SGT NEWS

Fundamentals of Inorganic Glasses

Professor Arun Varshneya of New York State College of Ceramics, Alfred University, New York, has published the second edition of his book *Fundamentals of Inorganic Glasses* through the Society of Glass Technology. The book provides an all round grounding in the basic science of glass through to the basic principles of manufacturing glass and its many applications. It is aimed at undergraduate students but offers a thorough basis for anyone interested in anything made of glass.

One of the author's primary purposes in writing this book is to convey that feeling of "identity" to the young that a glass scientist, engineer, or technologist belongs to a reputable material. The day is not far, probably, when some education about glass will find its way through every college-level engineering and science curriculum.

A second purpose is to bring together a host of fine quality books on glass into a single textbook for an undergraduate student - comprehensive, yet confining itself to a general understanding of the topics. Trying to strike a balance between the depth and the breadth has been the author's aim. This book is about inorganic glasses, and mostly about their science. Glasses based on carbon chains and macro-molecules have not been included. Also, details of the technology and engineering of glass and glass product manufacture have been spared for a later date.

The book is intended to be a textbook on glass science suitable for teaching at a junior/senior level in a materials curriculum. Its emphasis is upon developing the fundamental concepts, whether they were ultimately proven wrong or not. As such, the book might also be useful to industrial scientists and engineers who are attempting to acquire a basic knowledge in glass. All efforts have been made to avoid deep scientific discussions and heavy mathematics, but there are places where they are unavoidable.

The organisation of the chapters follows the author's "Introduction to Glass Science" course for students at Alfred University. The introduction gives a brief history of glass, this is followed by an initial look at glass families of interest: vitreous silica; soda-lime glass; borosilicate glass; lead silicate glass; aluminosilicate glass; other silica-based oxide glasses; other non-silica-based oxide glasses; halide glasses; amorphous semiconductors; chalcogenide glasses; glassy metals; glass-like carbon; and oxyhalide, oxynitride, and oxycarbide glasses. There is also a brief note on glasses found in nature.

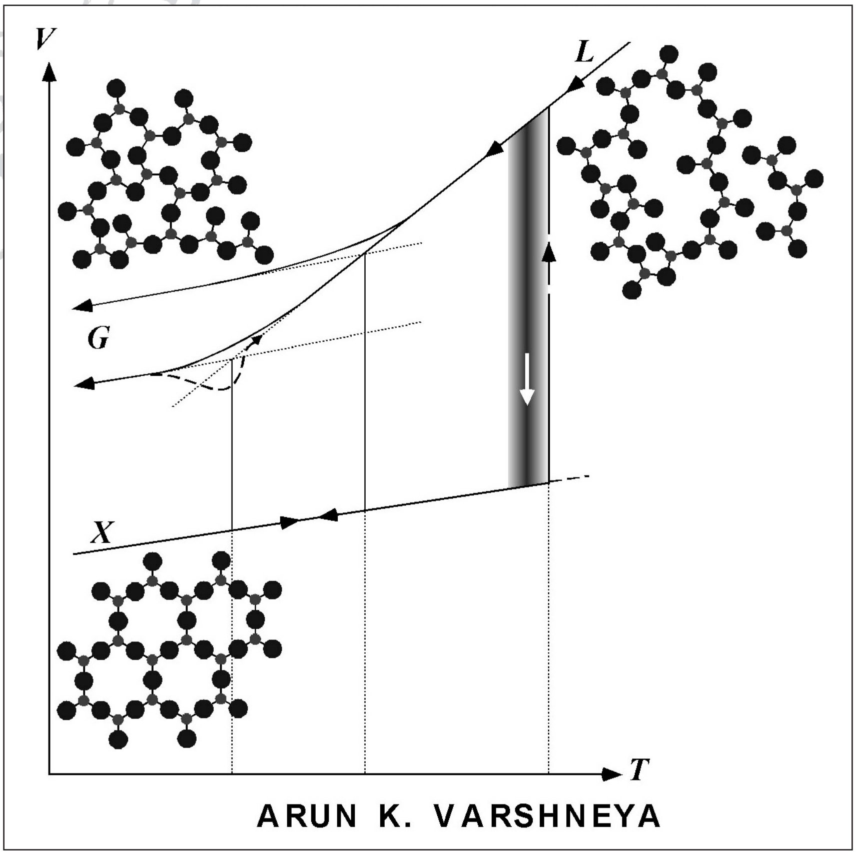
The remaining 19 chapters cover: fundamentals of the glassy state; glass formation principles; glass microstructure: phase separation and liquid immiscibility; glass compositions and structures; composition-structure-property relationship principles; density and molar volume; elastic properties and microhardness; viscosity and surface tension of glass; thermal expansion; heat capacity; thermal conductivity; glass transition range behaviour; permeation, diffusion and ionic conduction; dielectric properties; electronic conduction; chemical durability; strength and toughness; optical properties; and fundamentals of inorganic glass making. Each chapter is completed with some exercises to test the reader. Three appendices complete the book: Elements of Linear Elasticity, Who Wants To Earn an A?; and Units and Conversions.

Chapter 2 asks: What is Glass? Using the volume–temperature (V-T) diagram, it pairs correlation and radial distribution functions and goes back to look at anomalies in the V-T diagram. Chapter 3 looks at structural theories of glass formation: Zachariasen's random network theory, Sun's single bond strength criterion and Phillips' topological constraints hypothesis. It then looks at the Russian criticism of Zachariasen's random network model and the kinetic theory of glass formation: nucleation rate, crystal growth rate, and the Time–Temperature–Transformation (T-T-T) diagram.

Chapter 4 looks at the microstructure of glass, in particular, phase separation and liquid immiscibility. It examines the thermodynamics of mixing, formal analysis of phase separation, electron microscopy to observe phase separation in glass and observations of controlled-crystallisation in glass (glass-ceramics).

Chapter 5 looks at glass compositions and structures by first looking at the presentation of glass formulae, then at various compositions, the borate anomaly and glassy metals.

Chapter 6 outlines the composition-structure-property relationship principles, firstly in a general case and then as additivity relationships. These are expanded on in chapters on density and molar volume, elastic properties and microhardness, viscosity and surface tension of glass [including an explanation of the viscosity of common soda-lime-silicate glass at room temperature (the "urban legend")], thermal expansion, heat capacity and thermal conductivity.



▲The cover of *'Fundamentals of Inorganic Glasses'*.

Chapter 13 provides a substantial introduction to glass transition range behaviour: viscoelastic properties of glass, structural relaxation due to temperature change, viscosity free volume theories of glass transition, thermodynamics of glass transition, kinetics of glass transition, properties data in the Tg range, development of permanent stresses in glass by cooling through the glass transition range, and concepts of annealing and tempering.

Chapter 14 describes permeation, diffusion and ionic conduction; the atomic theory of diffusion and electrical conduction, measurement of gas permeability, measurement of diffusion coefficients, measurement of electrical conductivity, data on permeability and molecular diffusion of gases in glass, data on ionic diffusion and electrical conduction in glass, and some aspects of diffusion and electrical conduction phenomena. The following two chapters then look at dielectric properties and electronic conduction.

Chapter 17 looks at mechanisms of chemical durability, its measurement and methods of improving it. Chapter 18 is on strength and durability with an introduction to theoretical strength of a flawless brittle solid, strength of a flawed brittle solid: Griffith's analysis, and elementary fracture mechanics. It also looks at glass fatigue, mechanism of strength based upon slow crack growth, elementary fractographic analysis, fracture statistics, life prediction, experimental measurement of glass strength and fracture toughness, data on strength and fatigue parameters, and strengthening and toughening.

Chapter 19 details the optical properties of glass, initially by defining some theoretical concepts (dispersion, scattering, absorption in the visible region, absorption in the UV, absorption in the IR, photoelastic properties, and anomalous birefringence) before going on to look at measurement and data. Special applications such as photosensitive glasses, nonlinear optics, glass as a laser host, fibre optics, and coatings on glass to improve optical quality are detailed.

Chapter 20 on the fundamentals of inorganic glass making covers laboratory melting of glass, continuous melting of glass, and non-fusion based techniques of glass making: from solid, gaseous and sol-gel. The forming of glass products (containers, flat, fibre, tube and rod) then concludes the book.

The paperback version of the book is priced at £36 to SGT members, £50 to non-members, $50 to members in the North American Section. Orders can be made through the SGT website www.sgt.org.

Eighth ESG Conference on Glass Science and Technology

The Society of Glass Technology has been selected to host the 2006 meeting of the European Society of Glass Science and Technology. The meeting will be held on 10–14 September 2006 at St Peter's Campus, University of Sunderland.

The meeting is also the International Commission on Glass Annual Meeting for 2006 and the Society of Glass Technology's annual meeting.

The ESG series of meetings normally feature two or more parallel sessions, one covers purely scientific research the other covering industrial and technological developments. An added dimension will be the inclusion of studio artists throughout the programme with many opportunities to break down some of the artificial barriers that sometimes appear to divide the different communities.

The ICG holds an annual meeting in the years between the International Congress; the next Congress will be in Strasbourg, France on 2–6 July 2007.

The Sunderland meeting will draw some of its influence from the host city and the rich heritage of glass making and the strong support of current glass making that is provided in the region from the National Glass Centre and the glass based courses at the University of Sunderland.

The ESG Conference is held every two years in a different host country. The scope of this conference is to promote glass science and technology and, in particular, to enhance interaction among experts working in diverse areas such as glass manufacturing, glass archaeology, art and environmental issues, as well as glass science and applications.

Topics will include, but will not be limited to, the following: furnace technologies and refractories; glass melting and forming; water and sulphur in glass; energy; environmental issues; glass products and quality control; glass structure and properties; sol-gel processing; glass surfaces; nucleation and crystallisation; glassy and glass-ceramic nanomaterials; glasses in optics and photonics; novel glasses and applications in medicine, dentistry, biotechnology; glass art; and history and heritage of glass.

The most recent conference held in Athens in April 2004 attracted more than 200 delegates and included around 80 oral papers and 40 poster presentations covering a wide range of interests, eg Ta-Luft implementation of the European glass Bref, glass melting economies, sol-gel synthesis of bioglass composites, development of high gain tellurite and borophosphate glasses for broadband applications, and glass contact performance of traditional and novel pot materials.

The proceedings of the Athens meeting were published in *Glass Technology* and *Physics and Chemistry of Glasses* in April 2005.

The second announcement and call for abstract submissions will be sent out in November 2005 and the abstract submission deadline will be April 2006.

Further information can be obtained from Christine Brown at the Society.

Journal of the Society of Glass Technology – electronic versions

The Journal of the Society of Glass Technology *was published until 1959 when it was split into parts A and B;* Glass Technology *and* Physics and Chemistry of Glasses. *The 1917 has now been added to the 1918 and 1952 volumes that can be viewed through the SGT website.*

The contents pages of all the remaining volumes can be also be viewed on the site and copies of papers can be made to order.

The contents pages of Glass Technology *and* Physics and Chemistry of Glasses *can be seen on the website and Ingenta are the hosts of the full peer reviewed papers from 1998 to the present.*

CHANGE OF ADDRESS

The Society of Glass Technology has moved to a new office:
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Glassmaking in Britain

The History and Heritage Group Special Interest Group study day during the Society of Glass Technology Annual Meeting looked at the richness of the heritage of glassmaking in Britain. Glassmaking in the widest sense has had its place in Britain since Roman times, responding to the demands of the market place and constantly evolving under the impetus of new artistic trends, new technologies, new pressures of competition, new possibilities for market success.

Knowledge of glassmaking history leans heavily on the efforts of historians and archaeologists, the finding and interpretation of glass objects and glassmaking sites in their contexts. Today's science contributes strongly to that process, as it does to the business of protecting and restoring our legacy of glass heritage. The purpose of this History and Heritage day was to bring together these diverse strands of glass expertise in celebration of the glassmakers who, through the ages, have had such a signal impact on English culture and society.

Dr David Martlew welcomed everyone and introduced Dr Caroline Jackson of the Department of Archaeology, University of Sheffield the chair for the first session: Early Industrial Glassmaking in Britain.

Andrew Smith of Avon Archaeological Unit presented a review of the Nailsea Glassworks. The outline history of the glassworks at Nailsea has been known for some time, but recent developments meant that a closer look has been given to the site, its history, and its archaeology. Nailsea is 11 to 12km from the centre of Bristol but is regarded as one of the Bristol Glassworks. It was established in 1768, glass production finished in 1893 and the site closed in 1894. It began as a bottle maker but branched out to make sheet glass by its own patented method in 1805.

The glassworks is situated on the North Somerset levels where surface coal is present, not wide seams but reasonably good quality. It would have been a green field site by today's standards and was not constrained by Bristol's building regulations. Secrecy was also important – the site was walled to keep out competitors.

Archaeological work was carried out when Tesco built a supermarket on part of the site. A 1900 view of the glassworks showed evidence of three cones: these were documented as the New House, Old House and Lilley (little) cones.

The presenter hoped that his presentation might lead to some clarification – for example, Belgian lehrs and French kilns are noted, but we have only the slightest of evidence for their form. The structures for pot-arches stood until relatively recently, but no evidence seems to have been recorded as to how they were fired.

A good layout of the furnace was recorded, swing pits were built contemporary with the cone, then some additional ones added. Secondary airways were also added, metalwork supports – furnace bars – were noted. There had been no sign of metalwork originally - but revising the views it may be that there is some evidence. Furnace bars were not retained, but could be could be for cast iron grates. There was evidence of clay lined ducts leading to the Old House Cone furnace. This could have been for the generation of producer gas/water gas, the structures suggests a Frisbee feeder may have been present.

A full version of the study in five principal parts can be found on the internet:

http://ads.ahds.ac.uk/catalogue/library/nailsea_avon_2004/

PERCIVAL VICKERS FACTORY, MANCHESTER

Moving forward in time to the Percival Vickers factory at Jersey Street in Manchester, where the cone now is not a feature but manufacture still needs to get the best out of a coal fired furnace. Ian Miller of Oxford Archaeology North followed the innovation of the last half of the 19th century. Established in 1844, with two furnaces, annealing houses and workshops for mould making, the Ancoats factory of Percival Vickers was part of a large group of Manchester glassworks. By 1863 there were 373 employees, a third furnace was added in the early 1880s. Manchester was the largest employer of glass makers in 1872 and a big group of factories were established in Ancoats, there was a grouping in Hulme, then Salford developed later. Originally the main products were cut glass, then Manchester became known for its press moulding ware. By the late 1880s finances were looking bad for all the Manchester based glass makers as demand for pressed ware declined and many by the end of the century had closed. Percival Vickers closed in 1914.

English Heritage had an opportunity to inspect the site 90 years after it had closed. The site backed onto the Rochdale Canal, no wall on the canal side to allow wind to blow in and give draft to the furnaces.

The foundations of the furnaces were found when excavated, virtually intact. Two had the same physical build - no difference noticeable. Each had an inner lining of refractory on hand made brick. Channels run around the bottom of the flue/cone. There were ten pot furnaces. Refractory blocks probably from the Stourbridge area were used, no furnace grate was found. They were fed with coal via a stoke hole below the furnace. Flues (north to south) extended away from the furnace and were well preserved.

Workshops were found but there was not much evidence of a major engine house, only one small engine room, unexpected for the size of the site and puzzling if cutting machinery was to have been powered.

The third furnace had very different structure, showing an improved design, brick work and design of air passage around the structure. Plenty of evidence of air control: two ceramic pipes providing jet of air into the ceramic eye, a Frisbee feeder. This was a ten pot furnace – again.

Further information can be found on the website www.oxfordarch.co.uk/pages/glass.htm

SOME REFLECTIONS ON FURNACE OPERATION

Accounts of the English Glasshouse make various assertions about how such glassmaking facilities were constructed and operated. Archaeological investigations of the surviving basal remains sometimes uncover puzzling features. David Martlew looked at what must have been involved in operating these furnaces in order to appreciate the achievements of the men who made them work.

Control of air flow into a cone building would have been needed if the furnace was going to be efficient and hot enough to melt the raw materials and produce saleable glass – keeping breathable air for the workers – but also for the furnace.

Combustion space and plan area of grate dictates the economy of the furnace. Muscle was needed to place the coal in the right place on the grate, then do it for a whole shift.

Ash from the burning coal is also hard to deal with, it will melt and give a vitreous clinker which dictates operation.

Dr Martlew and Peter Pemberton-Ross have worked on a limited computer model of the glass cone, it is work in progress, a first attempt at looking at air pressure in the system.

The introduction of British lead crystal glass was a major turning point for the glass industry in Britain, yet its development in the 17th and 18th centuries has attracted surprisingly little research. This has resulted in some confused and fanciful accounts of its 'invention'. Colin Brain attempted to redress this and to highlight the differing motives that those involved had for promoting 'flint' glass; ranging from the alchemist's dream of a "philosophers' stone" to the high-refractive index "metal" prized by early glass cutters.

There is a sudden jump in the capabilities of the British glass industry: 15 years after the Great Fire it is first class. There is little to no information how it happened. George Ravenscroft as its discoverer is the simple explanation that initially worked. However, there is plenty of evidence for it being made before then.

There were preconditions for the revolutionary change - skills, raw materials, opportunities. Lead being reduced to metallic lead will drill a

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hole in the pot and escape taking the glass with it! Mark Taylor of the Roman Glass Makers reduced the lead with tartar to get metal and a damaged furnace. A strongly oxidising atmosphere is needed to get the glass you want. The batch components were not available until the 17th century.

Saltpetre/nitre shipped from India instead of ballast, is strongly oxidising, but its supply was originally limited because of its strategic importance as gunpowder component. When the Crown monopoly ended, its use as ballast reduced the cost of shipping and it found new applications. Flint also used as ships ballast, quite a trade of flint, coal barges from Newcastle were coming back with flint for glass grindstones.

At that time Christopher Merrett's translation of Neri's Art of Glass was timely and descriptive, but in 1652 Glauber's New Philosophical Furnaces was translated to English, lots of glass manufacturing experiments were reported in this book. Making flint glass in a two stage process – high lead starter glass followed by addition to a second glass.

The science based approach was beginning – published in books, with open sharing of the science knowledge was being transferred into industry as well formed technologies. Chemistry was no longer the domain of the alchemist searching for the philosopher's stone in secret.

Bringing in glass makers from elsewhere to help in the expansion (explosive expansion) of the glass industry in the England also helped. There were a number of prominent surnames associated with glass making: Rackett - London, Southwark, Chelsea, Stourbridge and Newcastle; Da Costa – Henley; Lowden - Bristol; Perrot - Stourbridge & Bristol; and Odacccio – Dublin. Genealogy databases show the possible location of other glass houses because of clusters of these names.

Coal fired furnaces came into their own in the from 1680s. Glass sellers wanted strength weight and durability. Lead crystal's suitability for cutting and engraving was accidental - not exploited for more than 100 years, glass properties were enough to explore to begin with.

Colour – there was not much English evidence - Dublin excavations showed otherwise but there is little evidence on the glass produced.

The 19th century was a period of unprecedented innovation in the Stourbridge glass industry and by the end of the century the area had established an international reputation for the fine quality of its tableware and decorative glass. The old established technique of copper-wheel engraving was given a new lease of life by the arrival of a group of highly skilled engravers from Bohemia, while the greatest achievement was the revival of the Roman cameo technique by John Northwood and his followers. Roger Dodsworth of Broadfield House Glass Museum looked at the Art of the Decorator – Glass engraving and cameo work in Stourbridge at this time.

Victorian era Stourbridge was on top of the world with great techniques and decoration but Stourbridge was a relatively poor area and cut off from the mainstream in London. Continental engraving began with an influx of engraving artists/craftsmen bringing the Bohemian lathe into the country.

In copper wheel engraving the decoration is sunk below the surface. This leaves a matt effect which is sometimes polished. Emery powder and oil are used as the abrasives but it has to be wiped off every 20 seconds or so – very stop start.

Frederick Kny was one of the first, he decorated the Elgin claret decanter in 1868, this featured the Parthenon Frieze. More information about engravers is coming to light today and new personalities and their details are surfacing: Joseph Keller wrote a pattern book, for other designers to copy, a notable style was a decanter with a bird attacking a snake.

Adolf Augustus Zinke was also an engraver, his descendants came along to an open meeting at Broadfield House with some of his work. Zinke who arrived in Brierley Hill from Bohemia at the age of 15 with a few clothes, a book full of beautiful drawings, and two painted glass vases. He was born in Steinschonau, a centre of glass engraving since the 17th century, although his father Adolf was a glass painter. Adding to a growing number of Bohemians to settle in the area, Adolf took up lodgings with his uncle Josef Schiller, one of the leading engravers with Stevens and Williams, in Moor Lane, Brierley Hill. Adolf also joined the firm, and after completing his indentures he left to do contract work with various local firms, including Stuart and Sons. Matt copper engraving by Thomas Webb & Sons was rewarded at the Paris exhibition, only one of two given to glass makers.

Relief engraving or rock crystal engraving is where thick glass blown and formed then cut and polished. A noted expert and artist was George Woodall, he was possibly the greatest and went on to excel at cameo glass when this was revived in Stourbridge.

White glass is cased over with a coloured glass, it is then painted over with a resist, dipped in acid to remove the rough outline of the glass. Then the detailed was carved in the glass by hand. Thomas Webb & Sons had 80 engravers working, it was said, at the height of this production processes. Padded cameo was used with splotches of colour rather than encasing.

George Woodall was in charge of cameo carving at Thomas Webb and he was responsible for some of the greatest pieces of the time. He retired in 1910, but kept on working from home until 1925.

The Science of Beauty - how light and glass interact: in appreciation of these achievements, John Parker set out to explain the science of how colour develops in glass, what refractive index is all about and how yesterday's beauty feeds forward into today's high tech world.

Hardwick Hall became famous for having "more glass than wall", it was a revolutionary building using glass and bringing the outside in. The transparent properties of glass were beginning to be exploited even the bull's eye, the point on the rotated glass disc that was held on the iron, a waste product was used in the windows of public houses for privacy, distorting the view while allowing in light.

Rich people could afford more windows and this brought the attention of the tax man, a tax was due for the numbers of windows in houses and the term daylight robbery came from this.

Glass, why is it transparent, this inorganic product of fusion. It is not a liquid but a non-crystalline solid and the lack of crystal grain boundaries allows it to be transparent.

It is a disordered structure - constantly reinvents itself, a random structure, with some short range order. Within this structure are lots of holes, holes that can accommodate ions of many different sizes. The colour of glass can be modified by what is added.

Not all colours are reproduced by dissolved ions sometimes it is a coating. Why does this colour glass? An energy levels explanation was presented. What happens when a glass re-emits its energy? Looking at other ways it can lose its energy, maybe in steps lose energy in small amounts. Sharp energy levels provide discrete colour, irregular floors allows a "spread" of colours, but also atoms move about too. Nothing remains still and there is a blurring out the energy levels.

Disordered and local order – order around colouring metals is different, cobalt has two possible colours, nickel has two also, there is some degree of order in there.

Amber glass is coloured by iron and sulphur - beer in clear bottles can be sun struck and this protects it. Excited electrons move back to the ground state after a millionth of a second, but a laser can pump it up to further levels, absorb smaller energies into visible light.

Precipitated particles can also be responsible for colour in glasses and the particles themselves might show differences in reflective and transmitted light.

Few important advances were made in the methods used by the glass industry from the invention of the blowpipe until the middle of the 19th century when the industrial revolution saw rapid progress, much of which was only possible following the invention of the Siemens regenerative furnace. Michael Cable illustrated the milestones in glass engineering in chronological order:

- precisely engineered moulds,
- the Owens machine,
- mechanizing the drawing of cylinders to make flat glass,
- the Fourcault process,
- the IS machine
- the Corning ribbon machine
- float glass.

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