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handbook of glass data

Part B

single-component and binary non-silicate oxide glasses

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FOREWORD

The present volume is the second part of the Handbook of Glass Data. Part A of this book, "Silica Glass and Binary Silicate Glasses" was published by Elsevier Science Publishers in 1983.

The reasons for undertaking an extensive work on compiling this reference book as well as some principles of its data selection and presentation are given in the foreword to part A of this book. Since each part of the reference book can be used independently, we thought it necessary to quote here the most essential statements of the foreword to part A.

A rapid increase of the variety of glass-forming substances has been noted in the last few decades, nevertheless we thought it expedient to limit the compositions covered by our reference book to purely oxide systems which are and probably will be of paramount importance among glass-forming substances both practically and theoretically.

Like most investigators of vitreous state, we hold to the idea that glass is a solid amorphous substance obtained on cooling a melt. Thus the reference book does not cover the data on non-crystalline solids obtained by any other means.

To have the optimal version of the reference book we have limited the range of the presented materials, on the one hand, and have tried to answer the needs of as many potential readers of the book as possible, on the other hand. Bearing this in mind we have eliminated the following sections: the properties of partially crystallized glasses, the properties of glasses after their exposure to any kinds of radiation, all spectral characteristics of glasses (the references are given to the publications containing the data on optical absorption spectra of glasses in the region of their optical transparency), electrode properties and magnetic properties of glasses (references are also given for the latter properties).

It is well known that very often a particular property of a particular glass-forming system has been studied independently by many scientists. In such cases to keep our reference book within the reasonable bounds we decided to present the data of only a few best papers (preferring the ones where glasses were obtained under the purest conditions, where they were analysed and their properties were measured with the greatest accuracy, etc.). The other papers have been only referred to, sometimes with the additinal information on the character of the presented data. At the same time we believe that in the majority of cases one paper is usually inadequate to reliably characterize any dependency. In practice, the discrepancies between similar studies made by different scientists very often considerably exceed the sum of errors reported by these scientists. Obviously the unforseen effects of some peculiarities of glass synthesis, preparation and storage of samples and measurement conditions are responsible for this. Thus only the comparison of the results of several independent high-quality studies makes it possible to have a reliable information of any property-composition dependence.

Here are the principles of the data selection and presentation which were applied when compiling this reference book.

1. The reference book covers information on the systems capable of forming glasses by cooling melts and does not contain any information on the properties of amorphous films obtained by deposition from a vapour phase.

2. The data on melt properties are presented only for the glass-forming systems. Nevertheless we present the data on melt properties over the whole investigated range of concentrations irrespective of whether this range is limited by a glass-forming region or not.

3. The notion of a "component" which is very important for determining the number of components in each investigated glass was defined by the authors in the following way:

a) An oxide entering into the composition of a glass is considered as a component. At the same time we did not consider the contents of several oxides of the same element but in a different valent state as a reason to transfer a glass to the category of the one with increased number of components. Such somewhat arbitrary approach was adopted to make the search for the information of interest easier. Actually, as a rule, specialists are interested in the influence of all oxides of a given element on glass properties regardless of the valence of the element.

b) If an analytical composition of a glass is given with impurities which were not introduced deliberately during its synthesis, these impurities will not be taken into consideration when classifying glasses with respect to the number of components, in case there is no reason to believe that the given impurities considerably change the corresponding property.

4. The data on the crystallization rates of glasses are included since this characteristic should be considered as one of the most

important glass properties.

5. In most cases the data on the so-called characteristic temperatures (deformation temperatures, upper and lower annealing points and others) are not given. Littleton's softening temperatures and glass transition temperatures are the only exceptions. According to Littleton (1927)* the softening temperature conforms to the viscosity of $10^{7.65}$ poises, though it is possible that drastic composition variations can lead to some changes of this value.

6. When the original papers reported viscosity and electric conduction logarithms accurate to three or four decimal places the authors of this reference book rounded the figures off to two decimal places, since with the present experimental technique a minimum measurement error of the indicated properties exceeds ± 2% of a measured value even in the best investigations.

It is well known that compositions of the investigated glasses are usually expressed either by mol% or wt% or both. To make the comparison of the data of different authors easier we have presented all the compositions in mol%. The compositions being available in wt%, we included both the characteristics of glass compositions, as well.

In the present reference book all binary systems are united into large groups according to the valency of the elements forming the corresponding oxides. Within each group of the systems the data are classified by properties. Their sequence is as follows: glass formation, crystallization, density, thermal expansion and other thermal properties, optical properties, viscosity, elastic properties and internal friction, strength, surface tension, chemical durability, electrical properties, diffusion, permeation and solubility of gases, ion diffusion, volatilization, magnetic properties.

The experimental data are given in a chronological order. Wherever possible, we preferred the data on glass properties in tabular form believing that it is this form that permits the fastest and most reliable use of the data with the highest possible accuracy of the information conveyed.

We have tried to give a comprehensive information on the experimental technique used in the corresponding studies. However in many papers such information was far from being sufficiently complete. In some cases the authors of the original papers were appealed to convey the missing details of their experimental technique. When received, this additional information was included in the reference book.

As was found by experience, the reference book of this kind is of use mainly for three categories of readers: those for whom the amount of the selected data presented by the book is adequate; those who are willing to know the literature on a particular property of a particular system as comprehensively as possible; and those who want to be positive that they are the first to undertake a particular study of glass properties. As far as the two latter categories of readers are concerned, the complete coverage of the literature will be the main value of this book. Therefore it seems expedient here to present the method of a search for the original sources of information. All volumes of the main journals on glass and silicates (Journal of the American Ceramic Society, Journal of the Society of Glass Technology, Physics and Chemistry of Glasses, Glastechnische Berichte, Journal of Non-Crystalline Solids, Neorganicheskie Materialy (Soviet Journal of Inorganic Materials) and Fizika i Khimiya Stekla (Soviet Journal of Physics and Chemistry of Glasses)) have been looked through beginning with their first volumes. The information on papers from other journals and conference proceedings, as well as on theses and so on has been obtained from abstract journals. In doing this we had in mind the fact that none of the abstract journals presents an exhaustive survey of the available literature on the subject of interest. Thus we have looked through the corresponding sections of several abstract journals where the abstracts of the papers on glass properties could be found. The necessary references to the publications which were issued before 1932 were taken from "Glastechnische Tabellen"*. The more recent information was obtained by reviewing the following abstract journals: Ceramic Abstracts, Chemical Abstracts, Reference Journal "Chemistry" (USSR), Reference Journal "Physics" (USSR) and the sections of abstracts of the following journals: Physics and Chemistry of Glasses, Verres and Réfractaires, Glastechnische Berichte. Review papers, reviews in theses, reference card indices taken from some glass specialists, etc. have been also widely used to supplement the list of the papers obtained. All this does not mean, however, that we have succeeded in collecting <u>all</u> the available information on the chosen field of knowledge. Nevertheless we take the liberty of stating that the amount of the sources of the corresponding information included in the present reference book surely exceeds ninety per cent of the available publications.

Original papers were found in the rich collections of scientific literature in Moscow and Leningrad libraries; in some cases the authors of the papers were appealed for reprints. We have also communicated with the authors in case any explanation concerning both their experimental results and the methods applied were needed. We would like to express acknowledgement and appreciation to these scientists for their most helpful cooperation.

We are most grateful to all the institutions and the authors for the permission to use figures and tables which are compiled in our reference book.

The present volume is based on volume 2 of the reference book "Properties of Glasses and Glass-Forming Melts" published in Russian by the Leningrad branch of the "Nauka" Publishing House (1975, 630 pages). However, the considerable changes have been introduced into this edition. They amounted to the following. The corresponding sections of the supplementary (the fourth) volume of the Russian edition has been added. The data of the papers published after 1978 have been added. A considerable amount of duplicating data on similar properties of similar systems has been withdrawn (see above the principles of data selection). Unlike the corresponding volume of Russian edition this volume has author, subject and formula indices.

Finally we think it expedient to repeat the concluding sentences of the foreword to part A:

A supplement is to follow the main volumes of the Handbook involving the data on single-component, binary and ternary oxide glasses published after the edition of the corresponding parts of the book as well as additional data taken from earlier publications. The authors appeal to all glass specialists for the reprints of their new publications concerning the data in question as well as the references to any earlier publications not covered in the present book. Any filling up of the existing lacunas in the book will increase the value of the book as a means of mutual information of the scientists about their latest studies and thus will contribute to further international coordination in the investigation of oxide glass properties.

Part B presents the results of the papers published up to 1982.

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* Littleton, J.T. 1927. J.Am.Ceram.Soc., 10, 4, 259-263.
Glastechnische Tabellen, 1932. Ed.W.Eitel, Berlin, 714 pp.

LIST OF SYMBOLS

a thermal diffusivity
b thickness of a dissolved layer; in the sections "Crystallization" it is the thickness of a crystalline layer
C specific heat (C_P, C_V)
c_l longitudinal sound velocity
c_t transverse sound velocity
D diffusion coefficient
d density
E "energy of activation", i.e. the characteristic of the temperature coefficient of any property p in the coordinates ln p, 1/T (E is calculated accordingly to the equations $\ln p = \ln p_o \pm E/kT$ or $\ln p = \ln p_o \pm E/RT$; the sign "+" is used for ρ and η, the sign "-" is used for κ, D and Q^{-1}); in the sections "Elastic properties" it is Young modulus
f frequency
G shear modulus
H microhardness
ΔH enthalpy, heat of solution, heat of crystallization, heat of evaporation
K coefficient of gas permeation; in the sections "Elastic properties" it is the bulk modulus
n refractive index
P pressure
Q^{-1} internal friction
S solubility coefficient
T temperature, K
t temperature, °C
T_g, t_g glass transition temperature
V volume
v velocity of a process
α linear thermal expansion coefficient; in the sections "Elastic properties" it is the absorption coefficient
β volume thermal expansion coefficient
Δ error of measurements
δ dielectric loss angle
δp change in property p
ε' permittivity

ε'_∞ permittivity for $f\to\infty$ or $T\to\infty$
ε'' loss coefficient, $\varepsilon'' = \varepsilon'\tan\delta$
η viscosity
κ electrical conductivity
λ thermal conductivity; in the sections "Internal friction" it is the logarithmic damping coefficient; in the sections "Optical properties" it is the wave length
μ Poisson ratio
ν dispersion coefficient
ρ electrical resistivity
σ surface tension
τ time
χ compressibility

The table of conversion of t,°C to $1/T, K^{-1}$

t,°C	$(1/T)\cdot10^4, K^{-1}$	t,°C	$(1/T)\cdot10^4, K^{-1}$	t,°C	$(1/T)\cdot10^4, K^{-1}$
-200	137.00	150	23.64	800	9.32
-100	57.80	200	21.14	900	8.53
-50	44.83	250	19.12	1000	7.86
0	36.63	300	17.45	1100	7.28
20	34.13	350	16.05	1200	6.79
40	31.95	400	14.86	1300	6.36
50	30.96	450	13.38	1400	5.98
60	30.03	500	12.94	1500	5.64
80	28.33	600	11.45	1600	5.34
100	26.81	700	10.28		

The table of conversion of $1/T, K^{-1}$ to t,°C

$(1/T)\cdot10^4, K^{-1}$	t,°C	$(1/T)\cdot10^4, K^{-1}$	t,°C	$(1/T)\cdot10^4, K^{-1}$	t,°C
5.0	1727	12.0	560	26.0	111
5.5	1545	13.0	496	28.0	84
6.0	1393	14.0	441	30.0	60
6.5	1265	15.0	394	35.0	12
7.0	1156	16.0	352	40.0	-23
7.5	1060	17.0	315	45.0	-51
8.0	977	18.0	283	50.0	-73
9.0	838	20.0	227	60.0	-106
10.0	727	22.0	182	80.0	-148
11.0	636	24.0	144	100.0	-173

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B_2O_3

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Shults, Borisova, Vedishcheva, Pivovarov, 1981.

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See also:

Uhlmann, Hays, Turnbull, 1967 (pressure effect)

DENSITY

Cousen, Turner, 1928a, 1928b.

Archimedes method using toluene, and flotation method using toluene or pentachloroethane and trimethylene dibromide mixture. $\Delta d = \pm 0.1\%$ d. Melting at 1400°C for 1 hr in platinum crucible.

t, °C	d, g/cm^3
25	1.8453

Gooding, Turner, 1934.

See the table on p. 80.

Wulff, Majumdar, 1936.

Flotation method. $\Delta d = \pm 2\%$ d. Temperature 25°C. Melting of H_3BO_3 at ~ 1200°C in platinum crucible.

Sample	Melting conditions	d, g/cm^3
1	Drying in vacuum, melting for 6 hr, rapid cooling	1.794_3
2	Melting in air for a long time, rapid cooling	1.813_3
3	Heating in vacuum for 24 hr, melting in vacuum for 24 hr and:	
	rapid cooling	1.778_1
	cooling for 8 hr	1.811_8
	cooling for 13 hr	1.812_2

(continued)

Sample	Melting conditions	d,g/cm^3
4	Melting at 800°C in air for 1 hr and:	
	rapid cooling	1.809_2
	cooling for 8 hr	1.838_0
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Genrikh, 1946.

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Bresker, Evstropiev, 1952.

See the table on p.82.

Shartsis, Capps, Spinner, 1953a.

Counterbalanced platinum sphere method. Melting and measurements in platinum crucible.

t,°C	d,g/cm^3	t,°C	d,g/cm^3	t,°C	d,g/cm^3
25	1.859*	518	1.621	1000	1.509
997	1.512	701	1.560	1103	1.498
804	1.536	804	1.538	1103	1.499
602	1.587	898	1.522	1201	1.478
452	1.698				

* Archimedes method using kerosene.

Weir, Shartsis, 1955.

Melting in platinum crucible. Annealing for 1 hr at temperature approximately halfway between softening point and lower critical temperature, cooling at the rate ~10 K/hr for ~80°C and then cooling in a freely cooling furnace for 16 hr.

Archimedes method.

t, °C	d, g/cm^3
21	1.844

Compressing under hydrostatic pressure at 21°C. δV is the calculated change in volume due to the change in pressure from 2000 to P atm; V_o is the volume of the specimen at 1 atm.

P, atm	$-\delta V/V_o$ Specimen 1	$-\delta V/V_o$ Specimen 2	P, atm	$-\delta V/V_o$ Specimen 1	$-\delta V/V_o$ Specimen 2
10000	0.0485	0.0487	5000	0.0194	0.0199
9000	0.0430	0.0434	4000	0.0132	0.0136
8000	0.0375	0.0379	3000	0.0067	0.0070
7000	0.0318	0.0321	2000	0.0000	0.0000
6000	0.0258	0.0262	1400	-0.0041	-0.0042

Coughanour, Shartsis, Shermer, 1958.

See the table on p.87.

Eversteijn, Stevels, Waterman, 1960a.

Flotation method using bromoform and xylene. $\Delta d = \pm 0.0002$ g/cm^3. Temperature 20°C. Melting of H_3BO_3 in platinum dish at 900-950°C for 20 hr. After cooling the glass was heated again to 900-950°C with gradual evacuation and exposition at pressure of 1 mm Hg for 8 hr. Quenching in dry benzene. After stabilization quenching in dry benzene again.

Stabilization conditions t, °C	Stabilization conditions τ, hr	d, g/cm^3	Stabilization conditions t, °C	Stabilization conditions τ, hr	d, g/cm^3
203	160	1.8475	252	20	1.8304
229	185	1.8462	270	96	1.8103
233.5	210	1.8458	292	100	1.7944
240	110	1.8432	324	60	1.7852
244	178	1.8390	347	26	1.7826
246	180	1.8333			

Flotation method using bromobenzene and dibromoethane (both well dried). Temperature 20°C. Melting of H_3BO_3 in platinum crucible.

A. Quenching (cooling of the liquid product rapidly in platinum crucible above a cold air stream).

Glass No.	Melting conditions	Wt% H_2O structurally bound (2.94μ)	Wt% H_2O from surface attack (3.13μ)	d, g/cm^3
1	Heated in air for 2 hr at about 1000°C	none	0.38	1.8131
2	Glass 1 subsequently heated for 4 hr at 900°C at a pressure of 2 mm Hg	none	0.37	1.8069
3	Glass 2 subsequently heated for 6 hr at 1190°C at a pressure of 2 mm Hg	none	0.40	1.8017

B. Annealing (stabilization of quenched glass at 261°C for 18 hr and cooling to 148°C with a mean cooling rate of 2.5 K/hr).

Glass No.	Melting conditions	Wt% H_2O structurally bound (2.94μ)	Wt% H_2O from surface attack (3.13μ)	d, g/cm^3
1	Heated in air for 2 hr at about 1000°C	-0.07% (difficult to estimate)	0.42	1.8565
2	Glass 1 subsequently heated for 4 hr at 900°C at a pressure of 2 mm Hg	doubtful	0.42	1.8407
3	Glass 2 subsequently heated for 6 hr at 1190°C at a pressure of 2 mm Hg	hardly detectable traces	0.43	1.8399

Milberg, Belitz, Silver, 1960.

Float-sink method using mixtures of diiodomethane and xylene. Temperature 25°C. Heating of H_3BO_3. Annealing time 3 weeks.