physical sciences data 15

handbook of glass data

Part A

silica glass and binary silicate glasses

o.v. mazurin, m.v. streltsina
and t.p. shvaiko-shvaikovskaya

physical sciences data 15

handbook of glass data

Part A

silica glass and binary silicate glasses

o.v. mazurin, m.v. streltsina

and t.p. shvaiko-shvaikovskaya

Institute of Silicate Chemistry of the Academy of Sciences of the U.S.S.R., nab. Makarova 2, Leningrad, 199164, U.S.S.R.

ELSEVIER

Amsterdam – Oxford – New York 1983

ELSEVIER SCIENCE PUBLISHERS B.V.
Molenwerf 1
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

Distributors for the United States and Canada:

ELSEVIER SCIENCE PUBLISHING COMPANY INC.
52 Vanderbilt Avenue
New York, NY 10017

Library of Congress Cataloging in Publication Data

Mazurin, Oleg Vsevolodovich.
Silica glass and binary silicate glasses.

(Handbook of glass data ; pt. A) (Physical sciences data ; v. 15)
Bibliography: p.
Includes indexes.
1. Glass. 2. Silicates. I. Strel'tsina, Marina Vladimirovna. II. Shvaĭko-Shvaĭkovskaia, Tat'iana Pavlovna. III. Title. IV. Series. V. Series: Physical sciences data ; v. 15.
TP848.M36 1983 pt.A 620.1'44'C212s [620.1'44'C212]
[TP857] 83-11643
ISBN 0-444-42215-3 (U.S. : v. 15)

ISBN 0-444-42215-3 (Vol. 15)
ISBN 0-444-41689-7 (Series)

Printed in The Netherlands

FOREWORD

During several decades scientists of many countries have been studying various properties of glass-forming melts and glasses. Their results are scattered in various scientific journals, numerous monographs, theses and proceedings published in various countries all over the world. Any scientist, engineer and information science worker knows too well how time-consuming it is to extract if only a part of the available information concerning any particular problem of interest. The present reference book makes it possible to find the complete enough information on the properties of one-component, binary and ternary oxide glass-forming melts and glasses with a minimum consumption of time.

The well-known "Glastechnische Tabellen" edited by W.Eitel and published in 1932 was the first comprehensive reference book on the properties of glass-forming melts and glasses. The book covered the information on all so far investigated glasses and this took up 714 pages of close printing. Since then the avaliable information in question has increased many-fold and to cover an adequate range of the data on each particular problem we had to restrict the scope of the problems of our reference book.

First of all we considered it expedient to abandon the data on multicomponent glasses and restrict ourselves only to the melts and glasses with the number of components not exceeding three. We proceeded from the assumption that, as a rule, the results on the glass-forming systems with a limited number of components are of interest to a much greater part of investigators than the data on the properties of multicomponent glasses. The latter data are mainly of interest to the consumers of particular industrial glasses and they are specifed in the publications of the corresponding firms. These data are of little interest, as soon as the given glass is not produced, while the systematic data on one-component, binary and ternary glasses keep useful for a very long time for various scientific, practical and educational purposes.

A rapid increase of the variety of glass-forming substanses 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 the 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 for any reader to have a reliable information of any property-composition dependence.

Here are the principles of the data selection and presentation which were applied in 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 the deposition from a vapour phase.

2. The data on the melt properties are presented only for the glass-forming systems. Nevertheless we present the data on the 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 the reason to transfer a glass to the category of the 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 the impurities which were not introduced deliberately during its synthesis, these impurities will not be take into consideration when classifying glasses 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 the two decimal places, since with the present experimental technique a minimum measurement error of the indicated properties exceeds ± 2% of the measured value even in the best investigations.

It is well known that the 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 and ternary 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 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, Neorganicheskiye 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 often encoutered with 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 was taken from "Glastechnische Tabellen". The later 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 at 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 all 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.

We wish also to express our gratitude to Professor C.T.Moynihan, of Rensselaer Polytechnic Institute, USA, for the helpful recomendations on the best wording of the figure and table captions of this book.

An idea of such reference book was suggested in 1967 independently by the former Director of the Institute of Silicate Chemistry Professor N.A.Toropov and by Dr.J.O.Isard (Sheffild University). Since then the authors of the present book worked on the realization of this idea. The first version of this book was published in Russian by the Leningrad branch of the "Nauka" Publishing House under the title "Properties of Glasses and Glass-Forming Melts". The edition included the following issues: Vol.I, Silica Glass and Binary Silicate Systems, 1973, 443 pp.; Vol.II, One-Component and Binary Oxide Non-Silicate Systems, 1975, 630 pp.; Vol.III, part 1, Ternary Silicate Systems, 1977, 585 pp.; Vol.III, part 2, Ternary Non-Silicate Systems, 1979, 485 pp.; Vol.IV, part 1, One-Component and Binary Oxide Systems (supplement to vols I and II), 1980, 462 pp.; Vol.IV, part 2, Ternary Oxide Systems (supplement to vol.III), 1981, 374 pp. That edition served as the basis for the present reference book. It should be noted, however, that considerable changes have been introduced into this edition, which amounted to the following. The corresponding sections of the additional (the fourth) volume has been added to the first three volumes. 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). Each volume of the present edition will have its own author, subject and formula indices. In the last part of this edition the comulative indices over all the volumes will be also published. The edition will comprise five parts: Part A, Silica Glass and Binary Silicate Glasses; Part B, Single-Component and Binary Non-Silicate Oxide Glasses; Part C, Ternary Silicate Glasses; Part D, Ternary Non-Silicate Oxide Glasses; Part E, Supplements.

The authors believe that the first four parts of the book will be published during the next four years. Supplements (Part E) are to follow which will involve the data on single-, two- and three-component 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 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 A presents the results of the papers published up to 1981.

LIST OF SYMBOLS

a temperature conductivity

b thickness of a dissolved layer; in 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 log 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's modulus

f frequency

G shear modulus

H microhardness

ΔH enthalpy, heat of solution, heat of crystallization

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 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 $T \to 0$

ε'' loss coefficient, $\varepsilon'' = \varepsilon' \mathrm{tg}\delta$

η viscosity

κ electrical conductivity
λ heat conductivity; in the sections "Internal friction" it is the logarithmic damping coefficient; in the sections "Optical properties" it is the wave length
μ Poisson's 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

CONTENTS

SiO_2

CRYSTALLIZATION

Bezborodov, Kurlyankin, 1946.

Crystallization in a porcelain tube for 3 hr.

t, °C	b, mm				
	air	CO_2	H_2	CO	H_2S
1200	0.03	0.03	0.03	0.03	0.03
1300	0.03	0.03	0.03	0.03	0.04
1400	0.07	0.08	0.12	0.14	0.16
1460	0.16	0.17	0.33	0.32	0.30

Brown, Kistler, 1959.

See the table on p. 540.

Ainslie, Morelock, Turnbull, 1962.

G.E.204a silica glass. Specimens were made from tubing, although in some cases solid rod was used.

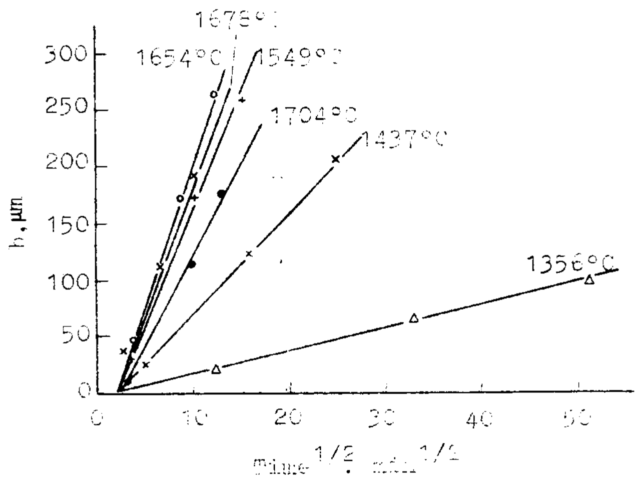

Fig. 1. b is the cristobalite layer thickness.

Wagstaff, Brown, Cutler, 1964.

b is the cristobalite layer thickness. $\Delta b = \pm 20\% \ b$.

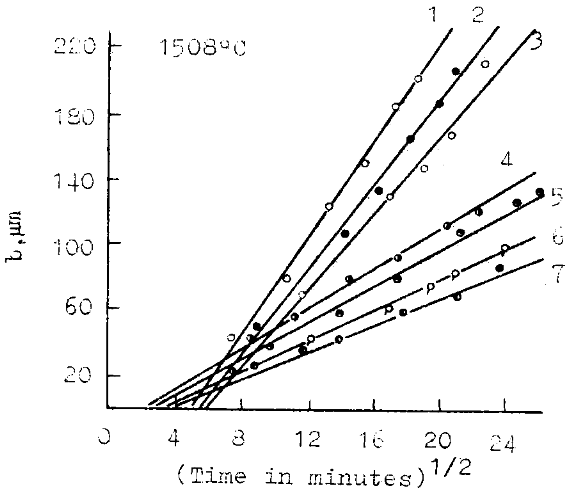

Fig. 2. Tubes of G.E.204a silica glass (total impurity 110 p.p.m., Al_2O_3 - 52 p.p.m., CaO - 23 p.p.m.). Atmosphere, mm Hg: 1 - H_2O, 567; 2 - H_2O, 295; 3 - H_2O, 121; 4 - O_2, 647; 5 - O_2, 485; 6 - O_2, 323; 7 - O_2, 161.

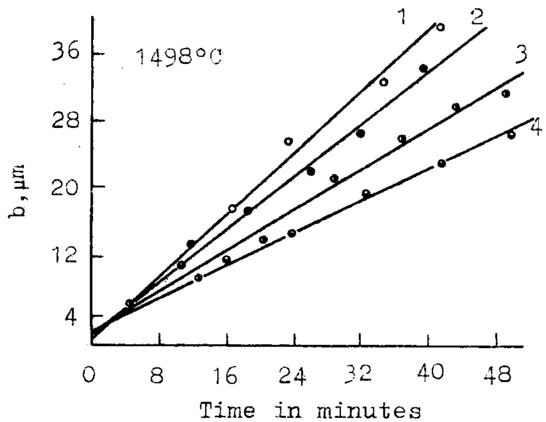

Fig. 3. Corning 7943 silica glass (0.001 wt% OH). H_2O vapour atmosphere, mm Hg: 1 - 535; 2 - 289; 3 - 130; 4 - 63.

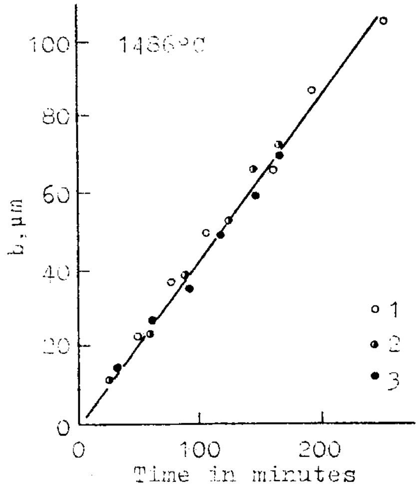

Fig. 4. Stoichiometric silica glass (Corning 7940 dewatered in vacuum) Atmosphere: 1 - 100% N_2; 2, 3 - 100% O_2.

In the publication some additional data on the growth rates of various silica glasses are given.

Hlaváč, Vašková, 1965.

Czechoslovakian reduced silica glass (impurity 10^{-2}%). Specimens in the form of tubes and rods are crystallized in air. $\Delta t = \pm 3$ K.

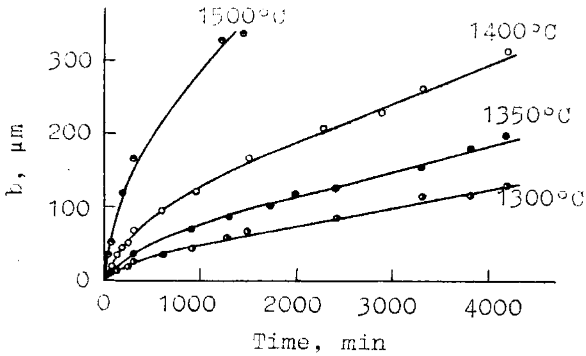

Fig. 5. b is the cristobalite layer thickness. $\Delta b = \pm 10$ µm.

In the publication similar data on the crystallization of French silica glass are given.