 ± .5		57.8 ± .5
$MgCO_3$(magnesite)	(.01)	(.17)	(1.14)	5.93	10.50	13.85	18.05	15.7 ± .2			15.7 ± .2
$MgCl_2(c)$	(.07)	(.88)	3.66	9.65	13.25	15.19	16.98	21.4 ± .2			21.4 ± .2
$MgCl_2 \cdot H_2O(c)$	(.12)	(1.51)	5.83	14.15	19.79	23.38	27.55	32.8 ± .5			32.8 ± .5
$MgCl_2 \cdot 2H_2O(c)$	(.16)	(1.95)	7.55	18.00	25.47	30.90	38.05	43.0 ± .5			43.0 ± .5
$MgCl_2 \cdot 4H_2O(c)$	(.25)	(3.02)	11.24	25.62	36.62	45.37	57.66	63.1 ± .7			63.1 ± .7
$MgCl_2 \cdot 6H_2O(c)$*	(.40)	(4.67)	16.89	36.69	49.35	60.24	75.30	87.5 ±1.0			87.5 ±1.0
$MgCl(g)$									55.0 ± .5		55.0 ± .5
$MgCr_2O_4(c)$	(.06)	(.74)	2.92	8.25	15.31	21.74	30.30	25.3 ± .2			25.3 ± .2
$MgF_2(c)$	(.01)	(.21)	1.33	5.20	9.00	11.66	14.72	13.68 ± .07			13.68± .07
$MgF(g)$									52.8 ± .5		52.8 ± .5
$MgH(g)$									46.11 ± .10		46.11± .10
$MgD(g)$									47.58 ± .10		47.58± .10
$Mg(OH)_2(c)$	(.02)	.18	1.18	5.15	9.80	13.60	18.43	15.09 ± .05			15.09± .05
$MgI(g)$									59.9 ± .5		59.9 ± .5
$Mg(NO_3)_2(c)$	(.20)	(2.05)	6.92	16.80	22.97	27.27	33.92	39.2 ± .4			39.2 ± .4
$MgSiO_3$(*clinoenstatite*)	(.01)	(.20)	1.33	5.72	10.42	14.29	19.62	16.22 ± .10			16.22± .10
$Mg_2SiO_4(c)$	(.02)	(.25)	1.57	7.74	14.81	20.61	28.18	22.75 ± .2			22.75± .2
$MgSO_4(c)$	(.03)	(.48)	2.64	8.71	13.64	17.54	23.06	21.9 ± .2			21.9 ± .2
$MgTiO_3(c)$	(.01)	(.15)	1.19	6.08	11.72	16.23	21.93	17.82 ± .10			17.82± .10
Manganese:											
$Mn(\alpha)$*	(.01)	(.17)	1.16	3.52	4.79	5.51	6.29	7.59 ± .04			7.59± .04
$Mn(\gamma)$	(.01)	(.18)	1.21	3.54	4.88	5.64	6.59	7.72 ± .04			7.72± .04
$Mn(g)$									41.50 ± .01		41.50± .01
$Mn^{++}(aq.)$										−19.1 ± .6	−19.1 ± .6
$MnO(c)$*	(.04)	(.54)	(2.50)	7.88	7.98	9.10	10.27	14.4 ± .6			14.4 ± .6
$MnO(g)$									53.0 ±1.5		53.0 ±1.5
$MnO_2(c)$*	(.02)	(.25)	1.50	5.18	7.34	9.68	12.91	12.68 ± .10			12.68± .10
$Mn_2O_3(c)$										22.9	22.9
$Mn_3O_4(c)$	(.06)	(.99)	(5.18)	14.41	21.95	27.37	33.29	35.5 ± .7			35.5 ± .7
$Mn_3C(c)$	(.04)	(.54)	3.06	10.13	15.06	18.36	22.33	23.6 ± .2			23.6 ± .2
$MnCO_3$(*rhodochrosite*)	(.03)	(.60)	2.86	8.64	12.82	15.61	19.48	20.5 ± .3			20.5 ± .3
$MnCl_2(c)$	(.13)	(1.54)	5.07	11.31	14.50	16.04	17.45	28.0 ± .5			28.0 ± .5

MnF_2(*c*)*	(.20)	1.83	5.79	8.47	11.73	13.88	16.24	22.25 ± .10	----	----	22.25± .10
MnSe(*c*)*	(.08)	(1.22)	5.05	10.48	11.85	12.62	12.20	21.7 ± .4	----	----	21.7 ± .4
$MnSiO_3$(*c*)	(.06)	(.88)	3.34	8.42	12.75	16.04	20.66	21.3 ± .2	----	----	21.3 ± .2
MnS(*c*)*	(.05)	(.74)	(3.46)	9.41	11.91	11.39	11.94	18.7 ± .4	----	----	18.7 ± .4
$MnSO_4$(*c*)	(.11)	(1.34)	4.70	11.26	15.75	19.09	24.02	26.8 ± .2	----	----	26.8 ± .2
MnTe(*c*)*	(.15)	(1.69)	5.47	10.07	12.05	13.34	17.40	22.4 ± .4	----	----	22.4 ± .4
MnS_2O_6	----	----	----	----	----	----	----	----	----	45	45
$MnS_2O_6.2H_2O$(*c*)	(.56)	(3.86)	12.68	27.11	38.06	46.34	57.63	66.7 ± .8	----	----	66.7 ± .8
$MnS_2O_6.6H_2O$(*c*)	----	----	----	----	----	----	----	----	----	110	110
MnO_4^-(*aq.*)	----	----	----	----	----	----	----	----	----	46.7 ± .4	46.7 ± .4
Mercury:											
Hg(*l*)†	1.10	3.15	5.02	5.90	6.27	6.57 (*c*)	6.65 (*l*)	18.53 ± .10	----	----	18.53± .10
Hg(*g*)	----	----	----	----	----	----	----	----	41.80± .01	----	41.80± .01
Hg_2(*g*)	----	----	----	----	----	----	----	----	----	66.0 ± 1.0	66.0 ± 1.0
Hg_2^{++}(*aq.*)	----	----	----	----	----	----	----	----	----	17.7 ± 3	17.7 ± 3
HgO(*c*)(*red*)	(.19)	1.94	4.31	6.89	8.39	9.46	10.93	16.6 ±1.0	----	----	16.6 ± 1.0
HgO(*c*)(*yellow*)	----	----	----	----	----	----	----	----	----	17.7 ± .5	17.7 ± .5
HgBr(*c*)	----	----	----	----	----	----	----	----	----	26.6 ± .5	26.6 ± .5
HgBr(*g*)	----	----	----	----	----	----	----	----	64.9 ± .5	----	64.9 ± .5
$HgBr_2$(*g*)	----	----	----	----	----	----	----	----	74.7 ±1.0	----	74.7 ± 1.0
$HgBr_2$(*c*)	----	----	----	----	----	----	----	----	----	38.9	38.9
HgCl(*c*)	(.48)	3.52	7.81	9.44	10.67	11.38	12.15	23.0 ± .7	----	23.5 ± .5	23.5 ± .5
HgCl(*g*)	----	----	----	----	----	----	----	----	62.2 ± .5	----	62.2 ± .5
$HgCl_2$(*g*)	----	----	----	----	----	----	----	----	70.3 ±1.0	----	70.3 ± 1.0
$HgCl_2$(*c*)	----	----	----	----	----	----	----	----	----	34.5	34.5
HgF(*g*)	----	----	----	----	----	----	----	----	----	58.6 ± 1.0	58.6 ± 1.0
HgH(*g*)	----	----	----	----	----	----	----	----	52.41± .10	----	52.41± .10
HgD(*g*)	----	----	----	----	----	----	----	----	52.87± .10	----	53.87± .10
HgI(*g*)	----	----	----	----	----	----	----	----	67.1 ± .5	----	67.1 ± .5
HgI_2(*g*)	----	----	----	----	----	----	----	----	78.7 ± 1.0	----	78.7 ± 1.0
HgI_2(*c*)	----	----	----	----	----	----	----	----	----	40.8	40.8
Hg_2SO_4(*c*)	(.80)	6.77	12.20	18.95	23.02	26.44	31.55	48.0 ± .5	----	47.9	48.0 ± .5
Molybdenum:											
Mo(*c*)	(.01)	.13	.94	3.19	4.49	5.10	5.61	6.83± .05	----	----	6.83± .05
Mo(*g*)	----	----	----	----	----	----	----	----	43.47± .01	----	43.47± .01
MoO_3(*c*)	(.06)	(.88)	(3.16)	7.31	11.04	13.79	17.57	18.7 ± .3	----	----	18.7 ± .4
MoS_2(molybdenite)	(.02)	(.33)	1.85	5.72	9.79	12.57	15.19	15.0 ± .2	----	----	15.0 ± .2
MoS_3(*c*)	----	----	----	----	----	----	----	----	----	15. 9± 1.0	15.9 ± 1.0
Neon: Ne(*g*)†	1.48 (*c*)	----	----	----	----	----	4.97(*g*)	35.01± .10	34.95± .01	----	34.95± .01
Nickel:											
Ni(*c*)	.01	.13	.99	3.24	4.64	5.38	6.16	7.12± .05	----	----	7.12± .05
Ni(*g*)	----	----	----	----	----	----	----	----	43.53± .01	----	43.53± .01
NiO(*c*)	(.01)	(.11)	(.78)	3.43	5.87	8.04	10.60	9.24± .10	----	----	9.24± .10
$Ni(CO)_4$(*g*)	----	----	----	----	----	----	----	----	97.0 ± 2	----	87.0 ± 2
$NiCl_2$(*c*)	(.25)	1.53	5.40	11.50	(14.94)	(16.68)	(18.57)	25.6 ± 1.0	----	----	25.6 ± 1.0
Nitrogen:											
N_2(*g*)†	(1.06)	6.50	9.92(c)	6.96(*g*)	6.96	6.96	6.96	45.93± .15	45.77± .01	----	45.77± .01
N(*g*)	----	----	----	----	----	----	----	----	36.62± .01	----	36.63± .01
N_2O(*g*)†	(.23)	2.49	6.56	9.92	12.18(*c*)	8.04(*g*)	9.23	51.43± .10	52.55± .03	----	52.55± .03
NO(*g*)†	(.28)	2.36	5.09	8.61(*c*)	7.44(*g*)	7.27	7.13	49.71± .10	50.34± .01	----	50.34± .01
NO_2(*g*)	----	----	----	----	----	----	----	----	57.46± .03	----	57.46± .03
N_2O_4(*g*)†	(.33)	3.20	8.70	14.51	18.35	21.92(*c*)	18.88(*g*)	72.7 ± .2	----	----	72.7 ± 2
N_2O_5(*c*)	----	----	----	15.11	21.63	26.07	(34.2)	36.6 ± 2	----	----	36.6 ± 2

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Nitrogen:—Continued											
$N_2O_5(g)$										82	82
$HNO_3(l)$†	(0.22)	1.93	5.86	10.06	12.37	14.70 (*c*)	26.26 (*l*)	37.19 ± .10			37.19± .10
$HNO_3(g)$								63.62 ± .2			63.62± .2
$HNO_3 \cdot H_2O(l)$†	(.20)	1.98	6.35	12.35	15.87	18.77 (*c*)	43.60 (*l*)	51.84 ± .1			51.84± .1
$HNO_3 \cdot 3H_2O(l)$†	(.34)	3.28	10.49	20.37	27.12	33.22 (*c*)	77.71 (*l*)	82.93 ± .2			82.93± .2
$H_2N_2O_2(aq.)$										52	52
$NO_3^-(aq.)$										35.0 ± .2	35.0 ± .2
$NO_2^-(aq.)$										29.9 ± 1.0	29.9 ± 1.0
$HN_2O_2^-(aq.)$										34	34
$N_2O_2^{--}(aq.)$										6.6	6.6
$NOBr(g)$										65.2 ± .2	65.2 ± .2
$NOCl(g)$										63.0 ± .3	63.0 ± .3
$NH_3(g)$†	(.06)	.66	2.66	6.25	9.27 (*c*)	17.58 (*l*)	8.48 (*g*)	45.96 ± .10	45.98 ± .03		45.98± .03
$NH_4^+(aq.)$										26.4 ± .5	26.4 ± .5
$NH(g)$									43.26 ± .10		43.26± .10
$NH_4Cl(c)$*	(.05)	.64	3.67	9.00	12.32	16.39	20.71	23.6 ± 1.0		23.9 ± 2.0	23.6 ± 1.0
$NH_4HCO_3(c)$										28.3 ± 2.0	28.3 ± 2.0
$NH_4HCO_3(aq.)$										49.7	49.7
$(NH_4)_2CO_3(aq.)$										41.2	41.2
$NH_4OH(aq.)$										42.8 ± .4	42.8 ± .4
$NH_4HS(c)$										27.1 ± 2.0	27.1 ± 2.0
$NH_4H_2AsO_4(c)$*	(.24)	2.48	7.10	15.98	22.95	29.02	36.13	41.12 ± .10			41.12± .10
$NH_4H_2PO_4(c)$*	(.12)	1.72	6.00	14.16	31.50	25.56	34.01	36.32 ± .10			36.32± .10
$(NH_4)_2SO_4(c)$*	(.26)	(2.54)	8.24	18.98	29.22	44.00	44.81	52.6 ± .3			52.6 ± .3
$NH_4VO_3(c)$	(.24)	(2.20)	5.48	13.24	19.47	24.18	30.91	33.6 ± .3			33.6 ± .3
$NH_4Al(SO_4)_2(c)$	(.10)	(1.37)	6.82	20.26	31.70	40.94	54.12	51.7 ± .3			51.7 ± .3
$NH_4Al(SO_4)_2 \cdot 12H_2O(c)$†	(.90)	(9.75)	28.42	62.60	91.16	117.4	163.3	166.6 ± 1.0			166.6 ± 1.0
$(NH_4)_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$ (*c*)	(.40)	(4.75)	20.10	59.67	99.50	134.0	185.3	164.2 ± 1.0			164.2 ± 1.0
Osmium:											
$Os(c)$	(7)							7.8 ± .5			7.8 ± .5
$Os(g)$									46.01± .01		46.01± .01
$OsO_4(g)$									65.6 ± .3		65.6 ± .3
$OsO_4(c)$ (*yellow*)										29.7 ± 1.0	29.7 ± 1.0
$OsO_4(c)$ (*white*)										34.7 ± 2.0	34.7 ± 2.0
Oxygen:											
$O_2(g)$†	(.60)	5.30	11.01 (*c*)	6.96(*g*)	6.96	6.96	7.02	49.10 ± .10	49.01± .01		49.01± .01
$O(g)$									38.48± .01		38.48± .01
$O_3(g)$									56.85± .10		56.85± .10
$OH(g)$									43.90± .02		43.90± .02
$OH^-(aq.)$										−2.49 ± .06	2.49± .06

Palladium:											
Pd(c)	(.08)	.41	1.97	4.27	5.30	5.79	6.21	9.03± .05			9.03± .05
Pd(g)									39.92± .01		39.29± .01
Phosphorus:											
P_2(g)									52.11± .10		52.11± .10
P_4(g)									66.85± .5		66.85± .5
P(g)									38.99± .01		38.99± .01
P(c) (*white*)										10.6 ± .5	10.6 ± .5
P(c) (*violet*)										7.4 ± .5	7.4 ± .5
P(c) (*black*)										5.3 ± .5	5.3 ± .5
PO(g)									53.15± .10		53.15± .10
PBr_3(g)									83.3 ±1.0		83.3 ± 1.0
PCl_3(g)									74.6 ±1.0		74.6 ± 1.0
PCl_3(l)										52.1 ± 2.0	52.1 ± 2.0
PCl_5(g)										84.3 ± 2.0	84.3 ± 2.0
PF_3(g)									64.1 ± .3		64.1 ± .3
PH_3(g)†	(.32)	2.66	10.80	11.18(c)	14.53(l)	8.11(g)	8.90	50.35± .10	50.37± .2		50.35± .10
PH(g)									46.9 ± .2		46.9 ± .2
PN(g)									50.43± .10		50.43± .10
$POCl_3$(g)									77.6 ±1.0		77.6 ± 1.0
$PSCl_3$(g)									79.3 ±1.0		79.3 ± 1.0
PH_4I(c)				12.74	16.57	19.07	26.16	32.1 ± .2			32.1 ± 2
H_3PO_4(aq.)										37.6 ± 1.0	37.6 ± 1.0
$H_2PO_4^-$(aq.)										21.6 ± .3	21.6 ± .3
HPO_4^{--}(aq.)										−8.7 ± 1.0	−8.7 ± 1.0
PO_4^{---}(aq.)										−52 ± 2	−52 ±2
Platinum:											
Pt(c)	.05	.65	2.54	4.70	5.52	5.93	6.35	10.00± .05			10.00± .05
Pt(g)									45.97± .01		45.97± .01
PtS(c)										12.2	12.2
PtS_2(c)										17.4	17.4
$PtCl_6^{--}$(aq.)										53.2 ± 2	53.2 ±2
Potassium:											
K(c)	(.49)	3.01	4.98	5.88	6.24	6.49	6.97	15.2 ± .2			15.2 ± .2
K(g)									38.30± .01		38.30± .01
K_2(g)									59.55± .10		59.55± .10
K^+(aq.)										24.2 ± .2	24.2 ± .2
KBr(c)			(8.34)	10.08	11.10	11.82	12.82	22.4 ±1.0		22.6 ± .5	22.6 ± .5
KBr(g)									59.9 ± .5		59.9 ± .5
KCl(c)	.10	1.30	5.04	9.38	10.89	11.58	12.31	19.76± .07		19.5 ± .5	19.76± .07
KCl(g)									57.2 ± .5	57.6	57.2 ± .5
KF(g)										55.4 ± 1.0	55.4 ± 1.0
KH(g)									47.26± .10		47.26± .10
KI(c)										24.1 ± .5	24.1 ± .5
KI(g)									61.7 ± .5		61.7 ± .5
$KBrO_3$(c)	(.26)	2.74	8.69	15.53	19.19	21.70	25.07	35.7 ± .2			35.7 ± .2
$KClO_3$(c)	(.21)	2.74	8.79	15.11	17.96	20.34	23.96	34.2 ± .2			34.2 ± .2
$KClO_4$(c)	(.46)	2.94	9.41	15.52	18.55	21.13	26.33	36.1 ± .2			36.1 ± .2
KIO_3(c)	(.30)	2.89	8.75	15.68	19.63	22.18	25.42	36.2 ± .2			36.2 ± .2
KNO_2(c)	(.18)	2.08	7.71	14.46	16.15	19.10	23.01	31.81± .15			31.81± .15

† $\bar{C}_p$=1.37 at 48.5°.

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Potassium—Continued											
$KMnO_4(c)$	(.59)	4.32	10.38	16.83	20.94	23.99	28.10	41.0 ±0.2			41.0 ± 0.2
$K_2SO_4(c)$	(.20)	(2.40)	9.95	18.83	23.19	26.34	31.08	42.0 ± .4			42.0 ± .4
$KAl(SO_4)_2(c)$	(.24)	(2.46)	8.27	19.50	28.33	35.51	46.12	48.9 ± .4			48.9± .4
$KAl(SO_4)_2 \cdot 12H_2O(c)$†	(1.13)	(11.85)	31.20	62.95	88.61	112.5	155.6	164.3 ±2.0			164.3 ± 2.0
$K_2O \cdot 3Al_2O_3 \cdot 5SO_3 \cdot 9H_2O(c)$	(.95)	(8.65)	30.39	80.82	128.6	174.3	251.9	222.8 ±1.6			222.8 ± 1.6
$K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$ (c) (*natural*)	(.20)	(2.90)	17.11	55.74	93.94	126.5	178.1	152.2 ± .9			152.2 ± .9
$K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O(c)$ (*synthetic*)	(.25)	(3.45)	17.86	56.69	95.44	129.8	183.3	156.8 ± .9			156.8 ± .9
$KH_2AsO_4(c)$*	(.19)	2.07	7.48	15.62	20.21	24.05	30.29	37.08 ± .10			37.08± .10
$KH_2PO_4(c)$*	(.10)	1.40	6.19	13.82	17.94	21.49	27.86	32.23 ± .10			32.23± .10
$K_2PtCl_6(c)$	(1.18)	8.74	20.37	34.32	41.19	45.15	49.26	79.8 ± .4			79.8 ± .4
KRb (*g*)										62.7 ± 1.0	62.7 ± 1.0
KCs (*g*)										64.5 ± 1.0	64.5 ± 1.0
Radium: Ra (*g*)									42.16 ± .01		42.16± .01
Radon: Rn (*g*)									42.10 ± .01		42.10± .01
Rhenium: Re (*g*)									45.14 ± .01		45.14± .01
Rhodium:											
Rh (*c*)	(8)							7.6 ± .5			7.6 ± .5
Rh (*g*)									44.40 ± .01		44.40± .01
Rubidium:											
Rb (*g*)									40.64 ± .01		40.64± .01
Rb (*c*)										16.6 ± 1.0	16.6 ± 1.0
$Rb_2(g)$										63.1 ± 1.5	63.1 ± 1.5
$Rb^+(aq.)$										28.7 ± .7	28.7 ± .7
RbBr(*g*)									62.1 ± .5		62.1 ± .5
RbCl(*g*)									59.6 ± .5		59.6 ± .5
$RbClO_3(c)$	(.33)	3.01	9.53	15.81	18.81	21.12	24.66	36.3 ± .4			36.3 ± .4
RbF(*g*)										57.2 ± 1.0	57.2 ± 1.0
RbH(*g*)									49.81± .10		49.81± .10
RbI(*g*)									63.8 ± .5		63.8 ± .5
Ruthenium:											
Ru(*c*)	(9)							6.9 ± .5			6.9 ± .5
Ru(*g*)									44.58± .01		44.58± .01
$RuS_2(c)$										12.5	12.5
Samarium: $Sm_2(SO_4)_2 \cdot 8H_2O(c)$	.70	7.67	27.40	62.30	88.00	109.2	144.9	160.9 ± .5			160.9 ± .5
Scandium: Sc(*g*)									41.77± .01		41.77± .01
Selenium:											
Se(*c*)	(.18)	(1.11)	2.52	4.36	5.19	5.61	5.92	10.0 ± .3			10.0 ± .3
Se(*g*)									42.22± .01		42.22± .01

$Se_2(g)$	----	----	----	----	----	----	----	----	60.3 ± .3	----	60.3 ± .3
$Se^{--}(aq.)$	----	----	----	----	----	----	----	----	----	41.5	41.5
$SeO(g)$	----	----	----	----	----	----	----	----	----	56.0 ± 1.0	56.0 ± 1.0
$SeF_6(g)$	----	----	----	----	----	----	----	----	75.1 ±1.0	----	75.1 ± 1.0
$H_2SeO_4(aq.)$	----	----	----	----	----	----	----	----	----	5.7	5.7
$HSeO_4^-(aq.)$	----	----	----	----	----	----	----	----	----	22.0	22.0
$SeO_4^{--}(aq.)$	----	----	----	----	----	----	----	----	----	5.7	5.7
$H_2SeO_3(aq.)$	----	----	----	----	----	----	----	----	----	45.7	45.7
$HSeO_3^-(aq.)$	----	----	----	----	----	----	----	----	----	30.4	30.4
$SeO_3^{--}(aq.)$	----	----	----	----	----	----	----	----	----	3.9	3.9
$H_2Se(aq.)$	----	----	----	----	----	----	----	----	----	39.9	39.9
$HSe^-(aq.)$	----	----	----	----	----	----	----	----	----	50.6	50.6
Silicon:											
$Si(c)$	(.00)	.06	.48	1.74	2.87	3.74	4.73	4.50 ± .05	----	----	4.50± .05
$Si(g)$	----	----	----	----	----	----	----	----	40.13± .01	----	40.13± .01
SiO_2(*quartz*)	(.03)	.38	1.38	3.72	5.97	7.82	10.62	10.00 ± .10	----	----	10.00± .10
SiO_2(*cristobalite*)	(.05)	.58	1.56	3.80	6.03	7.86	10.56	10.20 ± .10	----	----	10.20± .10
SiO_2(*tridymite*)	(.05)	(.58)	1.60	3.90	6.14	7.97	10.66	10.4 ± .2	----	----	10.4 ± .2
SiO_2(*glass*)	.06	.56	1.63	3.86	5.89	7.75	10.60	11.2 ± .4	----	----	11.2 ± .4
$SiO(g)$	----	----	----	----	----	----	----	----	50.55± .10	----	50.55± .10
$SiBr_4(g)$	----	----	----	----	----	----	----	----	90.3 ±1.0	----	90.3 ± 1.0
$SiC(c)$	(.00)	(.00)	.10	1.02	2.42	3.89	6.37	3.95 ± .02	----	----	3.95± .02
$SiCl_4(g)$	----	----	----	----	----	----	----	----	79.2 ±1.0	----	79.2 ± 1.0
$SiCl_4(l)$†	----	----	----	20.65	26.21	31.94(*c*)	34.73 (*l*)	57.2 ±2.0	----	57.4 ± 2.0	57.3 ± 2.0
$SiF_4(g)$	----	----	----	----	----	----	----	----	65.2 ± .5	----	67.2 ± .5
$SiF(g)$	----	----	----	----	----	----	----	----	52.7 ±1.5	----	52.7 ± 1.5
$SiH_4(g)$†	(.56)	3.27	8.41(*c*)	14.46 (*l*)	14.77	8.50(*g*)	10.24	48.7 ± .2	48.7 ± .2	----	48.7 ± .2
$SiH(g)$	----	----	----	----	----	----	----	----	48.28± .10	----	48.28± .10
$Si_3N_4(c)$	----	----	----	----	----	----	----	----	----	22.8	22.8
$SiN(g)$	----	----	----	----	----	----	----	----	51.89± .10	----	51.89± .10
Silver:											
$Ag(c)$	.05	.75	2.78	4.82	5.49	5.80	6.10	10.20 ± .05	----	----	10.20± .05
$Ag(g)$	----	----	----	----	----	----	----	----	41.33± .01	----	41.33± .01
$Ag^+(aq.)$	----	----	----	----	----	----	----	----	----	17.54± .15	17.54± .15
$Ag_2O(c)$*	(1.08)	5.26	8.44	10.75	12.47	13.93	15.75	29.1 ± .2	----	29.7	29.1 ± .2
$Ag_2S(\alpha)$	----	----	----	----	----	----	----	----	----	35.0 ± 1.0	35.0 ± 1.0
$AgBr(c)$	.56	3.72	8.02	10.83	11.68	12.10	12.52	25.60 ± .10	----	26.1 ± .5	25.60± 1.0
$AgBr(g)$	----	----	----	----	----	----	----	----	61.2 ± .5	----	61.2 ± .5
$AgCl(c)$	.40	2.95	6.59	10.00	11.22	11.88	12.14	23.00 ± .10	----	22.5 ± .5	23.00± .10
$AgCl(g)$	----	----	----	----	----	----	----	----	58.5 ± .5	59.7 ± 1.5	58.5 ± .5
$AgF(g)$	----	----	----	----	----	----	----	----	----	56.1 ± .5	56.1 ± .5
$AgH(g)$	----	----	----	----	----	----	----	----	48.87± .10	----	48.87± .10
$AgD(g)$	----	----	----	----	----	----	----	----	50.3 ± .1	----	50.3 ± .1
$AgI(c)$	(1.40)	4.48	8.00	10.99	11.94	12.50	13.58	27.6 ± .4	----	27.6 ± .4	27.6 ± .4
$AgI(g)$	----	----	----	----	----	----	----	----	63.0 ± .5	----	63.0 ± .5
$Ag_2CO_3(c)$	(.49	(3.90)	10.22	16.95	20.79	23.20	26.83	40.0 ± .9	----	----	40.0 ± .9
$AgClO_2(c)$	(.46)	3.25	8.15	13.82	16.58	18.50	20.87	32.2 ± .2	----	----	32.2 ± .2
$Ag_2CrO_4(c)$	(1.11)	6.04	12.83	21.10	26.28	28.92	34.00	52.0 ± .3	----	----	52.0 ± .3
$AgIO_3(c)$	(.45)	3.30	8.38	14.19	18.97	21.72	24.60	35.7 ±1.0	----	----	35.7 ± 1.0
$AgNO_3(c)$	(.57)	3.61	8.56	14.35	17.02	18.91	22.24	33.68 ± .15	----	----	33.68± .15

[8] $\overline{C}_p=1.27$ at 48.5°.

[9] $C_p=1.01$ at 48.5°.

Table 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Silver—Continued											
$AgNO_2(c)$	(.64)	3.46	7.73	12.89	15.45	17.17	19.17	30.64±0.15			30.64± 0.15
$Ag_2SiO_3(c)$	(1.28)	(4.78)	10.04	16.39	20.96	24.75	30.36	42.4 ± .6			42.4 ± .6
$Ag_2SO_4(c)$	(.88)	5.63	12.63	19.78	23.70	26.89	31.40	47.9 ± .2			47.9 ± .2
$Ag_2H_3IO_6(c)$†	(.65)	5.22	12.68	22.57	30.31	38.24	47.34	59.4 ± .3			59.4 ± .3
$Ag(NH_3)_2^+(aq.)$										57.8 ± 1.0	57.8 ± 1.0
Sodium:											
$Na(c)$	(.14)	1.44	3.82	5.40	5.93	6.25	6.79	12.23± .10			12.23± .10
$Na(g)$									36.72± .01		36.72± .01
$Na_2(g)$									54.90± .10		54.90± .10
$Na^+(aq.)$										14.0 ± .4	14.0 ± .4
$Na_2O(c)$										17 ± 1	17. ± 1
$NaBr(g)$									57.7 ± .5		57.7 ± .5
$NaBr(c)$										20.0 ± .5	20.0 ± .5
$NaCl(c)$	(.04)	.58	3.82	8.44	10.15	11.09	12.14	17.3 ± .3		17.2 ± .5	17.3 ± .3
$NaCl(g)$									55.0 ± .5	56.4	55.0 ± .5
$NaF(c)$										13.1 ± .5	13.1 ± .5
$NaF(g)$										53.1 ± .5	53.1 ± .5
$NaH(g)$									44.95± .10		44.95± .10
$NaD(g)$									46.50± .10		46.50± .10
$NaI(g)$									59.5 ± .5		59.5 ± .5
$NaI(c)$										21.8 ± .5	21.8 ± .5
$Na_2CO_3(c)$	(.16)	(1.84)	6.17	14.43	19.52	22.49	26.41	32.5 ± .6			32.5 ± .6
$NaHCO_3(c)$	(.05)	(.75)	4.06	11.01	14.85	17.40	20.94	24.4 ± .4			24.4 ± .4
$Na(OH)(c)$										13.8 ± 1.5	13.8 ± 1.5
$NaNO_3(c)$	(.12)	1.54	5.81	12.45	15.81	18.07	22.24	27.85± .10			27.85± .10
$Na_4SiO_4(c)$	(.04)	(.68)	6.37	20.30	29.82	36.24	43.79	46.8 ± .4			46.8 ± .4
$Na_2SiO_3(c)$	(.04)	(.45)	3.33	11.52	17.51	21.47	26.72	27.2 ± .2			27.2 ± .2
$Na_2Si_2O_5(c)$	(.17)	(1.84)	5.60	15.87	23.89	29.69	37.41	39.4 ± .3			39.4 ± .3
$Na_2SO_4(c)$	(.07)	1.22	6.36	15.92	21.42	25.27	30.42	35.73± .10			35.73± .10
$Na_2SO_4 \cdot 10H_2O(c)$	(.70)	7.35	24.75	56.20	79.55	99.0	141.3	140.5 ± .4			140.5 ± .4
$Na_2SO_3(c)$	(.07)	(1.18)	6.46	15.79	20.95	24.28	28.71	34.9 ± .3			34.9 ± .3
$Na_2TiO_3(c)$	(.04)	(.55)	3.29	11.60	18.68	23.71	30.02	29.1 ± .2			29.1 ± .2
$Na_2Ti_2O_5(c)$	(.09)	(1.15)	5.21	16.56	26.17	33.12	41.68	41.5 ± .3			41.5 ± .3
$Na_2Ti_3O_7(c)$	(.18)	(1.96)	7.55	22.30	34.62	43.62	54.85	55.9 ± .4			55.9 ± .4
$NaAlSi_3O_8$(*albite*)	(.12)	(1.81)	7.80	19.31	29.22	37.26	48.96	49.2 ± .3			49.2 ± .3
$NaAlSi_2O_6$(*jadeite*)	(.02)	(.35)	2.55	11.34	20.64	27.93	38.34	31.8 ± .2			31.8 ± .2
$NaCs(g)$										62.1 ± 1.0	62.1 ± 1.0
$NaK(g)$										58.6 ± .5	58.6 ± .5
$NaRb(g)$										60.4 ± 1.0	60.4 ± 1.0

Strontium:											
$Sr(g)$									39.33± .01		39.33± .01
$Sr(c)$										12.5 ± .5	12.5 ± .5
$Sr^{++}(aq.)$										−7.3 ± 1.5	−7.3 ± 1.5
$SrO(c)$	(.03)	(.38)	(2.09)	5.78	8.17	9.55	10.76	13.0 ± .2			13.0 ± .2
$SrO(g)$									54.79± .10		54.79± .10
$SrH(g)$									50.79± .10		50.79± .10
$SrCO_3(c)$	(.04)	(.72)	3.92	10.58	14.25	16.47	19.46	23.2 ± .4			23.2 ± .4
$SrSO_4(c)$										28.2	28.2
Sulfur:											
$S(rh)$	(.10)	(.86)	1.77	3.06	3.96	4.64	5.40	7.62± .04			7.62± .04
$S(mon)$	(.10)	(.86)	1.77	3.10	4.06	4.80	5.65	7.78± .06			7.78± .06
$S(g)$									40.09± .01		40.09± .01
$S_2(g)$									54.40± .10		54.40± .10
$S_6(g)$										92	92
$S_8(g)$										109	109
$SO(g)$									53.06± .10		53.06± .10
$SO_2(g)$†	(.28)	2.74	7.36	11.49	13.82(c)	20.97(l)	9.54(g)	59.24± .10	59.29± .15		59.24± .10
$SO_3(g)$									61.2 ±1.0		61.2 ± 1.0
$SO_3(l)$										29.1 ± 2.0	29.1 ± 2.0
$SCl_2(g)$									67.8 ±1.0		67.8 ± 1.0
$SO_2Cl_2(g)$									74.6 ±1.0		74.6 ± 1.0
$SO_2Cl_2(l)$										51.9 ± 2	51.9 ± 2
$SF_6(g)$†	(1.56)	7.09	11.52	13.94	17.96	24.88(c)	23.01(g)	70.3 ± .7	69.5 ± .5		69.5 ± .5
$H_2S(aq.)$										29.4 ± .3	29.4 ± .3
$HS^-(aq.)$										14.9 ± 1.0	14.9 ± 1.0
$S^{--}(aq.)$										5.3	5.3
$H_2SO_4(aq.)$										4.4 ± 1.0	4.4 ± 1.0
$HSO_4^-(aq.)$										30.6 ± 2	30.6 ± 2
$SO_4^{--}(aq.)$										4.4 ± 1.0	4.4 ± 1.0
$H_2SO_3(aq.)$										54.7 ± 1.0	54.7 ± 1.0
$HSO_3^-(aq)$										32.6 ± 1.5	32.6 ± 1.5
$SO_3^{--}(aq.)$										10.4	10.4
$H_2S_2O_8(aq.)$										35	35
$S_2O_3^{--}aq.)$										57.9	57.9
$S_2O_4^{--}(aq.)$										57	57
$S_2O_8^{--}(aq.)$										35	35
$S_4O_6^{--}(aq.)$										120.5	120.5
Tantalum:											
$Ta(c)$	.05	.59	2.60	4.78	5.47	5.77	6.05	9.94± .04			9.94± .04
$Ta(g)$									44.25± .01		44.25± .01
$Ta_2O_5(c)$	(.09)	(1.21)	5.29	13.87	20.68	25.70	32.30	34.2 ± .3			34.2 ± .3
$TaC(c)$	(.03)	(.37)	1.96	4.45	5.78	6.97	8.79	10.11± .08			10.11± .08
Tellurium:											
$Te(c)$	(.21)	1.55	3.55	5.16	5.66	5.90	6.14	11.88± .10			11.88± .10
$Te(g)$									43.65± .01		43.65± .01
$Te_2(g)$									64.1 ± .3		64.1 ± .3
$TeO_2(c)$										16.8 ± 1.0	16.8 ± 1.0
$TeF_6(g)$									80.7 ±1.0		80.7 ± 1.0
Thallium:											
$Tl(c)$	(.81)	3.21	5.01	5.84	6.06	6.15	6.29	15.35± .06			15.35± .06
$Tl(g)$									43.23± .01		43.23± .01
$Tl^+(aq.)$										30.5 ± .4	30.5 ± .4

TABLE 7.—*Low-temperature heat capacities and entropies at 298.16° K.*—Continued

Substance	Heat capacities, cal./deg./mole							Entropies at 298.16° K., cal./deg./mole			
	10° K.	25° K.	50° K.	100° K.	150° K.	200° K.	298.16° K.	Third law	Spectrographic or molecular constants	Other sources	Value recommended
Thallium—Continued											
$TlBr(c)$										26.8 ± 1.0	26.8 ± 1.0
$TlBr(g)$									64.0 ± .5		64.0 ± .5
$TlCl(c)$	(.62)	4.30	8.04	10.67	11.58	12.07	12.60	25.9 ± .6		27.0 ± .5	26.5 ± 1.0
$TlCl(g)$									61.3 ± .5		61.3 ± .5
$TlF(g)$										59.0 ± .5	59.0 ± .5
$TlI(c)$										29.9 ± 1.0	29.9 ± 1.0
$TlI(g)$									65.8 ± .5		65.8 ± .5
$TlH(g)$									51.36± .10		51.36± .10
$TlNO_3(c)$	(1.25)	5.10	10.53	15.58	17.83	19.68	23.78	38.4 ± .2			38.4 ± .2
Thorium: $Th(c)$	(10)							13.6 ± .8			13.6 ± .8
Tin:											
$Sn(white)$	.22	1.65	3.68	5.35	5.85	6.08	6.30	12.29± .06			12.29± .06
$Sn(gray)$	(.30)	1.24	2.69	4.67	5.44	5.81	6.16	10.75± .06			10.75± .06
$Sn(g)$									40.25± .01		40.25± .01
$Sn^{++}(aq.)$										−4.9 ± 1.0	−4.9 ± 1.0
$SnO(c)$	(.05)	(.66)	(2.69)	5.86	7.93	9.31	10.59	13.5 ± .3			13.5 ± .3
$SnO(g)$									55.46± .10		55.46± .10
$SnO_2(c)$	(.02)	(.25)	(1.55)	4.98	7.86	10.10	12.57	12.5 ± .3			12.5 ± .3
$SnS(g)$									57.9 ± .3		57.9 ± .3
$SnBr_4(g)$									98.2 ±1.0		98.2 ± 1.0
$SnCl_4(l)$†				24.12	28.66	31.60(c)	39.49(l)	61.8		62.2 ± 1.5	62.2 ± 1.5
$SnCl_4(g)$									87.3 ±1.0		87.3 ± 1.0
$SnTe(c)$										24.2 ± 1.0	24.2 ± 1.0
Titanium:											
$Ti(c)$	(.02)	(.16)	1.08	3.37	4.64	5.31	6.01	7.24± .05			7.24± .05
$Ti(g)$									43.08± .01		43.08± .01
$TiO(c)$	(.00)	(.09)	.65	3.05	5.47	7.34	9.55	8.31± .04			8.31± .04
$TiO(g)$									55.80± .10		55.80± .10
$Ti_2O_3(c)$*	(.01)	(.17)	1.26	6.30	12.30	17.26	23.27	18.83± .09			18.83± .09
$Ti_3O_5(c)$	(.02)	(.34)	2.43	11.00	20.10	27.35	37.00	30.9 ± .2			30.9 ± .2
$TiO_2(rutile)$	(.02)	(.22)	1.45	4.43	7.57	10.05	13.16	12.01± .07			12.01± .07
$TiO_2(anatase)$	(.01)	(.18)	1.17	4.59	7.62	10.00	13.22	11.93± .07			11.93± .07
$TiS_2(c)$	(.04)	(.65)	2.86	7.98	11.83	14.11	16.23	18.73± .15			18.73± .15
$TiC(c)$	(.00)	(.04)	.23	1.75	3.76	5.57	8.04	5.79± .05			5.79± .05
$TiCl_4(l)$†				22.77	27.14	30.12(c)	37.53(l)	59.5		60.3 ± 1.5	60.3± 1.5
$TiCl_4(g)$									84.3 ±1.0		84.3± 1.0
$TiN(c)$	(.00)	(.06)	.44	2.57	4.75	6.54	8.86	7.24± .04			7.24± .04
Tungsten:											
$W(c)$	(.02)	.21	1.47	3.90	5.00	5.51	5.97	8.04± .10			8.04± .10
$W(g)$									41.56± .01		41.56± .01
$WO_3(c)$	(.06)	(.82)	(3.15)	7.76	11.91	15.10	19.50	19.9 ± .4			19.9± .4
Uranium:											
$U(c)$	(11)							11.1 ± .6			11.1± .6
$UF_4(c)$	(.16)	1.90	6.98	15.77	21.37	24.70	28.12	36.1 ± .2			36.1± .2

$UF_6(c)$	(1.04)	5.53	12.34	22.49	28.30	32.65	39.86	54.5 ± .3			54.5± .3
$UF_6(g)$									90.2±2.0	90.8	90.2± 2.0
$UO_2F_2(c)$	(.30)	2.49	6.56	13.88	18.14	21.02	24.67	32.4 ± .2			32.4± .2
$UO_2(NO_3)_2{\cdot}6H_2O(c)$	(2.16)	9.06	23.02	47.70	64.40	79.90	111.6	120.8 ± .5			120.8 ± .5
$UO_2^{++}(aq.)$										−17. ±5	−17. ±5
$U(OH)_4^{++}(aq.)$										16. ±5	16. ±5
Vanadium:											
$V(c)$	(.01)	(.13)	.96	3.23	4.61	5.28	5.90	7.01± .10			7.01± .10
$V(g)$									43.55± .01		43.55± .01
$V_2O_3(c)$	(.03)	(.34)	(1.86)	6.86	14.58	19.27	24.67	23.5 ± .3			23.5± .3
$V_2O_4(c)$	(.03)	(.40)	(2.32)	8.80	15.88	21.45	27.96	24.5 ± .3			24.5± .3
$V_2O_5(c)$	(.05)	(.78)	(4.54)	12.43	19.24	24.16	30.51	31.3 ± .5			31.3± .5
$VO(g)$									54.47± .10		54.47± .10
$VC(c)$	(.00)	(.07)	0.52	2.51	4.42	5.92	7.97	6.77± .03			6.77± .03
$VCl_2(c)$	(.15)	(1.67)	4.62	10.05	13.63	15.52	17.26	23.2 ± .3			23.2 ± .3
$VCl_3(c)$*	(.21)	(2.30)	6.35	16.80	17.59	20.01	22.27	31.3 ± .4			31.3 ± .4
$VN(c)$	(.01)	(.17)	1.14	3.61	5.57	7.10	9.08	8.91± .04			8.91± .04
Xenon: $Xe(g)$†	1.94	4.73	5.99	6.75	8.04(c)	4.97(g)	4.97	40.7 ± .3	40.54± .01		40.54± .01
Ytterbium: $Yb(g)$									41.36± .01		41.36± .01
Yttrium: $Y(g)$									42.88± .01		42.88± .01
Zinc:											
$Zn(c)$	.05	.77	2.65	4.59	5.38	5.70	6.07	9.95± .05			9.95± .05
$Zn(g)$									38.46± .01		38.46± .01
$Zn^{++}(aq.)$										−25.8 ± .5	−25.8 ± .5
$ZnO(c)$	(.02)	(.36)	1.86	4.24	6.18	7.72	9.62	10.43± .10			10.43± .10
$ZnO(g)$									53.7 ± .5		53.7 ± .5
$ZnS(c)$	(.05)	.72	2.76	5.88	8.23	9.48	(11.00)	13.8 ± .2			13.8 ± .2
$ZnBr_2(c)$										32.7 ±1.0	32.7 ±1.0
$ZnBr(g)$									60.8 ± .5		60.8 ± .5
$ZnCl_2(g)$										25.9 ±1.0	25.9 ±1.0
$ZnCl(g)$									58.3 ± .5		58.3 ± .5
$ZnH(g)$									48.70± .10		48.70± .10
$ZnI_2(c)$										38.5 ±1.0	38.5 ±1.0
$ZnI(g)$									62.9 ± .5		62.9 ± .5
$ZnTe(c)$										18.9 ±1.0	18.9 ±1.0
$ZnCO_3(c)$	(.03)	(.50)	(2.60)	8.21	12.41	15.26	19.05	19.7 ± .3			19.7 ± .3
$ZnSO_4(c)$										30.6 ±2	30.6 ±2
$ZnSo_4{\cdot}6H_2O(c)$								85.9 ± .3			85.9 ± .3
$ZnSO_4{\cdot}7H_2O(c)$								92.9 ± .3			92.9 ± .3
$ZnSb(c)$										21.4 ±1.4	21.4 ±1.4
$Zn_3Sb_2(c)$										63.6 ±1.8	63.6 ±1.8
$Zn_4Sb_3(c)$										73.5 ±2.1	73.5 ±2.1
Zirconium:											
$Zr(c)$	(.03)	(.44)	2.21	4.44	5.34	5.76	6.19	9.28± .08			9.28± .08
$Zr(g)$									43.32± .01		43.32± .01
$ZrO_2(c)$	(.02)	(.18)	1.21	4.55	7.77	10.32	13.42	12.12± .08			12.12± .08
$ZrO(g)$									55.88± .10		55.88± .10
$ZrCl_4(c)$	(1.00)	(4.68)	10.70	18.59	23.23	25.89	28.65	44.5 ± .5			44.5 ± .5
$ZrCl_4(g)$										93.6± 2	93.6 ±2
$ZrN(c)$	(.01)	(.15)	1.04	3.72	5.91	7.60	9.66	9.29± .05			9.29± .05
$ZrSiO_4(c)$	(.03)	(.22)	1.62	7.48	13.22	17.67	12.56	20.2 ± .2			20.2 ± .2
Electron gas: E^-									4.99± .01		4.99± .01

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[10] $C_p=4.22$ at 48.5°.

[11] $C_p=3.04$ at 48.5°.

TABLE 8.—*Data for changes in state*

Substance	T. ° K.	Type of change	Heat absorbed, cal./mole
Argon : A	83.8	Fusion	281
	83.8	Sublimation at 0.6793 atm. pressure	1,899
	87.3	Vaporization at 1 atm. pressure	1,568
Arsenic trifluoride : AsF_3	267.21	Fusion	2,486
	292.50	Vaporization at 0.1863 atm. pressure	8,566
Boron trifluoride : BF_3	142.15	Transition	18
	144.46	Fusion	1,014
	154.5	Vaporization at 0.2185 atm. pressure	4,411
Bromine : Br_2	265.9	Fusion	2,580
Carbon monoxide : CO	61.55	Transition	151.3
	68.09	Fusion	199.7
	81.61	Vaporization at 1 atm. pressure	1,443.6
Carbon dioxide : CO_2	194.67	Sublimation at 1 atm. pressure	6,030
Carbon disulfide : CS_2	161.1	Fusion	1,049
Carbonyl sulfide : COS	134.31	do	1,129.8
	222.87	Vaporization at 1 atm. pressure	4,423
Carbon tetrachloride : CCl_4	225.35	Transition	1,095
	250.3	Fusion	601
Carbon tetrafluoride : CF_4	76.23	Transition	353.2
	89.47	Fusion	167.4
	122.0	Vaporization at 0.1365 atm. pressure	3,120
Carbonyl chloride : $COCl_2$	145.34	Fusion	1,371
	280.66	Vaporization at 1 atm. presure	5,832
Cyanogen : C_2N_2	245.27	Fusion	1,938
	251.95	Vaporization at 1 atm. pressure	5,576
Methane : CH_4	90.6	Fusion	224
	99.54	Vaporization at 0.3239 atm. pressure	2,036
	111.7	Vaporization at 1 atm. pressure	1,988
Chlorine : Cl_2	172.12	Fusion	1,531
	239.05	Vaporization at 1 atm. pressure	4,878
Monogermane : GeH_4	73.2	Transition	50
	76.5	do	85
	107.3	Fusion	199.5
	184.8	Vaporization at 1 atm. pressure	3,361
Hydrogen : H_2	13.95	Fusion	28.0
	13.95	Vaporization at 0.0708 atm. pressure	217.8
HD	16.60	Fusion	38.0
	16.60	Vaporization at 0.1250 atm. pressure	265
D_2	18.65	Fusion	47.0
	19.65	Vaporization at 0.2559 atm. pressure	302.3
Water : H_2O	273.16	Fusion	1,435.7
	298.16	Vaporization at 0.03126 atm. pressure	10,514
D_2O	273.16	Sublimation at 0.00480 atm. pressure	12,636
	276.98	Fusion	1,501
Hydrogen bromide : HBr	89.2	Transition	63.4
	113.2	do	78.8
	116.8	do	85.7
	186.24	Fusion	575.1
	206.38	Vaporization at 1 atm. pressure	4,210
Hydrogen chloride : HCl	98.36	Transition	284.3
	158.91	Fusion	476.0
	188.07	Vaporization at 1 atm. pressure	3,860
Hydrogen fluoride : HF	190.09	Fusion	1,094
Hydrogen iodide : HI	70.1	Transition	18.6
	125.6	do	192.4
	222.31	Fusion	686.3
	237.75	Vaporization at 1 atm. pressure	4,724
Hydrogen cyanide : HCN	170.37	Transition	3.8
	259.86	Fusion	2,009
	298.80	Vaporization at 1 atm. pressure	6,027
Hydrogen sulfide : H_2S	103.52	Transition	368.0
	126.22	do	121.3
	187.61	Fusion	568.1
	212.77	Vaporization at 1 atm. pressure	4,463
Krypton : Kr	115.95	Fusion	390.7
	119.93	Vaporization at 1 atm. pressure	2,158
Mercury : Hg	234.2	Fusion	557.2
Neon : Ne	24.57	Sublimation at 0.426 atm. pressure	511
Nitrogen : N_2	35.61	Transition	54.71
	63.14	Fusion	172.3
	77.32	Vaporization at 1 atm. pressure	1,333
Nitrous oxide : N_2O	182.26	Fusion	1,563
	184.59	Vaporization at 1 atm. pressure	3,958
Nitric oxide : NO	109.49	Fusion	549.5
	121.36	Vaporization at 1 atm. pressure	3,292.6
Nitrogen tetroxide : N_2O_4–NO_2	261.90	Fusion	3,502
	294.25	Vaporization at 1 atm. pressure	9,110
Nitric acid : HNO_3	231.51	Fusion	2,503
	298.16	Vaporization at 0.0828 atm. pressure	9,355

TABLE 8.—*Data for changes in state*—Continued

Substance	T. ° K.	Type of change	Heat absorbed, cal./mole
Nitric acid monohydrate : $HNO_3 \cdot H_2O$	235.48	Fusion	4,184
Nitric acid trihydrate : $HNO_3 \cdot 3H_2O$	254.63	do	6,954
Amonia : NH_3	195.36	do	1,351.6
	239.68	Vaporization at 1 atm. pressure	5,581
Ammonium alum : $NH_4Al(SO_4)_2 \cdot 12H_2O$	71.0	Transition	193.5
Oxygen : O_2	23.66	do	22.42
	43.76	do	177.6
	54.39	Fusion	106.3
	90.13	Vaporization at 1 atm. pressure	1,628.8
Phosphine : PH_3	30.29	Transition	19.6
	49.43	do	185.7
	88.10	do	115.8
	139.35	Fusion	270.4
	185.38	Vaporization at 1 atm. pressure	3,489
Potassium alum : $KAl(SO_4)_2 \cdot 12H_2O$	59.7	Transition	46.9
Silicon tetracholride : $SiCl_4$	203.3	Fusion	1,845
Monosilane : SiH_4	63.45	Transition	147.1
	88.48	Fusion	159.5
	161.5	Vaporization at 1 atm. pressure	2,955
Sulfur dioxide : SO_2	197.64	Fusion	1,769.1
	263.08	Vaporization at 1 atm. pressure	5,960
Sulfur hexafluoride : SF_6	94.30	Transition	384.2
	186.0	Sublimation at 0.161 atm. pressure	5,615
Tin tetrachloride : $SnCl_4$	239.9	Fusion	2,190
Titanium tetrachloride : $TiCl_4$	248.0	do	2,240
Xenon : Xe	161.3	do	548.5
	165.13	Vaporization at 1 atm. pressure	3,020

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