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Status of the Values of the Fundamental Constants for Physical Chemistry as of July 1, 1951¹

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As of July 1, 1949, the Subcommittee on Fundamental Constants of the Committee on Physical Chemistry of the National Research Council issued a report summarizing the status at that time of the values of the fundamental constants of importance in physical chemistry. The report carried a list of the fundamental constants which had been in wide use for several years in the tables of the American Petroleum Institute Research Project 44 and which appeared to be essentially the then best selections, but pointed out that the 1948 paper of DuMond and Cohen² indicated strongly the need for a significant revision of the value of the Faraday constant which had been accepted as "best" for several decades, as well as revision of the values of the Avogadro and Planck constants. DuMond and Cohen completed in 1951 a reanalysis and reevaluation of the values of the atomic constants, presenting the complete details of their work in the form of a report of some 200 pages entitled "A least-squares adjustment of the atomic constants as of December, 1950." This report was summarized in a short paper by DuMond and Cohen.³

There are needed in physical chemistry essentially only six basic constants, the values of which are obtained from experimental observations: the velocity of light, c ; the Planck constant, h ; the Avogadro constant, N ; the Faraday constant, \mathcal{F} ; the absolute temperature of the ice point, T_0° ; and the pressure-volume product for one mole of a gas at zero pressure and at the temperature of the ice point, $(PV)_{T_0^\circ}^{P=0}$.

As a result of the new calculations of DuMond and Cohen, changes in the values of c , h , N and \mathcal{F} are required to be made, as follows, respectively, in parts per 100,000: +5, -7, +6, +8. No

change is made at this time in the values of the other two basic constants listed above.

Bearden and Watts⁴ also published in 1951 a new table of values of the atomic constants, but without the complete documentation and description of the methods of calculation given in the report of DuMond and Cohen. For the four atomic constants with which we are concerned, the values selected by Bearden and Watts are, within the respective limits of uncertainty, in substantial accord with those of DuMond and Cohen.

The following tables give the recommended values of the fundamental constants for physical chemistry as of July 1, 1951. Table I gives values for the six basic constants which may be considered essentially to be evaluated from appropriate experimental measurements, the values for c , h , N and \mathcal{F} being from DuMond and Cohen³ and the values for the other two constants being the same as in the previous (July 1, 1949) report of this Committee. It should be noted here that the values of N and \mathcal{F} are expressed in terms of the chemists' mole, by applying the factor 1.000272 to the values given by DuMond and Cohen in terms of the physicists' mole.³ Table II gives values for the derived constants, obtained from the values in Table I and the appropriate physical relation. Actually, the mathematical treatment of DuMond and Cohen operates on \mathcal{F} and e simultaneously as "input" quantities,³ but they are in this report separated for simplicity. The uncertainties assigned to the values in Tables I and II correspond, as nearly as can be judged, to the standard deviation of the mean.

The uncertainty assigned to \mathcal{F} is probably too small.⁵ Table III gives values of the defined constants, which are fixed exactly by definition. Table IV gives values of certain auxiliary constants and relations, which are the same as in the previous

(1) Summary of a report of the Subcommittee on Fundamental Constants of the Committee on Physical Chemistry of the National Research Council, Washington 25, D. C.

(2) J. W. M. DuMond and E. R. Cohen, *Revs. Modern Phys.*, **20**, 82 (1948).

(3) J. W. M. DuMond and E. R. Cohen, *Phys. Rev.*, **82**, 555 (1951).

(4) J. A. Bearden and H. M. Watts, *ibid.*, **81**, 73 (1951).

(5) Private communication from Prof. J. W. M. DuMond, California Institute of Technology, Pasadena 4, California.

TABLE I
 VALUES OF THE BASIC CONSTANTS

Name	Symbol	Value	Units
Velocity of light	c	2.997902 ± 0.000013	} $\times 10^{10}$ cm./sec.
Planck constant	h	6.62377 ± 0.00027	
Avogadro constant	N	6.02380 ± 0.00016	} $\times 10^{23}$ number of molecules/mole
Faraday constant	\mathcal{F}	$96,493.1 \pm 1.0$	
Absolute temperature ^a of the "ice" point, 0°C.	$T_0^{\circ\text{C}}$	273.160 ± 0.010	°K.
Pressure-volume product for one mole of a gas at 0° and zero pressure	$(PV)_{T_0^{\circ\text{C}}}^P=0$	2271.16 ± 0.04	joules/mole

^a The corresponding value of the triple point of water, which is 0.0100°C., would be $273.170 \pm 0.010^{\circ}\text{K}$.

 TABLE II
 VALUES OF THE DERIVED CONSTANTS

Name	Symbol	Relation	Value	Units
Electronic charge	e	$e = \mathcal{F}/N$	1.601864 ± 0.000036	} $\times 10^{-19}$ coulomb
Gas constant	R	$R = \frac{(PV)_{T_0^{\circ\text{C}}}^P=0}{T_0^{\circ\text{C}}}$	8.31439 ± 0.00034	
Boltzmann constant	k	$k = R/N$	1.380257 ± 0.000067	} $\times 10^{-16}$ erg/deg. molecule
Constant relating wave number and energy	Z	$Z = Nhc$	11.96171 ± 0.00026	
Second radiation constant	c_2	$c_2 = hc/k$	1.438676 ± 0.000091	cm. deg.
Einstein constant relating mass and energy	Y	$Y = c^2$	8.987416 ± 0.000081	} $\times 10^{13}$ joules/g.

(July 1, 1949) report of this Committee. Table V gives values of the various constants expressed in different units.

The present report has been approved by the Committee on Physical Chemistry (Frederick D. Rossini, Chairman) and by the Division of Chemistry and Chemical Technology (W. Albert Noyes,

Jr., Chairman) of the National Research Council. It is hoped that investigators and writers in physical chemistry will, in so far as possible and consistent with their own individual practices, use the values recommended in this report in order to achieve a greater consistency in comparing calcula-

 TABLE III
 VALUES OF THE DEFINED CONSTANTS

Name	Symbol	Values	Units
Standard gravity	g_0	980.665	cm./sec. ²
Standard atmosphere	atm.	1,013,250	dynes/cm. ²
Standard millimeter of mercury pressure	mm. Hg	1/760	atm.
Calorie (thermochemical)	cal.	4.1840	joules

 TABLE IV
 VALUES OF CERTAIN AUXILIARY RELATIONS^a

1 second (mean solar) = 1.00273791 sidereal second			
1 joule = 0.999835 \pm 0.000052 international joule (NBS)			
1 ohm = 0.999505 \pm 0.000015 international ohm (NBS)			
1 ampere = 1.000165 \pm 0.000025 international ampere (NBS)			
1 volt = 0.999670 \pm 0.000029 international volt (NBS)			
1 coulomb = 1.000165 \pm 0.000025 international coulomb (NBS)			
1 watt = 0.999835 \pm 0.000052 international watt (NBS)			
1 liter = 1,000.028 \pm 0.004 cm. ³			

^a All electrical units are absolute unless otherwise indicated.

 TABLE V
 VALUES OF THE VARIOUS CONSTANTS EXPRESSED IN DIFFERENT UNITS

Constant	Values ^a	Units ^b
$(PV)_{T_0^{\circ\text{C}}}^P=0$	2271.16	joules/mole
	22,414.6	cm. ³ atm./mole
	22.4140	liter atm./mole
\mathcal{F}	96,493.1	coulombs/equivalent
	23,062.4	cal./volt equivalent
e	1.601864×10^{-19}	coulombs
	1.601864×10^{-20}	e.m.u.
	4.80223×10^{-10}	e.s.u.
R	8.31439	joules/deg. mole
	1.98719	cal./deg. mole
	82.0567	cm. ³ atm./deg. mole
	0.0820544	liter atm./deg. mole
Z	11.96171	joule cm./mole
	2.858917	cal. cm./mole
Y	8.987416×10^{13}	joules/g.
	2.148044×10^{13}	cal./g.
1 cal.	4.1840 (exact)	joules
	4.18331	int. joules
	41.2929	cm. ³ atm.
	0.0412917	liter atm.

^a See the preceding sections regarding the uncertainties.
^b All electrical units are absolute unless otherwise indicated.

tions and experimental results from different laboratories. The Committee plans to maintain this set of recommended values of the fundamental constants for physical chemistry up-to-date by revision at appropriate intervals and will appreciate being advised of any new information and data which may affect the values.

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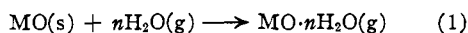
The Reaction of Beryllium Oxide with Water Vapor

BY LEONARD I. GROSSWEINER AND RALPH L. SEIFERT¹

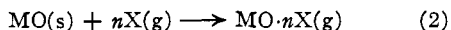
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At high temperatures the volatility of beryllium oxide is greatly increased by the presence of water vapor. Measurements of the effect of temperature and partial pressure of water on the rate of volatilization of beryllium oxide indicate that the increased volatility results from the reaction $\text{BeO}(s) + \text{H}_2\text{O}(g) \rightarrow \text{Be}(\text{OH})_2(g)$ for which $\log_{10} K_p = 1.63 - 9060/T$.

The volatility of a number of oxides is greatly increased by the presence of water vapor. This has been shown to be true by quantitative measurements with silicon dioxide,^{2,3} boron trioxide,^{4,5} beryllium oxide,^{6,7} and the oxides WO_3 , W_4O_{11} , WO_2 and MoO_3 .^{8,9} The volatile species may result from a reaction between the oxide and water



or between the oxide and a decomposition product of water



where X may be H_2 , O_2 , OH, H or O. The partial pressures of H_2 , O_2 and OH in water vapor are proportional to the $2/3$ power of the partial pressure of water. The partial pressures of H and O in water vapor are proportional to the $1/3$ power of the partial pressure of water. Whether reaction (1) or (2) occurs can be determined experimentally together with the correct value of n by plotting the logarithm of the equilibrium pressure of the volatile complex as a function of the logarithm of the partial pressure of water at constant temperature. If only one reaction is involved an integral value will be found for the slope if it is reaction (1) that occurs and n will equal the slope. If reaction (2) occurs and involves H_2 , O_2 or OH the slope will equal $2n/3$. If the reaction involves H or O the slope will equal $n/3$. Obviously ambiguous results will be obtained if n is a multiple of 3.

The necessary data may be obtained by observing

(1) Consultant to Argonne National Laboratory; permanent address: Department of Chemistry, Indiana University, Bloomington, Indiana.

(2) C. J. van Nieuwenburg and H. B. Blumendal, *Rec. trav. chim.*, **49**, 857 (1930).

(3) C. J. van Nieuwenburg and P. M. van Zon, *ibid.*, **54**, 129 (1935).

(4) M. v. Stackelburg, F. Quatram and Jutta Dressel, *Z. Elektrochem.*, **43**, 14 (1937).

(5) H. Tazaki, *J. Sci. Hiroshima Univ.*, **A10**, 109 (1940).

(6) M. G. Berkman and S. L. Simon, Argonne National Laboratory Report ANL-4177, July 15, 1948.

(7) C. A. Hutchison and J. G. Malm, *THIS JOURNAL*, **71**, 1338 (1949).

(8) C. J. van Nieuwenburg and H. B. Blumendal, *Rec. trav. chim.*, **50**, 994 (1931).

(9) T. Millner and J. Neugebauer, *Nature*, **163**, 601 (1949).

the loss in weight of a sample of oxide when known volumes of gas containing known pressures of water vapor are passed over the sample. The following experimental conditions must exist: the temperature must be maintained constant; the gas phase must come into equilibrium with the solid; and the solid must lose weight by only one mechanism. Of the earlier work only in the case of boric acid were the experimental requirements met sufficiently well to permit an unambiguous determination of n . However, the results of this earlier work^{3,4,9} are not inconsistent with the conclusion that the volatile species in the cases of SiO_2 , B_2O_3 and WO_3 are, respectively, $\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, H_3BO_3 or HBO_2 depending upon the temperature, and $\text{WO}_3 \cdot \text{H}_2\text{O}$. (The work with B_2O_3 ⁴ was carried out at temperatures where H_3BO_3 and HBO_2 were stable in the solid phase so that the treatment of these data differs somewhat from the procedure indicated above.)

In the earlier work with beryllium oxide^{6,7} the gas phase did not come into equilibrium with the solid beryllium oxide. However, it was observed that the volatility of beryllium oxide in water vapor increased with increasing temperature and with increasing pressure of water vapor. Crystalline needles of beryllium oxide were deposited from the vapor phase in the cool part of the apparatus.

This investigation was undertaken to study the influence of water vapor on the volatility of beryllium oxide under conditions that permit a much closer approach to the equilibrium state than was possible in the apparatus used by Berkman and Simon.⁶

Experimental

Apparatus.—The apparatus was designed so that a stream of gas, containing either helium and water vapor or water vapor alone, could be preheated, passed over beryllia chips that were heated to constant temperature, and could then be cooled to condense the water and beryllium oxide. The beryllia chips were contained in a platinum gauze basket that fitted closely inside a platinum-10% rhodium tube. The platinum-rhodium tube, 2.5 ft. long with an internal diameter of $7/16$ in., was placed vertically inside a 1.0 foot long platinum-wire wound aluminum tube furnace. The power input to the furnace was controlled by a Wheelco Proportioning Potentiometer with a platinum-10% rhodium thermocouple placed at the outer surface of the