A TOUCH OF GLASS

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Popular Science

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This book is dedicated with love to the memory of
Debjani Ghosh (Bubul didi) and to Sanjoy Ghosh (Sanjoyda)
for being my Go-To couple for everything
for as long as I can remember.

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AUTHOR

Preface

Translocation from one city to another, i.e., from one way of life to another is never easy; particularly not when the move is triggered by situations beyond one's control. For me too relocating to hometown Kolkata after over two decades was not an easy task. As cities, New Delhi and Kolkata march to different drummers; the pulse beats differ. The idioms in which these cities speak are different too. I struggled to adjust. I needed an escape.

The Central Glass and Ceramic Research Institute, Kolkata, which carries out pioneering work in the field of glass and ceramics presented a terrific escape route. The study of glass seemed to me a world as fascinating and as mysterious as any fairytale where imagination runs riot or the deepest reaches of science where facts that exist are often stranger than fiction. The more I read; the deeper I entered the realm of glass ,the more enamoured I became.

Glass was the first material to be mined; primitive man sent out mining parties to look for Obsidian...a volcanic proto-glass of sorts. Warriors fashioned spearheads and arrowheads out of Obsidian. Ancient Indian glass beads and bangles decorated the beauties of that age. Glass bottles once held the tears of the mourners in ancient Persia and Egypt. The pyramids housed the glass jewellery once worn by royalty. The bones of the owners are dust now but the beads and bottles still breathe their tales. The glass slipper of Cinderella is not just a tale; modern brides have wed wearing wedding dresses and accessories made of glass. And in 2016, Taiwan built a glass church shaped like a blue, high-heeled slipper.

Glass is embedded in human life. There is archaeological evidence that glass was first made in Eastern Mesopotamia and Egypt around 3500 BC. Clay tablets inscribed with formulae for making glass have been excavated and are on display in museums. Interestingly, these crude formulae still work although glassmaking is now an extremely sophisticated science. When glass was newly introduced, it commanded prices so high that only the wealthy could afford to buy glass objects. In time, glass became so easily available that at least one Roman Emperor refused to use glass because it was too common for royalty.

The Lucurgus Cup is ancient luxury glass cup that changes colours depending on the angle of light: it appears jade green when lit from the front but red when lit from behind. Recent studies have been shown that it contains nanoparticles of silver and gold. So did the 4^{th} century Romans know about Nanotechnology?

The history of glassmaking is a story full of tales of serendipitous discoveries, globalization of skills as artisans fled wars, failed attempts to maintain monopoly, royal patronage, lifelong experimentations by mavericks; even stories of deceit and betrayed trust. It is an unbroken lineage with many meandering streams of evolution. As with all flows, some streams disappeared in the sands of time. Some sorts of glass are no longer made today. The art is lost. However, there are modern types of glass that are being made with custom-made characteristics to suit the needs of thenew century.

The story of the Glass Industry in modern India is an inspirational one. It is the story of social inclusivity in action. Few know that first glass factory; The Paisa Fund Glass Works, came up at Talegaon near Pune, thanks to the contribution of just one paisa each from members of the general public. Today, India exports glass to countries such as USA, China, Brazil and Germany.

I hope that the readers enjoy discovering the many facets of Glass, as much as I have enjoyed writing about them.

SUKANYA DATTA

1

FACT AND FAIRYTALE

We hardly ever leave home without one last fleeting glance at the looking glass to see if we are looking our best or not. However, perhaps our first introduction to glass had happened when we were too young to care about dressing to impress. It probably happened when we drank milk out of a glass bottle and later, when we clamoured to hear a fairytale.

Fairy tales are rich in references to glass. The story of *Cinderella* is that of a young girl wearing pretty glass slippers that fit nobody else but her. The glass slipper helps the lovelorn Prince to track her down. This story is a universal favourite; and it has glass at its core!

Then there is a story about the beautiful Princess whose father decreed that to win her hand, the suitor must climb a glass mountain. So, the pretty maiden sat atop a glass mountain with three golden apples in her lap. Many came to try their luck but failed; the glass slope proved too slippery for human feet! The final contestant trotted up the glass mountain; each time on a different horse and wearing a suit of armour made of a different metal. On the first two days wearing armours of copper and silver respectively, he deliberately stopped short of the summit. He was rewarded with a golden apple every day for his endeavours. On the third day he galloped to the peak of the glass mountain wearing armour made of gold and earned the last golden apple... and after some minor twists in the tale; the hand of the Princess too.

In Hans Christian Anderson's story, *The Snow Queen*, Kai a little boy and Gerda, a little girl overcome many challenges and finally, love triumphs. The adventure begins when Kai gets a tiny sliver of Devil glass in his eye. This glass splinter comes from a magic mirror that has the power to distort the appearance of things reflected in it. So his vision is corrupted. Then, Kai falls into the clutches of the Snow Queen who freezes his emotions. Gerda searches for him. She bursts into tears when she finally finds him. Her warm tears melt his icy heart. His tears wash away the tiny shard of the magic mirror lodged in his eye and all is well.

And who can forget the 'Talking Glass' that the wicked stepmother in *Snow White and the Seven Dwarfs* used to find out who was the Fairest in the realm? Interestingly, when she conspires and tricks Snow White into eating the poisoned apple, Snow White is interred in a glass casket. Maybe the transparency of glass tempted Fate to send the Prince her way and become bewitched by her beauty, even as she lay in the casket, presumed dead.

It is amusing that Mike Elgan, a Silicon Valley-based writer, columnist and blogger who writes on cutting-edge technology should refer to the wicked stepmother's magic mirror in contemporary and IT-related language. He pens in his blog that perhaps the "...magic-mirror gadget was an augmented-reality display with face recognition and a voice-controlled artificial intelligence virtual assistant that was capable of querying remote databases of females ranked by fairness..."

And no, it is not a politically correct description of the wicked Queen's magic mirror but a sign of things to come. It is almost a description of glass that science has fashioned to rival the best stories we read as children. Thus, there is no need to rue that magical talking glasses have to be left behind, trapped inside the fairy tale book now closed, for Elgan goes on to describe some recent advances that do seem magical for all that they emanate from scientific laboratories.

Corning Incorporated, well known for its innovations in using glass for consumer electronics, has developed a technology to manufacture flexible glass as if it were printing wallpaper. The flexible glass can be used as a computerized touch surface. This has the potential to turn just about any surface into smart-touch displays that function like iPad devices. This glass will marry the moisture permeability, temperature tolerances and clarity of glass with the flexibility and low cost of plastic. Thus, refrigerator doors or countertops or even entire walls, will soon become interactive surfaces on command. Corning Inc. is also developing glass that kills bacteria and viruses on contact. In addition, it has created Smart mirrors, which need not necessarily, be transparent. Using existing two-way-mirror technology, smart mirrors can function like regular mirrors but optionally display information right on the surface of the mirror. Reminiscent isn't it, of the wicked Queen's interactive mirror?

And this is not all. Science has really trumped the 'Talking Looking-Glass' that merely gave information on demand about the Fairest in the realm! This new mirror has much better information to impart.

The EON Interactive Mirror is a 3D retail solution set up at Raffles City Mall, Singapore. Virtual 3D garments from leading fashion brands are featured in the EON Interactive Mirror. This Interactive Mirror allows users to mix-and-match clothes and accessories such as shoes and handbags in over 10,000 combinations by a simple flick of the hand. Changing from one dress to another, needs just a swipe. Customers are able to virtually try on any number of combinations and even take pictures on their mobile devices. If they need validation from their peers they can instantly share the picture on social networking sites to garner the 'likes'.

The next step apparently is to move these *virtual trial rooms* into every home. According to Mike Elgan, these smart mirrors may soon replace full-length mirrors in our bedrooms. These will also of course, show simple reflections like ordinary mirrors. However, when shopping online, these mirrors can help check how the clothes that we are planning to buy will look on us.

However, it is perhaps the Cybertecture® Mirror from James Law, adjunct Professor at the Korean Advance Institute of Science and Technology, that has made the mundane mirror take a quantum jump. At the touch of a button, this slim reflective surface becomes a conduit to information from the worldwide web. It displays information and content through feeds that stream onto the mirror surface. The Cybertecture® Mirror can be used to monitor the user's health status via its peripheral sensor pad. It can communicate with the owner's computer, mobile phone, or personal digital assistant. And it does not stop here. The Cybertecture® can be used to check for email, schedules, flight status notifications and even progress being made with diet and exercise. It can be connected to video-in as well as Internet streaming TV channels and programs. The best part? It can be hung just about anywhere.

The Cybertecture® Mirror can be controlled, customized and its information stored, via a web portal, for each user. The user can password-protect the contents. The Cybertecture® Mirror even has a virtual keyboard that appears when needed. No wonder, the Cybertecture® Mirror website bears the tagline, "Reflective window into a digital life."

The secret?

The Cybertecture® Mirror is seamlessly connected with the Internet via wireless communication technology. It is controlled, not via touch screen, but through remote control or alternatively, iPhones, iPads and any Android smart phone with wifi.

As science fiction author Arthur C. Clarke pointed out, "Any sufficiently advanced technology is indistinguishable from magic." And our own technology is finally becoming sufficiently advanced to bring magic mirrors out of the fairy tales and into our homes. The story of glass is then a journey from the magical realms of imagination to the magical realm of futuristic science in which is clearly reflected a segment of mankind's scientific odyssey.

2

FIRST LOOK

Ancient fragments displayed in museums bear mute testimony to the antiquity of glass. However, history is silent on the identity of the people who first made glass. Equally little is known about how they invented the process, although some information is available about the trade routes used to import and export glass products.

One hint comes from the writings of Pliny the Elder (Gaius Plinius Secundus, AD 23–AD 79), a Roman author, naturalist, and natural philosopher about how glass was first made.According to him, Phoenician traders serendipitously discovered glass manufacturing techniques on the banks of the River Belus that arises in Syria. Pliny's account places the discovery of glass to the north of modern Israel, just south of Lebanon. There are records that sand from the banks of River Belus was used as a Silica source for glassmakers working along the Syrian coast. The River Belus is now known as the River Na'aman.

According to Pliny the Elder, traders in natron (a kind of soda ash) once disembarked from their ship and cooked a meal on the shore of the River Belus. There were no stones to support their cooking pots, so they placed lumps of natron to balance the pots over the fire. When the fire was lit, the heat caused the natron to fuse with the sand on the beach. A stream of an unknown, translucent liquid flowed from it. Later, it cooled and solidified to form a sort of shiny crust.

Seventeenth-century glassmaker Antonio Neri, has left a similar account of how glassmaking got off to a flying start. In the manuscript of *L'Arte Vetraria* (*The Art of Glass)*, Neri quotes

Pliny the Elder and sets his story at the mouth of the River Belus. "Pliny saith, that Glass was found by chance in Syria, at the mouth of the river Bellus, by certain Merchants driven thither by the fortune of the Sea, and constrained to abide there and to dress their provisions, by making fire upon the ground, where was great store of this sort of herb which many call Kali, the ashes whereof make Barilla, and Rochetta; This herb burned with fire, and therewith the ashes & Salt being united with sand or stones frit to be vitrified is made Glass."

Interestingly, Pliny had also described how the sands from the mouth of the River Belus was later used for glassmaking. "The river is muddy and flows in a deep channel, revealing its sands only when the tide ebbs. For it is not until they have been tossed by the waves and cleansed of impurities that they glisten. Moreover, it is only at that moment, when they are thought to be affected by the sharp, astringent properties of the brine, that they become fit for use. The beach stretches for not more than half a mile, and yet for many centuries the production of glass depended on this area alone."

Scientists believe that the process of 'washing in brine' introduced lime in the form of seashells, which accounts for the formation of glass. And thus was glass born; or so the stories go!

In the 1920s, William L. Monro of the American Window Glass Co. decided to check if Pliny's story was a plausible one. He recreated the conditions described by Pliny and carried out a series of experiments. He built an open wood fire over a bed of sand mixed with an equal quantity of carbonate of soda and kept the fire burning for two hours. Finally, he found that a temperature of 1210° Celsius had been reached. When the fire died out, a portion of the bed was found to have become a vitreous mass. William Monro then repeated the process. This time he used a bed of sand mixed with an equal quantity of nitre. The results were pretty much the same as in the first experiment. In his third experiment, he used only a bed of sand. However, in the third experiment he found no trace of glass-like vitreous material. In none of the three experiments did William Monro observe the free-flowing liquid glass described by Pliny.

Critics pointed out that in the case of the merchant's fire, there would have been only a small interfacing of soda with sand, whereas in Munro's experiments, a large quantity of soda was mixed throughout the sand. Munro's conditions were therefore, tilted to favour the production of the vitreous products and thus, not an accurate recreation of Pliny's scenario. They also pointed out that a camp fire usually reaches about 600-650° Celsius and not 1210° Celsius as William Munro's fierce fire had. The stranded merchants cooking their simple meal would not have stoked the fires so high. However, William Munro countered that Kelp or seaweed ash contains soda and potash. Kelp was extensively used in the early days for glazing and glassmaking. History has it on record that kelp was an effective substitute for expensive Spanish '*Barilla soda*' prepared from salt marsh plants. He argued, "It requires no great stretch of the imagination to think that at some time there had been kindled along a sandy shore a great bonfire of dry seaweed, with perhaps a lot of driftwood, which left amid its charred embers the vitreous mass we now call glass."

This leads to another version of the story behind how glass was first made. According to this account, the fire was an inferno indeed because an entire forest was set on fire. First-century Romano-Jewish scholar and historian Flavius Josephus records that, "Some say that the children of Israel, having set fire to some forest; the fire was so fierce that it heated the nitre with the sand so as to make them melt and run down the slopes of the hills; and that thenceforward they sought to produce artificially what had been effected by accident in making glass."

Charming as these stories of serendipitous discovery of glass may be, scholars believe that glass was discovered either as a by-product of metallurgy, or that it developed in tandem with advances made in the development of ceramic materials.

It is interesting that despite the science of glassmaking having become so sophisticated, there is no consensus on the perfect definition for glass. There is no agreement on whether it is a 'super-cooled liquid of infinite viscosity', as the older text books say or merely a 'brittle and hard substance', or 'amorphous solid' that modern dictionaries prefer. All that is agreed upon is that glass is formed when a molten material cools so rapidly that it does not have time for its constituent atoms to form orderly lattice-like structure that characterizes crystals.

There is global consensus however, that glass combines qualities that appear to be polar opposites. Glass effortlessly straddles many worlds. No wonder, that artists and scientists value it alike. It is functional and beautiful on the dining table, aesthetically appealing in a museum's priceless display and corrective in spectacles. Glass is truly magic.

3

NATURAL GLASS

Glass and ceramics are the first materials made, thanks to human enterprise. These thus have the distinction of being the first engineering material ever exploited by the human race. Yet, although we think that glass is exclusively a man-made material; Mother Nature has some natural glasses up her sleeve too. These natural glasses are formed when sand is pounded by meteorites or when lighting hits it or even when volcanoes spew forth lava.

Fulgurites

Since lighting strikes can create natural tubes or crusts of glass called fulgurites, it is likely than ancient humans had seen glass or at least, glass-like stuff before they attempted to make some. Fulgurites are formed by the fusion of Silica (Silicon dioxide) sand or rock under very high temperatures. The word 'Fulgurite' is derived from the Latin word *fulgur* which means lightning. Fulgurites are also called petrified lightning.

According to geologist Carl Ege, all lightning strikes that hit the ground are capable of forming fulgurites. A temperature of 1800° Celsius is required to instantaneously melt sand and form fulgurites. Since most lightning strikes hit a high of 2500° Celsius; these are all potentially capable of forming fulgurites. According to one estimate, lightning can melt the quartz grains in sand within 100 microseconds.

The earliest recorded discovery of fulgurites was in 1706 by Pastor David Hermann in Germany. In 1805, Dr. Hentzen was credited with recognizing the true character of the tubes found in the sand dunes of Sennerheide, Germany. Fulgurites may form elongated and knobby hollow cones, or occur as elaborately branched networks. Fulgurites are fragile and call for careful handling when found.

There are two types of fulgurites depending on their source material. These are: sand fulgurites and rock fulgurites. Sand fulgurites are more common. These are found in beaches or in deserts where the sand is free of silt or clay. Sand fulgurites are branching tube-like structures. These have a rough surface, covered with partially melted sand grains. The inside of these tube-like structures is 'glassy' and contains bubbles. Most sand fulgurites average 25-50 mm in diameter and are about 75 cm long. Sand fulgurites are usually tan, greyish, or black in colour. White, almost-translucent sand fulgurites have been found in Florida, USA.

Rock fulgurites form crusts of glass on rocks. These fulgurites are often found as veins on a rock surface usually, at the peak or near mountain summits. Rock fulgurites usually occur in a wide variety of colours, depending on the composition of the host rock.

Tektites

So if glass-like fulgurites are formed when lightning strikes sandy areas, what happens when meteorites strike Earth? After all, this too is a high-temperature impact. Glass-like objects called tektites are sometimes formed when meteoric impacts take place.

The word 'Tektite' is derived from the Greek word *tektos,* which means molten. One of the earliest references to tektites (900 BC), is found in the book *Ling Piao Lu Yi*. The Chinese author Liu Sun described them as *Inkstone of the Thunder God*. Australian aborigines refer to them as *Mabon* or magic and believe that finding one brings good luck. The rarity of tektites would make it really so. The finder would have to be really lucky to find one.

There are several theories regarding how tektites are formed. According to a widely-accepted theory, tektites are formed by the rapid heating and subsequent cooling of quartz-rich soils and rocks. It is believed that these, pebble-like glassy objects were melted by meteorite impact, splashed up into the atmosphere, and they fell back to Earth again under gravity. Tektites acquire 'aerodynamic' shapes when they partially melt on their return journey. Tektite shapes are described as: cores, buttons, boats, lenses, dumb-bells, discs, teardrops and fragments. Tektites have a hardness of between 6 and 7 on the Mohs' scale.

Tektites are composed mainly of Silica with smaller amounts of various metal oxides, which account for the different colours. Perhaps because of their colours, tektites were valued by primitive humans such as the Cro-Magnon Man. Tektites are usually glossy-black on the outside, but thin sections are translucent and yellowish brown. Moldavite is a dark green tektite which is sometimes used as an ornamental stone. It contains traces of Aluminium, Calcium, Iron, Potassium and Sodium.

Micro-tektites are sort of tektite 'dust' found in deep-sea sediments in the Atlantic Ocean and the Indian Ocean. Tektites have been found only in certain parts of the world and tektites with similar chemical and physical properties are found in specific areas designated as strewn fields. Strewn fields from different meteorite impact-events are given distinctive names according to where they are found.

The four main strewn fields in the world are the central European (linked to the Ries crater in Germany), Ivory Coast (linked to the Bosumtwi crater in Ghana, West Africa), North American (linked to the Chesapeake crater, North America) and Australasian (source crater is as yet undiscovered). Individual tektite varieties are given specific names; derived from the region in which they are found. An example is Moldavite; named for the River Moldau (River Vltava). Other examples include Australites, Javanites, Indochinites, and Philippinites.

Tektites and fulgurites often contain tiny particles of lechatelierite; a colourless glass made of almost pure Silica. The name lechatelierite honours Henry le Châtelier (1850-1936), a noted French chemist.

Desert Glass

It is believed that Desert Glass is formed from the Silica in sand when lightning strikes it or when meteors impact it.

Libyan Desert Glass, which many consider to be a form of tektite, is greenish-yellow to straw yellow in colour. It glitters like a gem when the harsh desert sun rays strike it. Ancient Egyptians called it 'the Rock of God'. This beautiful naturally formed glass was used to create a scarab that decorated one of Pharaoh Tutankhamun's pectoral ornaments. More than three thousand years after its owner's death, the glass ornament still glitters like a gem. Libyan Desert Glass is sold online these days, sometimes as Egyptian Glass.

Edeowie Glass

Edeowie Glass is an opaque natural glass found in South Australia. The question about how this glass was formed has not been fully resolved yet. It is believed that Edeowie Glass may have originated thanks to either lightning strikes, or meteorite/ comet impact. Interestingly, lightning-created fulgurites have not been found alongside Edeowie Glass.

It is conjectured that heat because of an atmospheric explosion or a meteor strike raised surface temperatures to fusion point to create this type of glass. One reason why this theory finds takers is that some of the glassy material form flat sheets that appear to have formed at the surface, rather than having been flung there from a distance. In addition, shocked rock fragments have been found embedded in a few samples. These rock fragments resemble shocked materials from known meteorite craters. However, a vexing issue is the lack of any crater in the area, which is expected in case of a meteor strike.

Obsidian or Black Glass

Obsidian is natural glass of volcanic origin. Obsidian is produced when lava, rich in elements that form feldspar and quartz, thrown out from a volcano cools rapidly with minimum crystal growth. Rhyolite is an igneous rock that typically contains quartz and feldspar minerals. Obsidian is commonly found within the margins of rhyolitic lava flows and is very similar in composition to it. It is about 65 to 80 per cent Silica.

The name Obsidian comes from the term *obsianus lapis* or stone of the explorer Obsius. Pliny the Elder referred to it in his writing, the translation of which is: "Among the various kinds of glass, we may also reckon Obsian glass, a substance very similar to the stone which Obsius discovered in Æthiopia. The stone is of a very dark colour, and sometimes transparent..."

Obsidian has glassy lustre and is typically jet-black in colour. However, the presence of hematite (Iron oxide) may impart red/ brown shades. The sheen on Obsidian is a result of the tiny gas bubbles inside it. Obsidian with iridescent or metallic sheen is known as rainbow Obsidian, golden Obsidian or silver Obsidian, depending upon the colour of the sheen. Rarely, Obsidian is blue, red, orange or yellow. Obsidian samples with dark bands or gray, green, or yellow mottling are also, not uncommon. Sometimes Obsidian contains spherical clusters of needle-like crystals called spherulites.

Because Obsidian has smooth curved surfaces and sharp edges, it was used to make weapons, such as arrow heads, spear heads, knives and scraping tools. Although easily scratched or broken, the attractive and variegated colours led to its use in ornaments too. Freshly broken pieces of Obsidian have a very high lustre and the ancient Aztecs and Greeks used these as mirrors. Pieces of Obsidian were ground flat and polished to improve reflective abilities. One of the oldest tombs in Mexico, dating to about 600 BC, has yielded the figurine of a seated female wearing an Obsidian mirror on her chest. In 2012, two very rare funerary gift mirrors, made of Obsidian were discovered at the Neolithic archaeological site at Çatalhöyük, Turkey. Earlier, in 1995, an exquisitely polished Obsidian bracelet was discovered at Asıklı Höyük in Turkey. It is the earliest evidence of the working of Obsidian. Researcher Laurence Astruc, from the *Institut Français d'Etudes Anatoliennes*, Istanbul, and her colleagues analyzed the bracelet using extremely powerful computer technologies. In a research paper published in the December 2011 issue of the *Journal of Archaeological Science,* they reported that the technical expertise of craftsmen in the eighth millennium BC had reached great heights. Their skills were apparently on a par with today's polishing techniques.

The Stone Age people prized Obsidian for its many uses. They scouted far and wide for outcrops of Obsidian; making it the first target of organized mining. Geologists think that it is probably a safe bet that all natural Obsidian outcrops that are known today were discovered and utilized by ancient people. There was significant trade in Obsidian glass right from ancient times. Today, archaeologists can track the origin of the Obsidian to specific quarries, which can help to reveal ancient trade routes. This is because Obsidian has its own unique chemical signature that is associated with the moment of its birth. Each time a volcano erupts, the lava thrown out varies slightly in the trace amounts of elements in the magma. When this cools to make Obsidian, it contains a chemical signature unique to it. 'Fingerprinting' Obsidian is thus, the way to learn where it originated and how far it travelled and along which trade route.

Obsidian naturally breaks down over time because of the absorption of atmospheric water vapour. This process is called devitrification and it can be used to date Obsidian. Since Obsidian degrades over time, it is rare to find Obsidian older than 20 million years or so. No Obsidian older than the Cretaceous Period (65-145 million years ago) exists in geologic records.

Trinitite: Accidentally-created Glass

One type of man-made glass is similar to glass formed by meteoritic impacts and by lightning strikes. This is the glass which was formed on 16 July 1945 after the first Atomic detonation, known as the Trinity Test. This glass was named Trinitite or Atomsite or Alamogordo Glass.

The detonation left a crater of glass at the Trinity Test Site in the desert of New Mexico. During the explosion, sand was sucked up into the nuclear fireball, and it fell back on Earth as molten glass. Sometimes the name Trinitite is used for all glassy residues of atomic testing but strictly speaking, it ought to be restricted to material from the original Trinity test. Trinitite is nearly pure melted Silica with traces of Olivine, Feldspar and other minerals. Trinitite is mildly radioactive.

Most Trinitite is light green in colour although a black Trinitite is known. Black Trinitite contains Iron from the metal tower constructed for the test. Much rarer is the red Trinitite which contains Copper from the device used in the blast or from the communication cable wiring used on the site. Trinitite 'pearls' have a uniformly round shape. These were formed when the melted Silica solidified while still airborne before raining down on Earth.

Mineral collectors scraped up quite a lot of Trinitite when it was first formed and traded it as a novelty-collectible. Subsequently, the area was bulldozed and it was made illegal to remove any more Trinitite from the area. However, the glass that had already been collected could be traded freely. Much of it is still being sold online; reportedly augmented by substantial amounts of faux Trinitite by unscrupulous dealers.

These are all types of glass that are found naturally across the world. The other type is glass that has been deliberately made under controlled conditions to meet a need; be it aesthetic or functional or both.

4

MAKING GLASS

Glass has the distinction of being one of the earliest artificial materials made by human beings. It is likely that ancient humans experimented with various materials in an attempt to replicate natural glass and that over time, they perfected various formulae. Initially, they would have begun with sand (Silica) and soda. Even today, Silica sand, lime and soda are the raw materials that are used to make glass. Impurities such as Iron, Manganese and Sulphur in beach sand would have given them coloured glass. Yellow, brown and green would have been common colours.

Interestingly, the origin of the word 'glass' derives from the Old English word *glæs* and the Proto-Indo-European word *gel* meaning 'to shine.' This is also the root work for the Irish and Welsh word *glas* meaning green and blue respectively.

Oldest Formula for Making Glass

The oldest known formula for making glass comes from the library of the Assyrian King Assurbanipal (reigned 668 BC-627 BC). In this library there are clay tablets covered in cuneiform script that spell out the oldest existing recipe to make glass. In English, the instructions read: 'Take 60 parts sand, 180 parts ash from sea plants, 5 parts chalk and you get glass.' Ancient chemists have left behind detailed descriptions of the basic composition of glass, the know-how to colour it, and even instructions on how a glass furnace must be constructed.

Glass Furnaces

Furnace designs have changed over time. Wood was used to heat glass furnaces until the 17th century and after that, coal came into use. From the 1860s onwards gas-fired furnaces were used. Modern furnaces are sophisticated structures.

In the ancient days, there were only two basic types of furnaces: pot furnaces and tank furnaces. Most furnaces were pot furnaces. These had shelves on which containers, known as pots or crucibles were kept. These pots contained the melted glass. Some pot furnaces had a central fire and ash pit; these were commonly circular in plan. Other pot furnaces were rectangular in shape or else had an elongated fire trench and parallel platforms, known as 'sieges', on each side for the pots. Tank furnaces had a built-in tank to contain the molten glass.

Contemporary furnaces bear no resemblance to their humble ancestors. A modern industrial glass melting furnace is made up of many subsections. This includes foundations, superstructure, refractory brick work and retaining walls. It also includes raw material charger systems, heat exchangers, melter cooling system, exhaust system, fuel supply and electrical boosting equipment. There are integral control systems and instrumentation; and also systems for conditioning and distributing molten glass. In some glassworks, the machinery used can even include forming apparatuses. It is a sophisticated, computer-controlled set-up.

Tricks of Glassmaking

Apparently, glassmaking was considered a divine art and many dos and don'ts defined the process. The website of the Corning Museum of Glass has an interesting webpage on the kind of strict instructions that governed glassmaking. The website of the Corning Museum of Glass also has a translation from one of King Assurbanipal's clay tablets that are now, part of the collection of the British Museum. The English translation of the writing on the tablets has been taken from *Glass and Glassmaking in Ancient Mesopotamia* by Viennese-born Assyriologist Adolf Leo Oppenheim. It states:

"When you set up the foundation of kiln to make glass, you first search in a favorable month for a propitious day, and only then you set up the foundation of the kiln. As soon as you have completely finished in the building of the kiln, and you go and place Kubu-images there, no outsider or stranger should enter the building thereafter; an unclean person must not even pass in front of the images. You regularly perform libation offerings before the Kubu-images. On the day when you plan to place the glass in the kiln, you make a sheep sacrifice before the Kubu-images, you place juniper incense on the censer, you pour out a libation of honey and liquid butter, and then only, you make a fire in the hearth of the kiln and place the glass in the kiln...

If you want to produce zagindurû-coloured [greenish type of lapis lazuli] glass, you finely grind, separately, ten minas [about one pound] of immanakku-stone [sand], fifteen minas of naga-plant ashes, and 1 2/3 minas of 'white plant.' You mix these together. You put them into a cold kiln which has four fire openings, and arrange the mixture between the four openings... You keep a good and smokeless fire burning until the glass glows golden yellow. You pour it on a kiln-fired brick and this is called zukû-glass. You place ten minas of "slow" Copper-compound in a clean dabtu-pan. You put it into a hot chamber kiln... You crush and grind finely ten minas of zukû -glass.

You open the door of the kiln and throw the ground glass upon the Copper compound...When the glass assumes the colour of ripe grapes, you keep it boiling for a time...After it has become yellow [hot], you observe some drops forming at the tip of the rake. If the glass is homogeneous, you pour it inside the kiln in a new dabtu-pan, and out of the cooled-off kiln emerges zagindurû-coloured glass."

Present day glass technologists would say sand instead of *immanakku-stone* and soda-ash instead of *naga-plant ashes*. The *slow Copper compound* was most probably a colourant. The identity of the *white plant* remains unknown. It is interesting that the raw material used to make glass remains largely unchanged even today although over time, the technology has evolved enormously.

Ancient Advances

Ancient chemists soon began to add soda-rich ashes derived from salt-loving plants that grew in coastal areas. They realized that these ashes helped the raw materials to melt and fuse at a lower temperature. Today such chemicals are called flux additives. The right amount of the correct flux is a crucial element in glassmaking.

The ashes of plants growing in desert or marine areas, for example the *Salicornia* species and kelp or seaweed, are soda- rich. The ashes of fern or bracken species are more potash-rich. Plant ashes also contain many other components, in particular lime (CaO) and magnesia (MgO). Ashes from woody species are dominated by lime with less potash. These lime-rich ashes from beech and oak trees were used to make post-medieval, high-lime low-alkali (HLLA) glass. Although these were often unintentional additions to the glass, they affected its properties, such as durability, and acted as fluxes at temperatures of about 1300°C or more.

Around the beginning of the first millennium BC, the ashes were replaced by the mineral trona. Trona is formed by evaporation, in alkali-rich lakes such as the ones in Wadi el Natrun, Egypt. These deposits are commonly known as natron and are a fairly pure source of soda. 'Natron glass' was made on a massive scale for more than a millennium, around the Roman period. The glass found in Britain from the Iron Age, Roman and much of the early medieval periods are mostly natron glass.

Silica is used in the production of glass. It is most commonly found in nature as sand or quartz. Siliceous ooze is soft Silica-containing sediment that covers large areas of the deep ocean floor. This ooze derives from the Silica-based skeletal remains of marine micro-organisms. Silica is also found in the cell walls of diatoms, which are a type of algae found both in freshwater and marine water. Deep-sea glass sponges have a skeleton made up of glass-like spicules made of Silica.

Plants too have cells that are rich in Silica. An individual cell, differing from its neighbours in size, structure, or contents is called an Idioblast. One type of idioblast cells found in plants contains Silica. Certain plants, such as the horsetails are particularly rich in Silica; so much so, that the ash analysis of these plants shows 93 per cent Silica. Grasses and sedges contain rows of Silica-containing cells in their epidermal layers which give strength and rigidity to the leaves. These Silica deposits also increase the abrasiveness of the leaves which serves as a deterrent for many herbivores. Insects such as locusts avoid high-Silica grasses because they cannot digest it easily. It is this high Silica content that leads to the formation of 'haystack' glass when hay catches fire. The potash and other inorganic elements in the hay combine and melt in the heat to form lumps of glass-like material. Hay glass is brittle. It can be disc-shaped, ellipsoidal, dumb-bell shaped, teardrop-shaped; even pear-shaped or canoe-shaped. Hay glass may be pale smoky-brown, yellowish-green or even black in colour.

The difference between the Silica-rich grass and hay ash, and the Silica-poor ash, is known to all traditional potters who use ash for glazing ceramic items. Hay ash (high in Silica) is known as 'hard ash,' while the low Silica ash is termed 'soft ash.'

It is generally accepted that the process of melting glass was discovered around 5000 BC in Mesopotamia or in Egypt, most probably by potters firing their pots. The 'glass' so formed would actually have been only a thin, shiny glaze on the surface of the pot. The next major milestone in glassmaking was the creation of solid glass beads. By 1500 BC, craftsmen in Mesopotamia and Egypt were making small brightly coloured vessels. They would do so by first forming a core of sand or clay into the desired shape. Then, layers of glass would be built around this core, probably by dipping it repeatedly into molten glass. This was done until a reasonably thick wall of glass was formed around the core. Then the object was cooled and the inner core removed to yield a hollow container. In time this came to be known as the core-mould process.

Around 300 BC, a genius glassmaker figured out that a hot blob of molten glass gathered at the end of a hollow tube could be blown into different shapes. Ancient Syrians are most widely credited with the discovery that molten glass could be blown from the end of a hollow tube into different shapes. This revolutionized the ancient Glass Industry.

In ancient times, a wood-guzzling furnace was used to keep the glass in a molten state. It takes a lot of wood to heat a furnace to over 1000° Celsius. Specific details about just how much wood would be needed to maintain high enough temperature is not available. However, according to an estimate, the wood needed to fire a furnace for one run could well be enough to build a two-storey house. No wonder, glassmaking was seriously bad news for trees! Perhaps this was a reason why glassmakers were itinerant; moving from place to place in search of wood and raw materials. This of course meant that their ideas, style and expertise travelled with them and that there was a lot of cross-fertilization of ideas, styles and learning along the way. Any specific style of making glass soon spread because the workers were constantly changing their techniques, or learning new techniques from each other.

Ancient Egypt, a powerful civilization, had a well-developed glassmaking Industry and in museums, we can see exquisite samples of old Egyptian glass. However, it is almost universally accepted that the Egyptians did not invent glass. They merely applied a glassy/vitreous layer or what is known as Egyptian faience. The first examples of Egyptian faience date back to about 4000 BC...which makes this technology about 7000 years old. The technology is considered ideally suitable to cover small objects. The ancient Egyptians used it to make beads.

These beads found widespread use in jewellery, tiles, bowls, jars, and also, funerary equipment. For example, the *Flexible Collar of Nekhbet* that was found in the tomb of Pharaoh Tutankhamun was made up of 256 gold plaques inlaid with multi-coloured glass and threaded together with borders of tiny beads. Another example is the *Network of beads necklace* made up of more than a thousand blue faience beads that was found in the priest Iufaa's tomb; the first un-robbed shaft tomb to be found in Egypt since 1941.

Interestingly although Egyptian faience enjoys the reputation of being the *world's first high-tech ceramic*, no massive object made in Egyptian faience has ever been found. This is interesting since most of ancient Egypt's structures tended to be enormous. However, Egyptian faience is not, strictly speaking a ceramic.
It is a paste made of quartz or sand, calcite lime and a mixture of Sodium, Potassium, Calcium, Magnesium and, sometimes, Copper oxides. The paste was applied directly to wet clay. When the clay was fired, the paste turned into a brilliant glaze.

Faience is therefore, a sort of transparent proto-glass, used to create a glassy-glaze layer over a Silica core. Chemical analysis has shown that faience consists primarily of Silica with small amounts of soda and other impurities. It has also been shown that while making faience, the material was heated to a temperature no higher than about 870° Celsius.

Study of Egyptian faience technology indicates that its formulae changed over time and differed from place to place. Perhaps this is why a second school of thought believes that glass was developed as an evolution of faience. It is believed that the initial discovery of glass occurred, thanks to some simple accidental (later, intentional) variations in the production method of faience. Such variations could easily have introduced because of poor composition or temperature control as when excess soda was added or the temperature was too high.

It is speculated that artisans, curious about the results of variable conditions on faience production, might have carried out intentional variations. They might have experimented by altering the ratio of sodium carbonate to powdered quartz or by firing the paste at either a higher temperature or for a longer period of time. All such variations would have led to a greater fusion of quartz and soda so that a more 'glassy' material would have resulted.

The next step, aided by judicious tweaking, could have led to the production of true glass. This theory is supported by the fact that there is a type of faience known as 'glassy faience,' which has a structure an intermediate between that of faience and that of true glass. It thus seems to be a bridge linking these two materials; an intermediate in the path leading from faience to glass. Unfortunately, it is not firmly established that glassy faience was created before true glass itself was made; as is necessary for this theory to be proved.

Another inconsistency of this theory is that while faience fully flowered in Egypt getting the name Egyptian faience in the process; glass is thought to have originated in Mesopotamia and Syria. The technology for making glass apparently reached Egypt much later. Now, as faience production reached enviable heights in Egypt shouldn't concomitant transition from faience to glass also have taken place in Egypt as artisans experimented with more sophisticated production techniques of faience?

Proponents of the 'faience to glass' theory argue that the Egyptian craftsmen continued to perfect the production of faience without the transition to the new material...because they were so good at it that they saw no need to better their products! The less advanced faience artisans of Mesopotamia made the leap to glassmaking.

Contemporary archaeologists believe that faience, frit and glass were all made in the same workshop complexes. Yet, they point out that the main difference between the production of faience and that of glass was that production of glass vessels involved the manipulation of heated, viscous fluids, while the making of faience did not. So, in a way glassmaking was more similar to metallurgical processes. Scientists believe that although the production of faience, and glass involved the same combination of essentially identical raw materials, the change from cold-working for faience to hot-working for glass may not have been a logical progression or even an easy transition. Again, there is speculation that the ancient metal workers who were familiar with working with molten materials at high temperatures gave inputs to those who worked with faience.

Ancient metal workers greatly valued Copper and made the first tools, implements and weapons using this metal. Copper was derived from its ore malachite by a process called smelting. Smelting uses heat and a reducing agent to decompose the ore. In the process other elements are discarded till finally, only the desired metal is left behind. It used to be thought that Copper was smelted for the first time when malachite was accidentally dropped into a campfire.

However, campfire temperatures normally reach only about 600°C-650°C and a much higher temperature is needed for smelting Copper. It is more probable that early Copper smelting was discovered by ancient potters whose charcoal-fuelled, clay firing furnace could reach temperatures of 1100°C-1200°C. If malachite was added to these furnaces, Copper nodules would easily be formed because the incomplete combustion of the charcoal would result in a strong reducing atmosphere of carbon monoxide, which would reduce the Copper in the ore to metallic Copper.

Now comes the most interesting part linking metallurgy to glass production. Researchers say that it is possible that while collecting malachite, a good deal of other rocks and stones would have been collected as well. Common rock is made up of various Silicates including alumina-Silicates. These Silicates do not easily melt at the temperatures needed for smelting Copper. Thus, their presence would result in contamination of the metallic Copper formed. This mixture of rock and raw metal would have to be broken up and the metal removed. The process would have been irksome to say the least. The idea proposed is that the ancient chemists began to add flux to assist with the melting of the residual Silicates. Early common fluxes for Copper smelting were Iron pyrites and also, simple carbonate, sulphate, and nitrate salts.

Addition of flux resulted in a combination of molten metal and a fused mixture of rock and flux. This is called slag. Slag and molten metal are not miscible. So two distinctly different molten layers are formed within the smelting furnace. The layers have to be drained off; one layer at a time by a process called liquation. When cooled, molten slag turns into a rigid, glassy solid similar to Obsidian. Lo and behold, man-made glass!

There is archaeological evidence at such a co-production really happened. At Qantir in Egypt (late second millennium BCE), there is evidence for red opaque glass ingots and bronze casting. This provides a clear example of the production of coloured glass taking place at the very site where metallurgical by-products were being generated. Additionally, scientists point out that the red glass found at Qantir was created using Copper in a reducing atmosphere. This is not just a feather in the cap of modern archaeologists who made this discovery; ancient Egyptian chemists get a share of the credit too. Red glasses are relatively difficult to produce, requiring a high level of technical know-how.

Perhaps, Seth Rasmussen, Associate Professor of Chemistry at North Dakota State University USA, got it right, when in his book, *How Glass Changed the World: The History and Chemistry of Glass from Antiquity to the 13th Century,* he said:

> "While arguments can be made for either of the two commonly proposed pathways to the origin of glass, it is clear that either path is not completely independent of the other. In the first case, metallurgy is thought to originate in the pottery kilns, potentially as a consequence of using metal ores in glazes. In the second case, the high temperatures required for the production and working of glass is thought to have required input from metal workers. As such, it is quite reasonable to propose a combined path in which transfer of knowledge and observation between the two groups of craftsmen resulted in the discovery of glass with origins in both metallurgy and siliceous glazes."

The most commonly encountered colour of Egyptian faience is blue. Archaeologists think that blue was a favoured colour because it imitated the shades displayed by valuable gems, such as turquoise and lapis lazuli. So a faience bead could look like a gem and be worn as one. Besides blue, faience was also available in yellow, green, purple, black and white. The variations in colour were achieved by tweaking the additives. For example, addition of Copper gave turquoise colour and the addition of Manganese gave black/purple. Faience was made by the ancient Sumerians and Greeks too and widely traded.

The ancient Egyptians called faience *tjehenet* meaning dazzling. And dazzling it was! Dazzling enough to be poised for a second and more contemporary innings in the 21st century. Professor Stephen Hoskins, Director of the University of West England, Bristol's Centre for Fine Print Research and David Huson, Research Fellow, have received funding to undertake a major investigation into a self-glazing 3D printed ceramic, inspired by Egyptian faience. The researchers hope to create a self-glazing 3D printed ceramic which only need just one firing; rather than the usual two. This would be a huge advancement in the development of 3D printing technologies. It is also expected to significantly lower costs.

From Faience to Glass

It was a short step from Egyptian faience to glass. Yet is believed that it was not the Egyptians, but the people living in Syria, Babylonia (Iraq) and Mesopotamia (Iran), who discovered the process; and that too, probably by accident. The time is thought to be sometime around 3,000 BC.

Ancient glass vessels were produced in moulds. The earliest datable example of moulded glass was found in the tomb of Pharaoh Thutmose III's three foreign wives named Menhet, Menwi and Merti respectively. This lavish rock-cut tomb at Wady Gabbanat el-Qurud has yielded a moulded glass vessel and a large number of glass beads and inlays, as well as two unusual vitreous vessels. This has led to the speculation that glassmaking came to Egypt from the Syro-Palestine area during the reign of Pharaoh Thutmose III. Anyway, whether or not it did, the ancient Egyptians seem to have loved glass as much as they loved faience.

In the *Annals of Pharaoh Thutmose III* at Karnak, glass is listed right after gold and silver, indicating how highly the Pharaoh valued it.

Glass beads are among the earliest attempts at glass production and have been found at ancient glass manufacturing sites in the eastern Mediterranean. Ancient glass beads have been recovered from tombs of many ancient civilizations. For example, Assyrian graves of high-status individuals have regularly yielded beads of semi-precious stones as well as glass and faience.

Ship wrecks such as the Late Bronze Age Uluburun, discovered off the Turkish coast in 1982, have also been equally rich sources. The Uluburun finds included glass ingots, about 75,000 faience beads and 9,500 glass beads. These finds indicate that glass and faience beads were considered significant as funerary gifts for the departed, as well as important enough, for trade.

Ancient Experiments

Ancient glass was made from sand (quartz). Soda ash was added as flux. The quality of glass was inferior if only soda and sand were used to make it. However, adding limestone as a stabilizer resulted in much higher quality soda glass. So this became the accepted process.

Ancient glass often contained Iron and Manganese as impurities derived from the sand that was used to make it. Luckily, these impurities gave it attractive colours. Iron gave the glass a light-green tinge and presence of Manganese resulted in pink to violet colours. Some beach sands also contained Sulphur, which made glass yellow to dark green depending on the amount of Sulphur in the sand.

These impurities were blessings in disguise. Ancient glass-makers soon learnt to deliberately add chosen minerals to get glass of a desired colour. Only a pinch of the salts/oxides was necessary to add colour to the entire batch being processed. Blue glass was made by adding Copper compounds. Dark blue glass was produced by adding Cobalt-rich minerals. A brilliant yellow colour was achieved by mixing Antimony and Lead. Cadmium sulphide helped make canary or yellow glass. To make the opaque, red glass, the glassmakers mixed Copper and Lead compounds and then had to keep the firing furnace oxygen free (reducing atmosphere). In the reducing atmosphere, cuprous oxide gave the glass a rust-red opaque colour. Even a whiff of air would have oxidized the Copper ions and the glass would have become blue instead of red. This was sophisticated chemistry at work, but even this complicated chemistry became pretty routine stuff for glassworkers by the 9th century BC.

However, making colourless glass was another story altogether. Colourless glass can be produced either by selecting raw materials that are low in Iron or by adding a decolourizer to the glass. Iron-free Silica was not easy to find and so, ancient glassmakers had to add Antimony and Manganese to decolourize glass.

Antimony and Manganese decolourize glass by oxidizing the Iron. However, the reactions between Iron, Manganese, and other compounds in the glass are complex. This has led some scholars to believe that initially these entered the batch accidentally as contaminants of the raw materials. Still, it has to be acknowledged that very soon; master glassmakers were deliberately adding these, in controlled quantities, to make colourless glass.

Archaeologists have found colourless glass from the early periods in glassmaking history but finds indicate that its popularity increased during the Roman period. According to C. M. Jackson:

> "Roman glass is recognized as a masterful feat of technology in terms of both manufacture and design. The most striking visible sign is the control over colour, where colourizers and decolourizers are used skillfully, in conjunction with the control of furnace parameters, to provide a wide variety of hues."

From the writings of Pliny, it is clear that colourless glass was greatly prized. In his words, "...the most highly valued glass is colourless and transparent, as closely as possible resembling rock-crystal..." Glasses made of low-impurity sands along with higher levels of Antimony were usually used to fashion more elaborate and 'high-status' vessels. No wonder that from the late First century AD, plenty of colourless glass was produced for good quality tableware.

Cristallo Glass

In order to make highly transparent, colourless glass, the Venetians combined a quality Silica source with soda-rich ash that was imported from Syria and referred to as *allume catino, cenere vegetale*, or *rocchetta*. From the thirteenth century onwards, Venetian glassmakers started producing *Vitrum blanchum*, a colourless and transparent glass that resembled rock crystal. In the next two centuries, they improved their techniques to produce *cristallo* glass. It was named *cristallo* because it looked just like rock crystal. The invention of *cristallo* glass is attributed to the Venetian glassmaker, Angelo Barovier. *Cristallo* glass appears to have been exclusive to Italy during the Middle Ages and no doubt, would have commanded a high price.

One of the reasons why this glass was of such fine quality was that the raw materials were of exceptional quality too. Every attempt was made to drive out the last trace of any lingering impurity. Ordinary sand was replaced by Silica-rich chert pebbles from the bottom of the River Ticino. Chert is far superior to the other sand sources of Silica. These pebbles were called *cogoli ticino or lapides ticino*. However, even the *cogoli* were not used straightaway, but were repeatedly heated and dipped into cold water to remove impurities. Apparently, the outstanding quality of *cristallo* was also due to the purification step that was introduced.

The technique also required burning the salt-loving *barilla* plants and using the ash as an additive when making the glass. Even this process involved grinding of the ash, leaching it with boiling water, followed by filtering and re-crystallisation of the salts from the solution. Only then was the ash fused with Silica. *Barilla* was not a single species. It is believed that the term included the Glasswort plants *Salsola soda, Salsola kali*, and *Halogeton sativus*. It is interesting that there are records indicating that in 1189, the Royal Abbey of Santa Maria de Poblet in Catalonia, Spain (today a UNESCO World Heritage Site) granted to the glassblower Guillem the right to gather *barilla* plants in return for tithe and two hundred pounds of sheet glass; paid annually.

The best Spanish *barilla* prepared by master chemists known as *barrilleros*—contained about 30 per cent sodium carbonate. So highly was the product valued that according to Spanish laws, the export of the seeds was an offence punishable by death because it had the potential of influencing the trade in *barilla*.

Cristallo glass was often elaborately decorated with blue, green and purple coloured glass, or else it was gilded and enamelled. The beauty of this glass was that despite ornate designs, the glass always looked delicate. Today, *cristallo* glass is considered the forerunner of the modern optical glass used to make telescopes, etc.

The secret of glassmaking came to Britain with the Romans. However, the skills and technology required to make glass were closely guarded by the Romans too. It was not till the Roman Empire fell, that the art of glassmaking spread throughout Europe. In the fifth century, craftsmen of the Roman Empire began to flee east to escape invasions. Many found refuge in the areas around the Venetian lagoon. Slowly, glassmaking began to expand into Italy, specifically Venice. The *Domenico vetrario* donation document, dating back to 982 AD, is the oldest official document on Venetian glassmaking. It details donations made by the Doge Tribuno Menio to the church of Saint George. Co-signatories on the document include one Domenico Fiolaro (Phiolarius). The word *fiola* is specific for narrow-necked vases for liquids...obviously Domenico was a glass worker who specialized in making *fiolas*. Based on this document, in 1982, celebrations were held to commemorate one thousand years of glassmaking in Venice. It is a tribute to Venetian glassmaking that even in the twenty-first century collectors avidly seek to purchase works of long-dead un-named Venetian glassmakers. A case in point is the Bonhams auction of the 15th century blue glass bowl with a stand in 2009. Its estimated value was between £180,000 - £220,000.

By 1292, all glassmaking in Venice became restricted to the island of Murano. This was on the order of the Venetian Maggior Consiglio (Grand Council) to localize fire hazard of glass furnaces. Some say this was actually an astute move to guard trade secrets and assure monopoly by restricting the masters of the art to a small island. The fallout in any case was favourable. The island gained a reputation and the master glassblowers became fiercely competitive with their peers...and the products began to command enviable prices. This is when Venice consolidated its reputation as a pioneer in glassmaking.

Organised guilds made sure that the glassworkers complied with the strict rules. The knowledge was perceived as communal property to be used for the benefit of the Venetian commune of glassworkers and the guild. There was an embargo on leaving the island; any glassworker who left was accused of treason which was punishable by death. Even boatmen who ferried the escapee from Murano was liable to be prosecuted!

As early as in 1271, glassworkers were warned that "...anyone of the aforementioned art who will have gone out beyond Venice with the aim of practicing the said art" would pay a stiff fine. In 1281, the fine was hiked as a deterrent...to little avail because in 1295, the Great Council deplored the loss of glassmaking secrets to the competition abroad. It noted that the furnaces had been set up at Treviso, Vicenza, Padua, Mantua, Ferrara, Ancona and Bologna. The guild ruled that glassworkers who left Venice to work outside would be banished from the guild and forbidden to work in Venice again...but that did little to curb the wanderlust that was in the blood of these artists of glass.

Besides the loss of artists, there was yet another threat; that of industrial espionage! According to a story that may or may not be true, in the 15th century Giorgio Ballarin, pretending to be just a simple-minded lad took up apprenticeship under Angelo Barovier. As expected, Angelo Barovier closely guarded his trade secrets. His trusted custodian was his daughter Marietta. She took pity on Giorgio Ballarin. One day she let her guard down and forgot to hide the manuscript containing the secrets of glassworking from his sight. Perhaps, she thought he was intellectually too feeble to understand what was written in the manuscript. Giorgio Ballarin did not waste the opportunity and transcribed everything he saw.

It was a major coup! He now had access to proprietary knowledge. Venetian law forbade foreigners from setting up their own furnaces, and Giorgio Ballarin was not a Venetian. So, he made over the secrets he had appropriated to another glassmaker who had an eligible daughter. The ill-gotten dowry was well-appreciated and through marriage, Giorgio Ballarin was able to acquire a furnace of his own. He started his own business and soon became one of the richest entrepreneurs of the island. The Barovier family flourished too. Angelo Barovier's descendant Giovanni Barovier and his three nephews were great glassworkers. His nephew Giuseppe Barovier is recognized as "...one of the finest glassmakers the world has ever seen." In 1866, Venice was ceded to Italy and the Murano glass factories, showed signs of rejuvenation under the Baroviers. The glassmaking industry spread slowly from Venice to France and then, gradually extended into England.

Other parts of Italy were also emerging as a centre of glassworking in their own right. It is believed that the Benedictine monks introduced glassmaking in Altare around the 11th-12th centuries, and that glassmaking flourished thanks to French and/or Flemish craftsmen. Altare soon gained a reputation for making good glass. Interestingly, the tight-knit community of the men of the Art of Glass had their own University of Vitreous Art which was founded in 1495 to "safeguard and govern the profession of the master glassmaker." Its statutes held sway until 1823. The Altare School operated in contrast to the way the glassworkers of Venice did. They had no veil of secrecy to shroud their operations. The Altare glassmakers actually had an obligation to work abroad for a while. Since the Altare glassmakers were not governed by the strict statutes of Venetian secrecy, they helped in taking glass technologies to new shores in Europe. France, Portugal, Austria, the Netherlands and Germany were major beneficiaries.

Forest Glass

Interestingly, small, but independent, school of glassworkers had been active in Germany since Roman times. These glassworkers made what is now known as Forest Glass (*Waldglas* in German) using wood ash and sand as the main raw materials. *Waldglas* was made in factories known as glass-houses in forested areas where wood was available in plenty; hence the name. *Waldglas* was rustic and robust; usually greenish in colour. The Forest Glass made in France was called *verre de fougere*. A small amount of Forest Glass was made in the Weald area of Southern England. It is now called Weald Glass. Weald, similar to the German word *Wald*, is an old English word meaning forest.

Waldglas was used to make items of distinctive shapes such as beakers called *Krautstrunk*, literally meaning cabbage stalk. *Waldglas* objects often have ‘prunts’ or blobs of glass forming a regular pattern of pointed protrusions on the external surface. Not just decorative, these prunts allowed the original users to get a secure grip on the glass even with greasy hands. These are today, a collector’s delight. In 2013, Christie’s auctioneers sold an early 16th century *Krautstrunk* glass beaker with twelve large hollow prunts for £1,188.

Millefiori Glass

In contrast to the stark simplicity of *cristallo* glass is *millefiori* glass. Its name literally means thousands of flowers. Colourful and decorative *millefiori* glass is made by combining slices of coloured rods of glass to make a pattern that resembles a bouquet of flowers. Sometimes, though not always, the *millefiori* patterns were created on a base of *cristallo* glass. More often, however, *millefiori* patterns were placed on coloured or opaque glass. *Millefiori* glass was usually red, white, and bright blue.

In 2009, a Roman *millefiori* dish was discovered in London as part of grave goods of a Londoner whose ashes had been buried along with an assortment of rare glass and ceramic objects. The dish was made up of translucent blue indented glass petals, bordered with white and embedded in a bright red glass matrix. It is believed to be the first discovery of a complete *millefiori* dish outside the eastern Roman Empire.

Millefiori glass was often made into extravagantly decorated paperweights. The exact year and origin of the manufacture of the first glass paperweight is debated. However, it is known for certain that in 1845, Pietro Bigaglia of Venice exhibited the first signed and dated millefiori glass paperweights at the Exhibition of Austrian Industry in Vienna. It is no surprise therefore that his name should create waves at modern-day auctions. In 2010, Bonhams sold an 1847-made Pietro Bigaglia millefiori glass paperweight for £9,600.

Lattimo Glass

Another style of glass believed to have been created in about 1392 in Venice was the opaque *lattimo* or Milk Glass. It is made by adding lead, lime, or tin lime to the glass making recipe. In later centuries, decorations were applied to the milky white surface and the end result looked a lot like porcelain from China.

Filigrana Glass

Lattimo and *cristallo* Glass were often used together with another method of glassmaking called *filigrana,* or *canna filigrana.* This gave the glass great appeal. *Filigrana* Glass designs became popular early in the 16th century, when enamelled and gilt encrusted *cristallo* works became old-fashioned! Canna means a cane of circular glass. This could be a single colour or a riot of colours. It could be either transparent or opaque. *Filigrana* Glass could also contain opaque or colourful threads or ribbon-like decorations. The two types of *filigrana* are *reticello* and *retortoli.*

Reticello, or Reticulated Glass, has a web-like design that gives a mesh effect. The name literally, means glass with a small network. This was a glass form made exclusively in Venice. It involved taking two layers of glass-containing threads twisting in opposite directions and fusing them together at right angles. Because both layers of glass are slightly ribbed as a result of the incorporation of the threads, small bubbles of air become trapped between them when fusion took place. *Ritortoli* is filigree that is twisted into spirals. *Ghiaccio*, or ice glass, was developed around 1570. This was clear glass with very fine internal cracks. *Retorti filigree* was patented in 1527 by Filippo Catani. The next step was *latticinio* in which rods of opaque glass, usually white or gold, were incorporated in the body of the clear glass vessel and worked in lattice patterns.

In the 14th century, French glassblowers developed the process known as Crown Glass. Crown Glass manufacture involved blowing a small bubble on a long metal blowpipe to the size of a large globe. When it was the right size an iron rod called a pontil or punty was attached at the base of the globe to remove it from the blowpipe. It was then transferred to another rod and widened into a large U-shaped bowl. Then, it was spun so fast that it flattened out into a disc. These discs were placed in a kiln to strengthen the glass. Finally, the discs were cooled to remove the stresses built up during manufacture. Such glass had a dimple in its centre and many air bubbles which often lined up in alignment with the direction of the spin. It also had a characteristic pattern of semi- circular lines or concentric circles.

The art of making Crown Glass was a well-kept trade secret and did not spread even across the English Channel for many years! When this technology finally arrived in England in 1678, the manufacturer etched a crown on the glass, and used that as a trademark. This gave the glass its name. Making Crown Glass was a skilled task. Today, the art is no longer practiced and is a lost skill.

A la façon de Venise

So superior was Venetian glass, that glass was said to be *à la façon de Venise* when it imitated the style of Venetian glass. Such glass was made during, and after, the late 16th century in the Netherlands, parts of Germany and by Giacomo Verzelini in England. Frenchman Jean Carré was the owner of the Crutched Friars Glasshouse, London. In 1571, he brought Giacomo (Jacob) Verzelini to England. Verzelini brought with him a wealth of experience because he had worked in Antwerp for twenty years. In 1575, shortly after Jean Carré's death, he took charge of the glasshouse.

Queen Elizabeth I, who was on the throne at that time granted him a twenty-one year monopoly to make Venetian *cristallo* glass in England. This Royal largesse was further bolstered by the embargo on the import of Venetian glass. The only condition attached was that he would have to train the English in the art of making such glass. Unfortunately, very few of Verzelini's glass objects have survived the passage of time. After the twenty-one year licence lapsed, a second *cristallo* glasshouse was set up at Blackfriar.

Over time the British Glass Industry prospered. At the beginning of the 17th century, a new glass furnace was invented that could be heated with coal instead of wood. Since wood-fired furnaces devoured entire forests and denuded lush green areas, wood-fired furnaceswere declared illegal.

From 1615-1642, Sir Robert Mansell held the monopoly of glassmaking in England. In 1673, English glassmaker George Ravenscroft set up a glasshouse in London, where he produced a '*crystalline*' glass. He obtained a seven-year patent for this glass in 1674. The early formula for making this glass used an excess of potash which led to the formation of a crackled surface. This was called crizzling. The issue was addressed. Subsequently, the manufacturer using a Raven's Head seal on the improved glass to indicate that it was free of crizzling. By 1676, he developed a glass containing 37 per cent lead. This glass surpassed Venetian glass in brilliance; it also gave off a resonant ringing tone when lightly struck with a fork.

Meanwhile, the glass-blowers in Murano continued to produce glass of unparalleled excellence. By the 8th century, they had gained an enviable reputation for designing intricate designs using multi-coloured enamels. They also experimented with making different types of decorative glass. They were the leaders in working glass in an innovative and novel manner. With the emigration of glassworkers from Murano, the *à la façon de Venise* style spread throughout the world.

What aided the dissemination of the secrets of Venetian glassworks was the publication of the formula book *L'Arte Vetraria* or *The Art of Glass* by Antonio Neri in 1612. An English translation by Christopher Merrett, Fellow of the Royal Society, was published in 1662. He added very extensive notes which almost doubled the length of the book. The English version became very popular and was eventually translated into Latin, French, German and Spanish. It was reprinted at least twenty times over almost two centuries. It is still available in print; Online!

Today, Venetian glass still holds its own and commands royal prices. Art connoisseurs consider it one of the best in the world. The *Vetro Artistico Murano* trademark was registered in 1994. Glass connoisseurs insist on this trademark. It guarantees that the product is genuine Murano glass, made on Murano island according to age-old glassmaking traditions.

Mirror Mirror

Another item that made a quantum leap not just in quality but also in the numbers in which it began to be produced once the Glass Industry advanced was the mirror.

Prehistoric humans no doubt had to remain satisfied with seeing their reflections in still pools of water. Later came highly polished Obsidian mirrors, examples of which have been unearthed from Çatalhöyük or Catal Huyuk – a Neolithic site in modern Turkey dated to 6200 BC. A piece of shiny mineral called Selenite and remains of a wooden frame around it have been discovered in El-Badari, Egypt. This artefact has been dated to around 4500 BC and is thought to have been a mirror. Another mirror in the shape of a large piece of reflective mica with a hole at one end, perhaps to facilitate hanging it on the wall has been unearthed from the same time period in Egypt.

Copper mirrors have been found in Iran and dated to 4000 BC. Similar items have been found in the graves of Egyptian Pharoahs who died around 2900 BC. Pharaoh Tutankhamun was buried with a mirror in an exquisitely decorated mirror case. Unfortunately, the mirror was stolen in antiquity and is now lost. However, the case in which the mirror was housed is pretty spectacular in itself. It is made of wood shaped into an *ankh* and overlaid in sheet Gold. Thin sheets of Silver line the interior and the knobs used to seal the case are made of Silver too. Coloured glass, cornelian and quartz were used in the inlays to decorate the top of the case. Perhaps the shape is an ancient Egyptian pun; a spot of fun the craftsmen had, and which still brings a smile to the lips of Egyptologists, because they appreciate that *ankh* can mean 'life,' and also, 'mirror.' These elaborate ornamentations on the case indicate how precious the content was considered to be.

Other ancient words waft down time too; courtesy mirrors from another age and another civilization and in a material other than glass.

Bronze-working reached enviable heights in China as early as 2000 BC. Soon highly polished bronze pieces were used as mirrors. These mirrors were usually cast using clay moulds. One side was highly polished and the other side was decorated with intricate designs and inscriptions. Bronze mirrors were luxury items, used by the Royals and the aristocrats. An ancient bronze mirror from the Western Han dynasty, China, bears an inscription that reads:

May you enjoy noble status and blessings for a long time; May you have pleasure without incident;
May you have delight every day;
May you have plentiful wine and food;
And may you regularly obtain lordly delights.

Not just bronze or Copper, ancient mirrors were made of Silver, Gold and even Lead. During the Tang Dynasty, the decorated side of some mirrors was made of Gold or Silver sheets. By the middle of the Qing dynasty bronze mirrors began to be replaced by glass mirrors. Yet, the so-called Chinese (and Japanese) Magic Mirrors continue to fascinate both chemists and physicists and hold the attention of modern scientists.

The Kyoto National Museum has such a mirror in its collection. When sunlight reflects off the surface, this bronze mirror 'projects' on the wall, the patterns engraved on its back. Some ancient Chinese mirrors are known to function similarly. Historians say that the early Christians who were under persecution in Japan made similar devices to pray before the holy images of Christianity. Scientists say that the so-called magical properties arise because of the unevenness on the polished surface. The concave parts focus light, while convex parts diffuse light, resulting in the projected image. The art of making magical metal mirrors is lost although the fascination remains undimmed.

However, metal mirrors have enjoyed an uninterrupted run in India where the Aranmula Kannadi metal mirrors are still made in Kerala. These mirrors are made by small group of families and the exact nature of the alloy used is a closely guarded secret; although it is believed to involve Copper, Silver and Tin. Aranmula Kannadi mirrors were granted Geographical Indication (GI) status in 2004-2005. A GI is the name of a region or locality and designates a product which originates in that region or locality. This recognition has allowed the Indian metal mirror to enter a privileged class of products that can command premium prices.

The Romans were the first to produce glass mirrors in large quantities. It was this huge increase in production that allowed the common citizen to own a glass mirror. In Europe, the first mention of a 'glass' mirror is a statement made by Alexander Neckam, an English scholar. In 1180, he apparently went on record stating that, "Take away the lead which is behind the glass and there will be no image of the one looking in."

By the 14th century, convex glass mirrors were produced in Germany and Holland and exported to England. Convex or pennyware mirrors were made from forest glass and were thick and tinted green. These were made from glass that had been blown into globes and lined with lead. Pennyware mirrors did not need polishing, but the reflections they showed were distorted.

Thus, the demand for metal mirrors remained undiminished till the 16th century. In 1500, Flemish mirror makers developed a new process for silvering the glass of convex mirrors. They began to use an alloy of Mercury and Tin instead of Lead. This was a definite improvement and the Venetian glassmakers used it on *cristallo* glass. This allowed them to make thin and light, portable mirrors. These mirrors reflected a clear, undistorted image and never needed polishing. By 1570, crystal mirrors were produced in Venice, Antwerp and Rouen and exported to England. Early mirrors were also used for decoration and amusement. In the 16th century, Italian noblewoman and Queen of France, Catherine de Medici installed 119 Venetian mirrors in the panelling of her palace in Paris. This led to glass panelled rooms becoming quite the rage; fuelling even more demand.

In 1678, Bernard Perrot (originally named Bernardo Perroto), master of the Orléans glassworks under the French King Louis XIV discovered how to cast glass on an iron plate to produce flat, rectangular pieces. This radically new process greatly facilitated the production of mirrors. Louis XIV, France's Sun King indulged his love of mirrors by creating a *Galerie des glaces* or Hall of Mirrors in Versailles. According to a description, there were seventeen mirror-clad arches. Each arch contained twenty-one mirrors. For celebrations, twenty thousand candles and ornate glass chandeliers transformed the Hall of Mirrors into a *corridor of light*.

It has been whispered that there was a dark side to this *corridor of light*...one that was linked to Venice's stranglehold on the Glass Industry. Apparently it was customary that whatever was used to decorate the Palace at Versailles had to be made in

France. So, Jean-Baptiste Colbert, who was the Finance Minister at that time, lured away some glassworkers from Venice to make mirrors at the *Manufacture royale de glaces de miroirs.* It is believed that in retaliation, agents from Venice actually came over to France to assassinate the deserters!

In 1835, German chemist Justus von Liebig developed a process for applying a thin layer of metallic Silver to one side of a pane of clear glass. This technique was soon adapted and mirrors began to be mass produced.

In 1896, Gletschergarten; a maze was created out of 90 mirrors to mark the Swiss national exhibition in Geneva. A few years later, it was moved to Lucerne. In 1900, a Hall of Mirrors was set up at the *Palais des mirages* in Paris. There is a mirror maze in Prague too. For a while, many travelling carnivals used to have shows that featured convex and concave and mirrors with aberrations that distorted the viewer's reflection and elicited delighted giggles from the children.

In time, mirrors made their mark almost everywhere from dining table tops to commodes. English decorator Syrie Maugham devised a room-height folding screen made of mirror- panels framed in chrome or bevelled glass. Decorator Mark Hampton described it best when he wrote, "It opened up to look like silvery accordion pleats ...the screen gave the effect of a row of giant prisms." Not to be outdone, American decorator Elsie de Wolfe wanted "...mirrors and sunshine in all rooms." Perhaps it was in that quest that she designed a bedroom that was all- mirror and this included a fireplace, cornices, floor-boards and furniture decorated with mirrors.

A more futuristic mirror is the one labelled 'The Persuasive Mirror'. This mirror uses sophisticated gadgetry to track a person's movements, plot the lifestyle and reflect a realistic reflection of the user's future self. A less scary future for the mirror has been unveiled by Toshiba. The user can 'connect' with the smart mirror using gestures and get the required input depending on where the mirror is located. For example, in the kitchen, the smart mirror can help in "... finding, adjusting and preparing recipes."

Mirrors even haunted ones, command good prices at auctions too.. A reportedly haunted grand Victorian style mirror was sold in London for £100 in 2013. Bonhams auctioneers had better luck with two George II carved giltwood mirrors, which fetched £120,000 in 2010.

From a pool of water to smart mirrors; from naturally found obsidian to glass made to order...the journey has been one that has married serendipity, careful observation, cautious experimentation, imposed secrecy, flamboyant style and creative genius at every step. The history of glass is a magnum opus in its own right.

5

TECHNIQUES AND TOOLS OF TRADE

Glass, in many ways brings together totally opposing qualities. For example, it is fragile but can be tough enough to withstand the forces of nature. Corning's Gorilla® Glass 3 is only chemically strengthened to ensure that it is extra durable. Glass can be either transparent or translucent or opaque to the eye. Glass is often the material of choice of gifted artists who usually manipulate it manually to create one-of-a kind works of art. It is also the choice of canny businessmen who use automated plants to produce float glass or sheet glass in bulk to feed the needs of the world.

One reason perhaps why glass enjoys global popularity is that its mechanical, electrical, chemical, optical and thermal properties can be manipulated by tweaking its extremely simple formula that is most uncomplicated, needs only sand, limestone, and other minor ingredients.

Three groups make up the essence of glass. These are: formers, fluxes, and modifiers/fining agents. All raw materials have to be carefully weighed and mixed together in appropriate amounts. This is called a 'batch'. The ingredients for the batch must be precisely measured and mixed properly according to the formula for the type of glass to be made. Batch mixtures or agitators of different types are used to mix up the batch. The batch process of a modern glass manufacturing facility is computerized and automated.

- Formers are the major ingredients. These make up the largest percentage of the mixture to be melted. In common soda-lime-silica glass, Silica sand or quartz sand is a former.

- Fluxes lower the temperature at which the formers finally melt. Soda (Sodium carbonate) and Potash (Potassium carbonate) are the commonly used fluxes. These are often present together in the so-called 'mixed-alkali glass,' although generally one or the other dominates, giving rise to the terms 'soda glass' and 'potash glass' respectively.
- Modifiers make the glass strong. Calcium carbonate, often called calcined limestone, acts as a stabilizer. The addition of fluxes lead to serious degradations in many properties of glass and modifiers are added to counteract these changes. Examples of modifiers include: alumina.

Chemicals added to aid the removal of bubbles from the melt are called fining agents. Fining agents work in two ways. These either cause the buoyant rise of bubbles or they cause the dissolution of the bubbles. Either way, they get rid of the undesirable bubbles in the melt.

Melting the raw materials calls for a major heat source. This is what makes glassmaking an energy-guzzling process. Ordinary Silica-based glass is made in a gas-fired furnace. Specialty glasses may need electric melters, pot furnaces or kilns.

Adding the batch to the furnace is called charging the furnace. This is usually an automated process. Large furnaces, such as those with capacities of over 10 tons a day, have to be continuously charged. If the furnace is smaller it is charged in batches; usually the next batch is added when the furnace has been almost worked through the former cycle and is almost empty.

It is important when making glass is to use only good quality Silica sand or quartz sand. The sand must be free of impurities containing Iron as this causes the resultant glass to have a green tinge. If the sand is coarse-grained, it has to be pulverized because uniformly fine-grained particles melt quickly and more evenly.

The next step in making glass involves the addition of fluxes. Sodium carbonate lowers the melting point of Silica to about 1,000°C. It is added to make the process more energy efficient.

Glass can be recycled over and over again...almost infinitely. Broken, imperfect or waste glass is called cullet. Cullet is usually added to a batch to increase the rate of heat gain and reduce fuel costs. Silica, sodium carbonate, calcium oxide, magnesium oxide and aluminium oxide are heated till these melt to produce common Soda-lime glass.

Soda-lime glass is 70-72 per cent Silica by weight. It is the commonest type of commercially produced glass. It is comparatively affordable, chemically stable and reasonably hard. Because it can be re-softened/re-melted many times, it is suitable for recycling/reworking. Soda-lime glass is of two types:

- *Flat glass* – which is used for windows, glass doors, transparent walls, windshields, etc.
- *Container glass* – which is used to make bottles, etc.

Customizing Glass

Usually, glass does not deteriorate, corrode, stain or fade easily; although it may crack, break or disintegrate. Glass is used in buildings, illumination, electrical transmission, instruments for scientific research, optical instruments, domestic tools, packaging material, insulating material and even textiles. So obviously different types of glass meant for the various uses demand different compositions which impart the desirable characteristics.

Depending on the qualities that are sought in the glass other chemicals are also added to the basic batch. Magnesium oxide and/or aluminium oxide make the glass more durable. Addition of lead oxide increases brilliance, density and index of refraction. Glass with high lead content can be *cut* to create facets that reflect light brilliantly. Lead glasses include optical and ophthalmic glasses; the best stemware and art objects. Lanthanum oxide imparts excellent light reflective properties and this sort of glass is used to make high quality camera lenses. Borates lower melting temperatures; increase mechanical strength and resistance to heat in the final product. Borosilicate glass is highly resistant to corrosion when exposed to acids and alkaline liquids. It is often the glass of choice for laboratory use and for bake and serve cookware.

There is an interesting story about how borosilicate glass came to be used in cookware. In July 1913, Dr. Jesse Littleton, scientist at Corning Glass Works asked his wife to bake a cake in the base of a heat-resistant glass lamp. Mrs. Bessie Littleton did so with spectacular success. In addition to having made a good sponge cake, she noted that the baking time had been reduced and that the cake had not stuck to the side of the glass. Plus, the cake had been baked uniformly and the glass had not retained any residual odour. The cherry on the top was that the transparent dish had allowed her to observe the cake as it was being baked and she had known when it was done!

Co-workers of Dr. Littleton who tasted the cake appreciated not just its taste, but its "remarkable uniform shade of brown." The cake was finished in no time at all, but it took two years of relentless labour to introduce ovenproof or heat-resistant glassware.

The concept of 'glassware for baking' arrived on 18th May 1915, when a Boston department store placed the first order for PYREX™ bakeware.

Coloured Glass

The choice of minor additives determines the colour of the final product. The ancient glass worker carried out many experiments to derive their colours of choice. They also wrote down the recipes. The oldest recipes for coloured glass are found in the Assyrian cuneiform tablets from Nineveh, the Library of Ashurbanipal. In the 8th century, the Persian chemist Jābir ibn Hayyān elaborated 46 formulae for producing coloured glass in *Kitab al-Durra al-Maknuna* (*The Book of the Hidden Pearl*).

Iron oxide produces bluish-green glass. Just one gram of it used in a ton of Silica can yield glass with a green tint. Chromium produces a rich green colour. Sulphur, Carbon and Iron salts produce coloured glass ranging from amber to almost black. Sulphur added to a Boron-rich batch makes the glass blue.

Adding Calcium makes the glass deep yellow. A small amount of Manganese added to a batch of Silica sand containing Iron impurities can remove the greenish tinge in the resultant glass, but if a large amount is added, it results in amethyst coloured glass.

Selenium is used to decolourize glass. In higher concentrations it imparts a reddish colour. If it is used together with cadmium sulphide it produces a brilliant red coloured glass known as Selenium Ruby glass. Addition of pure metallic Copper produces a very dark red, opaque glass. Cobalt is used to make blue glass.

Milk Glass which is an opaque and white glass, as its name suggests, is made by adding tin oxide with Antimony and Arsenic to the batch.

Turquoise coloured glass calls for the addition of copper oxide. Addition of Nickel to the batch yields a glass that is blue to violet, and even black, depending upon the concentration used. Chromium gives dark green colour and black colour, in higher concentrations. Cadmium and Sulphur in the batch create the deep yellow colours used in glazes.

Titanium gives rise to a yellowish-brown colour.

Metallic Gold in the batch gives rise to an entire spectrum ranging from pretty cranberry pink to ruby red colour depending upon the concentrations used. Silver nitrate produces a range of colours in shades of orange-red to yellow; again, depending on the concentrations. Uranium produces shades of yellowish to green colour.

Treatment

Once all the raw materials have been added in the correct ratio, the batch is poured into a suitable container. The container in which the operation is to be carried out has to be able to tolerate high temperature; often in excess of 1500°C. The furnace and feeder channels carrying molten glass have to be lined with heat and corrosion- tolerant materials too. Such materials are called refractory materials.

Four types of refractories are used in the Glass Industry. These are: Fused cast refractories based on Alumina-Zirconia-Silica or AZS; Magnesite based refractories such as Magnesia mix, Magnesia-Alumina and Magnesia-Zircon; Silica refractories used mainly in furnace construction and Castable, which are based on Mullite, Alumina, Magnesia-Alumina and AZS. There is an entire Industry dedicated to refractories, which has grown as the Glass Industry has progressed.

Glass melting crucibles are available in many different sizes ranging from small ones for those making glass items as a hobby to really large ones for industrial use. Materials such as Sillimanite, Zirconia and Mullite are usually used to make these vessels. The crucible has to be designed such that it can be handled using hooks and poles, etc.; because obviously it will get too hot to handle! Platinum and Platinum alloys are also used for melting glass. Platinum's inert nature, high melting point and resistance to corrosion allow it to tolerate the corrosive action of molten glass.

An important property of glass is that it does not have a definite melting point. It softens gradually over a range of temperatures. The batch is initially heated to 1400° C, and then the temperature is raised depending on the exact composition of the glass being made. Inside the white-hot furnace, the batch melts into a syrupy liquid. This syrupy liquid contains trapped air and gases, which are generated during the breaking up of the carbonates and nitrates used. It is stirred until it achieves a good homogeneity. Chemicals such as sodium sulphate, sodium chloride or antimony oxide are added to it.

There is a working temperature range for every glass composition. Glass can be processed by cutting or grinding it while it is kept at a temperature 500° C below its melting point. Moreover, molten glass can be poured into a mould and allowed to cool so that it solidifies into the desired shape. This method was used by the ancient Egyptians, and it is also how many lenses are created today. Alternatively, some molten glass can be gathered at the end of a hollow tube, and then enormous lung power used to blow it while the tube is turned. The glass is shaped by the air entering the tube, gravity pulling on the molten glass and the tools the artisan glassblower uses to work the molten glass. Commercial glass making is an Industry-scale operation.

Inside a Glass Factory

Modern glass factories have two ends: the hot end and the cold end. The hot end, true to its name includes the furnaces, annealing ovens, and forming machines that shape containers such as jars and bottles.

The furnace can be said to be the heart of the glass factory. Modern furnaces are sophisticated structures and increasingly incorporate features that reduce energy consumption, facilitate low emissions, increase capacity and give glass of better quality. Modern furnaces work twenty-four hours a day; seven days a week and are retired after about 8-10 years.

Annealing ovens, like washing machines, can be either top-loading or front loading. The annealing oven slowly and evenly heats the glass to annealing temperature. After a brief 'soaking' period that ensures even heat distribution throughout the glass, the temperature is slowly brought back to room temperature. All this is done under controlled conditions. Modern annealing ovens can be customized for the specific needs of the manufacturers.

Annealing is carried out to remove internal stresses in the glass. Un-annealed glass is prone to fracturing. As its name implies the cold end does not involve the use of heat in any way. This is where the products are inspected and packaged.

Batch Mixing

Glass factories also have arrangements for storage of raw material and batch-mixing, etc. Since the ingredients may be sourced from very far away, enormous silos are needed to store them. To begin with, incoming raw materials are offloaded on to a conveyor and transported to their respective storage silos. The glassmaking process begins when the raw materials are removed from their silos, weighed, and sent via a conveyor belt to a mixer prior to charging in the melting furnace. Mixing is an important step that is necessary to produce homogenization of glass. Cullet is then introduced to the mixture.

However, before cullet is added to the batch, it has to pass through certain steps too. Waste glass is always sorted by colour because each individual colour adds distinct contaminant(s) to the batch of fresh glass being produced. Optical sorters and other techniques are used to separate cullet based on colour before cullet is added to a batch.

If the clear recycled glass is required, erbium oxide and manganese oxide are added to the glass cullet to help remove all the colours from the glass cullet. Then the cullet is finely crushed. The finely crushed cullet is passed through a magnetic field, where metal inclusions are removed from it. Material such as paper and plastic are picked up manually or by an automated process. Ceramic materials in the cullet can lead to structural defects in the glass. Care has to be exercised to remove every contaminant from the cullet; otherwise the quality of glass will be compromised.

Entering the Furnace

The batch mixture is then transported to the furnace. The furnace consists of three main parts: the melter, the refiner, and the distribution channels or forehearth. Pre-heated air is pumped into the chamber by fans. The pre-heated air is then combined with jet streams of natural gas. This leads to tongues of flames spewing across the batch causing it to melt. It takes about 24 hours for the raw materials entering the furnace to turn into glass. The huge furnaces of the Pilkington Company can simultaneously handle the different stages of melting and homogenizing etc., because these take place in separate zones. The continuous melting process may last as 50 hours. Small gassy bubbles, known as 'seeds', form in the glass during the melting cycle. Helped by gravity, the molten glass flows through the refiner out along the forehearth. Here, it cools a little and also achieves the desired viscosity. Modern commercial furnaces can handle amounts as huge as 2,000 tonnes of molten glass per batch.

The next process is called Fining. During this step, the bubbles that are formed during the melting process rise to the surface and escape into the chamber atmosphere. Patented methods exist to remove these bubbles from molten glass so that the final product is flawless.

The liquid glass moves through a canal into the float bath and hardens on a bath of liquid Tin starting at about 1,100°C. The Tin bath roof demands a huge electrical heating system and usually hundreds of silicon-carbide heating elements are used. Toothed wheels are used to alter the thickness and width of the glass at this point. In addition, heating elements above the stretch machines also control the thickness of the glass as it slowly moves out and leaving the float bath as flat glass at 600°C.

Considerable stresses are developed in the flat glass as it cools. The stresses, if not relieved, cause the glass to shatter when cut. Therefore, it is of utmost importance that the stresses are removed. The next process is called annealing. During annealing, the glass is heated until the temperature reaches a stress-relief point, called the annealing temperature or annealing point. The glass is now still too hard to deform, but soft enough for the stresses to relax.

The glass even when it is ready to be annealed is still very hot. It needs to be cooled both along and across the ribbon of flat glass.

The furnace temperature is slowly cooled down to room temperature after annealing. This ensures that further stresses are not generated in the glass. The glass is lifted out of the liquid Tin bath and placed on conveyor belts that take it to the cooling kiln called Annealing Lehr. The Lehr further cools the glass at a controlled rate. Pilkington Company has developed technology which automatically gives feedback about stress levels in the glass so that the temperatures in the Lehr can be controlled. The glass comes out of the Annealing Lehr and is cooled some more by open air fans. The Annealing Lehr releases any internal stresses in the glass and enables the cutting and further processing of the glass.

It is then allowed to heat-soak until its temperature is even throughout. Heat soaking is a process in which a pane of tempered glass is subjected to a temperature gradient. The time necessary for this step varies depending on the type of glass and its thickness. Flawed glass fractures at this point. However, this is no cause for grief. The broken bits are simply recycled again. Heat-soaking makes sure that the faulty glass breaks at the factory itself minimizing breakages because of inherent faults, at the site of use.

Then the glass is slowly cooled at a predetermined rate until its temperature is below a certain level called the strain point. Once this temperature is reached, the temperature can safely be reduced to room temperature at a rate depending on the properties of the type of glass being produced.

The durability of glass is influenced by how well it has been annealed. Composition of glass aside, glass which has not been annealed is likely to crack or shatter more easily when subjected to even small temperature change or mechanical shock. So important is the role of the Lehr that these days, research papers are being published on mathematical modelling and linear algorithms to improve design and operation. Of course, despite all care taken to ensure that the glass turns out perfect, due attention is paid to detect flaw(s) prior to cutting/drilling or polishing the glass. Modern inspection technology now allows more than 100 million measurements a second to be made across the ribbon of glass. Computerized data is fed to 'intelligent' cutters that trim off selvedge or stressed edges/faults and cuts the glass to the size required.

Commercial Glass Making

The Glass Industry consists of four main segments: Flat glass, Container glass, Specialty glass and Fibre glass.

Flat Glass

Flat glass segment comprises of float glass and rolled glass, which are mostly used as windows in buildings and by the automobile industry.

The earliest windows were just holes punched into walls. These let in rain, pests and dust along with the sunlight. Some believe that the ancient Romans were the first to develop flat glass for use in windows; at least on a limited scale. They base their assumption on a piece of greenish blue coloured window glass that has been discovered in the ruins of Pompeii. Yet, the small piece of window glass at Pompeii notwithstanding, it is generally believed that the Romans did not achieve a high degree of proficiency in making flat glass. They did not discover the art of grinding and polishing cast glass to make it transparent but used thin, translucent sheets of alabaster to let light in.

By 1825, the cylinder process of making glass had become popular. Molten glass was blown into the shape of a cylinder. After the cylinder cooled, it was sliced on one side and rolled out on a flat surface while still hot. When reheated, it opened up to form a large sheet of thin, clear window glass.

The small sections of glass produced by these methods were assembled into a framework using strips of lead called *kames* and a series of small nails called *sprigs*. A putty-like material enriched with linseed oil was also used to fix the glass firmly in place. The final pieces were mounted in windows where they provided a distorted view of the outside but let in copious amounts of sunshine.

It was not till the end of the 17^{th} century, however, that the art of grinding and polishing cast glass was worked out in France which began to produce plate glass. But it was still an expensive method. Flat glass for windows was still rare during much of the 17^{th} and 18^{th} centuries in all of Europe. The 19^{th} century saw huge advances being made in the manufacture of flat glass. Compressed air technology led to improved glass panes. Controlled amounts of air were used to blow a large glass cylinder, which was slit lengthwise, reheated and allowed to flatten under its own weight.

Later, steam and then electricity made the processes of grinding and polishing of heavy glass plates much easier and swifter, too. In 1851, the window tax (some say the phrase “daylight robbery” originated from this tax since the poor could not afford to put up windows and were thus, robbed of daylight), was repealed in the UK leading to an increase in the use of glass. Globally too, the twentieth century saw an explosion in the use of glass. The escalating demand was met by fortuitous inventions and re-working of existing techniques for the manufacture of flat glass.

For example, in 1902, Belgian engineer Émile Fourcault developed a process to vertically draw a continuous sheet of glass of a consistent width from the tank. The glass was drawn vertically from kiln through a *debiteuse*. As the glass travelled upwards it was cooled in a vertical annealing Lehr. Later, he patented this process. However, because of the fine-tuning necessary for the process, it was not till 1914 that regular commercial production of sheet glass using the Fourcault process became common.

Around the end of the First World War, Emil Bicheroux another Belgian engineer, developed a process where the molten glass was poured from a pot directly through two rollers and onto a rollway. Glass made by this process was of more even-thickness which made the subsequent grinding and polishing easier and more economical too. This was called the rolled plate technique.

However, the actual revolution in flat glass was triggered by British engineer and businessman Sir Lionel Alexander Bethune Pilkington who invented the ‘float’ method of glassmaking in 1958. He was interested in making distortion-free glass for shop windows, automobiles and mirrors, etc. At that point in time, plate glass used to be made which was expensive. Plate glass had to be ground and polished to produce the parallel surfaces so that optical perfection could be achieved in the finished product. What Sir Alastair Pilkington did was brilliant in its simplicity.

He made a continuous ribbon of glass come out of the melting furnace and float on the mirror-like surface of molten Tin. Tin oxidizes in contact with oxygen so, an atmosphere of nitrogen and hydrogen was maintained above the bath. The glass ribbon was held in the Tin bath long enough for the irregularities to melt. Now, since the surface of the molten Tin is flat, the glass also became flat too. The process got its name from the fact that the ribbon of glass 'floated' on the bath of molten tin. The glass was then cooled down while still on the bath of molten Tin. In this way, a glass of uniform thickness was produced. It had bright, fire-polished surfaces and did not need for grinding and polishing. Alastair Pilkington, who died in 1995, was honoured with a knighthood in 1970. The float glass process is also known as the Pilkingtonprocess.

The float process became economically viable by the 1960s. It remains the predominant method for the manufacture of architectural glass today. The advantage is that coatings can be applied to the cooling ribbon of flat glass to bring out desired changes in optical properties. An off-shoot of the advances in flat glass production was the development of laminated glass. In this process, a layer of celluloid material is inserted between two sheets of glass. The process was invented by the French scientist Edouard Benedictus, who named this glass Triplex and patented it in 1910. Laminated glass is a type of safety glass. Safety glass is glass that has been especially treated to make it less likely to break or glass that poses less of a danger when it does break.

Container Glass

Container glass is used to make containers such as jars, bottles, drinkware, laboratory apparatus, pitchers and vases, etc. It is believed that the first hollow glass container was made in 1500 BC by covering a core of sand with a layer of molten glass.

In modern furnaces, the amount of molten glass flowing through a hole in the bottom of the feeder is controlled by a ceramic plunger. This is synchronously timed with a shearing device that cuts the glass flow as it exits the feeder. This 'cuts off' a specific amount of molten glass or gob, which will be formed into individual containers. The shape and temperature of every individual gob is precisely controlled. The gob also conforms to the pre-determined weight required to make a single bottle. The gobs of molten glass are then individually fed into the moulds of the bottle-making machine.

In the next step called Forming, the gob is given the shape of a hollow container. The gob travels down to the Individual Section machine or I.S. machine. An I.S. machine has 4-20 sections. Each section can produce 1-4 bottles. The gob drops into the blank side mould, which produces a hollow and partially formed container (parison). Depending on what sort of vessel that is desired, the methods used may be: blow and blow; wide-mouth press and blow; or narrow mouth neck press and blow. During the blow and blow process, compressed air forces the molten gob into a partially formed container in the forming machine. The press and blow processes use a metal plunger to shape the gob. This allows increase in productivity along with reduction in weight and variations in the thickness of bottles.

The parison is now inverted over to the blow mould, where compressed air is used to blow the container into its final shape. The newly formed bottle is coated with a thin layer of tin oxide to strengthen it.

It then enters the Annealing Lehr. In the Lehr, the bottle is cooled in a controlled manner to remove the stresses induced by uneven cooling. This process takes from 30 minutes to two hours.

For scratch-resistant bottles, the hot vessel is treated with a surface coating before the bottles enter the Annealing Lehr and a second coating is applied once these leave the Lehr. The finished products are inspected. Rejected vessels go back to the furnace as cullet. Those that pass the tests are packed and shipped out.

Container Glass Techniques: Ancient and Modern

Core forming is one of the earliest glassmaking techniques. It involves coating molten glass around a core of dung and clay mixed with a little water and attached to a rod. Trails of coloured hot glass are wound around it. Handles and rim are added later. Patterns can be combed on with a pointed instrument. The vessel is allowed to cool and then the rod and core are removed. Most of the ancient containers made by this method are small flasks for storing perfumed oil.

Casting is the technique of pouring hot glass into a mould. After the glass cooled, it was ground and cut to the desired form and decorative patterns were cut into the sides with a cutting wheel. Bowls were often made by this method. Alternatively, the mould could be filled with frits or chips of glass and then heated to melt the glass. Most ancient moulds had two or more interlocking parts. Modern moulds are sometimes made with clean sand and the binder clay Bentonite, or plaster, or even wood or metal.

Mosaic glass vessels were made in Mesopotamia, Greece, Italy, Egypt and Syria as early as the 15th century BC. These hemispherical glass vessels were made by fusing many strips of cane into moulds until they melted together into a swirl of colours. After the glass was fused into a disc, it was slumped into or over a heat-resistant mould to create a hollow vessel. Roman wine cups were made in this way.

It is believed that another ancient casting method involved the use of wax. A wax model of the bottle was made and covered with clay. Holes were left at the bottom and the top. When the mould was heated, the wax melted and ran out of the bottom hole. Then the glass was introduced through the opening at the top and the mould was placed in a furnace. Many modern artists still use a similar technique to create works of art.

Bottles were made by yet another technique, known as *glass pressing*. In this method, molten glass was poured into one mould, and another mould was pressed down into it. Evident seams run the length of the junctions of the mould in such glassware.

Glassblowing: A Giant Leap

It is thought that craftsmen in Phoenicia (Lebanon and Syria) made a momentous discovery sometime around 300 BC. They realized all they needed to expand the glass into a pear-shaped bubble was a pot to melt glass and a pipe to blow through it.

Then the glass needed to be partially cooled and hardened to a point where it still retained some softness and pliability. It could then be detached from the pipe and given its final shape. This still remains the basic and foremost method for making glass by hand.

Glassblowing reached great heights during Roman times. It completely transformed the Glass Industry. The technique allowed vessels to be made with thinner walls and so the glass became more translucent. Tableware and storage containers could now be easily made in a variety of shapes and sizes. Because container glass was manufactured as cheaply as possible, most glass bottles used commonly available sand with iron oxide as an impurity. Thus, the bottles were usually tinted green. Archaeologists termed this shade 'aqua' but in popular parlance, it was called common green.

However, not all ancient bottles were made of cheap glass. Coloured glass was used for perfume bottles because it was decorative. In addition, it reduced exposure to light and allowed the perfume to retain its scent for longer. Venetian glassmakers learnt to combine glass with Copper, Silver or Gold to produce a sparkling glass called Aventurine. Aventurine was mostly used to make perfume bottles because it is so attractive.

Egyptian perfume bottles were works of art. Early scholars called them *Lacrymosa* or tear bottles as they thought these were used to hold the tears of those that were mourning the departed soul. However, chemical tests have showed that these had once contained, not tears, but sweetly-scented oil and perfume. These bottles are now called *unguentaria*. Ancient Egyptian tombs have also yielded glass kohl tubes used to store a *kajal*-like cosmetic.

Cultures around the world have buried various items with the dead. These had been either owned by the departed or were highly valued by contemporary society or left behind as a parting gift to be used in the after-life by the deceased. For example, ancient Chinese graves have yielded carved or enamelled bottles; some of these even had painted decorations on the inside. The designs usually depict landscapes, portraits or bear inscriptions.

Now these funerary items are providing a window of opportunity to take a long look at vanished technology and defunct trade routes.

Sometimes excavated ancient glass vessels shine a light into the obscuring darkness of time to throw into sharp relief a long-forgotten historic figure. One such event occurred when the English excavator Austen Henry Layard discovered a light-green coloured glass vessel from the palace of King Ashurnasirpal II (reigned 883-859 BC). On it, written in the cuneiform script, were these words: *Palace of Sargon King of Assyria* and there was a picture of a pacing lion on it as well. Interestingly, the mark of a lion is associated with King Sargon II (reigned 722-705 BC).

The vessel is pear shaped. It has an ovoid body, a flat rim, and a short and broad concave neck. The lip is small and it has two vertical handles. It was originally covered with an opaque white layer. What is intriguing is that the jar is not similar to any Assyrian vessel and is thought to be of Phoenician origin. It is speculated that the ancient traders had transported this fragile object from its place of origin to its remote resting place in the palace.

Advances in Making Container Glass

Today, all commercial processes are automatic but until the second half of the 19th century, bottles were made by hand gathering, blowing and finishing the neck. It was not till 1850 that a semi-automatic method was developed to make bottles. The advances that took place between 1880 and 1920 revolutionized the Glass Industry. It helped replace the age-old manual practices with mechanized activity. By 1924, the English glass container industry was under *fairly complete mechanization* although not much is known about the history of the transition from man-made to machine-made glass in Europe. It is believed that Canada gained early access to these advantageous developments because of its proximity to USA and the dissemination of knowledge, thanks to glass workers moving between these two countries.

Glassblowing is a technique that involves inflating molten glass into a bubble (parison), with the aid of a blow tube.

Irrespective of whether it is a semi-automatic or an automatic set-up, there are three separate moulding steps. These involve a ring mould, a parison and a blow or full-size mould. The ring mould shapes the finish; the parison or part-size mould gives initial shape to the hot glass, and the blow mould forms the container's final shape and size. It also embosses the design on the surface.

Semi-automatic Machines

Before bottle-blowing machines came into operation, glass-blowing was a specialized task and glass blowers were very well paid. Rapid adoption of machines for manufacturing glass containers was a matter of economics. A study carried out in 1927, revealed that depending upon the size of containers being produced, semi-automatic machines were 42-171 per cent more productive per man-hour than hand production methods. Likewise, fully automatic machines were 642-3806 per cent more productive than hand-manufacture. The same study showed that the labour cost per gross of bottles produced on the semi-automatic machines were 23-52 per cent cheaper than hand-blown bottles. Labour costs per gross of bottles produced on fully-automatic machines were 90-97 per cent lower than hand- blown bottles.

In the early days of manufacture, the semi-automatic machines were operated by semi-skilled labourers who fed the machine with gobs of molten glass. So the speed at which the production system operated depended on how skilled and swift the operators were. However, this bottleneck was overcome when the automatic machines came into use.

Two different semi-automatic blowing machines were developed in the 1880s. American glassmaker Philip Arbogast, patented his machine in 1881 in USA. However, it did not enter large-scale production until 1893. Howard Ashley patented another model in 1886 in England for producing small-mouthed containers. It began to be used for the mass production of containers from 1899.

Fully-automatic Machines

In 1903, Michael Joseph Owens of the Libbey Glass Works, USA, patented his fully automatic glassblowing machine. His machines had 6-20 arms; each capable of blowing a bottle. The finished piece would be automatically detached and delivered to a conveyor belt that took it to the Annealing oven. AR, which was one version of his bottle-blowing machine, contained 10,000 parts and weighed 50 tons. The impact of such machines when introduced into a till-then manually-operated Industry can be easily understood.

American entrepreneurs Karl E. Peiler, William Honiss and William A. Lorenz and four other associates formed the Hartford-Fairmont Company. The Hartford-Fairmont Company developed the first glass gob shearing and feeding device. It also introduced the first plunger feeder. These developments during 1912-1913 laid firm foundations for the automation of the Glass Industry. In 1922, Hartford-Fairmont merged with Empire Machine Company, USA, to form the Hartford-Empire.

The one step that raised a semi-automatic machine to the status of an automatic one was the automatic feeding device. One of the earliest such devices to be successfully used was the Brooke's stream feeder. It was patented in 1903. In the first of such feeder devices, a refractory called, fire clay was used to make a paddle. The paddle pushed a gob of molten glass from the furnace onto a moist metal chute. The moist chute moved the gob on a cushion of stream enroute to the mould. In 1915, this device was used to make bottles with wide mouths. In 1918, Engineer Karl E. Peiler created an improved gob feeder, called a Paddle-needle Feeder.

Use of the gob feeders with bottle-blowing machines involved using rotating tables for the mechanical alignment of parison and blow moulds. Glassmaking pioneer Henry W. Ingle joined the Hartford-Empire Company and created the first individual section (I.S.) machine, which went into operation in 1925. The I.S. feeder had a bank of parison and blow moulds in a straight line on a fixed-bed plate. Gobs of hot glass were delivered to each mould in sequence. The moulds could be changed without stopping production in the other sections. This was a huge advantage.

Semi-automatic and automatic glass bottle-blowing machines increased the productivity of the workers and eliminated the need for highly-skilled craftsmen. Automatic machines also made semi-skilled workers redundant because these machines did not need human intervention. The use of these machines was therefore, initially, governed by labour-union rules that took the labourers' welfare into cognizance. However, one social change that was affected by the mechanization of the glassblowing process by American glass-manufacturer Michael Joseph Owens was that it eliminated child labour from the glass-bottle factories. It is pertinent to remember that Michael Owens himself had worked in one such factory since the age of ten. At age fifteen, he had graduated to being a glass-blower.

End-use of Modern Container Glass

Container glass is the largest segment in the glass sector. It comprises of glass packaging for consumer goods and pharmaceuticals, etc. Once the basic containers are formed, certain steps are carried out depending on its end-use.

Alcohol Packaging: If the container is meant to store alcohol, it has to undergo a process called de-alkalization. By this process, a thin surface layer is created that has a lower concentration of alkali ions as compared to the underlying parts of the container. This ensures that the surface in contact with the alcohol will not react with it.

Pharmaceuticals and Healthcare: The pharmaceutical industry prefers glass because the smooth surface of fire-polished glass makes it easy to completely remove contamination, which may occur after the production process has been completed. Since glass has high shape-stability till temperatures of up to 500°C, even thin-walled containers provide guaranteed protection of the contents. Transparent glass allows easy visual checks during filling and subsequent processing.

Ultra-violet light has been associated with the degradation of pharmaceutical products. This is called photo-degradation. Amber coloured glass offers protection from the photo-degradation because it stops ultra-violet light from entering. Yet, this glass is transparent enough for visual inspections.

Pharmaceutical glass containers such as vials, bottles, cartridges, syringes, etc. need to be made with extra care. Smart pharmaceutical (or neutral) glass can be engineered in such a way that when in contact with aqueous solutions, it creates the same *pH* as is found in the human body.

Poison: In the pre-electricity days, glass vials and bottles that contained hazardous substances such as carbolic acid or ammonia were specially designed so that people would not make the potentially fatal mistake by a candle's dim glow. These glass bottles felt distinctively different to the touch. The user immediately knew, by touch alone, that the contents were likely to be hazardous. Some glass bottles were even shaped like coffins or skulls. Other bottles had the warning 'not to be taken' embossed on the sides or even a series of raised dots that could be felt easily even in pitch darkness. Such glass items were made during 1860s-1920s. Most are collector's items these days.

Cosmetics: Not for nothing has glass been called, "...the poetry of packaging mediums." Nowhere is this poetry more lyrical than in the cosmetic industry. Since Brand-image is critical for the company and customers alike; the cosmetics industry usually goes for customized container designs. Sometimes the bottle's shape becomes iconic. Colour plays an important role. Electronically controlled acid etching can give a pearlized finish. Metalizing glass bottles, or the creation of artwork by laser removal of some parts of this container are all new developments. An added advantage is that glass can be used as a primary container. This makes outer paper or plastic packaging redundant, reducing both material costs and waste. The right container is visually tempting; leading to shelf appeal, consumer recognition, and it makes a distinct style statement.

Food and Beverages: Plastic and Aluminium represent the most robust competition for container glass. Unlike plastic cans and multi-layered cartons, glass containers do not need a petroleum-based plastic layer or other chemical additives to preserve the taste, flavour, aroma and colour of foods and beverages. Yet, so ubiquitous is the glass jar today, that its impact when it first hit the market has long been forgotten. However, social historians recall a time when in the West, a milk wagon used to make the rounds loaded with milk stored in large metal vats. According to a local legend, New York druggist, Dr. Hervey Thatcher was horrified when he saw a little girl drop a dirty rag doll into an open milk container full of milk.

However, Dr. Hervey Thatcher himself wrote that it was the milkman's story that had galvanized him into action. Apparently when the milkman started his rounds, the cream would rise to the top and the first customer got ample amounts of it. In subsequent dips, the dipper would introduce foreign material such as dust from the street or hair from the horses. The last customer generally got skimmed milk fortified with all sorts of rubbish. Dr. Hervey Thatcher decided that milk needed to be handled more hygienically.

The first patented milk bottle appeared in 1875. However, it was his new sealed milk bottles that set Industry standards. The milk jar had the words 'THATCHER MILK PROTECTOR' embossed on it. Soon, most dairies had their own bottles with their names acid-etched on them. These dairies also had regular return-the-bottle plans for the customers. Uniquely enough, early dairy bottles were reused many times; probably because milk had a short shelf life and was only sold locally. A United States Department of Agriculture Survey in the early 1900s found that the average life span of a milk bottle was 22.5 trips.

Laboratory-ware: Good-quality laboratory-ware is usually made of borosilicate glass. This is made mainly of Silica and boric oxide with smaller amounts of sodium oxide, potassium oxide and aluminium oxide. Ordinary glass expands rapidly when heated, so a tumbler cracks when boiling water is poured into it. But, borosilicate glass hardly expands at all. So, it doesn't break when exposed to changing temperatures. Such glass is ideally suited for laboratory apparatus and ovenware.

Eyewear: Photo-chromatic glasses darken on exposure to ultra-violet light but regain transparency soon after the light source is removed. These glasses are generally alkali boroalumino-silicates with a touch of silver halide and a small amount of copper. Such glass was first developed by Corning Inc., and commercially released in 1964.

Specialty Glass

Specialty glass is mainly used in technical applications such as electronics and engineering. Stringent quality specifications have to be met for such glasses; often these are half a millimetre thick with zero defects.

Specialized glasses include:

- ***Vitreous Silica Glass***: This glass contains tiny holes created by using acids. Porous glasses can have a wide range of porosities.
- ***Alumino-Silicate Glass***: This glass is able to withstand high temperatures and so is used in halogen-tungsten lamps.
- ***Alkali-Barium Silicate Glass***: This is the type of glass that is used to shield the X-rays given out by television sets.
- ***Technical Glass***: This includes glasses used in the Electronics Industry.
- ***Glass-ceramics***: Normally, glass does not contain crystals. However, by deliberately stimulating crystal growth in glass it is possible to produce a type of glass with a certain amount of crystallites. Such type of glass combines many

features of ceramics and glass—hence the name. Missile nose-cones use such material. The need for glass ceramics arose in the attempt to overcome some poor mechanical properties of glass. Currently, glass-ceramics are used in many applications such as: cooktops and biomedical implants, etc.

- ***Optical Glass***: This is the type of high quality glass used in microscopes, cameras, binoculars, and telescopes etc.
- ***Sealing Glass***: This includes a wide variety of glass compositions that are used to seal electrical and electronic components.

Laminated or Safety Glass

In 1909, French chemist Edouard Benedictus stumbled on to the idea that led to the invention of laminated glass. This fortunate idea came to him after he accidentally broke a bottle of cellulose acetate. He discovered that cellulose acetate, upon hardening, could hold the fragments of glass together. Today, laminated glass is made by sandwiching a layer of polyvinyl butyral between two panes of glass under heat and pressure. Laminated glass may crack upon impact, but the glass fragments are largely held captive by the plastic inner-layer and the sharp shards do not go flying about. Such glass is used for automobile windshields.

Fibre Glass

Fibreglass is glass-reinforced plastics. It is lightweight but strong. It has diverse applications ranging from roof insulation to medical equipment, and its exact composition varies depending upon its application. It is used in boats, automobiles, baths, hot tubs, water tanks, roofing and pipes, etc.

Glass wool is an insulating material made from fibres of glass arranged into a texture resembling wool. Optical fibre is a flexible, transparent fibre made of high quality optically pure glass; it is slightly thicker than a human hair and can carry digital information over long distances without distortion. Long-distance phone calls, cable TV and even the Internet owes an enormous debt to these thin glass fibres. Life in the twenty-first century owes a huge debt to glass.

Iconic Container Glass

Glass containers were used mainly for medicinal, aromatic and cosmetic substances. Once the ancient container Glass Industry advanced, there was a concomitant advantage for the traders. Ancient Greeks and Romans began to transport liquids such as wine and oils as well as other perishables in bottles of assorted shapes and sizes. Archaeological evidence from the bases of many of these glass containers provide clues to distinctive trademarks and sometimes also, the names of the producers and traders too.

That glass containers can make history is exemplified by the glass bottle in which the soft drink Coca-Cola is marketed. Over the years its shape has evolved, but it remains instantly recognizable. This glass bottle was first launched in 1916. The brief for the designer read, "...a Coca-Cola bottle which a person will recognise as a Coca-Cola bottle even if he feels it in the dark. The Coca-Cola bottle should be so shaped that, even if broken, a person could tell at a glance what it was." Earl R. Dean and Raymond Loewy contributed to the design of this now-iconic bottle. The final design was IP-protected and could not be infringed by imitators or competitors. The Company used the shape of the glass bottle to reinforce their company's brand...this came to be known as contourization strategy.

Glass containers need not always be square or cylindrical in shape. Interesting shapes include a gun-shaped bottle of tequila; vodka bottles shaped like a Kalashnikov gun and a vintage car respectively; shoe-shaped, skull-shaped and animal-shaped bottles of liquor to name a few. America has its own National Bottle Museum which showcases thousands of glass bottles that once housed medicine, perfume, milk or liquor—to name a few contents. These have been carefully curated and conserved instead of being turned into cullet.

In India, as elsewhere wherever recycling has set down deep roots, glass bottles are sold as scrap. But not all bottles go for a pittance. In 2013, a large green, globular Roman glass bottle from the 1st - 2nd Century AD was sold by Bonhams auctioneers for £3,500. The same year, they sold a more modern emerald-green glass snuff bottle made during 1750-1820 for US$ 2,250. In 2004, they sold a Hellenistic opaque dark red glass bottle for £116,650.

Plate 1: Trinitite.

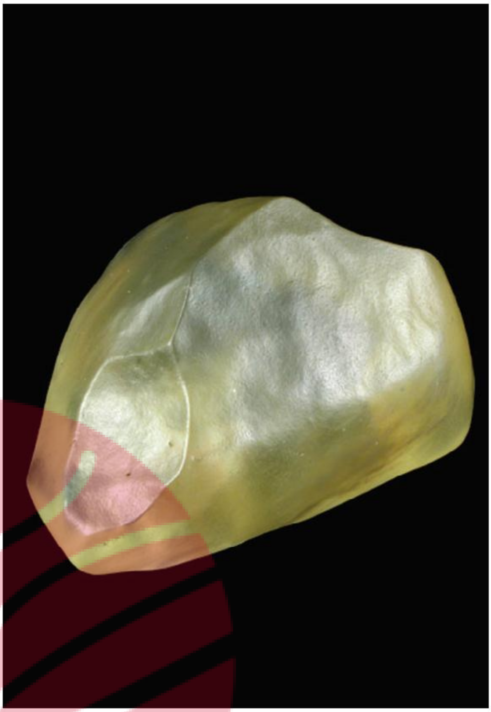

Plate 2: Libyan desert glass.

Plate 3: Obsidian arrowhead.

Plate 4: Ancient Mesopotamia "instructions" for glassmaking written on a clay tablet.

Plate 5: Babylonian formula for making Red glass (1400-1200 BC).

Plate 6: Bead-making furnance found at Lothal, a 4500-year-old port city of the ancient Indus valley civilisation. *(Picture by author)*

Plate 7: Sasanian cut glass (6th century)

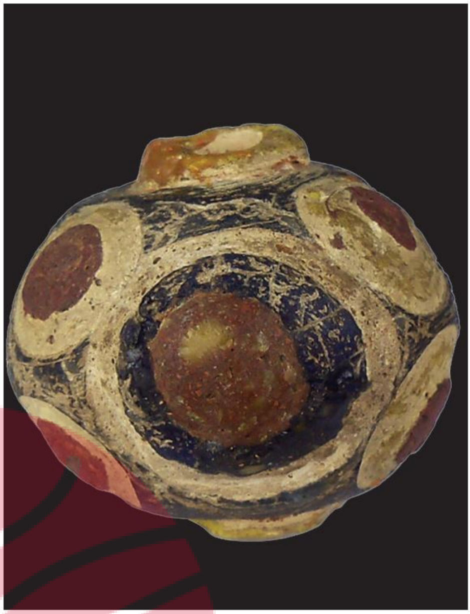

Plate 8: Phoenician glass bead.

Plate 9: Restored Abbasid ruby lustre glass plate (8th/9th century).

Plate 10: Core formed glass (2nd - 1st century BC).

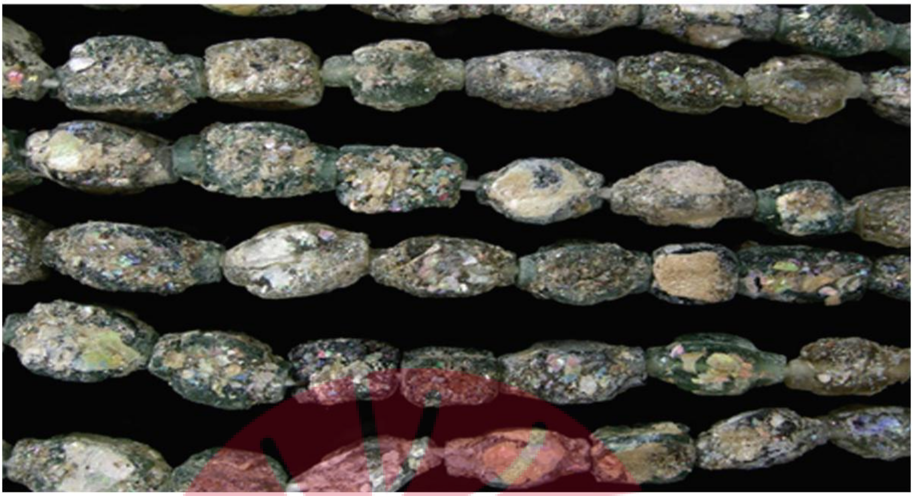

Plate 11: Ancient Indian glass beads.

Plate 12: Glass eyes.

Plate 13: Roman Emperor Diocletian attempted to fix maximum prices of glassware.

Plate 14: Emperor Gallienus refused to drink from a glass vessel because it was common.

Plate 15: Pierre-Louis Guinand, a Swiss glassmaker who developed optical glass.

Plate 16: Father of microscopy, Antonie van Leeuwenhoek.

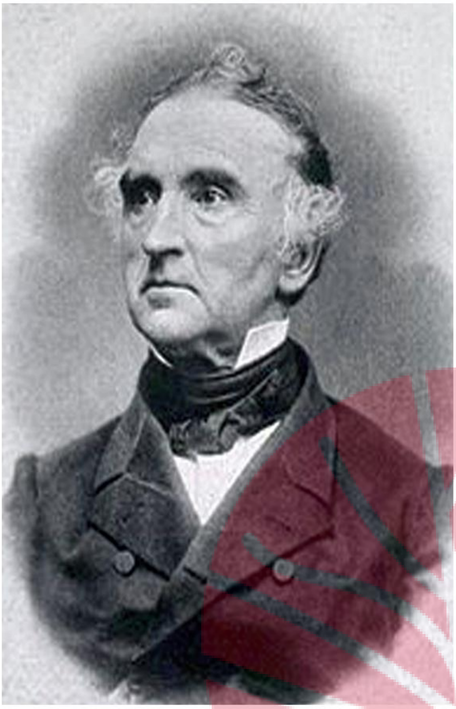

Plate 17: Justus von Liebig, a German chemist, developed the silvered-glass mirror.

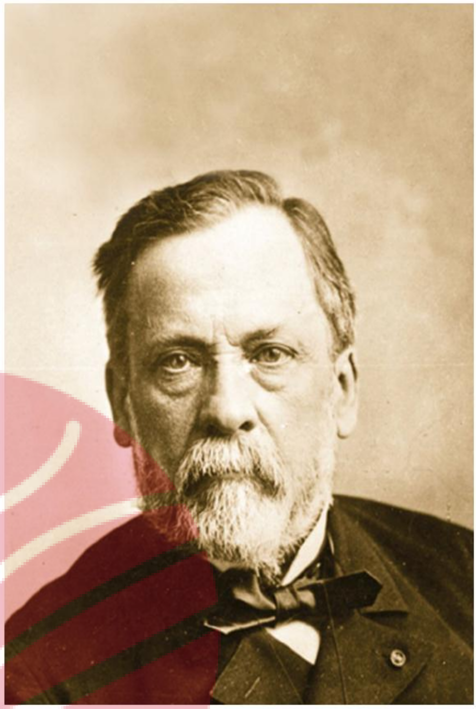

Plate 18: Louis Pasteur.

Plate 19: Galileo Galilei.

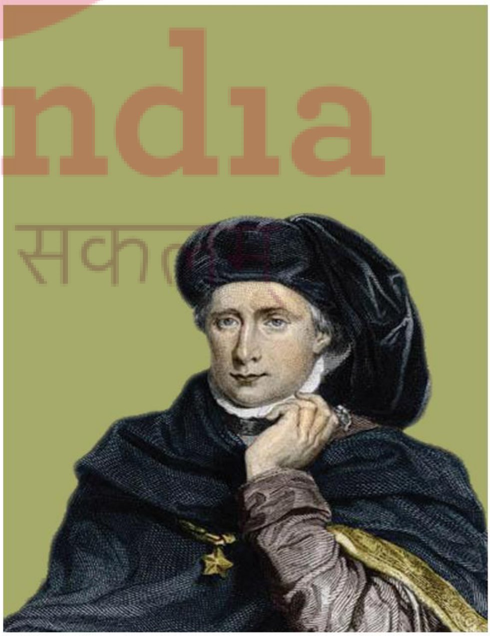

Plate 20: King Charles VI of France. He suffered from glass delusion.

Plate 21: Byzantine mosaic glass tesserae.

Plate 22: Stained glass window. *(Picture by author)*

Plate 23: Roman glass flask in the shape of a date (1st century AD).

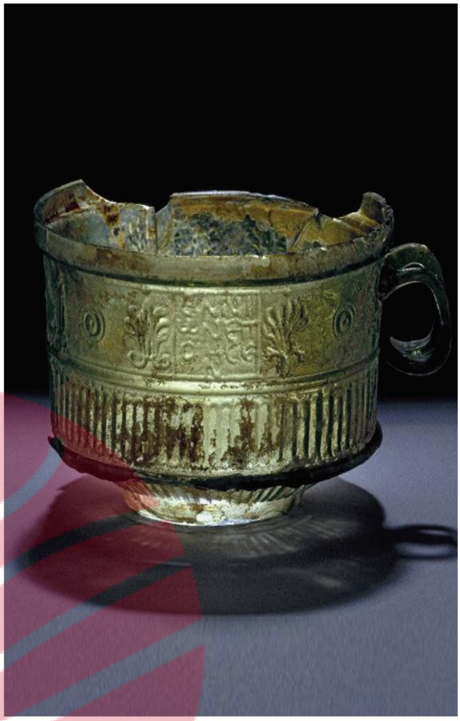

Plate 24: Green mould-blown glass cup, signed by its maker Ennion (1st century AD).

Plate 25: Ancient Egyptian weeping glass scarab.

Plate 26: Roman Trivulzio cage cup (4th century AD).

Plate 27: Constable-Maxwell cage cup (4th century AD).

Plate 28: Carved ruby-red glass bird-form ewer.

Plate 29: Lycurgus cup (4th century AD).

Plate 30: Krautstrunk (cabbage stalk) made in Germany (15-16th century).

Plate 31: Swan-neck glass bottle made in Iran (19th century).

Plate 32: Mughal blue glass spittoon (18th - 19th century).

Plate 33: Mughal gilt-decorated glass huqqa base (18th century).

Plate 34: Filigrana glass originated in Italy.

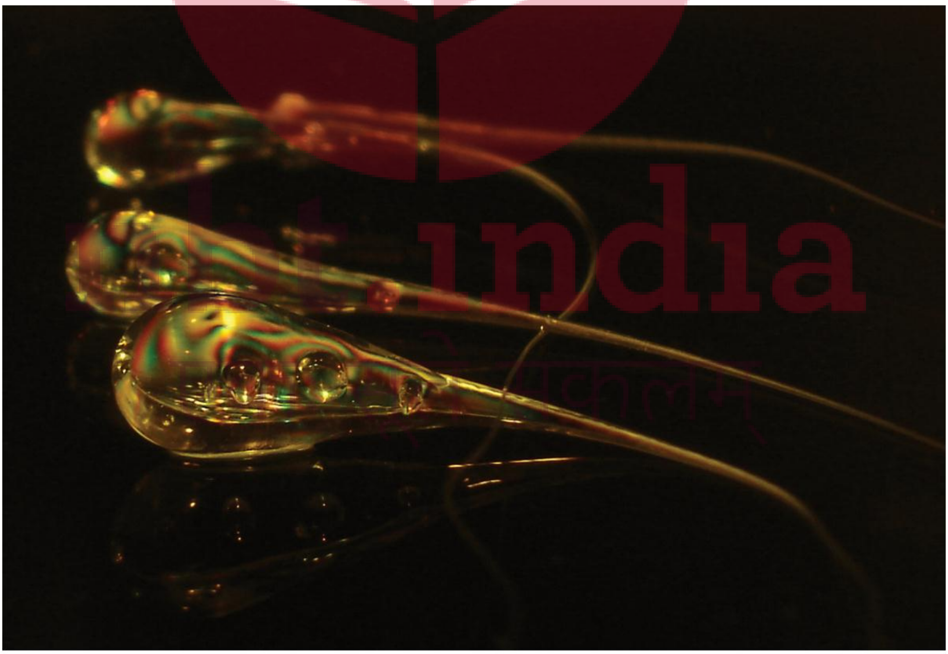

Plate 35: Prince Rupert’s drops.

Plate 36: Glassblowing is one of the oldest glassmaking technique.

Plate 37: Crown glass being made with the help of a disc and rod.

Plate 38: A skilled glassmaker at a workshop in Venice. *(Picture 36 and 38 by Dr. Arup Ray)*

Plate 39: Glass temple at Shantiniketan. *(Picture by Dr. Shiladitya Sinha)*

Plate 40: Louvre Pyramid in Paris. *(Picture by author)*

Plate 41: Traditional Indian costumes adorned with glasswork.

Plate 42: Hut with glass decoration. *(Picture 41 and 42 by author)*

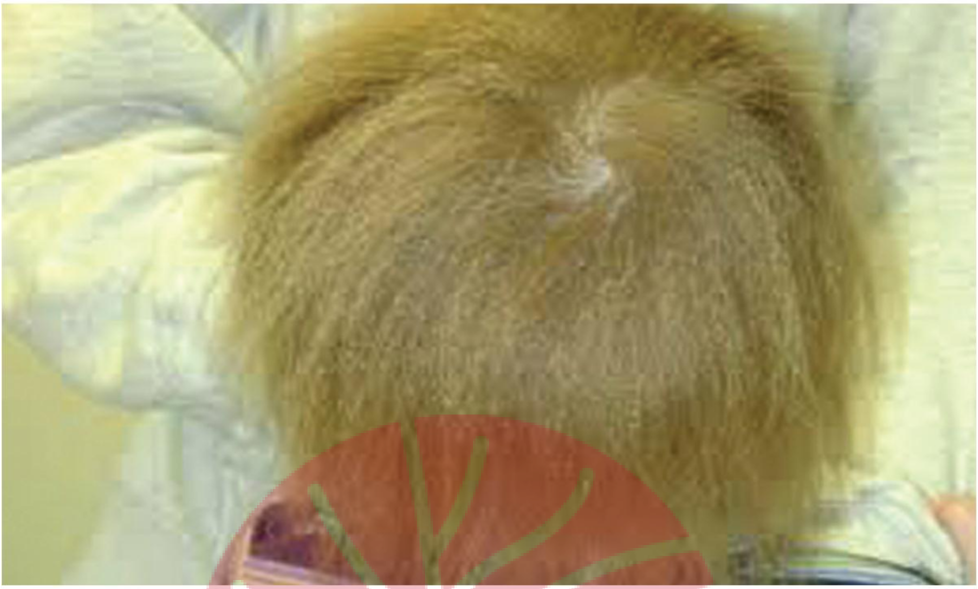

Plate 43: Spun glass hair, a rare disorder of the hair shaft of the scalp.

Plate 44: Glass potato chips.

Plate 45: Glass staircase.

Plate 46: Glass maze.

6

GLASS INDUSTRY IN THE ANCIENT WORLD

Mesopotamia, Egypt, Greece, Rome, China...the names resonate in history and the radiance of these great civilizations still lights up the contemporary, scientifically advanced and globalized world with wonder.

Mesopotamia

Mesopotamia is a Greek word meaning 'between the rivers.' The two rivers are, River Tigris and the River Euphrates. The people of Mesopotamia were true pioneers and Mesopotamia is celebrated in history as the 'cradle of civilisation.' It is globally believed that glassmaking was discovered here, about 4,000 years ago.

In those early days, glassblowing was yet to be discovered. What was known was the technique of core-forming. This was a process of shaping the glass around a core of the desired form, a technique that probably originated in the Mitanni Kingdom between the Rivers Tigris and Euphrates. Of course, the earliest glass was not the sophisticated kind seen today. It was limited to glass beads and sundry small items; rather crudely made at that. Evidence for ancient production of glazes and faience has been found at various 'digs' in this area. Nuzi (Nuzu; Gasur) was an ancient Mesopotamian city located in Iraq. The dig at Yorgan Tepe was carried out by Harvard University during 1925-1931. Small glass items were found during the excavation. The most common colour for Nuzi-glass is dark blue. This is perhaps because the ancients used it as an inexpensive substitute for the more-expensive lapis lazuli or turquoise.

The finds were housed at the Harvard Semitic Museum, USA. In 2008, the Harvard Semitic Museum; Cranfield University UK; Harvard Art Museum; the Catholic University of Leuven, Belgium and the Getty Conservation Institute, USA, collaborated to examine these items using a sophisticated multi-disciplinary approach. Given its importance, glass was chosen as the first category of material for study. The researchers believed that glass could be used to track the trade routes and technological advances in Late Bronze Age Mesopotamia and to compare the results with those of ancient Egypt. Perhaps, another reason that tipped the scales in favour of glass was the 2007 study done by Andrew Shortland of Cranfield University and Katherine Eremin of Harvard Art Museum. They found a way to chemically distinguish between the Mesopotamian glass and Egyptian glass. Using inductively coupled plasma mass spectrometry, these two scientists proved that there are consistent differences in the trace element compositions of Egyptian and Mesopotamian glasses (many of these from Nuzi), because of the different materials used in their manufacture.

The study of Nuzi glass items showed that there was hardly any trade in glass between Egypt and Nuzi that was worth mentioning. Almost all the glasses found in Egypt had the *Egyptian signature* or trace element composition. Similarly, all the glass from different sites in Mesopotamia had a unique *Mesopotamian signature*.

It was known that ancient glass was held in such esteem that it was a Royal monopoly to produce glass. It has been speculated that since glass was so rare and so valued in ancient days that it might have been a sort of diplomatic currency used to secure goodwill! And since the Egyptian Pharaoh had his own glassworks and thus, a monopoly on glass production, his clout would have been enormous. So these findings suggest that although Royalty may have given gifts of glass to those equal in stature, these two major Late Bronze Age cultures were not engaged in robust trade in the item. It is now thought that is more likely that local demand for glass was satisfied by local production.

Interestingly, Mycenaean (Late Bronze Age Greece) beads from the J. Paul Getty Museum, which were also analyzed as part of the study, were found to have both Egyptian and Mesopotamian signatures. This seems to indicate that there was active trade in glass between Mycenaean Greece and both, Egypt and Mesopotamia. Unfortunately, further analyses of the chemical constituents of some highly coloured glass beads from Nuzi revealed higher Aluminium levels than normally seen in glasses from this period. It also showed the presence of Lead- Tin yellow colourant that was not used in glass until the Roman period, which came later. This led some scientists to believe that these beads were *intrusive material* that do not belong to the Bronze Age but are more recent in origin.

To the common man, archaeological excavations are exciting projects involving the discovery of buried gems, gold and other hidden treasures along with the mortal remains of the Kings and Queens of old. One such discovery was made by British archaeologist Sir Charles Leonard Woolley in a grave at Ur (present-day Iraq). Ur was the burial site for many Sumerian royals and was excavated during 1922-1934. The most spectacular find was the almost undisturbed burial chamber of Queen Pu-abi. In her grave was found the only Obsidian vessel excavated from the Royal Cemetery. A fluted dark-brown glass bottle decorated with a turquoise blue thread wound around it was also found.

A faience mask was found in a tomb in the *Gipar-ku* (residence of the High Priestess of the Moon god Nanna) at Ur. The mask had been made by heat-glazing finely powdered quartz grain and then using a mould to fashion it. Bituminous paste had been used to fill the grooves representing eyebrows. Once upon a time, bright colours such as white, red and yellow would have been evident on the mask. Now the colours have been dimmed by time.

Among the other items recovered from Ur are wooden furniture made for the Assyrian court. These items still retain the remnants of gorgeous decorations. The colourful glass pieces, inlaid in ivory were meant to look like precious stones and really do!

Other finds at Ur include an elegant, pale blue-green, transparent glass vessel with a tapered body, a high, narrow neck and a funnel-like mouth with a moulded rim. It has two twisted coils of glass that serve as handles. The body of the vessel is partially covered with a hexagonal honeycomb motif. A thick, pale green glass hemispherical bowl with four rows of oblong facets has also survived from this age. Weathering has added rainbow iridescence to its surface. Similarly, faceted bowls have been found in excavations of Mesopotamian and Iranian sites dating to the fifth, sixth and seventh centuries AD. Such bowls were carried via the Silk Route to the Far East. These bowls even reached Japan.

A Late Bronze Age statue, believed to be the statue of King Idrimi, has been found at Tell Atchana (ancient Alalakh) in Turkey. The statue deserves mention because it has inlaid glass eyes much like the glass eyes of some statues of the ancient Pharaohs of Egypt. However, this is only to be expected because even as the art and science of glass was being developed in Mesopotamia, ancient Egypt was catching up swiftly.

Egypt

Ancient Egypt leaves the modern world speechless. Whether it is mummies that still remain life-like five thousand years after the person took the last breath, or the pyramids that have almost conquered time and stun because meticulous precision goes hand in hand with enormous scale...the advances made by ancient Egypt deserve applause.

It is more or less agreed that glassmaking began around 1500 BC in Mesopotamia. However, little was known till recently about the Second Runner-up in this race. Thankfully, since the early part of the 20th century, evidence began surfacing about the role that ancient Egypt had played in advancing this science and art-form. It is now believed that the Egyptians mastered the art of glassmaking very soon after the Mesopotamians did and that they were making glass as early as around 1250 BC. Ancient Egyptians called glass, *stone of the kind that flows*. Apparently, Egypt, like China, preferred bronze and restricted the use of glass to high-end products such as jewellery, figurines or expensive vessels.

The first glazed objects; beads appear at about the same time in both Egypt and Mesopotamia. Faience objects appear as early as the Pre-dynastic period (4500–3100 BC) in ancient Egypt. Glass appeared during the New Kingdom (1550–1070 BC). Faience was treated like a highly valued gemstone. It reached its height of manufacture and use in the Eighteenth Dynasty, especially in the Amarna period; it covers the seventeen-year reign of the Pharaoh Akhenaten. One of the best examples of art produced during this period is an opaque turquoise glass portrait of the Pharaoh Akhenaten himself. The eyebrow and eye were likely to have been once filled with coloured glass inlays. The glass is not perfect and contains bubbles, which is a sign of flaws in technique. While the glass portrait is in itself stunningly beautiful, it was once part of a larger composition that showed the imposing figure of the Pharaoh in full. The Corning Museum of Glass acquired this piece in 2013.

Copper was a readily available mineral for colouring faience and glass in Egypt. Ancient Egyptian chemists knew that the difference in oxidized state of Copper could be exploited to make two totally different colours; blue and red. They learnt to produce richer and deeper colours by adding metal oxides to the batch. White, green, purple, amber, black and yellow were made by adding Antimony, Lead, Tin, Iron, Manganese, Cobalt and other minerals to the basic soda-lime-silica batch. Purple colour was achieved by adding manganese oxide.

Purple coloured glass or amethyst glass was first used in ancient Egypt. Antimony, Tin and Cobalt are thought to have been very rare in Egypt and were probably imported. Historians have traced the ascendancy and decline in political power of Egypt with the waxing and waning use of the colours which depended on imported minerals. The equation is pretty straightforward. The more powerful the Pharaoh, the more robust was the economy, and thus, more stuff was imported. However, whether relying on imported ingredients or not, so good was Egyptian chemistry that the coloured glass ancient Egypt produced was appreciated worldwide. Egyptian amethyst glass is a collector's item today.

The earliest examples of Egyptian glassware are three vases bearing the name of the Pharaoh Thutmose III (1504-1450 BC), who brought glassmakers to Egypt as prisoners following a successful military campaign in Asia. One such vase in the collection of The British Museum is turquoise in colour with designs in yellow and white. Decorations on the vase include a dotted pattern, enamelled tamarisk trees and scales. The name of the Pharaoh is also enamelled on it. The vase is the earliest known example of this technique in Egypt. However, the earliest example of glass found in Egypt, with a datable inscription, is a large bead bearing the cartouche of Pharaoh Amenhotep (1551–1527 BC).

To make a glass vessel, a core of sandy clay was moulded over the end of a metal rod to create the interior shape. The rod was dipped into the molten glass and spun to coat the core. The glassworker used tongs to add handles and bases to the vessel while the glass was still hot.

Faience and glass objects in ancient Egypt were not put to daily use. These were used in religious ceremonies or were symbols of luxury and status. The funerary items recovered from the pyramids and graves of ancient Egyptians have revealed many objects made of faience and glass. Multi-coloured faience was used to make delicate cosmetic jars, inlaid tiles and royal rings. A novel glass article is the turquoise-blue glass headrest of Pharaoh Tutankhamun. This head rest was probably padded with linen to make it comfortable. The head rest is decorated with the names and titles of the Pharaoh Tutankhamun. It also displays the signs of the *Ankh* (symbol of life) and the Was Sceptre (symbol of prosperity and dominion). Pharaoh Tutankhamun's funerary goods included an *Ankh* mirror case decorated with coloured glass, carnelian and quartz. It is thought to have once housed a silver mirror polished to high perfection. His treasure trove also yielded the *heqa* or scepter and *nekhakha*, (crook and flail) that the Pharaoh ritually held crossed over his chest and which was part of ceremonial regalia. The staffs are made of heavy bronze covered with alternating sleeves of blue glass and gold.

Sometimes, statues and even mummies were given eyes made of glass. In 2006, a cache of termite-eaten coffins were discovered in Tomb KV63 in Egypt's Valley of the Kings. Faces had once been painted on these coffins. Interestingly, one of the faces had eyes rimmed with blue glass. It would have looked remarkably pretty when new. Then there is the story that the labourers who first uncovered statues with eyes of glass fled in terror on first catching sight of these statues. Apparently, the glass eyes gleamed eerily by torchlight and the labourers thought that the statues were alive!

That ancient Egypt was fascinated by glass and held it in high esteem is clear. But was the glass they made of high quality? And how did ancient Egypt take such an early lead in glass making? These are the questions that artists, historians and scientists have been asking for years. Perhaps, the answer lies with Mother Nature.

It is largely accepted that the ancient soda-lime-silica glasses are of two types: (i) Low-magnesia, low-potash glasses and (ii) High-magnesia, high-potash glasses. Relatively pure inorganic or mineral soda is needed to make low-magnesia, low-potash glass. Egypt had deposits of natron in Wadi Natrun. Natron is a relatively pure form of soda. It was mixed with a type of sand that, in addition to grains of quartz, contained the right amount of lime, in the form of shells or limestone. Glasses of this type are termed natron glasses. Egypt was indeed fortuitously placed! No wonder, many ancient glassmaking sites have been uncovered here.

For high-magnesia, high-potash glasses, soda-rich plant ash is needed as a flux. A relatively pure source of Silica is also needed for making glass of this type. This may be quartz-rich sand or crushed quartz pebbles. Such glasses are termed soda ash or plant ash glass.

In the early first millennium BC, there was a move away from the use of plant ash soda as a flux and towards increased use of natron, which eventually developed into the Greco-Roman Glass Industry. Many believe that this trend, which is also apparent in some glasses found, (although not necessarily made) in Mesopotamia, is of immense importance in the history of glass technology. It is most likely to have begun in Egypt, where the natron sources were located. Scholars think that the switch- over from the former type of soda lime glass to the latter type across the world is linked to the problems associated with the easy procurement ofnatron.

Egypt, particularly its mummies, have always been associated with unexplained phenomenon in the public mind. There would have been consternation, if the public had come to know that an ancient Egyptian glass scarab was weeping droplets of real liquid! The incident happened at the British Museum and involved a glass scarab that had been acquired in 1891.

Weeping is condition in glass where droplets of liquid appear on its surface. Unstable glass composition make the product susceptible to weeping. Weeping is most often seen in ancient glass. During weeping, alkalis from the glass are leached to the surface by moisture from the atmosphere. These then form hygroscopic salts that attract more water. Thus, a vicious cycle is set up that promotes yet more corrosion.

The British Museum made special efforts at conservation of the glass scarab but to no avail. Analysis of the glass scarab showed it was of an unstable formulation with high soda and low lime concentrations. The composition of the scarab's glass showed that its soda content was 23.9 per cent. This was excep- tionally high for Egyptian glass. Its sulphate content was 1.3 per cent. Again, this was more than double the values normally encountered in New Kingdom glasses. It became clear that the chemistry of the scarab's glass held the clue to its deterioration.

Lime and magnesia are stabilizers in glass but the levels of these oxides in excess of 5 per cent, or other stabilizers such as iron oxide and alumina, are typically needed to prevent deterioration of soda-Silica glass. In the case of the scarab, the concentration of stabilizers in the glass is insufficient to stop the weeping.

The composition of the scarab's blue glass was found to be similar to rare glass items found in the tomb of Nesikhons, wife of the high priest Pinudjem II. An inscription accurately dates her burial to 9th April 974 BC, so the glasses cannot be any older than that. Analyses of this glass showed that soda content ranged between 18.2–23.4 per cent, lime content ranged between 1.3–4.8 per cent and magnesia content ranged between 0.3–1.2 per cent. These values closely approximate the values for the scarab's glass. It is believed that the glasses such as the type used to make the scarab and the Nesikhons vessels are of historical importance because these represent early uses of natron rather than plant ash as the primary glass flux, mixed with lime-poor sand or quartz.

It is fortunate that the weeping scarab was not recycled because of its poor quality by the unknown glassmaker who made it. Historians think that coloured glass in ancient Egypt may not have been largely recycled as adding different coloured glasses to the batch results in muddied colours and opaque glass. They think that the broken fragments of coloured glass were treasured by more low-ranking individuals who could not afford items made of coloured glass. The fragments of coloured glass may have been pierced and worn as amulets or displayed as curios. That is why, many fragments of glass have been preserved through time. It may be a reason why the crumbling blue scarab is now an exhibit holding the attention of modern glass technologists and fascinating the visitors lucky enough to see glass weep.

Some bits and pieces of glass have also been recovered from sites where ancient glass furnaces were once located. Qantir-Piramesses flourished in the 13th century BC when it served as a northern capital of the Pharaohs. Excavations here have thrown up a treasure trove in the shape of the remains of a glass factory. Dr. Thilo Rehren, of the Institute of Archaeology, University College London and Dr. Edgar B. Pusch, of the Pelizaeus Museum, Germany, successfully excavated remains of raw materials in various stages of production of glass. These included semi-finished glass and coloured glass fragments in blue, red and purple. Of the 40 glass vessels discovered at Qantir, 37 are red in colour. This is unusual because most glass from this period in Egypt is blue in colour. Mesopotamia, on the other hand, specialized in white and yellow glass which required Antimony from the Caucasus region.

Red glass is relatively rare and it is being speculated that the red glass of Egypt gave it an edge in diplomatic negotiations. Interestingly, the coloured glass ingots discovered here match those recovered from the cargo of a Late Bronze Age shipwreck off southern Turkey. In addition, the chemical composition of glass objects, vessels and plaques discovered at many archaeological sites scattered throughout the Mediterranean is similar to the Qantir ingots.

The manufacturing process of glass at Qantir involved two steps. Raw materials, including Silica and plant ash as flux, were heated inside vessels. After cooling, the jars were smashed to remove the semi-finished glass inside. This semi-finished product was crushed and washed to remove salt from the plant ash. The processed powder was then poured through funnels into specialized crucibles and additives added for colour. This mixture was melted a second time in cylindrical moulds. The crucibles had a thin layer of lime on their inner sides. This prevented the glass from sticking to the sides and facilitated easy removal. Finally, the round, glass ingots were transported to workshops to receive the attention of gifted artists.

British archaeologist Flinders Petrie had earlier uncovered evidence of Bronze Age glass production at Amarna, which was associated with the reign of Pharaoh Akhenaten (1352-1336 BC) and which pre-dates Qantir. At that time it was believed that this site was not a factory, but only a place where glass ingots were reworked into finished goods. Later, two furnaces were discovered here, which put a spin on the formerly- held ideas.

In 2007, Dr. Paul Nicholson of Cardiff University, UK, and his colleague Dr. Caroline Jackson of Sheffield University experimentally reconstructed a furnace near the site and demonstrated that it was possible to use local sand to produce glass ingots. They discovered that the site also contained a potter's workshop and facilities for making blue pigment and faience.

Merchants travelling by established trade routes carried new products to distant places. That Egypt's glass and beads were appreciated in far-away lands is evident from archaeological finds. In 2004, archaeologist Yelena Borodovsky found an intact necklace of 17 brightly-coloured Egyptian laminated glass beads around the now-skeletal neck of a young lady laid to rest in a 2,400-year-old burial mound in Altai, Siberia. The necklace has been dubbed *Cleopatra's Necklace*, and is thought to date back to 4th century BC. The beads sport beautiful shades of deep and light yellow and blue. The necklace is currently in the safe keeping of the Institute of Archaeology and Ethnography, Novosibirsk. The discovery of this necklace with its still-brilliant beads speaks volumes about the artistic mastery the ancient Egyptians had achieved over glass.

Greece

The next in line is the list of ancient glassworks is Rhodes, Greece, which dates to around 200 BC—more than a thousand years after the ancient Egyptian glassworks. Some believe that after the fall of Assyria, the glassworkers may have settled in Rhodes. A glass works of antiquity that produced glass beads has been recently uncovered here.

Ancient Greece readily embraced the revolutionary technique of glassblowing. The Greeks made lovely small bottles by winding threads of molten coloured glass onto a core of clay mixed with manure, then making incisions with a knife on the semi-soft glass to make the colour spread.

Unfortunately, no technical treatises on ancient glass production in ancient Greece have yet been found. However, it is known that Plato mentioned natron and its use. Interestingly, although Wadi Natrun is considered the main, or even the only source of natron for glassmaking, Natron deposits also existed in Greece, in the region of Macedonia. This is how Pliny, the Elder identified the site:

> "At Clitae in Macedonia it is found in abundance the best, called Chalastraion, white and pure like salt. There is an alkaline lake there, with a little spring of fresh water rising up in the centre. Nitron forms there when the Dog Star rises for nine days, ceases for nine days, comes to the surface again and then ceases."

Greek glasses from Archaic, Classical and Hellenistic times are natron glass. The Hellenistic Age is when glass production in Greece intensified. This period spans the time between the death of Alexander the Great in 323 BC and the emergence of the Roman Empire. In the Hellenistic Age, glassware became more elaborate and also, affordable. This period is also well known for the emergence of Gold-sandwich glass. This involves the creation of a 'sandwich' of two decolourized glass layers, with a sheet of gold leaf in between. Vessels made in this way needed two castings and then these were ground and polished. Moulded plain and ribbed bowls in green, blue and brown glass were made, which were greatly admired. The process involved using multiple sophisticated steps and the designs were beautiful.

The earliest evidence of blown glass in the Hellenistic Age are a few small blown bottles once used to store perfume and oil, which were recovered from the glass workshops on the Greek island of Samothrace and at Corinth in mainland Greece. Glassware from this period can command premium prices. Bonhams auctioneers sold a Hellenistic pale Olive-green Glass Cup with a stand for £182,650 in 2004. The Cup is thought to date from the late 3rd - 2nd century BC.

Many glass vessels in the Hellenistic period were made of decolourized glass; perhaps because they resembled expensive and desirable rock-crystal vessels. The J. Paul Getty Museum, USA, has in its collection some exquisite examples of Grecian glass. One such is the white marble look-alike glass flask with handle. It had once held perfume. It is believed to date from between 600-300 BC. Ancient glassmakers had shaped the body around a core of ceramic-like material. Then they had twisted trails of hot, coloured glass around it. Once the vessel cooled, they had removed the core creating an object of beauty that stands a little over 12 cm tall and has lovely purple zigzag designs on its surface.

The Museum also boasts of the Greek *patella* cup. The word *patella* is the Latin form of *patina*; a broad shallow dish. The Greeks used such vessels in myriad ways. The one in the Museum's collection has a beautiful pattern in blue, yellow and white glass...it was last used about 2000 years ago.

Glass is not just utilitarian; it is versatile and finds use in play and in making a style statement too. Towards the end of the 4th century BC, board games with glass counters became popular in Macedonia. Fashionable ladies sported rings made of coloured glass. A Hellenistic green glass ring made between 3rd - 2nd century BC was sold by Bonhams auctioneers in 2013 for £3,500...by a strange co-incidence the same year, an unknown donor had given the Salvation Army, Florida, USA, a modern diamond ring worth the same amount! It shows that be it glass or diamond, true value lies in the eyes of the beholder.

Grecian furniture was increasingly decorated with inlaid glass. Seals were made using colourless glass with intaglio representations of divine figures. There is some evidence for the trade of raw glass to the Mycenaean states but more evidence needs to be uncovered for the picture to become as clear as glass.

It is widely held that in ancient Greece, raw glass was brought to glassworkers in the form of ingots from remote locations. The production of finished items took place at these secondary sites where glass vessels, inlays, jewellery, etc., were made. These were then traded. The exception to this practice seems to have been the factory-cum-workshop at Rhodes, which was involved in both glassmaking and glassworking.

Scientists know that at the time when Nuzi was at its prime, glass was mainly manufactured in two regions: Mesopotamia and Egypt. These two glass producers carried out a lively trade. However, Egyptian glass did not land up in Mesopotamia and neither did Mesopotamian glass show up in Egypt. Yet, glass from both these sites has been excavated in Greece; indicating ancient Greek society's avidity for it and its readiness to embrace it regardless of its point of origin.

Rome

Greek colours and patterns in glass greatly influenced the ancient Roman artists who adopted and adapted many colour combinations and also drew inspiration from Greek designs. Like their contemporaries, the Romans loved glass which once in a while reached horrific lengths. Publius Vedius Pollio was a Roman equestrian and a friend of Emperor Augustus. One day when they were dining together, a slave accidentally broke a glass cup. Vedius Pollio ordered him thrown to the lampreys, a type of marine fish that would have eaten him alive. The Emperor intervened and ordered that all of Pollio's valuable cups should be smashed so that no one else could be punished for breaking them. Obviously, Emperor Augustus could not be punished by an ordinary Roman citizen.

Since the ancient Romans made luxury glass cups of stunning craftsmanship, it is easy to understand an owner's obsession with these glass objects. Examples that have survived the ravages of time include the Lycurgus Cup, Trivulzio Cage Cup and the Munich Cage Cup. The Lycurgus Cup was carved in the 4th century and is now in the collection of the British Museum in London. The glass of this cup resembles jade with an opaque greenish-yellow hue. However, when light shines through the glass it appears to be of a translucent ruby colour. It has been demonstrated that the spectacular colour change is caused by colloidal metal; nanocrystals of a Silver-Gold alloy dispersed throughout the glassy matrix. The Trivulzio Cage Cup is made of whitish glass with green and has blue stand-out lettering that spell out *BIBE VIVAS MULTIS ANNIS* meaning, *Drink! May you live many years.*

The Munich Cage Cup bears a shortened version of the same inscription. The Constable-Maxwell Cage-Cup was sold in 2004 by Bonhams auctioneers for £2,646,650. This particular cage consists of three circular mesh-like concentric rings. There are fourteen in the top two rings, seven in the third and a single circular mesh in the centre of the base. At the junction of every pair of meshes is a small cross that conceals the bridge which connects the cage to the inner body. Creating this cup was undoubtedly an unhurried process, fraught with the potential for disaster. It would have been very much in a league of its own when first made and even today its rarity justifies its price.

Cups such as these were created by carving away thick layers of the glass leaving a latticework design on the main body of the vessel. The multi layers of glass formed the contrasts for the image. Usually carved out of a single piece of glass, these cups are decorated by undercutting so that the outside or surface decoration stands free from the body of the glass, being connected to it only by slender struts. Cameo glass is a form of Case glass. An image is cut out in relief on the multiple layers of glass.

Cage cups or *diatreta*, are believed to have been created during the mid-3rd to the mid-4th century; the same time as the Roman cameo glass vessels. These represent the zenith of Roman achievements in making glass containers. An example of Roman cameo glass vessels, also in the collection of the British Museum, is the Portland Vase or the Barberini Vase. This ancient Roman vase is made of dark cobalt blue glass with translucent white glass cameo design. It was made by the dip-overlay method. (In this, an elongated bubble of glass is partially dipped into a crucible of white glass, before the two are blown together.) After cooling, the white layer was cut away to leave just the design. Cameo glass such as this, is believed to be the result of only a few decades of experimentation in the 1st century BC. The Portland Vase fascinated Josiah Wedgwood, so much so that he laboured for over three years and carried out almost 3000 experiments to launch a look-alike brand; Jasperware in the 1770s.

The citizens of the Roman Empire used more glass than the people of any other ancient civilization. This is because it was by this time that glass was no longer treated as being a material fit only for Emperors and limited to the upper echelons of society. Glass won many hearts and soon became fashionable enough for everyday use. In due course, glass became commonplace; and in a reversal of fortune witnessed a situation when Caesar Publius Licinius Egnatius Gallienus Augustus refused to drink from a glass vessel "*...because nothing was more common.*" Roman aristocrats even used the phrase *vitera fracta* or broken glass, to mean rubbish.

Still, not all was lost. Its inert nature endeared itself to traders in food, perfumes, and medicines. In his agricultural treatise *De Re Rustica,* Roman soldier and farmer, Lucius Junius Moderatus Columella recommended glass jars for preserving pickles. Scribonius Largus, court physician to the Roman Emperor Claudius, insisted that certain medicine be stored only in glass vials.

However, the glass used in Rome was still translucent or opaque. The Romans did not manage to achieve true transparency till around 100 AD. Then, Roman villas and palaces began using glass in windows and became cheerily sunlit.

Then, as now, the new material developed soon began to be taxed! In 301 AD, Emperor Diocletian issued the *Edictum de pretiis* (Edict on Prices), which established maximum prices and wages throughout the Roman Empire and attempted to fix export prices throughout the Roman Empire. He listed two types of glassware: *Vitri judaica* (Judaic glass) and *Vitri Alessandrini* (glass made in Alexandria). Bits of the edict were recovered at Aphrodisias, Turkey, in the 1970s. In English, the part about taxes on glass reads as follows:

- Alexandrian glass, one pound: 24 denarii
- Judaean greenish glass, one pound: 13 denarii
- Alexandrian plain glass cups and vessels, one pound: 30 denarii
- Judaean plain glass cups and vessels, one pound: 20 denarii

- Window glass, best, one pound: 8 denarii
- Window glass, second grade, one pound: 6 denarii

Vitri judaica

The term *Vitri judaica* is thought to mean glass made by the Jewish people. This is an interesting term because Abraham, one of the most revered patriarchs of Judaism came from Mesopotamia. The Hebrew word for glass is *zekhukhit*. It comes from the same root as *zakh* which means clear or pure. Etymologically, it is akin to the Akkadian *zakakatu* and the Aramaic *zegugita*.

That the ancient Jewish glassmakers had achieved extraordinary proficiency in making glass is evident in the colossal slab of glass discovered at Bet She'arim close to Haifa. It was at Bet She'arim that the Mishnah Jewish Oral Law was codified, which makes it one of Judaism's Holy places. Rabbenu HaQadosh or Rabbi Judah the Prince was buried here. This place soon became a Jewish necropolis. Sages and savants, not only from Israel, but from lands which now fall under Saudi Arabia, Turkey, Iraq, Syria and Lebanon were buried here. There are more than 30 cave burial systems carved out of the soft limestone and only a fraction has been fully excavated as yet.

Just adjacent to the catacombs is a natural cave. In 1956, there was a proposal to convert this cave into a museum. The bulldozer used to clear the rubbish ran into what seemed to be a slab of concrete about 2m x 3.3m in size. It was about 46cm thick and its top was absolutely even and level. It was estimated to weigh about nine tons. It was too big to be removed and so was left in place when the surrounding area was paved.

In 1963, a joint expedition of the Corning Museum of Glass and the University of Missouri was undertaken to look for remains of ancient glass factories. It was suggested that the Bet She'arim slab might be made of glass. The suggestion was greeted with scepticism. One member of the group even professed that he would eat it, if it transpired that the slab was indeed made of glass. History has not recorded whether he was made to make good on his rather rash offer when chemical analysis confirmed that it was indeed, made of glass.

The Bet She'arim slab is one of the largest pieces of glass in the world and is estimated to have been made about 1600 years ago. About 11 tons of raw materials had to be continually heated to 1100°C for perhaps 5-10 days to create it. It is homogeneous from the top down, until almost near the bottom. The ingredients at the bottom had not completely melted so at that part the glass is of unacceptable quality. Researchers believe that this is evidence that the heat had been applied from above, but had not penetrated all the way through.

The glass slab at Bet She'arim is an imperfect one. It has bubbles in it. The glass is not quite transparent either. A chemical analysis using modern methods found that it contains twice the amount of lime than the optimum amount. Some researchers think that the limestone from the roof of the cave fell into the batch and contaminated the glass being made. When glasses with excess lime cool slowly it becomes partially crystallized. The tiny crystals make the glass opaque. The Bet She'arim glass slab is bubble-infested and opaque too.

Other scientists point out that this huge slab of glass was not meant to be fashioned into an object. It was meant to be broken up into ingots, transported and then re-melted. Had it been perfect, it could have provided material for almost 50 to 60 thousand small vessels. However, the Bet She'arim glass was found to be useless and so, abandoned at the site where it was made. Still, its presence points to Bet She'arim being a primary production centre: a place where glass was produced.

Modern Israel gives so much importance to ancient glass that the Israel Antiquities Authority (IAA) has a separate Ancient Glass Department. The Ancient Glass Housing Center in the National Campus for the Archaeology of Israel is designed to house all finds of glass and similar material. The IAA's collection of ancient glass includes more than 9,000 complete objects such as bowls, glasses, wine glasses, bottles, jars, beakers, lamps, beads, jewellery, amulets, and thousands of fragments.

Vitri Alessandrini

Alexandria was an important centre for glassmaking. Alexandrian glassware was exported to Rome, and from there to the frontiers of the empire. The power of imperial Rome provided the framework for extensive trade networks and cultural exchange. It is no surprise therefore, that Roman glass found its way to many Saharan cities along the trade-routes and also penetrated deep into Asia.

Alexandrian glassmakers mostly addressed the niche luxury item market as compared to their contemporary Syrian glassmakers who usually made utilitarian glassware. Glass workers of ancient Rome created beautiful works of art, many of which grace the museums around the world. Some items made in ancient Rome have no modern counterparts partly because of a vanished lifestyle. One such is the fish-shaped dispenser for the fish sauce, *garum*. In 2013, Bonhams auctioned a 3rd century AD, green fish-shaped containerfor £20,000.

Ancient Roman glassworkers also experimented to produce glass with improved properties. One legend that has come down from that age, albeit the product itself has not, is that of *vitrum flexile* or flexible glass. This legendary lost invention supposedly dates back to the times of the Roman Emperor, Tiberius Caesar (14-37 AD).

Apparently, the proud craftsman presented a drinking bowl made of flexible glass to Caesar who threw it to the floor. The bowl did not shatter; it was merely slightly dented. The inventor repaired the damage by hammering the bowl back into shape. Emperor Tiberius Caesar quizzed him about the number of people who had access to this knowledge and quickly had the craftsman beheaded once he boasted that he alone knew the technology. The inventor took his secret to the grave. Emperor Tiberius Caesar was afraid that widespread use of such a material would undermine the value of gold and silver or as he put it, "Gold would be as mud and the value of all metals forfeit."

Interestingly, Corning Inc., has come out with flexible Willow Glass™ which is being described as "... a thin and flexible

glass substrate that will enable low cost manufacturing of ultra- slim, curved and flexible displays, as well as touch sensors.
...Willow Glass combines the inherent benefits of glass: optical purity, thermal stability and an exceptionally clean, smooth and flat surface – with a mechanically bendable form factor." And with the creation of glass with such properties, the legend of vitrum flexile of ancient Rome has finally found fruition in the realm of reality.

Professor François Barthelat and his team of researchers at McGill University, Canada may be the intellectual disciples of the late-lamented innovative Roman pioneer who paid with his head for having created flexible glass. The luckier modern-day researchers have found a way to make glass less brittle, so it will not shatter when dropped it. They drew their inspiration from mollusc shells.

The outer layer of mollusc shells is largely composed of brittle chalk. However, the inside is coated with nacre, or mother-of-pearl which exhibits phenomenal fracture strength and toughness. Nacre is 95 per cent aragonite, a hard but brittle calcium carbonate mineral and the rest is made up of soft organic molecules. Yet, nacre can be 3,000 times (in energy terms) more resistant to fracture than aragonite. The secret lies in the structure of nacre. Nacre has 'brick and mortar' micro-architecture with interlaced ceramic platelets separated by soft biopolymer. The microstructure of the biopolymer shows that it consists of millions of organic fibres; each fibre consists of nano-sized modules. When tension is applied, the modules unwind prior to fibre fracture. The internal structure of nacre also revealed that it was made up of individual interlocking bits. The researchers noticed that the boundaries between the interlocking bits were not straight but somewhat contoured; like the edges of jigsaw puzzle pieces.

Professor François Barthelat and his team recreated these boundaries in glass microscope slides, using lasers to engrave networks of wavy 3D 'micro-cracks' within them. Almost paradoxically, these glass slides turned out to be 200 times stronger than non-engraved slides. The researchers realized that by creating the pattern of micro-cracks, much like a jigsaw puzzle, they were able to stop the cracks from propagating and becoming larger under stress. The researchers also filled these cracks with polyurethane, though according to Prof. Barthelat, this step is not essential as the micro-cracks are enough to provide the flexibility needed. Drawing inspiration from living beings to provide sustainable solutions to present day challenges is called Biomimicry...and the humble mollusc may have finally handed humans the secret to making glass that will bend but not break. Emperor Tiberius Caesar merely delayed the arrival of flexible glass...he was not able to stop its birth.

The invention of glassblowing allowed Roman glassblowers to make beautiful vessels. By about 50 AD, they had fine-tuned the process to blow glass into hollow moulds with two or more sides. They became masters of mould blowing and made glass items in elaborate shapes and designs. One such example is that of jars shaped like dates. One particularly well- executed specimen of such a jar has survived since 1 AD. The dark brown colour matches that of dried dates and the exterior truthfully mimics the wrinkles and folds of a real dried date. Most date flasks were blown in two-part moulds with a continuous, visible seam; however, this one was created using a three-part mould. The seams were carefully hidden as wrinkles. This is truly the work of an artist who was also a good technician; pity history has not recorded his name.

At around this time, some glassworkers started signing their pieces. About 130 names of Roman glassworkers from ancient times have survived. For example, master glassworker Ennion who worked in Sidon (modern Lebanon) during 1-50 AD often etched his name on glass vessels blown by him. He was the first glassmaker to sign his name on glass items, which have survived till modern times. Ennion's signature is known from over thirty objects. Other items are also attributed to him on the basis of style. He signed his name in Greek but scholars have argued that his is not a Greek name and that he was of Semetic origin and that

Ennion is a version of the Hebrew name *Ananiah*. Interestingly there is report of a family tomb in Bel She'arim,that bears the name Ennion. Some think that it is belonged to the glassmaker's family. Others who signed the decorated mould-blown tableware include Neikais, Meges, and Ennion's apprentices Jason and Aristeas.

A transparentbluecup withtwo narrow strap handlessilently proclaims,"Ennion made me. Let the buyer be remembered!" "Let the buyer be remembered," was a traditional Semitic greeting. It is thought that this was Ennion's way of ensuring that his name was advertised and also, his way of paying tribute to a patron of the arts...the buyer! Ennion's name has been remembered by posterity. The Corning Museum of Glass has set up the Ennion Society. It honours those who gift $1,200 or more annually so that the Museum can acquire more glass objects to add to its truly amazing collection.

Ennion's handiwork is celebrated for its fine detailing and clarity of the relief decoration. Scholars believe that his designs are akin to that found in contemporary silver ware. They think that Ennion was a silversmith who diversified into glassworking. He used his skills of embossing and chasing metal to make glass vessels. He minimized the visibility of the lines caused by the seams in the mould. Roman glassworkers usually polished the cut decorations on glass vessels. However, sometimes they deliberately left rough areas to contrast with the smooth background. This technique is called abrasion. Exquisite examples of abrasion-decorated glassware from the late Roman period are the Populonia bottles: a set of nine similar vessels decorated with natural scenes and famous buildings in and around Baiae; a Roman harbour town. These bottles got their name from Populonia in Tuscany, Italy where these were excavated in 1812.

Glass produced in the Roman world has a relatively uniform composition. Scholars think that this shows that glass production was restricted to only a few small centres. This glass was then transported to the far reaches of the mighty Empire.

It was at these places, scattered across the Empire that the glass was reworked into different shapes.

At about this time, there was an explosive advance in furnace technology. Bigger and better furnaces were built. One such ancient furnace now excavated, shows evidence that it could melt up to 40 tons of glass at one time!

Roman archaeological remains in Britain suggest that two types of furnaces were in use. An early Roman furnace in London contained a built-in, tile-lined tank for holding the molten glass. It is likely to have had an ash pit and provision for adding wood to the fire. In the later Roman period, however, it appears that the glass was held in ceramic crucibles or pots. The crucibles were seated on a shelf or platform within the furnace. This type of furnace continued to be used until the early medieval period.

Glass became subject to the dictates of fashion and choice when it began to be available easily. After Constantine the Great converted to Christianity in 318 AD, Roman glass became increasingly more Byzantine in its appearance.

The Byzantine Empire was the Greek-speaking continuation of the Roman Empire during the Middle Ages. Its capital city was originally known as Byzantium and later, as Constantinople (now Istanbul). The term *yalopsos* meaning a glassmaker appears in early Byzantine codices and later texts also confirm the existence of glass-making activity in Byzantine Constantinople. The *Codex Theodosianus*, which is a compilation of the laws of the Roman Empire under the Christian Emperors mentions glassmakers among the craftsmen that were granted tax-exemption.

The Romans first began to use bits of coloured glass to make a design. Then they mounted it on the window frame. When sunlight streamed through the glass, the visual effect was nothing short of magical. These stained-glass windows, as they are known, are tourist attractions even in the 21st century. Stained glass inserts in doors and windows are old hat for interior designers. What is making waves now is using Instagram digital photographs to make a sort of stained glass panel for the windows.

Much of what is known about this form of art has come down thanks to the efforts of a 12th century German monk named Theophilus. Not only was he a metal worker and an artist; he was an author too. He wrote a text called *On Diverse Arts*, and detailed all that he had learnt while observing glaziers and glass-painters as they created windows of "...inestimable beauty."

That is how it is now known that pieces of coloured glass were laid out on the design board. The edges of each piece fitted into *cames* or H-shaped strips of Lead, which were soldered to one another forming a latticed network of Lead. Putty was inserted between the glass and the *cames*. Finally, metal armature stabilized the glass pane which was mounted in the window.

Stained glass was also used to decorate churches in Constantinople. However, evidence that glass was produced here on a large scale has not yet been unearthed. Examples of stained glass has been uncovered at many churches, including the Church of St. Polyeuktos/palace of Anikia Juliana and the churches of Pantokrator (Zeyrek Camii) and Chora (Kariye Camii).

Glass was the chosen material for beautifying walls and vaults in early Christian and Byzantine churches. Mosaics became a common art form too. A *tessera* (plural: *tesserae*) is a single tile, used in creating a mosaic. The Romans used coloured stones for their mosaics but later, Christian artists used glass *tesserae*, which allowed the use of almost-infinite combinations of glowing colours. Each colour was available in many hues of opacity and sometimes, two different glasses were used together to create bi-colour *tesserae*.

Coloured glass to be used in mosaics was made by manipulating the four elements: Iron, Copper, Manganese and Cobalt. By using different combinations of these elements in varying proportions and by adding agents such as Antimony and Tin which imparted opaqueness, it was possible to obtain a very wide range of colours. The nature of opacifiers changed over time. Byzantine glass *tesserae* as for example those found in Israel and Jordan was opacified using only compounds of Tin. Greek *tesserae* made a couple of centuries later, used the cheaper and more easily available crushed quartz. *Tesserae* from the Basilica of San Vitale, in Ravenna, Italy are made of Roman glass using Antimony as an opacifier. This is quite rare in Byzantine mosaic work.

According to the *Encyclopedia of the Hellenic World*, Constantinople appears to have been an importance site of coloured glass *tesserae* production. However, Prof. Liz James, of Sussex University, who has established a database of Byzantine glass mosaics, finds it "...perfectly plausible that raw glass was never made in Constantinople but rather was imported from the Levant and worked in the city; no evidence has been found for raw glass manufactories in Constantinople because there is none to find...Easier by far would be the acquisition of coloured glass, as cakes or sheets or even tesserae." She rues the fact that despite the several tons of mosaic glass in Constantinople alone, it has been said of Byzantine glass that, "...almost nothing survives."

Analyses of Byzantine mosaic *tesserae* have shown interesting results and given much food for thought to art historians and glass researchers.

Tesserae from the 5th century Tel Shikmona near Haifa, Israel, revealed that the *tesserae* glass was of a low-potassium, low-magnesium containing soda-lime-silica variety, i.e. it was Roman glass. It is known that Roman mosaic *tesserae* were a ready source of coloured glass in the Western medieval world. For example, Roman *tesserae* were used to create coloured glass panels at the monastery San Vincenzo al Volturno in Italy. However, there is no evidence that points to the use Roman *tesserae* as colourants in Byzantine mosaicglass.

Tesserae from the 10th century walled monastery of Hosios Loukas in Greece was made of soda-lime-silica variety glass containing high levels of magnesium; i.e., Islamic glass. *Tesserae* from Basilica di San Marco, Venice (11th - 13th century) was made of potash glass with a high lime and phosphate content; i.e., Western glass.

There were some similarities too. Manganese was used as a colourant but the different sites used it in different proportions.

Within the *tesserae* from a particular site, however, the amount of Manganese used remained pretty consistent though. Tin was used as an opacifier only at Tel Shikmona and Basilica di San Marco. Although the chemical fingerprints of the glass indicated a single source for each group of *tesserae* there were certain major deviations. Small groups of *tesserae* at all three sites stood apart. Examples include: opaque red glass at Tell Shikmona; blue glass at Hosios Loukas; and the gold glass at Basilica di San Marco. British Art-Historian Prof. Liz James thinks that it is likely that while most colours were made on site, perhaps the more sophisticated and technically demanding colours were imported. Some scholars think that the technique for making stained glass was a Byzantine invention that later spread to the West. However, according to another school of thought it was the other way around; the West influenced Byzantium, during the period of the Latin occupation of Constantinople (1204-1261). It is largely agreed that Byzantine artisans who fled to Venice when Constantinople was overrun in 1204 and again in the middle of the 15th century, made a significant contribution to the Glass Industry of Italy.

In 2002, a raw glass furnace was discovered during excavations in the Byzantine city of Apollonia-arsuf, near Jaffa. Two furnaces had already been uncovered here in the 1950s. These furnaces are the only primary glass installations in Palestine that have so far been confirmed as operating in the late Byzantine period. These are also the earliest identified primary glassmaking furnaces in that region. The glasses recovered from near these furnaces are soda-lime-silica glasses. This is typical of late Byzantine and early Islamic glass of this region. This sort of glass has higher alumina content as compared to Roman blue-green glass.

Palestinian coastal beach sand contains approximately the correct amounts of quartz and calcite needed to make good glass. This sand mixed with soda from the Wadi el Natrun in Egypt would have given the exact formula for making a blue- green soda-lime-silica glass, samples of which have been found on site. Researchers think that the glass was produced in primary workshops but worked in separate secondary workshops by a different set of craftsmen.

Islamic Glass

After the fall of the Roman Empire, there was political turmoil and economic instability, which led to a decline in glassmaking. However, glassmaking continued in the Byzantine Empire. In the early years the glassmakers received little or no royal patronage and so, kept on making traditional or Roman glass. They had almost no incentive to exercise creativity or to show innovativeness. These glass works are considered *transitional*, and clubbed under the heading: 'Proto-Islamic'. There was so little change in these two types of glasses that even expert art-historians have trouble distinguishing late Roman glass from early Islamic glass.

Islamic glass is divided into different periods: Early Glass, dating from 7th -10th century; Early Medieval Glass, dating from 11th- mid 13th century; Late Medieval Glass, dating from mid- 13th to 15th century and Late Islamic Glass, dating from 16th-19th century. Islamic glass is usually richly coloured and decorated. The three most prolific sites for Islamic glass are Fustat (Old Cairo) in Egypt, Samarra in Iraq, and Nishapur in Iran. Islamic glassware was highly prized and traded along the Silk Route.

Sasanian/Persian Glass or Pre-Islamic glass is glassware produced within the limits of the Sasanian Empire, (modern Northern Iraq, Iran and Central Asia). It is a soda-lime-silica glass usually with high levels of Potash and Magnesium. This means plant-ash was used as a source of soda. Best known is the 5th century AD Sasanian glass decorated with overall patterns of hollow facets which were ground, cut and polished.

Sasanian cut glass and deep bowls with shallow circular facets were exported to China where these were greatly favoured. The Silk Route through which it reached the empire was sometimes referred to as the Glass Road. A typical Sasanian cut-glass bowl was unearthed at Emperor Ankan's tumulus (AD 535), and is now displayed at the Japanese Archaeology Gallery. Another Sasanian glass bowl is preserved in the treasury house of Shoso-in, Nara, Japan. Even in the Byzantine and Arab world, Sasanian Glass was valued as exotic imports; globally, it is still considered priceless. In 2013, Bonhams auctioned an early Sasanian green glass facet-cut bowl dated to 5th-6th century AD for £15,000.

In the 8th century, a technique of decorating glass, and later pottery, with lustrous metallic stains was discovered. This became celebrated as lustre painting. Experts differ as to whether it was a discovery made by ancient Egyptians or ancient Romans or whether it originated in Fustat or Iraq, or Iran or Syria. By the 9th century, Lustre glassware is thought to have been used for serving wine or small delicacies. Its use was restricted to Royal courts. An example of large-scale use of lustred tiles is the audience hall of main Palace at the Samarra complex in Iraq, which has been called the largest archaeological site in the world. Whatever the story of its origin, lustreware was produced continuously till the 14th century. Further developments were made in lustreware as recently as in the 19th century in USA, where copper lustreware was greatly appreciated. The British Museum has in its collection, an 11th century AD, glass vessel that has travelled through time in a perfectly preserved condition. Careful study has revealed that it had been painted with a mixture containing copper oxides which fused with the glass when the vessel was heated. The kiln used was a special one that limited oxygen supply. Such a kiln is called a reduction kiln.

It was this kiln that gave the vessel its metallic lustrous sheen that fascinates visitors even today.

The oldest lustre painted glass cup comes from Fustat and is dated 779 AD. However, there is another one from Damascus, which a school of thought dates to 786 AD. Study of the sheen on the glass has shown that Copper and Silver containing compounds were used along with a reducing agent and a sort of thickening agent. The paste was applied on the glass which was then re-heated at a moderate temperature. This heat treatment made the metal migrate into the body of the glass. These miniscule colloidal particles of metal caused a permanent yellow staining of the glass. The presence of Copper made the colour more amber-like in colour. Ancient lustreware is greatly prized by collectors. Fragments or damaged pieces can also command high prized; as for example, the very rare Abbasid ruby lustre glass dish from Iraq. It was dated to the 8th - 9th century. The dish had been recovered in fragments and had been restored. Yet, Bonhams auctioneers could sell it in 2012 for a whopping £34,850.

Silver staining in medieval stained-glass windows of Western Europe took another five hundred years to arrive. An example still survives in the Norman church of Le Mesnil Villeman (a village in the Manche, France). It is dated to 1313.

Islamic glassware, particularly the relatively rare cameo glass excavated from the 10th century, continues to amaze because of its beauty and delicacy. One such is the narrow-necked and extremely elegant Corning Ewer; so-called because it is one of the most significant possessions of the Corning Museum. This pear-shaped container is made of a layer of light green glass over colourless glass, and decorated with a stylized hunting scene.

Evidence of the evolution of Islamic glass providentially found its way into the hands of scientists in the shape of *Glass Wreck*; an 11th century shipwreck at Serçe Limani on the south coast of Turkey, opposite Rhodes. It was investigated in the late 1970s by Professor George Bass of the Institute of Nautical Archaeology, USA. The ship is thought to have sunk on its voyage from Syria to Constantinople. Its cargo included three metric tons of very fine quality cullet, which also served as the ship's ballast. Besides glass and amphorae, its cargo included ceramic objects such as tableware and cookingware. The wreck also yielded millions of shards from broken glassware along with eighty pieces of glassware; amazingly still intact. The broken bits came from different types of beakers, cups, bowls, bottles, jars, ewers, jugs, plates and lamps. These vessels recovered from the *Glass Wreck* provide excellent examples of the medieval Islamic glassware made in Syria.

Apart from the fact that the glass samples recovered are varied as well as abundant, it is also firmly dated to about 1025 by weights stamped with the years of the reigns of Caliphs of the Fatimid dynasty, and by coins of Emperor Basil II, a Byzantine Emperor who ruled from 10th January 976 to 15th December 1025.

Over the centuries, Syrian artists learntthe artof extensively applying enamels on glass. From the 13th - 15th century, they produced large quantities of enamelled glass in many varied shapes and sizes; all with brilliant multi-coloured designs.

The Cavour Vase from the late 13th century is a spectacular example of glassware of this type. It is one of a group of cobalt-blue and purple gilded and enamelled glass vessels made in Syria and Egypt. It is named after its owner, Count Camillo Benso di Cavour who lived in the 19th century. The vase bears elaborate multi-coloured decoration. Inscriptions around its neck praise an anonymous Sultan who probably lived in the 13th century.

Luck of Edenhall, a 14th century luxury is a bell-mouthed, clear glass beaker. Decorated with blue, green, red and white enamels plus gilding, it is a superb example of the glassware of the times. It was made in Syria or perhaps, Egypt. It is called the *Luck of Edenhall* because for a long time it was in the possession of the Musgrave family of Edenhall, Cumberland, UK. Local legend however, has it that fairies left it behind when they were surprised while drinking out of it. As they took flight, they yelled a warning, "If this cup should break or fall, Farewell the Luck of Edenhall." And apparently that is how the beaker got its name. Since 1958, the *Luck of Edenhall* has been proudly displayed at the Victoria and Albert Museum in London.

During the 15th and 16th centuries, Islamic Glass Industry faced a challenge from the rising demand for European—mostly Venetian—glass. Paradoxically almost, the industry was revived in Iran by Venetian glassworkers who taught local craftsmen how to make vessels for everyday use as well as luxury items. One of the most widely produced forms was the *swan-necked* bottles with a mouth that resembles an upside-down teardrop or maybe a bud. These elegant vases were very popular and usually used for the storing and serving wine. Sometimes, these would be filled with coloured water and displayed in the niches cut into the walls.

Spain

Pliny, in his writings states that glass was manufactured in Spain. This statement is buoyed up by the discovery of small uncoloured glass vessels in Galacia, Spain. This glass is Pre-Roman era in age. Another written record that offers interesting glimpses into glassmaking in Spain is the *Lapidario;* a treatise originally written in Hebrew and rather uncertainly dated. It states that a stone called *ecce*, used in glassmaking, was found in Spain :

> "... the stone is of an intense black colour, spotted with yellow drops. It is shiny and porous, brittle, and of light weight ...; and if it be ground up with honey, and the glass be smeared with it and submitted to the fire, it dyes the glass of a beautiful gold colour, and makes it stronger than it was before, so that it does not melt so readily, or snap asunder with such ease."

It also talks about the use of diamond to cut glass. It makes it clear that a diamond can :

> "...breaketh all other kind of stones, boring holes in them or cutting them, and no other stone is able to bruise it; nay more, it powdereth all other stones if it be rubbed upon them ...; and such as seek to cut or perforate those other stones take portions of a diamond, small and slender and sharp-pointed, and mount them on slips of silver or of copper, and with them make the holes or cuttings they require. Thus do they grave and carve intaglios."

Ancient glass produced in parts of Southern Spain including Granada, Andalusia and Almeria was influenced by the style of the near East. Almeria was celebrated for its Glass Industry and it rose to become the most important centre of Spanish-Moorish glassmaking. The glass produced in this part of Spain was usually green in colour and Persian in style. The vessels produced here characteristically had multiple handles. These handles were serrated and covered with projections, much like the twigs of a tree. Researchers think that the ornamentation was done by melting canes of glass and attaching them to the surface while the glass was still soft and pliable.

However, glass produced on the northeastern coast, for example, at Barcelona and throughout the province of Catalonia, was influenced by the glassmakers of Venice/ Murano. In Barcelona, an edict was issued in 1324 prohibiting the glass factories from being established inside the city limits. A glassmakers' guild was set up in 1455. These are reminiscent of developments in Venice. Contemporary accounts reveal that glass made here could be compared favourably with that of Venice. No wonder, it was extensively exported to Rome.

In 1475, Queen Isabella I of Castille granted the monks of the convent of San Geronimo de Guisando the privilege of establishing a glass furnace at Venta de los Toros de Guisando. She also exempted them from paying tax. A few years later, perhaps in belated thanksgiving, Ferdinand the Catholic sent the Queen two hundred and seventy-four pieces of Barcelona glass. The story does not end here. In 1523, Venetian Ambassador Andrea Navagero visited Spain and was much impressed by the quality of the glassware from Barcelona. Marineus Siculus, the chronicler of King Ferdinand II of Aragon and Queen Isabella I also went on to record that "...the best glass made in Spain is made in Barcelona." Interestingly, in 2013 excavations at the cave of Can Sadurní, near Barcelona, have revealed four human skeletons believed to be from the Neolithic age. One of these skeletons was found along with an ovoid glass vessel with two handles. It now needs to be seen where this glass originated.

During the 15th century, many glassmakers from Venice settled in Spain. They brought their techniques with them. Spanish glass during the 16th and 17th centuries shows a distinct Moorish influence. In the 17th century, Islamic glass scaled new heights under the patronage of the Ottomans in Turkey and the Near East.

The most vivid example of Ottoman patronage of glassmaking appears in the Imperial Festival Book or *Surnama-i Hümayun*, an illustrated manuscript from 1582. It depicts royal celebrations during the time of Sultan Murat III–the Sedentary Sultan. The manuscript shows artisans on parade before the Sultan. This includes glassmakers, window-makers and manufacturers of flasks, pitchers and bottles as they demonstrate their craft 'live' for the entertainment of the Sultan and the common spectators. In the illustrations, a wheeled kiln is shown. The artisans are depicted in the process of manufacturing glass as the parade moves along. Perhaps, this reflects the status of glassmakers as being one of a valued group of artisans making enormous contribution to society.

Over the years, royal patronage resulted in further advancement. It is largely agreed that towards the end of the 18th century, The Turkish Sultan Selim III sent Mehmet Dede, to Venice. There he learnt glassmaking techniques. Subsequently, Mehmet Dede opened a workshop in Beykoz, Turkey and the glass produced here came to be known as Beykoz glass. Very enterprisingly, Mehmet Dede tweaked the process that he had learned to make a type of glass called *cesm-i bulbul* or the eye of the nightingale. As expected, this is a heritage artisan glass produced and sold locally much to the delight of modern tourists. Few, if any, tourist haggling over the *cesm-i bulbul glass* would have spared a thought about the past that lay buried under the streets busy with hawkers and the bargain-seekers. However, a serendipitous development during the Marmaray rail transport project in Istanbul proved to be a blessing in disguise. When the land was being dug up to build the terminal, it soon became obvious that there was archaeological material that needed to be excavated, if it was to be saved for posterity. The project was delayed by almost four years, but the finds were priceless too; justifying the delay.

Traces of the city wall built by Constantine the Great, remains of several ships, the only ancient/early medieval galley ever discovered, plus the oldest evidence of settlement in Istanbul were found. Artefacts included amphorae, pottery fragments, shells and human skulls found in a bag, dating back to 6,000 BC. Glass found at Sirkeci, Turkey, appears to have come from different periods including the Hellenistic, Roman, Byzantine, Ottoman and Venetian periods. Fragments of an Ennion's cup, colourless and deep purple Late Roman, thick cut glass with wheel-cut decorations have been found. Lamps of many kinds, goblets in eye-catching colours, tumblers, bracelets and different kinds of glass for window panes from the Byzantine period have also surfaced here. Interestingly, the goblets found here are of two types: fine and coarse. Obviously, these represent goblets for everyday and those for festive occasions, respectively. A large amount of Venetian glass has also been excavated. These are thought to have been the regular use vessels of the Italian families settled at Sirkeci.

Ottoman glass from the 15th - 17th century has also been dug up. Much of the glass from the 5th - 16th century was made into spirally ribbed, pear-shaped, bi-convex bottles. With time, the demand for taller bottles began to grow and most of these bottles began to be produced in turquoise coloured glass. Beautiful drawings of these turquoise coloured long-necked bottles can be seen in the 16th century Imperial Festival Book of Ottoman miniature paintings called *Surname-i Hümayun*. Some of these are virtually identical with those shown in the 18th century Ottoman miniature paintings of *Surname-i Vehbi* and in the carvings on the fountains of King Ahmed the Third. Samples of 19th century glasses discovered at Sirkeci were totally different; being mostly just decolourized Beykoz-ware. Such discoveries are proof that glass items had an uninterrupted history of use for at least two thousand years in Sirkeci, Turkey.

Several pieces of waste glass and glass chunks in colours such as amber, blue-green, cobalt-blue, green, light blue, olive, turquoise and yellow-green were found at Sirkeci too. Scholars think that this glass might have been brought here to be re-melted and re-used. Interestingly, there is a local belief that there once existed a 'Gate of Glassmakers' here. Unfortunately, this Gate has not yet been identified firmly. It is pleasant to conjecture, however, what such a discovery would mean for those studying the history ofglassmaking.

The Safavid dynasty (1502-1737) in Iran was a patron of the arts but in glassmaking they ranked lower as compared to the Mughals in India and the Ottomans in Turkey. Since they could not make perfectly transparent glass, they focussed on coloured glass instead. Safavid glass vessels are usually blue or purple. These are simple in design but gracefully moulded. A few samples that have found their way into museums also show that specific glass items were made to suit the cultural requirements of the time; for example, a distinctive vessel made especially to sprinkle fragrant rosewater on the hands and feet.

Glassmaking entered the artistic mainstream in Mughal India at the beginning of the 18th century. Of particular beauty are the lavishly decorated huqqa bases, which were ornamented in enamels and gold. Interestingly, the huqqa was introduced at the Mughal court from Iran at the beginning of the 17thcentury. Spittoons are elegant receptacles for spit and were used by those who chewed *paan* or betel leaf with catechu, betel nut and flavouring substances of choice. Also called *pikdan,* these were companions to the *paandan* or containers in which *paan* was kept prior to use. One of the best depictions of spittoons in action can be seen in the wall-painting in the Safavid Palace, Chehel Sotoun (Forty Columns) in Isfahan, Iran. It shows Shah Tahmasp-I welcoming Emperor Humayun to his court. The two monarchs are shown surrounded by the courtiers and nautch girls. Plates of fruit and ewer-like vessels are conspicuous, as are the two personal imperial spittoons.

Few glass spittoons have survived the ravages of time, but the ones that have, can command quite high prices. In 2007, Sothebys auctioned a rare Mughal blue glass spittoon. The description read, "... the free blown blue glass body of baluster form with bell-shaped base, narrow neck with wide flanged rim, finely painted in gold leaf with a design of poppy-heads and scrolling garlands reserved against a gold ground, bordered by narrow gilt hatched and poppy-leaf bands." The auctioneers noted that this type of vessel may have been inspired by Chinese prototypes.

From the late Islamic era came the beautiful cut, gilded, and enamelled wares that grace museums today. This is thought to be due to better patronage by the nobles and thus, increase in demand. Examples include the five enamelled finger bowls from Egypt or Syria which have been dated to the 14th century. *The Rothschild Bucket* is one of these. It got its name from Baron Alphonse de Rothschild who purchased it at an auction in 1893. Vividly coloured, this rare glass beaker which stands 20 cm tall, is enamelled with blue lettering that reads, "I am a toy for the hands... and I contain cool water." The design on it includes a white scroll, red leaves and various animal heads depicted in green, yellow and black on the top half. The lower part sports pictures of bright blue lions and double headed eagles outlined in red. In 2009, Sothebys' auctioneers estimated it to be worth £600,000 – £800,000. At Sotheby's auction, Arts of the Islamic World, the *Rothschild Bucket* was sold to a bidder for £1.55 million. A delighted Edward Gibbs, Head of the Department of Islamic Art at Sotheby's said: "The price... is a testament to the quality and rarity of this superb piece of Mamluk glassware..."

The Mamluk Kings of Egypt and Syria, who ruled between 250-1517 also commissioned enamelled and gilded glass lamps for illuminating mosques. Many mosque lamps were inscribed with holy verses. These also bore the names or depicted the Coat of Arms of the Royal patrons and noblemen who had commissioned these lamps. Most lamps had a flared neck, rounded body with handles through which chains would pass so that it could be hung from walls/ceiling, and a wide foot.

The Victoria and Albert Museum, UK, has a signature piece in the shape of a 16th century absolutely transparent mosque lamp. Surprisingly, it was not made either in Syria or in Egypt. Venice was its birthplace. Art historians point out that although Mamluk glassmaking reached its zenith from the 13th century onwards, by the 15th century the quality of their glass had begun to wane. Venice was where the best glass items were now being made although the early Venetian glass items drew heavily from Mamluk designs.

In 1569, Grand Vizier Sokullu Mehmed Pacha of Istanbul, placed an order for 900 Venetian glass oil lamps. He even sent specific drawings for the designs he wanted. These drawings are today preserved in the Venetian state archives. It is conjectured that the mosque lamp at the Victoria and Albert Museum was part of this consignment and was a *blank* that would have been further decorated by local artists once it reached its destination. Coloured or gilded Islamic glass was greatly prized in Europe.
In the 19th century, items decorated in the Islamic style began to be made in Austria, Bohemia and France. Much still survives as precious content in cathedral treasuries. The Ottomans (Turkey, the Near East and the Balkans), the Safavids (Iran) and the Mughals (India) have left behind incomparable samples of their craftsmanship. There is evidence that Islamic glass was exported to China, particularly during the 11th century. Kings of the powerful Liao dynasty probably paid the Uighur merchants in silk and silver in return for the luxury goods which included glassware. Some glass items, mostly pitchers of different kinds, have been excavated from stupas and the tombs of ancient Chinese royals and noblemen.

China

China is one of the oldest civilizations of the world. In ancient Chinese writings, one comes across terms such as: *miaolin langgan, liulin, liuli,* or *boli.* These occur in historical books such as *Mutianzi Zhuan Shangshu- Yugong* and *Shanhaijin - Zhongshan.* However, it appears that these words were used as general terms for natural gemstones. Indigenously made Chinese glass, mainly small items, pre-dating the 3rd century AD was referred to as *liu-li* (meaning radiance). *Liu-li* was coloured glass, either opaque or translucent. It could even be coloured ceramic glaze. *Liu-li* was considered a substitute for natural gemstones, especially for green and blue ones and sometimes confused with real minerals, such as lapis lazuli, beryl and turquoise. Some historians equate *Liu-li* with the *vaidūrya* gem (lapis lazuli or beryl) and do not consider it as a term for glass. The other category of glassware was called *Bo-li* (or *Po-li*) and usually referred to transparent vessels from the Tang dynasty onwards.

In China, metals and ceramics occupied centre-stage while glass was relegated more to the sideline. Anecdotes blame the Chinese love of tea to their less than enthusiastic embrace of glass in the early years. Apparently, the West readily took to using glass because wine looked lovely as it was poured out of a glass decanter into a glass goblet but glass vessels cracked when these were used to boil water to brew tea. Since time has obscured the facts forever, explanations such as these, offer charming alternatives with perhaps a grain or two of truth hidden within. Sometimes, much-loved myths and legends also hold cultural clues. One such Chinese mythological story has come down from the 4th century BC. It tells the story of how the collapse of a pillar supporting Heaven damaged the sky; whereupon the Goddess Nüwa smelted stones of all five colours to repair the blue sky. Scholars believe that although glass is not explicitly mentioned, the idea of smelting stone suggests glassmaking. They also point out that ancient glass has a strong tendency to show rainbow colours (iridescence). The suggestion is that this is a garbled reference to glassmaking and to the fact that the Chinese people of 4th century BC had had some exposure to the art. Be that as it may, it is believed China manufactured glass for the first time in around 5th century AD. There is evidence that ancient China independently developed the art of using multiple layers of differently coloured glass which was then carved.

Other scholars argue that Chinese glassmaking resulted from exposure to Western glassmaking. They opine that it was not a result of an independent, innovative experimentation and subsequent evolution. As proof, they cite the relatively few glass objects, particularly glass vessels that have been excavated as compared to finds of bronze, ceramic and precious stones.

They suggest that glass was not very highly valued in ancient China. This stream of thought does not take into account that glass, particularly ancient glass, is fragile; and items produced at that time would have been small. So, the really early pieces may not have survived the passage of time. Therefore, until evidence surfaces, it is premature to say that the ancient Chinese did not value glass. Perhaps it would be better to say that glass had serious competition from metal, lacquer, jade and of course, porcelain in ancient China.

It is accepted that the production of faience pre-dates the production of proper glass. Chinese faience items too have been excavated from Shanxi and Henan provinces (the Yellow River valley), dating from the Western Zhou (around 1050-771 BC) to the Spring and Autumn period (around 720- 480 BC). For example, more than 1000 pieces of once blue-green bubble-infested glassy beads have been unearthed from the tomb of the Nobleman Yu and his wife, dating back to the mid-Western Zhou dynasty indicating that these could have been produced locally at that time.

Interestingly, according to a paper published by the *Society of Bead Researchers*, USA, the Tani tribes of Arunachal Pradesh who wear ancestral or heirloom necklaces may actually be sporting ancient Chinese beads. These beads are highly distinctive melon-shaped and made of turquoise-blue glass. These were already quite old, valuable and highly prized in the early 19th century. The Tanis believe that their beads were made by a mythical ancestor. Historians differ; they think that the bubble-containing, opaque blue glass suggests a Chinese origin.

Western glassware first came to China during the Han Dynasty. It is known that multi-coloured western beads were imported into China...perhaps via the much-used Silk Route. These became very popular. The locals began to try and produce beads in imitation of the ones they liked so much. So, since the ancient Chinese did make glass beads in the 5th century BC, howsoever rough, rude and rustic—it cannot be said that they had no technology of their own.

It is now believed that the ancient glass objects found in China are of three types: (i) made using indigenous technology and local ingredients, (ii) made using foreign technology but still using local raw materials; (iii) imported.

The ancient Chinese were pioneers and world leaders in working with bronze. So, they simply extended the mould-casting technology to glass-making and by the time the Han dynasty came to power, China was capable of producing large glass plates. Ancient Chinese glasses were mostly made into ritual utensils and ornaments to imitate expensive jade.

The timeline of 5th century BC as the period when the Chinese took to glassmaking remained accepted until the discovery of an alkali-lime inlay on a 12th century BC bronze *qi* axe. This axe, now in the Freer Gallery of Art, USA, made historians and scientists sit up and take a second look. The red substance on the axe was identified as *siliceous enamel* in 1962. This led some to propose that the inlay is evidence for Chinese glassmaking in the late Shang period.

The Shang dynasty is the first Chinese dynasty for which there is both documentary and archaeological evidence. This dynasty ruled during the Bronze Age of China but the exact dates when it came to power and lost it are still being debated. The Shang potters developed hard glazes, which were black lacquer-like material but not considered to be true glass. A middle view is that the Glass Industry was not established during the Shang period, but blown glass of the 5th century BC was eventually derived from evolution of the siliceous enamel type material as found in the Freer Gallery's *qi* axe inlay.

So, in Chinese history there is a considerable gap in from the 12th-5th century BC. Unfortunately, no archaeological evidence has been recovered that can account for this gap or shine a light into the status of glassmaking in China during this period.

However, it is known that the potash-lime glass in the 5th century BC was eventually replaced by Lead-Barium glass in the 4th century BC. Even the glass beads of Chinese origin showed the presence of Lead and Barium; a distinctive composition not seen in beads made elsewhere. The chemical compositions of ancient glasses, dating from the pre-Han dynasty to the Tang dynasty, reveal that these contained lead oxide and barium oxide which sets it apart from the ancient soda-lime-silicate glasses of West Asia, Egypt and Rome that contained sodium oxide and calcium oxide. An example of blue, potash lime glass of Chinese origin can be seen in the six pieces inlaid on the pommel of the Copper sword of Yue King Goujian (771- 403 BC). This ancient sword is an iconic national cultural relic of China.

Few tombs in China have yielded glass vessels as funerary objects. The earliest known Chinese glass vessels come from Western Han dynasty tombs. Other tombs include that of Liu Dao, Prince of Chu (150-129 BC) and the tomb of Liu Sheng, Prince Jing of Zhongshan (113 BC). Prince Liu Dao's tomb yielded sixteen light green (jade-lookalike) cylindrical cups of various sizes. Prince Liu Sheng's tomb contained two shallow double-handled cups and a plate. All the vessels were traditional Chinese shapes and made of Lead-Barium glass, indicating Chinese origin. The tomb of Dou Jiao, a member of the Tang imperial family who served as a military officer for his cousin, the Emperor Taizong has yielded an exquisite belt buckle set with glass plaques. Blue glass plaques have also been found in the Mausoleum of the Nanyue King, dating from late 2^{nd} century BC.

Much of the glass unearthed in Guangdong and Guangxi in China are Potassium-silica glass, which are very different from either the soda-lime glass in Western Asia, or the Lead- Barium glass so characteristic of the rest of China. The glasses are interesting because these appear to have been made only in parts of Asia (including India) but only for about 400 years or so from 200 BC-200AD.

During the rule of the Han dynasty (206-220 AD), the orifices of the dead body were plugged with jade. Plaques of jade were placed on the eyes. The ancient Chinese regarded cicadas as a symbol of rebirth and jade cicadas were placed in the mouth of the departed. Jade was expensive and soon the common people began to use cheaper green glass instead.

As Chinese glassworkers persisted in their quest to develop an acceptable substitute for jade, they gained proficiency in bead-making too. Some of the most technically complex glass beads were produced in China during 481-221 BC. These beads differed from the contemporaneous beads both in style and in the composition. Since Chinese glass of this period contained a significant amount of Lead and Barium, these beads were heavier than the others.

The Chinese soon learnt to make composite beads too. This consisted of glass layered on a core that was made on a base core of terracotta. Horned eye beads of complex designs were made during the height of Chinese eye-bead production. The 'eyes' protrude from the surface in rosettes set all around the bead giving it a characteristically 'bumpy' appearance.

Lead and Barium were readily available and Chinese bronze-workers were familiar with the use of Lead. The early Chinese glassworkers found that using Lead and Barium lowered the melting temperature of glass, i.e. it acted as a flux. In addition, the glass that resulted was brilliant and sparkling. The Chinese love for sparkling and light glassware is perhaps the reason they opted for Lead-Barium glass.

An ancient Chinese treatise contrasted the qualities of Chinese glass with those of Western glassware in these words:

> "...The liuli which is made in China is rather different from that which comes from abroad. The Chinese variety is bright and sparkling, and the material is light but fragile. If you pour hot wine into it, it will immediately break. That which is brought by sea is rather rough and unrefined, and the colour is also slightly darker. But the strange thing is that even if hot water is poured into it a hundred times, it behaves like porcelain or silver and will never break..."

Scientists have argued that it is the fragile nature of Lead-Barium glass, that is the reason why glass vessels and glass windows are absent in finds from earlier times. They also pointed out that the few glass funerary vessels found are of poor quality as these were full of bubbles. This demonstrates that the Chinese were still not skilled enough to make Lead- Barium glass vessels as fine as the Western soda lime ones.

Auctioneers, art historians and students of glass have pointed out that Chinese jade art or ivory art or rhinoceros horn carvings, or even porcelain have commanded centre stage and Chinese glass has not really basked in the limelight that it deserves. So perhaps, the cognoscenti had had a change of heart when they set an auction record for a piece of Chinese glass during Christie's auction of the Shorenstein Collection. The Qianlong ruby glass phoenix-form ewer sold for more than $2 million in 2011.

However, perhaps the ancient Chinese who were gifted at making advanced ceramic products such as porcelain did not need to compete with the glassmakers of the world. Chinese porcelain was made using white kaolin, which was vitrified using the mineral feldspar. The term porcelain came from the West because of the product's supposed resemblance to *porcellana* (meaning, little pig).

Still, by the 13^{th} century, China was exporting glass, especially to Southeast Asia. According to Rosemary Scott, International Academic Director of Christie's Asian Art Department, Chinese glass dating from that period has been found in Singapore. Apparently Chinese glassware had become sophisticated enough to sport contrasting colours, either incorporated into the main glass body or inlaid into specially cut grooves.

It is known that in 1696 or 1697, the Emperor Kangxi established the Imperial Palace Workshops in Peking (now Beijing), under the supervision of Jesuit missionary Kilian Stumpf. The glass produced here looked a lot like imitation-porcelain although Father Stumpf did make telescope lenses for the imperial observatories. Ancient Chinese glass was also made in imitation of gem stones such as jade, or ivory or bamboo. The workers experimented and worked out different formulae for glass making. They also used colloidal gold to make ruby red glass.

Initially glass made in this workshop was flawed and showed crizzling. However, the quality improved when European glass specialists, Gabriel-Léonard de Broussard and Pierre d'Incarville joined the imperial glassworks in 1740.

However, despite the reference to porcine appearance, the West loved Chinese porcelain. Since the early 13th century, Europe's royalty had been importing porcelain paying extravagant prices. China also exported glass to Japan and India. Merchant ships almost mandatorily carried Chinese porcelain as their cargo and almost every household in Europe had especial cabinet(s) to display *Porcelaine de Chine*!

Although the Chinese managed to keep the formula for making porcelain a closely guarded secret; Father Francois Xavier d'Entrecolles in 1712 cracked the code by direct observation and by accessing published Chinese technical literature. He wrote to Father Louis-François Orry, of the Jesuit missions to China and India. His letters were published in the annual report *Lettres édifiantes et curieuses de Chine par des missionnaires jésuites*. Subsequently, his letter was reprinted many times.

There are reports that unknown to Father d'Entrecolles, Johann Friedrich Böttger had already discovered the secret of hard-paste porcelain manufacture. There is also conjecture that the cat was let out of the bag not by Johann Böttger but by Ehrenfried Walther von Tschirnhaus in 1708. In any case, the revelation led to the establishment of the Meissen Porcelain Manufactory at Albrechtsburg Castle, Meissen, Germany, in 1710.

Inspired France

An early copycat version of porcelain, named *pâte tendre* was made in France. It wasn't really porcelain but soft paste. Earlier to that, French potter Edme Poterat had in 1670 begun producing soft artificial porcelain at Rouen, which could be considered a forerunner of *pâte tendre*. It is considered 'artificial' because it does not contain kaolin; a key ingredient of true Chinese porcelain.

A French nobleman by the name of Jean-Henri-Louis Orry de Fulvy wanted to develop porcelain that was better than that produced in China or by the Meissen factory belonging to the King of Saxony. The French porcelain factory opened in the Chateau de Vincennes in 1738 and enjoyed Royal patronage. On 24 July 1745, French King Louis XV signed a decree granting Charles Adam, Orry de Fulvy's servant, the exclusive privilege to manufacture porcelain in the Meissen style. The factory was shifted to Sèvres in 1756. Louis XV was first a customer and then became a major shareholder of the enterprise. Finally, he became its proprietor by acquiring it wholly as royal property in 1759. Sèvres porcelain was whiter than any of its French rivals. Soon Sèvres became the leading production house of *porcelaine de France* or soft-paste porcelain. True (hard) porcelain, containing kaolin, was made at Sèvres in 1769.

Sèvres porcelain is still produced and is much sought after. Two Sèvres porcelain vases, made as recently as 1883, were auctioned in 2013 by Bonhams for $3,750. The astounding price of $152,500 was paid at a Bonhams auction the same year for a large Sèvres porcelain plaque dated 1819. The Royal Collection at Buckingham Palace, UK, displays an absolute extravaganza of Sèvres porcelain. Thus, artificial or not, soft paste or ersatz porcelain can also command a goodly price. It goes to show just how highly the world regarded Chinese porcelain and why China could afford to neglect glass for as long as it did !

England's Contribution

The tremendous advance made by France does not mean that the English were lagging behind in their attempt to mimic Chinese porcelain. William Cookworthy, a Quaker pharmacist identified English minerals with properties that could be exploited to make porcelain in accordance to the method described by Father d'Entrecolles. He discovered that Cornish china clay and Cornish stone were adequate equivalents to Chinese kaolin. In 1768, he founded a factory at Plymouth to make hard-paste porcelain. The factory was shifted to Bristol in 1770. Hard paste Bristolware is distinguished by its harsh glittering glaze.

Benjamin Lund, one of the principal manufacturers of early English porcelain established a soft paste porcelain manufactory in Bristol in about 1750. Although production was not continued for long, his products are recognized as *Lund's Bristol* In 2013, Bonham auctioneers sold a scallop shell shaped pickle dish made out of Lund's Bristol for £18,750. The 8.5 cm long pickle dish was painted in blue with a Chinaman holding a fan beside a flowering plant with two flocks of birds above him.

Japan

In early Japan, glass was used for sacred objects, such as relic jars and as offerings at shrines. Ruri, a blue glass that resembled lapis lazuli, was popular. The first example of glass in Japan was found among archaeological remains dating to the Yayoi period (3rd century BC to 3rd century AD).

In the early years, much of Japanese glass was imported. In 2013, researchers from Japan's Nara National Research Institute for Cultural Properties announced that the glass beads recovered from the 5th century Utsukushii burial site near Kyoto were Roman in origin. These beads are made of light yellow natron glass. These are also the oldest multi-layered glass products discovered as yet in Japan. Glass beads have also been recovered from the 4th century AD Satsuma No.11 tumulus near Takatori town in Japan. *Gobeunok* or *Gogok* are comma-shaped beads typically found in Korea and Japan. Many of the ancient comma- shaped beads discovered in Japan are made of bronze. However, comma-shaped green glass beads and 90 pieces of cylindrical glass decorations have been excavated from a tomb dating from the Yayoi Period (300 BC-300 AD).

Later, imported glassware from the West reached Japan by sea; courtesy Portuguese merchants. Paintings from the Momoyama period (1573–1615) allow a glimpse into Japanese lifestyle during that period. These lavishly ornamented paintings show some of the imported goods brought into Japan. Prominently displayed are European glassware such as cut glass bowls and spectacles.

The first Edo Kiriko or Japanese traditional cut glass originated during the Edo period (1603-1868). It is believed to have been made by Kyubei Kagaya—proprietor of a glassware shop and master glassworker. Many basic patterns used by artisans during the Edo period have survived and this type of cut glass is still appreciated in contemporary Japanese society. Glass-making progressed rapidly in later years and by 1650, Japan was known for the variety of its glassware. This ranged from lenses for spectacles to telescope lenses and large vases.

Swiss Invention

Between 1784-1790, Swiss carpenter Pierre Louis Guinand began to experiment with optical glass. He entered this field because after making clock-cases and bells, he wanted to make telescopes. Initially, he faced many setbacks and incurred financial losses but he persevered. Finally, he made a huge breakthrough when he replaced the long wooden rods used to mix the hot glass in the furnace with stirrers made of clay. These stirrers made the bubbles rise to the surface. It also mixed the glass well enough to produce a homogeneous, nearly-flawless material free of unmelted particles and bubbles. This procedure remained a trade secret for some time.

Interestingly, even after almost two centuries, stirring is a principal operation to ensure homogeneity. Of course the stirring is now computer-controlled for greater precision and clay stirrers have been replaced by stirrers made of ceramics or metals such as Molybdenum or Platinum and its alloys.

Glass that is chemically homogeneous shows uniform refraction and is suitable for making lenses. Pierre Louis Guinand began to produce this homogeneous glass at his workshop in Les Brenets (Switzerland) and in Germany in collaboration with Joseph Utzschneider and Joseph Fraunhofer. After his death in 1842, optical glassmaking was taken up in France in collaboration with his successors. In 1848, the technique came to England when Chance Bros. Set up a factory at Birmingham after collaborating with Georges Bontemps, a French technician who had worked with Pierre Louis Guinand's descendants. The technology for making optical glass was readily available in the 19th century with three countries: Germany, France and England.

Impact on Modern Society

But was all this, merely artistic or scientific advance with simple economics at its base? Or did the evolution of glass also trigger societal transformation? In the final analysis what was the major impact these advances had on the lives of the common people?

Well, by the 17th century, European glass was cheap enough for ordinary people to use it for windowpanes. No longer did they have to look through a glass, darkly. Transparent glass let in natural sunlight; reducing the use of soot-generating fires for illumination. It also kept rain out reducing humidity that encouraged the growth of fungi and microbes. Dirt and vermin became visible and so, easy to stamp out. This has been recognized as a great triumph for hygiene.

Can it be denied that the huge advances in the arts, science and technology that took place during this time, owe substantially to advances in glass technology? When scientists needed to look at objects that are very far away or those that are too small to be seen, it is glass that came to their aid. With better glass came better microscope, better telescopes, better barometers, better binoculars, better magnifying glasses, better prisms and even better spectacles. Glassware suitable for scientific experiments enabled the discovery of biological phenomenon taught in schools today.

Anton van Leeuwenhoek opened up the entire branch of Microbiology thanks to the fine lens he made for his microscopes. On 17th September 1683, he communicated his findings on the microflora of dental plaque. Part of his letter to the Royal Society, UK, reads:

> "I ... saw, with great wonder, that in the said matter there were many very little living animalcules, very prettily a-moving. The biggest.... had a very strong and swift motion, and shot through the water (or spittle) like a pike

does through the water. The second ... oft-times spun round like a top... and these were far more in number."

It was one of the first observations on living bacteria! Among his many other discoveries that pushed forward the boundary of Biology, was the existence of blood cells. He was the first to see living sperm cells of animals. He discovered nematodes and rotifers...all thanks to good-quality glass lenses.

An important experiment that conclusively laid to rest the theory of spontaneous generation of life was carried out by Louis Pasteur. He used glass swan-necked flasks for his experiments.

In the years after 1609, when he became the first person to observe the Moon through a telescope, Galileo Galilei used the telescope to transform astronomy. In 1990, the Hubble Space Telescope did that again! From its inception, therefore, glass has catalyzed scientific and social transformation.

7

GLASS INDUSTRY IN ANCIENT INDIA

In India, glass has been reported from at least 200 archaeological sites starting from the early Iron Age period. About 37 of these are thought to have been primary glassmaking sites.

Kaca (Kacha) is the Sanskrit term used for glass. Reference to *Kaca* is found in the *Yajur Veda, Shatapatha Brahmana*, *Vinaya Pitaka, Ramayana, Kautiliya Arthasashtra, Charaka Samhita, Hitapodesa* and *BrihatSamhita.*

In the *Yajur Veda* (1200 BC), glass is mentioned in the context of ornaments which were made by stringing beads with gold thread. The *Shatapatha Brahmana* (800 BC) notes the detail that 101 *Kacha* beads were used to decorate the tail of the sacrificial horse used for the *Ashwamedha Yagya.* The *Taittiriya Brahmana* also refers to the wearing of glass beads. *Vinaya Pitaka* which is a code of conduct for Buddhist monks and nuns forbids the use of glass alms bowls on account of these being fragile and easily broken. Monks are also cautioned against using shoes studded with crystals or glass beads. The *Ramayana* refers to *Kachakara* (glassmakers) while listing different types of traders and craftsmen who had sent a representation pleading that Lord Rama not undertake the *vana-vas* or banishment to the forest. The fact that glass workers were identified using a specific term, points to the possibility that glassmaking was a thriving industrial activity. In the *Arthashashtra* (c.300 BC) the word *kacha* is mentioned in at least ten different contexts. From *Hitopadesha* (c.500 AD), comes this quote: “The jewel is trodden by the feet; glass is upheld on the head. Be it as it may, for glass is glass and jewel is jewel.” Some interpret this to mean that it was well-known that coloured glass resembled gems but wasn't really of equivalent value.

References to glass vessels for preserving medicines appear in the *Charaka Samhita* and *Susruta Samhita*. The *Brihat Samhita* (6th century AD) and *Ratna-Pariksha*, etc. also refer to the use of glass. The former lists glass objects as being a lucrative item for trade. In the *Amarakosa* (7th century AD), mention is made of glass vessels such as cups and dishes. The *Vyasoyogi Carita* by Somnath Kavi (1446-1539 AD) records the use of spectacles to correct vision. The *Katha Sarit Sagar* (11th century AD) refers to cases of cheating in which glass objects were sold as real jewels. Interestingly, faux gems made of glass were termed *kacha-mani* in Kautilya's *Arthashashtra*. The *Arthashashtra* lists various punishments for stealing. It prescribes a fine for stealing articles made of bronze, copper, *glass*, tin or ivory.

In ancient India, a certain amount of money had to be paid in advance by an entrepreneur who wanted to make glass. This indicates that the ancient Glass Industry in India attracted a sort of license fee payable in advance. So, glass, glassmakers and glassmaking all had a significant presence in ancient Indian society.

However, though India had close trade and cultural relations with West Asia where glass technology was known even in the 3rd millennium BC, the people of the Indus Civilization did not show a great preference for this material. They chose faience instead.

In the olden days in India, glass did not enjoy a social status similar to that of metals and pottery. Vessels made out of pottery and metals were (and still are) used on religious occasions. In Indian cultural practice, glass was not really appreciated except perhaps as ornaments for those who could not afford precious metals and gems. Apparently, even today metal glasses still have ascendency over glass tumblers. May be this is why glass making did not quite flourish in ancient India. Yet, Pliny and other scholars considered Indian glass to be of high quality as it was reportedly made of pounded quartz rather than Silica.

Beads, bangles, small vessels and other artefacts have been discovered at the archaeological dig sites at Taxila, now in Pakistan. According to James W. Lankton, of the UCL Institute of Archaeology, London, the early glass found in India had certain chemical compositional characteristics that were unusual outside Asia.

Chemical composition of glassware recovered from Taxila appears to be similar to Assyrian glass of the same period. Lead was discovered in both these types of glasses although Lead is not present in other Indian glassware of the period. This has led to the belief that either the Assyrian formula for making glass was adopted in these parts or that the glassware was imported from Assyria. In a few Taxila glass specimens, Barium has also been found, confounding experts who believe that the use of such glass-making was unknown in the ancient world. It appears that the composition of early glass in India is very different from those in Southeast and Northeast Asia, where most of the glass was imported. In contrast, India seems to have been an exporter of both glass and glass technology. Paradoxically, there seems to be relatively little exchange of glass artefacts, between North and South India...or perhaps there are interesting archaeological discoveries waiting to be made.

Recent archaeological digs are shining a light on this relatively little studied aspect. Long-lost glass factories, such as the 2,300 year old one at Basti have been unearthed along with a host of glass beads, glass bangles and other glass items. Some other important sites associated with the ancient Glass Industry in India are:

Ahar, near Udaipur, Rajasthan: Coloured glass bangles in shades ranging from turquoise, sea-green to milky-white have been found here. The bangles are rather crudely made, of uneven thickness, translucent and full of bubbles. Due to the leaching out of the alkalis, the bangles were covered with a whitish filmy patina by the time these were excavated.

Ahicchatra, Uttar Pradesh: Many glass beads have been recovered from this site.

Ahmednagar, Maharashtra: Eight green and greenish-blue

glass flasks and thirteen Chinese porcelain-type bowls have been discovered here. These items date to the famous Ming period indicating a thriving trade in glassware between China and India.
Bhagwanpura, Haryana: This is the site that has yielded the oldest finds of glass in India. Glass bangles have been found here.
Broach, Gujarat (ancient Bharukachha or Barygaza): The excavation site is divided into three periods. Period I (3rd century BC) yielded glass beads in association with the beads of semi-precious stones such as agate, chert, chalcedony and jasper.

Eran, Madhya Pradesh (ancient Erakina or Erakanya): Situated on the banks of the River Bina, Eran was located on an ancient trade route. Excavations have yielded glass beads and glass bangles.

Hastinapur, Uttar Pradesh: This is one of the earliest sites from which glass has been reported. Opaque or translucent, colourful glass bangles have been recovered from the site. According to the Archaeological Survey of India, these are the earliest known bangles found anywhere in India (as yet)!

Kolhapur, Maharashtra: The presence of glass slag and numerous glass beads at various stages of manufacture indicates that there was a flourishing bead-making industry here in ancient times. The quality of glass recovered is excellent and also, well preserved. A huge quantity of bangles, both complete and incomplete, suggests the existence of a glass bangle industry here.
Kondapur, Andhra Pradesh: The excavation yielded a large number of glass vessels indicating Roman influence and regular trade. The Kondapur site is tentatively dated to 200 BC - 1st century AD.

Kopia, Uttar Pradesh: Kopia was a manufacturing centre for glass and a major player in ancient glass trade from at least the 3rd century BC onward. The entire economy of this ancient settlement revolved around glassmaking and glass-working. The earliest example of any glass furnace found in India was discovered at Kopia. The finds from excavations here prove that India had mastered certain important aspects of glassmaking because Kopia lay along the southern Silk Route and had little or no contact with Rome; a sophisticated centre for glass works in those days. According to Dr. Alok Kumar Kanungo of Deccan College, Pune, this makes Kopia a pre-Indo-Roman contact glass manufacturing site.

Many pieces of glass, glass slag, and crucible fragments with solidified molten glass still attached have been found here. Kopia glass exists not only in the common colours such as coppery, red, green and blue, but is also yellow, black, brown, light blue, and orange. White glass and glass in transparent shades have also been discovered. Glass samples found at Kopia have high strontium isotope ratios that are totally different from those of glasses from more westerly sources and from East Asia. Glass researchers such as Alok Kumar Kanungo and Robert Brill (expert on ancient glass), opine that this indicates the existence of an *Indian family* of glass that was made in the locality.

Kopia produced more variants of coloured and transparent, bubble-free glass than any other contemporary Glass Industry. Many types of glass beads, glass bangles in various colours and a neck fragment of a bottle dating to the first century AD have been found here. The largest chunk of ancient glass found in India was also produced at Kopia. It weighs about 27 kg, and it is now in the Lucknow Museum.

Maheshwar and Navdatoli, Madhya Pradesh: Multi-coloured glass beads in a bewilderingly diverse range of shapes such as spherical, truncated barrel, globular, hexagonalor cylindrical have been found here. The colours range from deep blue, deep green, yellow, sea-green to dirty white. Glass bangles in single and multiple colours have also been found here.

Nasik, Maharashtra: Glass beads, glass bangles, glass rings and other miscellaneous artefacts have been recovered from here. Green, blue and white appear to have been preferred colours for the glass bangles.

Nevasa, Madhya Pradesh: Excavations at this site on the banks of a tributary of the River Mahanadi have yielded material from the early Stone Age to the Muslim-Maratha period (1700 AD). Many glass beads and glass bangles have been recovered and interestingly, these beads reveal different types of glass and bead making techniques. Beads found at Nevasa are mostly in shades of green, blue and yellow. Beads with gold-foil and with lemon yellow matrix have also been recovered. Glass bangles in single colours such as black, yellow, green, blue or red have been found; with black being the most popular. Multi-coloured glass rings have also been discovered at the site.

Paiyampalli, Tamil Nadu: The excavation recovered glass beads and bangles.

Pasi-Medu, Tamil Nadu: In Tamil, Pasi-Medu means *mound of beads*. Evidence of a glass making unit that functioned about 2000 years ago has been discovered here following excavations at village Porunthal on the bank of the River Porunthal. Porunthal has been acknowledged to be the largest glass bead- manufacturing site in southern India. The site lies very close to the ancient trade route between the Pandiya capital of Madurai and the Chera capital of Vanji.

Over 2,000 glass beads in many colours were unearthed. It is believed that the sand from the river bank was used as the raw material for making glass beads. However, no glass slag or waste material has been found so the researchers think that the glass beads were not produced at Pasi Medu but merely 'finished' here. Artisans may have brought the semi-finished glass beads to Pasi Medu, reheated them in the furnace and polished them with the triangular terrocotta pieces found during the excavation. The glass furnace, the first such discovery in Tamil Nadu, is believed to date back to the first-century AD. Skeletal remains from a burial were found over a bed of about 3,000 beads of different kinds.

Pataliputra, Bihar (also known as Kusmnapura, Puspapura and Kusuma-dhvaja): This site has yielded glass beads along with a few finished and unfinished seals including a glass seal with a Mauryan inscription.

Prakash, Maharashtra: The site at the confluence of the River Tapti and the River Gomai has yielded glass bangles of single colours.

Sirpur, Chhattisgarh: Excavations on the banks of the River Mahanadi have revealed pottery shards from storage jars (*rafijans*) in which glass was melted or annealed in ancient times. The discovery of huge amounts of glass slag and drawn wires suggest that glass was actually made and worked here. A variety of bangles in many different colours such as dark leafy green, amber, purple and translucent green have been discovered at this site. Amber and brandy coloured glass used for bracelets have also been found.

Sulur and Pattanam, Kerala: A large number of colourful beads have been found in the middens. The colours include green, red, black, blue, yellow, opaque orange, garnet, pale brown, white, and clear. Waste materials from bead manufacturing and fragments of Roman glass bowls have also been found. Ever since remains of a port-town near Pattanam have been unearthed there has been speculation that this could be the remains of the famous Muziris port.

Ujjain, Madhya Pradesh: The excavation has yielded a number of glass beads and glass bangles belonging to the period 500 BC to 1st century AD. A seal made of black glass with a green tinge was also recovered; and dated to about 300 BC. Spool shaped ear ornaments called ear-reels were also found at this site.

It would thus seem that the use of glass in ancient India was largely ornamental and thus limited to bangles, beads and rings, etc. Perhaps, the fragile nature of glass did not encourage its generalized use in everyday life. However, from the references to beautiful glass vessels and medical instruments made of glass, crystal and quartz in *Susruta Samhita* it becomes evident that by the 6th century BC, glass was increasingly being used for utilitarian purposes.

The first reference to glassmaking in Mughal India is in Abu- al Fazl's *Ain-i-Akbari,* which documents glassmaking in Bihar and near Agra. The Mughals left an indelible mark on the cultural landscape of India. Their lavish lifestyle is still recalled with awe. Yet glass production in Mughal India was limited. Much of the glass was imported from Iran and Europe. Yet, made in India or not, intact pieces of the glassware that has survived from the Mughal era fall into four or five distinct categories. For example, huqqa bowls, dishes with or without covers, spittoons, mirrors, and spectacles, etc. All Mughal era glass was not clear. Many had trapped air bubbles clearly visible, which is a sign of poor quality.

It is believed that imported glass was embellished in India to suit local tastes. For example, Bidriware hookah bases of the early 17th century served as models for those made in glass. Green and gold were favoured colours. In later Mughal-era glassware gilded, bright, opaque lemon-yellow glass seems to have found favour too.

Mughal-era huqqa bases are greatly sought after by collectors. In 2013, a late Mughal gilt decorated green glass huqqa base was sold by Bonhams auctioneers for £3,500. In 2010, the same auctioneers had sold a rare and intact Mughal gilt-decorated glass huqqa base, dated to the first half of the 18th century for a whopping £234,000. Its pre-sale estimated price had been £8,000 to £12,000. This particular huqqa base had a globular body and short cylindrical neck. The green glass body was decorated with golden poppy plants alternating with golden cypress trees. The base and shoulder showed a band of acanthus leaves and the neck had decorative poppy stems.

The world has always taken a keen interest in documenting how glass was made in ancient times. It is sad but true for the attempts made at documenting dying arts, much knowledge would be lost forever, as is evident from this story from India.

A video documentary carried out by the Corning Museum of Glass reported that a special type of glass was made in Kapadwan, Gujarat till recently. The area has a history of glassmaking dating back at least three centuries. Scientists say that similar technology to make glass can be dated back to the 5th century in the Eastern Mediterranean region. It is thus speculated that the Indian technology might be just as ancient. Apparently, this type of glass was once produced in a small factory owned by one Mohamed Siddiq Shishgar. The method employed by him to make glass included re-softening of cullet from a television tube factory. The melted glass was inflated into large, elliptically shaped globes. Then the blow iron was cracked off. The globe was stuck up on a punty. After the glass was reheated, molten lead was introduced via the opening where the blow iron had been removed. The interior was thus covered with a metallic mirror coating. The globes were then broken into small pieces. Small bits were pinched off from the edge of the piece of glass with nippers or pliers to trim them to shape. This process is called grozing.

The bits of glass are used for decorative embroidery or mirror work, which has been in vogue for centuries. It is popularly known as *Shisha* or *Abhala Bharat* embroidery. Clothes with mirror work are also worn in parts of Pakistan and Afghanistan. Mirrored glass of the same type has been used for the decoration of palace walls, such as the Sheesh Mahal in Jaipur. The Mughal Emperor Shah Jahan used this technique to decorate the Taj Mahal. This is indeed a fitting tribute as it is believed that it was Mumtaz Mahal who patronized the technique of using mirrors in embroidery. However, before glass was worked in such a manner, tiny pieces of mica or shiny beetle wings were used in a similar way.

The use of mirror work, in embroidery found easy acceptance because in those days people believed that mirrors could ward off the effects of the evil eye or at least reflect it away from the wearer, or dazzle the evil eye into either blinding it or causing it to blink so that the wearer would be protected. *Shisha* Embroidery was used widely by the tribes who lived in desert areas. Of course, the Banjara tribe of Andhra Pradesh is also well-known for their embroidery skills using beads and bits of glass. A Lambani lady's costume comprises of *Lehenga, Choli* and *Odhni*; each ornately covered with a mosaic of patchwork mirrors.

The French poet Pierre Jules Théophile Gautier wrote, "Indian embroidery seeks to engage in a contest with the sun...to have a duel to the death with the blinding light and glowing sky. At all costs its duty is to shine and glitter and to send forth the prismatic rays: it must be blazing, blinding and phosphorescent-and so the sun acknowledges defeat."

Shisha embroidery, apart from its glittering beauty, gave users a distinct advantage too. It made those approaching visible from afar, because the mirrors shimmer and shine under the bright sun. No wonder, textiles with mirror work embroidery set down deep roots in places blessed with sunshine.

It is clear that while ancient Indians did not take to using glass as tableware or drinkware, (perhaps because they were used to shattering earthenware cups after drinking as has been pointed out by some scholars) they did embrace glass whole- heartedly when it came to ornamentation...be it of the self or the house or clothes or domestic animals. It is therefore, a pleasant experience when tour operators abroad advertise the beauties of mirror–decorated tribal mud houses in India and organize trips to showcase these traditional dwellings.

Perhaps, excavations at newer sites and deeper digs at the older ones may reveal more clues to the way the Glass Industry developed in ancient India.

8

GLASS INDUSTRY OF MODERNINDIA

Pliny wrote about the *superior Indian glass* made from crystals. However, no traces of this ancient Industry have survived the passage of time. There is also some difference of opinion about exactly how advanced ancient India's technology had been. While the actual level of sophistication achieved by very ancient Indian glass is debated, it is known for certain that in the 16th century, glassworkers were able to produce bangles for which this region has always manifested an abiding fascination. These glassworkers also produced small bottles, flasks and sundry other items.

In the mid 1930s, J. Coggin Brown, Superintendent of the Geological Survey of India wrote a treatise entitled *Guide to the Occurrences and Economics of the Useful Minerals of the Indian Empire*. According to him, an inferior glass has long been made in India by fusing the alkaline efflorescence known as *reh/rallar/ sajji mati* and lime. It is a mixture of sodium carbonate, sodium bicarbonate, sodium sulphate and sodium chloride together with varying proportions of calcium and magnesium salts. *Reh* is found on the surface of alluvial soils in the drier districts of the Gangetic plains. Glass made with *reh* is rich in alumina. Surveys have showed that such glass was being made in India till the 1990s.

In his book, Coggin Brown, places on record the existence of an indigenous Glass Industry that had existed for over 120 years at Matrod, Mysore. There are reports that in 1856 there were two glass factories near the Lonar soda lake. These factories produced bangles. Between 1892-1893, five glass factories of the 'modern' type were established but sooner or later, all five businesses folded up. Eventually the last factory failed in 1908.

However, it was the Pioneer Glass Works established in Titagarh in 1890 that is considered to be the first really modern glass factory in India. Then came the Paisa Fund Glass Works founded at Talegaon near Pune on 16 October 1905, by stalwarts such as Ishwar Das Varshney, a pioneer of the Glass Industry in India and Antaji Damodar Kale with help from Lokmanya Bal Gangadhar Tilak. It was the culmination of the attempts to encourage the *Swadeshi* movement. Many ideas were discussed; suggestions were made about setting up small industries devoted to buttons, oils and brushes and the impact of these proposals were evaluated. However, it was the proposal for setting up a Glass Industry that was finally chosen.

The story behind the collection of the Paisa Fund is an inspirational one. Lokmanya Balgangadhar Tilak, assisted by leading Indian Industrialists including the Tatas, had organized the 'Swadeshi Co-operative Stores'. He was also the Treasurer of a special fund (the Paise Fund) established in 1905 to promote industrial production. This Fund was a central reserve built up through the contribution of one paisa and above from people from all strata of society. Those who had contributed a reasonable minimum had a voice in its administration which was in the hands of an elected body.

At one of the public meetings, held for the collection of the Fund, Lokamanya Tilak said,

> "Come all, join and subscribe; I do not want one man to contribute thousand rupees to the Paise Fund, but I want a thousand contributors each giving one rupee and making up a thousand. Such a spirit of contribution will show me that there are more men who take real interest in the welfare of their country. It will demonstrate an organized effort. A man who contributes a thousand at a stroke has nothing further in his head, nothing higher in his mind than a looming fact: Dividend. The thousand poor contributors have a nobler aim. So rally around all men and subscribe your humble paisa."

His speech resonated with the *Swadeshi* wave that was sweeping the country and many common people came forward with their meager yet priceless contributions. Construction of the Paisa Fund Glass factory began in 1908.

The modern Indian Glass Industry did not make much progress until 1914, although about 16 small-scale glass factories were started during the 1906-1913 as products of purely Indian enterprise. The First World War proved to be a blessing in disguise for the Indian Glass Industry because imports from foreign countries stopped, putting the onus on indigenous production to meet demands. The Indian Munitions Board encouraged the setting up of new factories. There were only three or so glass factories worth the name before the First World War but in 1918 the number rose to twenty. By 1921, there were about thirty-two glass factories in existence. However, many of these factories were in remote locations and the lack of suitable transportation was a major constraint. Sometimes raw material and fuel had to be carried hundreds of kilometres by rail. Transportation of finished products was an expensive proposition too that ate into profitability. By 1924, the number had dropped to 17 and by 1928; to 16. The numbers kept dropping. By 1927, there were 14, largely insignificant glass factories at Bombay (Mumbai), Jubbulpore (Jabbalpore), Allahabad, Naini, Bijhoi, Ambala, Lahore and Calcutta (Kolkata), etc.

Imported glass continued to pour into the country. An analysis of the imported glassware during 1924-1928 revealed that about half of the foreign glass was in the form of the bangles and beads. Bottles formed 9-13 per cent of the glassware. Sheet and plate glass came next, comprising 12 per cent of the total. Globes, glass parts of lamps and funnels accounted for about 7 per cent, table-ware constituted 3-9 per cent, the rest was medley of scientific glassware and other miscellaneous glassware. Japan was a great beneficiary of India's thirst for bangles and beads. In 1919, Japan supplied 65 per cent by value of the total imports: a further 20 per cent came from the United Kingdom. Belgium, Austria- Hungary and Italy sold between 1 and 2 per cent each.

The late 1930s were turbulent times globally. Dark war clouds were massing overhead. The military's need for glass during Second World War whipped the Indian Glass Industry into venturing into hitherto unexplored areas. Yet even after that the Indian Glass Industry languished in neglect. Experts in the field cried out for modern equipment, skilled technicians and trained managers to improve the quality of the products and to bring it up to global standards. Very little help was forthcoming and equally little progress was made.

Looking back, it is clear that there was genuine interest in glassmaking but there were also the almost-insurmountable problems of cheap foreign imports, lack of trained manpower, poor quality and inefficient furnaces/firing equipment, insufficient supply of essential materials such as coal, soda, sand and lime, unsatisfactory annealing lehrs and inadequate finance. No wonder, the glass produced was brittle and not up to the mark.

Glass manufacture, even in its simplest form, is a highly technical task. The development of glass is the result of the application of scientific methods to industrial production. It calls for scientific know-how and skilled workers. It demands a sound knowledge of engineering for furnace design. It also needs a sound understanding of logistics, physics and chemistry. In addition to improvements of the method and technique of manufacture there is the demand for optimal marketing arrangements. None of this was forthcoming in India at that time. No wonder, the Glass Industry in India remained in the form of the cottage industry till the beginning of the 20th century.

It was a no-win situation against which the scientists were waging a relentless battle. The major difficulty in manufacturing glass in India until comparatively recent times was the absence of knowledge regarding sands of the requisite degree of chemical purity and mechanical fineness.

Glass sands must be free from impurities such as Iron compounds, which impart undesirable colours to the finished items. The sand needs to be of proper grain size. This allows the chemical reactions which take place in the crucible or furnace to proceed evenly and quickly during melting and does not leave behind any undissolved particles. On the other hand, too fine a grain, has certain disadvantages as it may give rise to turbid glass.

Indian glass manufacturers kept searching for good glass sands. The Damuda sandstones of Mangal Hat and Pir Pahar in the Rajmahal hills, Bihar and Odisha, had been investigated by Murray Stuart in 1908. After crushing and washing these yielded sand suitable for making ordinary glass. However, its kaolin content rendered it unsuitable for making high-quality glass.

Coggin Brown reported that beds of sand practically free from Iron compounds were found at Patarghatta in Bhagalpur, Bihar. Crushed sandstone from Loghra and Borgarh (Naini), in the United Provinces, yielded remarkably pure sand, which were used at many Indian glass factories. Others sourced sands from Jaijon Doaba, Hoshiarpur, Punjab, and from Sawai Madhopur, in Jaipur State. Good sand was also obtained from sandstones at Sankheda and from the River Sabarmati, both in Baroda State; from the friable sandstones of Madh in Bikaner; from a loosely compacted grit, near Barodhia in Bundi State, Rajputana; and from an old sea beach at Ennore, north of Madras. According to geologist D. N. Wadia, a soft, white quartzite of exceptional purity, suitable for easy conversion into glass sand existed in Kashmir.

In recent years, good glass sands have been found in many parts of India. Silica sand from Cherthala, Kerala is an example. According to the Department of Mining and Geology of the State Government of Kerala, Silica sand of Pallippuram is suitable as raw material for silica refractory and glassmaking. The brown sands occurring below the white sand in Varanad area are suitable for making high-quality colourless glass. With beneficiation, the sand can be used by the optical and ophthalmic Glass Industry. It conforms to the specifications of the US Bureau of Standards for making sheet, rolled and polished glass. Important deposits exist in Andhra Pradesh, Bihar, Goa, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tamil Nadu and Uttar Pradesh. Haryana, Uttar Pradesh and Maharashtra are leading producers of Silica sand.

The unorganized sector was the leading producer of glass before, and for a while, even after Independence. However, this does not mean that the glass from India today is in any way inferior or that the volume of glass produced in India is too little to find mention. It is quite the reverse. Today, the Indian Glass Industry is sparkling and poised for explosive growth. To know how this transformation was effected, it is necessary to turn back the clock and follow the story of how a nascent nation used the scant resources at her command to build a chain of national R&D laboratories. In short, to evaluate modern India's contribution to glass research, the genesis of the Council of Scientific and Industrial Research (CSIR) has to be understood in the context of time.

National Network of R&D Laboratories

The years before Independence were tumultuous times for India, but it is incredible how much forethought and planning went into laying the foundation of a robust scientific R&D network. The Council of Scientific and Industrial Research was registered as a Society on 26 September 1942 under the Registration of Societies Act XXI of 1860. This was the umbrella or mother organisation under whose aegis the Central Glass and Ceramic Research Institute (CSIR-CGCRI) was formally inaugurated in Calcutta on 26 August 1950. The Institute had, till fairly recently, the distinction of being the only one of its kind in the Indian subcontinent and one of only a handful in the entire Asia-Pacific region. Of course, the genesis of CSIR-CGCRI cannot be summed up in just one line. It was actually the culmination of a series of events that began in the early 1900s.

The Indian Industrial Commission (IIC) had been set up in 1916 and "was instructed to examine and report upon the possibilities of further industrial development in India..."

One of the first things the IIC noted was, "An organization is wanted to take up the whole industry, including men who can deal with the furnace problem, the preparation of refractory materials for furnaces, crucibles and pots, the chemistry of glass, the manipulation of the crude products and its conversion into finished forms, whether by skilled blowers or by highly complex and semi-automatic machinery." Yet, the situation did not change and the Glass Industry languished until a Tariff Board was set up in 1931.

The Tariff Board, in its turn, noted: "The difficulties experienced by Indian manufacturers of glass are to be attributed largely to the lack of adequate provision for the investigation of scientific problems connected with the industry and for the training of managers possessing the requisite knowledge of technology and modern methods of manufacture." Still, the situation was not remedied.

In 1937, the first-ever Department of Glass Technology was set up at the Benares Hindu University to complement the existing Department of Ceramics. No one knew it then, but the tide was beginning to turn. The future of glass research in the country would be bright and the Glass Industry would shine soon...but before that could happen, a lot still needed to be done.

The first step was taken in April 1940, when the Board of Scientific and Industrial Research (BSIR) was established bringing together eminent scientists and industrialists. BSIR was the fruits of the dogged persistence of Sir Arcot Ramasamy Mudalair, the-then Member, Commerce and Labour of the Viceroy's Executive Council. Eventually; the BSIR would give way to the CSIR.

The BSIR met for the first time on 1 April, 1940. The venue was the Commerce Member's room in the Assembly Chambers (later Parliament House). Sir Arcot Ramasamy Mudalair chaired the meeting. The eminent members included scientists such as Jagadish Chandra Bose, Nazir Ahmed, Meghnad Saha, as well as esteemed civilians namely H.P. Mody, Syed Sultan Ahmed, and industrialists such as Kasturbhai Lalbhai, Lala Shri Ram, P.F.G. Warren and N.N. Law. In addition, the Secretary of the Commerce Department and the Economic Adviser to the Government of India also graced the first meeting with their presence. The members were charged with surveying the state of industrial research and the institutions engaged in, and capable of undertaking such research.

At its second meeting, the Board decided to set up research committees with eminent scientists such as C.V. Raman, Meghnad Saha, S.K. Mitra and J.C. Ghosh to evaluate proposals from collaborating universities and research institutions. It was a beginning no doubt, but an inadequate one when compared to the magnitude of the need. As S.P.K. Gupta put it,

> "By the year end were engaged some 80 researchers including 20 directly employed by BSIR. The war provided the stimulus but a mere four lakh rupees had to be shared by 16 committees which met once a year to review and report on vegetable oils, fertilizers, drugs, plastics, sulphur, scientific instruments, graphite carbon and electrodes, molasses, glass and refractories, vegetable dyes, fuel and cellulose."

Inadequate or not, what is important that Glass had made its way into the list. Research in this field would now be given the importance it deserved.

A push came at the right time in the form of an Editorial on the 'Need of a school of glass technology in India and Indian Glass Industry', which was published in *Science and Culture* in April 1941. The Editor, Meghnad Saha argued:

> "If the Glass Industry in India has to be placed on a firm basis, it is of immediate importance that there should be a School of Glass Technology in a suitable centre which will arrange for adequate and effective provisions for training and research with the objectives: (i) Training of students in glass technologies including refractory and fuels, (ii) carrying out investigations for the benefit of Industry and also, fundamental research, (iii) testing, and standardization of raw materials, refractories, finished glassware, etc,

and (iv) giving technical advice to the Industry whenever necessary."

This Editorial in the journal established by Meghnad Saha and Acharya Prafulla Chandra Ray had the effect of shaking up the stalwarts of science. Prof. Meghnad Saha and Dr. Shanti Swarup Bhatnagar (the founding father of CSIR), visited BHU with the idea of utilizing the setup there to formalize an Institute of Glass Research. On their return they submitted a report to the BSIR.

Subsequently, in March 1942, the BSIR appointed a Central Glass Research Institute Committee to advise it. Dr. S.S. Bhatnagar was the Chairman and eminent scientists such as Prof. Meghnad Saha, Prof. J.N. Mukherjee, Prof. P. Ray, Mr. I.D. Varshney and Dr. A. Nadel were members. The Committee met for the first time in the Forman Christian College at Lahore on 27 April 1942. It was resolved that the Central Glass Institute should be devoted to glass research and to the introduction of industrial processes that were new to India. All means, technical or otherwise was to be adopted to achieve the objective. On 1 July 1942 the Committee submitted its report to the BSIR. On 12 July 1943, approval was accorded to the recommendations of the BSIR regarding the "...organization of the Central Glass and Silicate Research Institute." The proposed new Institute was initially named the Central Glass and Silicate Research Institute. The name was changed to Central Glass and Ceramic Research Institute (CGCRI) in 1945 when it was realized that ceramics was a vital component of quality glass manufacture.

By this time, the CSIR had already been set up. It had the mandate to promote scientific and industrial research by helping establish institutions, laboratories and workshops, instituting studentships and fellowships, and disseminating research and industrial information through scientific papers. Dr. Shanti Swarup Bhatnagar was at the helm of CSIR and he had a crystal clear vision and a plan of action. He visualised a chain of national laboratories with the help of industry for industry. He would elaborate on this later, in a paper entitled 'National

Research Laboratories of India' (1947). In it, he categorically defined his vision in these words: "The scope of work of each Laboratory could, perhaps be best described to be of "the form of a continuous spectrum, at one end of which research work of the purest academic type and of the highest quality is carried out and at the other, the technical development of processes and equipment proceeds by stages."

Plans for setting up eleven specialized National Laboratories were drawn up between 1942 and 1947. One of these would be a research institute dedicated to glass and ceramics. This was announced on 1 August 1944 by Dr. Shanti Swarup Bhatnagar; but before that Research Committees had to be constituted to shape the activities of CSIR and to steer the plan to success.

Twenty Research Committees were constituted by 1945. The Glass and Refractories Committee was constituted on 9 July 1940 under the Chairmanship of Dr. A. Nadel. A detailed report was submitted to Dr. Atma Ram who would go on to become the Director of the Institute.

The question that now arose was about the location of the proposed institute. Quite a few prospective locations vied for the honour. The Committee set up to look into the matter offered a choice by listing five sites: Benares, Calcutta, Delhi, Lahore or a place in Uttar Pradesh other than Benares. However, it soon became clear that there were actually just three places which offered advantages. These were Bengal, Uttar Pradesh and Bombay. The Glass and Silicates Research Committee took a closer look and finally, recommended Calcutta if Bengal were to be chosen and Delhi, if vicinity to Uttar Pradesh was a criterion. Finally, the decision was taken to locate the institute at Calcutta.

Preliminary estimate for setting up Central Glass Research Institute (estimated cost) was Capital... Rs. 1,71,000 + Rs. 1,30,000 Recurring. CSIR-CGCRI received Rs. 10,000 each from the Bengal and the UP Glass Manufacturers' Associations as well as from Sir U.N. Brahmachari and I.D. Varshney. The authorities of Jadavpur College offered to rent out 5 *bighas* of land for a nominal sum. This offer was made at the behest of the then Mayor of Calcutta.

M/S Ballardie, Thompson and Matthew were chosen as the architects for the new building. Construction began on 1st September 1945. The Foundation stone of the Institute was laid by the Hon'ble Ardeshir Dalal on 24th December 1945. A couple of days before the Institute flung open its gates; Dr. Bhatnagar dropped in to check on the progress of the work. He took one look at the building and spontaneously exclaimed, *"Oh! What a pearl of a laboratory."* This laboratory would go on to become a jewel in the crown of CSIR.

The Institute was formally inaugurated on 26 August 1950 by Dr. Bidhan Chandra Roy, the-then Chief Minister of West Bengal. Speaking at the Inaugural function of CGCRI in 1950, Dr. Bhatnagar explained the rationale behind choosing Calcutta. He said:

> "We have chosen Calcutta for the location of the Institute as it is one of the principal centres of the glass and ceramic industry. For the establishment of a successful glass and ceramic industry, we are as much dependent on science and technology as on decorative and creative art requiring delicate touches which only deft hands can impart, and as we know that Bengal possesses artistic talents which few others can equal, as well as scientific acumen of a high order, we feel we have acted rightly in locating the Institute, here."

The new Institute was dedicated to scientific and industrial/ applied research of national importance in the fields of glass, ceramics, refractories, vitreous enamels and mica. It would undertake R&D directed towards proper utilization of the country's resources of related materials, import substitution, new technologies related to the needs of the country, assisting the industry and basic research. The ambit of the proposed institute included pottery, refractories and enamels in addition to glass.

CSIR-CGCRI: A Centre of Excellence

The entire history of CSIR-CGCRI's evolution against an ever-changing backdrop of emerging India makes a fascinating study in learning how the institution was conceived, nurtured and guided to grow into a mammoth S&T structure underpinning, to a greater or lesser extent, almost all of modern India's S&T ventures in the field of glass and ceramics.

Dr. Atma Ram, the first Director of CSIR-CGCRI was of the opinion that indigenous research should focus on "...areas of felt needs...", and which others have not touched should have greater attention in the country's research.

A typical example of an area of felt need was the glass bangle industry in Firozabad, which was starved of an imported material for producing red bangles. The industry, specific to India and Pakistan produced Rs. 4.5 crore worth of goods. Nobody abroad was interested in this Industry but in India red bangles are a symbol of happy wedlock and thus of great cultural importance. So, this became a field of applied research for CSIR-CGCRI. Dr. Atma Ram later wrote:

> "There is no known source of selenium in the country, and quite often there has been scarcity of this material. Because of the dependence of this cottage industry on imports of its key raw material, investigations were taken up at the Institute to produce red glass. It is known that copper oxide when introduced in a glass batch imparts red colour under reducing conditions of melting but its production particularly in regard to brightness and uniformity of colour has been reported to be one of the most difficult of all coloured glasses. That possibly explains why, in spite of copper being quite cheap and copper red glass known for over a century, bulk of the red glasses is made by using costly selenium."

Dr. Atma Ram and his colleagues studied the problem in detail. They focussed on the conditions needed to ensure that bright and uniform copper red colour could be produced under commercial conditions. Soon they worked out the details to be kept in mind when using Copper instead of imported Selenium to produce ruby red glass suitable for making bangles. Another seminal contribution of Dr. Atma Ram and his colleagues was the development of red glass that could be used by the Indian Railways for signalling.

Import substitution was the watchword. CSIR-CGCRI also developed Boron-free enamels, chemical porcelain, ceramic components of automobile spark plugs, hot face insulation bricks, Lead and Boron-free glazes, glasses for glass to metal seals, glass electrodes for *pH* meters, partial substitution of cobalt oxide in making blue coloured bottles, autoclave plaster of Paris and Lithium chemicals from indigenous lepidolite.

Major economic benefit was reaped by the new nation from the heat insulating bricks made from waste mica that was used to replace imported diatomite products. Indigenous zircon sand was used to make opacifiers for ceramic glazes. The cost of opaque glazes was also reduced to less than one-third by using indigenous opacifiers and reducing the Lead content of glaze. This was of immeasurable profit for village potters who made red clay pottery.

An outstanding achievement was the development of Neodymium-doped laser glass rods which were used to make sophisticated range-finders. CSIR-CGCRI contributed tremendously towards developing dental porcelain, which was not made in India at that time. It is clear that from making glass for delicate bangles, to glass that could shield from radiation; from dental porcelain to porcelain spark plugs, the newly-created institute straddled many spheres; the linking thread being the motto of service to the nation.

The range of specialty glass made by CSIR-CGCRI is large and includes the following:

Optical Glass: Optical glass is glass of the highest quality. It is isotropic or optically homogeneous, highly transparent, free from colour, chemically durable and physically stable with good mechanical strength. As can be imagined, it is not easy to achieve such high standards without technical competence. At a time when only half a dozen countries had access to this closely-guarded technology, CSIR-CGCRI developed this glass that was of enormous benefit to the nation.

This strategic material used in the manufacture of microscopes, telescopes, interfometers, theodolites, cameras, binoculars, range finders, gun sights and submarine periscopes, to name a few, opened up new vistas in the field of optical industries in India. Actually, it would be myopic to speak of only Indian vistas that were opened up; the scope of optical glass is truly global. Its reach extends into space as well as the depths of the oceans. It allows entrance into worlds hitherto invisible; almost un-knowable.

In a lecture delivered in 1961, Dr. Atma Ram had spoken about the making of optical glass in India and its lessons for industrial development. Hesaid:

> "This remarkable material has become so much a part of modern civilization that it is difficult to imagine what progress could have been achieved without its services. As an essential material of the telescope, optical glass relieved science from the clutches of superstition and dogma and helped in the establishment of the laws of planetary motion. But for optical glass which, has provided that wonderful instrument the microscope; many of the present day science and industries would not have made such advance. Thus, the science of bacteriology would not have been born; fermentation industries which are amongst the major industries would have made but little progress; photography and cinematography would have been unknown and the development of astronomy would have remained stunted. Optical glass has extended human vision from the microscopic world to the macroscopic."

Radiation Shielding Glass: Polished and transparent glass with very high Lead content that could prevent harmful atomic radiation from passing through it was developed very early in the

Institute's history. Over the decades, CSIR-CGCRI has mastered the science behind the making of Radiation Shielding Glass (RSG) which is needed to shield the workers from being exposed to radiation as they go about their work. It is also commendable that process technology for making special borosilicate glass nodules for encapsulation of nuclear waste leading to its immobilization for safe storage have also been developed indigenously.

Infra-red Transmitting Glass: Required by the Defence Sector for use in vehicle headlights/searchlights, this glass cuts off visible light but allows invisible heat radiations to pass. It is invaluable to spot enemy-positions in the dark without revealing one's own position.

Glasses for Glass to Metal Seals: These glasses were entirely imported when India became independent. So, CSIR-CGCRI developed a technology that used Nickel–Cobalt-ferrous alloy (Kovar alloy) and Tungsten to develop an indigenous version of such glasses.

Foam Glass or Multicellular Glass: This glass is as light as cork and a very efficient low-temperature thermal insulator. It finds use in the petrochemical and fertilizer industries, cold storage facilities and for thermal insulation of hot/cold pipes, etc. Secrecy shrouded its manufacture as countries with know-how guarded information closely. CSIR-CGCRI used indigenous materials as well as an in-house production process to develop this type of glass that compares very favourably to international brand names.

Chemically Toughened Glass: This is a special Boron- free alumina-Silicate glass, developed by CSIR-CGCRI. It has high resistance to thermal shock and chemical attack. It is particularly suitable for making laboratory glassware, ovenware, lantern chimney and other items which are usually subjected to chemical/mechanical shock and heat during use.

Laser Glass: Two-types of Laser-glass i.e., Silicate and Phosphate (Neodymium-doped) were developed at CSIR-CGCRI for development of high-powered lasers.

Bioglasses/Glass-ceramics: Bioglass was one of the first completely synthetic materials that had bio-compatibility and osteogenic capacity. Prof. Larry Hench developed Bioglass in USA, in the late 1960s. CSIR-CGCRI developed this technology in India in the late 1980s.

Glass-reinforced Gypsum: CSIR-CGCRI developed Glass-reinforced gypsum to serve as a substitute for wood used in housing projects. This low-cost composite material can be used to make doors, windows, furniture, partitions and ceilings; thus, lessening the load on swiftly depleting natural resources.

Ultra Low Expansion Translucent Glass (ULET): These glasses have almost zero thermal expansion over a wide thermal range. These also have excellent thermal shock resistance. CSIR-CGCRI has developed technology to make ULET.

It is important to remember that specialty glasses, such as those developed at CSIR-CGCRI, are usually never manufactured in bulk, unlike container or float glasses which are made in huge volumes. Yet, their importance for the nation's social and strategic sectors remains beyond question.

Indian Glass Industry:Drivers and Challenges

India is blessed in that it has complete indigenous availability of all the raw materials needed to make glass. Plus there is increasing availability of Natural Gas as a fuel to drive the furnaces. Apart from these two natural reasons, the Indian Glass Industry is thriving, thanks to a fortunate convergence of developments in certain sectors including Real estate, automobile, packaging and a general upward trend in spending on aesthetics. Glass is increasingly being used in modern buildings worldwide and India is no exception. The boom in retail estate; infrastructure and realty sectors has spelt good news for the Glass Industry. Huge advances have taken place in ophthalmic glasses used to make lenses for spectacles and signal lenses used in the control of rail, road and air traffic.

The Indian automobile segment is growing at a robust pace. Automobiles use a lot of glass and the growing use of glass in the automotive sector is a driver for the Indian Glass Industry.

Interestingly, there is a global trend linked to the growing use of glass in cars. Apparently, in many countries, the demand for bulletproof security glass in cars has skyrocketed. This has led analysts to forecast that the global bulletproof glass market will grow at a lively 18.73 per cent over the period 2012-2016.

More and more glass is being used in solar appliances and other eco-friendly products. This is boosting glass production too.

Across the world, glass is considered to be a good packaging material. It is the only material rated as GRAS (**G**enerally **R**egarded **A**s **S**afe) by the US Food and Drug Association. A glass container does not need an extra protective coating inside. It is inert and does not react with the contents; it does not leach harmful chemicals into the product or alter the taste, smell or composition of the products. It is impermeable to air and water, so it confers higher shelf-life. Glass containers can withstand vacuum or high pressure sealing. Its transparency allows the products to be seen from outside. All these properties have led to increased use of glass in packaging for food & beverages, alcohol, pharmaceuticals, cosmetics, solar products, etc. The Indian Glass Industry is riding a surge in demand owing to the growing awareness among the consumers. Interestingly, the consumers themselves have higher disposable income and are exhibiting enhanced demand for artistic glass objects. Even earlier, luxury items such as perfume, packaging bottles were traditionally made of glass. Modern technology is introducing stunning new colours and designs.

However, it is not unalloyed good news all the way. The Indian Glass Industry still has to surmount certain problems. Key challenges to the Indian Glass Industry include cheap Chinese imports and the rise in price of soda ash that are driving up production costs. There is lingering concern about pollution and poor working conditions in small glass units but the situation is improving. Institutes such as The Energy Research Institute (TERI), New Delhi, have provided much-needed interventions in terms of energy-efficient furnaces. Child labour, once a bane of the Glass Industry is on the wane.

In addition, the country has been far-sighted in encouraging organisations such as The All India Glass Manufacturers' Federation and research laboratories such as the CSIR-Central Glass and Ceramic Research Institute.

Glass Institutes across the World

There is increasing attention being paid to glass research in recent times. China had set up the Beijing Glass Research Institute as early as in 1960. Bangladesh has set up the Institute of Glass and Ceramic Research and Testing at Dhaka, to carry out research in diverse areas of glass, ceramic, bio-ceramic, tiles, pigment, enamel, high alumina ceramic, bone china ceramic, self-glaze ceramic and porcelain, etc. Germany has set up Otto-Schott-Institute for Glass Chemistry. It is named after Friedrich Otto-Schott, German glass technologist and inventor of borosilicate glass. Brazil, one of the Big Four countries, set up The Center for Research, Technology and Education in Vitreous Materials (CeRTEV) in 2013 with generous funding by The São Paulo State Research Foundation.

Globally too, institutions are coming forward to create networks for the Glass Industry. One such is the Lehigh University's International Materials Institute for New Functionality in Glass (IMI-NFG), which was founded in 2004. The Institute's goal is the creation of a worldwide network in glass research for new applications, and the development of a new generation of scientists and engineers with enhanced international leadership capabilities. Currently, Glafo-the Glass Research Institute in Växjö, Sweden, works on the entire chain from raw material to complete glass production.

The Institute for International Research in Glass, UK, promotes and facilitates research in glass at a national and international level. There is an interesting legend attached to this institute. Apparently, Abbott Benedict Biscop, in the 7th century, insisted "on better and more spiritually uplifting glass for his new monastery of St Peter's (now the new site of the University and of the National Glass Centre)." He sent emissaries to Gaul to find and bring back expert glassmakers. Subsequently, these artisans settled at a place called Monkwearmouth and began to produce what is now known as English Antique Mouth Blown Glass. This tradition continued throughout the medieval period. It ultimately led to the production of high quality glass in the region from the start of the Industrial Revolution to the latter part of the 20th century.

The existence of these institutions and others across the globe just goes to show that the world has woken up to the need for cutting edge research in the area of glass. Thanks, to the foresight of India's S&T leadership, modern India has not lagged behind in this quest. On the contrary, India's successful indigenous efforts at developing many types of glass have earned it the admiration and envy of nations and in this, CSIR-GCRI has played a stellar role.

9

GALLERY OF ART GLASS

Nelson Mandela once said, *"There is nothing like returning to a place that remains unchanged to find the ways in which you yourself have altered."*

Modern glass production facilities have changed a great deal and an ancient glassworker would not be able to reconcile his experiences with what goes on in modern production facilities. However, if he walked into a glass-blowing studio where contemporary artists work; he would still feel right at home. He would see that his *capable hands and strong lungs* still held the key to shaping molten glass. He would also know that gravity and centrifugal force would aid his attempts if he decided to take up practicing the craft of creating art glass again. Of course, imagination and artistic ability would still be the foremost necessities too. Art Glass, as the name implies, is glassware designed primarily for decorative purposes.

Some of the art glasses created over the ages are:

Amen Glass: Amen Glass is a rare type of English wine glass. These display engraved emblems associated with the Jacobite uprising of 1715, verses from Jacobite hymns and the word Amen, which gives it the name Amen Glass.

Amberina Glass: This is the name of glassware originally made from 1883-1900. Amberina was patented by Joseph Locke and Edward D. Libby of the New England Glass Company, USA. Amberina Glass is two-toned; usually always red on the top and with shades of amber-yellow towards the bottom. If a piece of the glass has yellow on the top and shades of amber- to red towards the bottom, it is called ***Reversed Amberina***. Glass which is shaded in colours from blue to amber is known as ***Blue Amberina*** or ***Bluerina***. The first Amberina was produced by adding gold chloride to amber-coloured glass while it was still molten. After the glass cooled, it was reheated, and the Gold salt caused those parts of the glass that reached high temperatures to turn red. Plated Amberina is considered to be the Queen of Amberina. It has a cream-coloured lining and has small ridges or ribs on the outside; hence the name. As befits its royal stature, this is an expensive type of glass.

Heat-sensitive Amberina has been made by adding selenium and cadmium sulphide rather than gold chloride to the molten glass. While gold chloride gave the glass a pinkish red to deep ruby red colour; selenium and cadmium sulphide imparted an orange cast to the red glass. Some collectors opine that Selenium-based Amberina is not true Amberina. Mount Washington Glass Works, USA, produced a dark coloured glass in the early 1880s which was sold as Amberina. However, following disputes it was marketed as *Rose Amber* but even this had to be discontinued after 1886.

Amethyst Glass: This is a generic term for dark purple glassware that resembles the colour of amethyst, a semi-precious gemstone. Sometimes this is called desert glass, or sun-coloured amethyst glass. Very dark purple glass is called black amethyst. This attractively coloured glass is collected avidly by many. Unscrupulous dealers often irradiate old glass to produce the amethyst colour. It is reported that when exposed to the radioactive isotopes such as Cobalt-60 and Cesium-137, most Manganese glass turns amethyst in colour, while glass made with Selenium becomes either straw, wheat, or honey coloured. Interestingly old Manganese glass tends to turn purple when exposed to strong sunlight over a period of time; a fraudster's trick that has fooled many collectors.

Ancient Glass: Ancient Glass usually refers to pre-Roman and ancient Romanglass.

Annagrün Glass: This is a type of glass which is coloured yellowish-green by adding Uranium oxide to the batch. It was developed by Josef Riedel who named it for his wife, Ann. This glass was made only during the 1830s and 1840s. A pair of Annagrün glass candlesticks along with a sugar-bowl and cover was auctioned by Christie's in 2004 for $1,793.

Apsley Pellatt Glass: Apsley Pellatt Glass is a type of glass with a decorative ceramic object or medallion encased in it. It is also called sulphides or *Cameo incrustation*. This sort of glass was patented in 1819 by Apsley Pellatt IV, who called it "*crystallo ceramie*". The ceramic medallion or figurine was inserted into the glass by cutting a hole in the hot glass which was resealed afterwards. Paperweights, jugs and decanters made in this style were once extremely popular. An Apsley Pellatt cut glass scent flask with a sulphide portrait of William IV and stopper with a sulphide lion fetched £1,062 at an auction by Bonhams in 2014.

Apothecary Glass: This type of glass was used to store or transport medicines in ancient times. These were produced in large numbers from the 1st century AD onwards. Samples of apothecary glass from Roman times are labelled 'Unguentaria' and often seen in museums. In 2010, a set of four olive-green glass apothecary bottles with gold cartouches made in the late 18th century was sold by Christie's for £1,250. These bottles had once contained tinctures of different kinds including quinine- a medicine used to treat malaria.

Art Deco Glass: Art Deco Glass is a decorative style popular during 1925-1940. It is characterized by geometric designs and bold colours.

Art Nouveau Glass: Art Nouveau Glass is a decorative style popular in the 1890s and 1900s. It is characterized by the use of motifs based on nature.

Aventurine Glass: Aventurine is a glass in which metallic Copper particles are suspended or incorporated to give the glass a shimmery appearance. The Copper reflects light through the glass making it sparkle, and look like Gold. Aventurine Glass has also been called *Avventurato* meaning fortunate. The name suggests that a fortunate accident led to the creation of this type of glass. The story is that this type of glass was invented when Copper filling was spilled by accident into glass that was being melted. Vincenzo Miotti is said to be the lucky creator of Aventurine Glass. The Doge of Venice granted him the exclusive right to make it in 1677. The secret of its production was closely guarded and passed down through the family. Other glassmakers tried to imitate it, especially the Bertolini brothers in the 18th century but their glass was not quite as good. In 1811, a widow of the Miotti family let the cat out of the bag and soon many other families improved upon the Miotti process. A cranberry coloured Aventurine Glass ewer with a snake-shaped handle wrapped around the body and a goblet with a flared bowl was sold for £688 by Christie's in 2009.

Baccarat Glass: This is high-quality crystal glassware from Baccarat, France. Monseigneur de Montmorency-Laval, the Bishop of Metz, petitioned King Louis XV to allow him to set up a glassworks factory on the banks of the River Meurthe, France. By the royal decree of King Louis XV, the Compagnie des Cristalleries de Baccarat was established in 1765. It was the first French glassworks firm created to compete with glass imported from Bohemia.

Baccarat Glass has been called the *Glass of Kings and the King of Glass* not just because it was established by Royal decree. It has earned the title because it has adorned the tables of many Maharajahs of India, the Czars of erstwhile Russia, Emperors of Japan, Emperor Haile Selassie of Ethiopia, Sultans of Turkey, Kings of Portugal, Kings of Siam, Kings of Greece, Kings of Spain, Kings of France, all the Presidents of the French Republic, many American Presidents, the Aga Khan, and Pope Benedict XV to name a few.

One of the first Russian czars made it a law that glassware used by Royalty could never be used by another. Baccarat glassware was a court favourite at that time and many fabulous pieces were smashed after just one use. Perhaps apocryphal, yet amusing, nonetheless is the story involving Baccarat crystal and the Maharaja of Gwalior, India. Apparently, when a massive and ornate chandelier commissioned by the Maharaja was finally hung in the Palace; it brought the roof down...quite literally! A late 20th century Baccarat cut glass chandelier was sold by Bonhams for £8,750 in 2013 and a Baccarat millefiori paperweight, dated 1847, for £1,800 in 2011.

Blown-Out Glass or Embossed Pattern Glass: This is a type of glass that has been blown inside a mould which has a pattern machined into the surface of the mould. The glass retains this pattern when it cools.

Bubble Glass: Air trapped in the glass shows up bubbles. Bubbles trapped in glass are considered to be a result of crude technique or the work of a novice. Yet, bubbles intentionally introduced into glass are considered art; the glass is called Bubble Glass. An example is ***Clutha Glass***. It was first made by Christopher Dresser and James Couper in the 1890s. *Clutha* is the Gaelic word for the River Clyde. Clutha glassware has little specks of colour, and bubbles throughout its body. Bonhams sold a 38cm tall light green *Clutha Glass* vase for £792 in 2007.

Bubbles can be produced inside the glass by adding chemicals such as sodium carbonate or bicarbonate to it. When heated, these give out Carbon dioxide that creates random bubbles. during the melting process. In Italian, this is called ***Pulegoso Glass***. *Pulegoso Glass* appears to light, almost spongy because of the bubbles. Too many bubbles in *Pulegoso Glass* can render it almost opaque. In the 1920s, Napoleone Martinuzzi created this type of glass in Murano, Italy. Murano *Pulegoso Glass* chandeliers can command quite good prices at auctions. In 2009, Bonhams sold one in an inverted mushroom shape for $ 3,660; a second in the shape of a ribbed bowl for $ 3,050 and a third with downwardly scrolling plumes encircling a shallow bowl for US$ 6,710.

Glass with a regular design of bubbles is called *Bullicante Glass*. Sometimes a single bubble is pushed in to molten glass with a spike-like instrument. When the glass cools, the bubble gives a silvered effect. Murano glass artists in the 1950s made a lot of this type of glass. A 20th century Murano *Bullicante Glass* decorative item shaped like a pair of fish in amethyst and rose pink colour was sold for $720 by Cowan's Auctions, Inc.

Burmese Glass: Burmese Glass is opaque, coloured glass shading from yellow on the bottom to pink on the top. The glass formula calls for uranium oxide and tincture of Gold. Uranium oxide gives the yellow colour and gold contributes the pink colour when the glass is re-heated in the furnace. The length of time in the furnace determines the intensity of the pink colour. Interestingly, if the piece of glass is reheated again, it reverts to yellow colour.

Frederick S. Shirley patented the formula for Burmese Glass in 1885 in agreement with the Mount Washington Glass Co., USA. Apparently, the formula differed from Joseph Lock's Amberina formula in that it had more uranium oxide. Queen Victoria was presented a number of pieces of decorated Burmese ware including a tea set by glass-manufacturer Frederick S. Shirley in 1886. She loved it on sight and exclaimed, "*It looks like a Burmese sunset.*" And that is how this glass got its name. The Queen liked this range so much that she also purchased additional pieces. The same year Thomas Webb & Sons, a British company, received a license to produce not only the original Burmese Glass but their own version known as Queen's Burmese Ware.

Carnival Glass: Carnival Glass is pressed glass with an iridescent surface. Carnival Glass has been described to have an *oil on water multi colour look.* It was first produced by Fenton Art Glass Company, USA, in 1907. Carnival glass was made by exposing hot glass to sprays, fumes, or vapours from heated metallic oxides. This treatment left a lustrous, rainbow coloured coating on the surface of the glass. A final firing of the glass brought out the iridescent shine in all its beauty.

Carnival glass was often used to make decorative hatpins, vases, plates, ashtrays, bottles and pitchers. In the early days it was called *Iridill* and Rainbow Lustre Glass. Apparently when it began to lose popularity, items made out of this type of glass were given away as gifts at fairs and carnivals-hence the name. Today Carnival Glass is a valued collectible item.

Cased Glass: Cased Glass is made by layering one colour over another. It involves making an outer casing first. One end is knocked off so that a cup-like shell is formed. This shell is then placed in a metal mould. Then, a different coloured glass is blown into it. The combined piece is removed from the mould and reheated so that the two layers fuse. Cased Glass can be made in up to four colours. The outer layers can be partially carved to create innovative designs characterized by the juxtaposition of contrasting colours. In 2008, Bonhams auctioned a 26 cm tall Cased Glass vase with an orange core and internal bubbles for £2,640.

Cathedral Glass: Cathedral Glass is usually transparent glass of one colour on which decorative patterns have been created so that light passing through it is diffused.

Chalk Glass: Chalk Glass is a colourless glass in which potash has been combined with chalk. It was first developed in Bohemia in the late 17th century and is also called Bohemian Glass. Chalk Glass was clearer and more brilliant than Venetian *cristallo* and harder than English Flint Glass. In 2013, Bonhams auctioned two 84 cm tall Bohemian Glass goblets made in the mid 19th century for £47,500.

Chocolate Glass: Chocolate Glass was developed by American glassmaker Jacob Rosenthal in 1900 and only he knew the formula to make this type of glass. Chocolate Glass varies considerably in colour ranging from *café au lait* hue to a deep rich brown. Some even have a pronounced red-brown tone on the edges. These are called 'Red Agate' by collectors. Chocolate Glass with variegated streaks of colour is informally referred to as 'Caramel Slag'. This glass was well received by both Industry and the public. In the issue dated 28th December 1901, the weekly journal *China, Glass and Lamps,* lauded this glass as "...glass colour winner". It was said that it "...has proven to be just the sort of a novel colour for glass ware that the trade was looking for and it is proving the warmest seller of the season." Today, the Greentown Glass Museum in Greentown, USA showcases many samples of this glassware.

Coralene Glass: This type of glass has a distinctive decoration on its surface. An image was painted onto a piece of glass with thick enamel paint and tiny glass balls were then applied to this surface. It was then reheated so the glass balls partially melted into the surface of the glass piece. The resultant rough-finish on the surface resembled coral, hence the name. Coralene was first patented in Germany in 1883 by Arthur Schierholz. Coralene Glass was sometime called 'Coral Beaded' or 'Coralene Beaded.'

Cloud Glass: The George Davidson Glasshouse, England, was founded in 1867. It introduced the Cloud Glass range in 1923 and discontinued it after the Second World War. Cloud Glass was made by adding trails of dark semi-molten glass to a lighter coloured semi-molten glass. When compressed in a mould, unique wispy patterns were formed that was reminiscent of clouds in the sky...albeit multi-coloured ones. Different colours were introduced over the years; purple was introduced in 1923, blue in 1925, amber in 1929, green in 1934 and red-orange in 1929 and orange, in 1934.

Crackle Glass: It is also called Ice Glass Craquelle, Snakeskin Glass, Frosted ware, or Ice- Glass. In France, it is known as *verre craquelé*, and in Italy as *vetro a ghiaccio.*

The process was developed by Venetian glassmakers in the 16th century. Molten hot glass was immersed in cold water, which caused it to crack; giving it a frosted appearance. The glass was then reheated and either moulded or blown into shape. The process of blowing caused the cracks to form a network of cracks. The reheating of the glass sealed the cracks. New, and cheaper, methods of crackle glass production appeared in the 19th century, making it more affordable. Collectors of Crackle Glass adore the 'cracks', so the cheaper the variety the fewer 'cracks' it has and vice-versa! In 2006, Bonhams auctioned a late 19th century Crackle Glass ewer and goblet set for £82.

Overshot Glass is a sort of Crackle Glass. One way to make Overshot Glass was to roll hot glass in a pile of glass powder. The powdered glass adhered to the hot glass. Then the treated glass was reheated in a furnace. This melted the small bits of glass causing them to lose their sharp edges. The glass was then blown into the desired object. Glass made in this manner is usually smooth on the surface. Interestingly, the production of Overshot Glass had stopped sometime before 1800. It was reintroduced during 1845-1850 by Apslaey Pellat, owner of Falcon Glass Works, London, who used the name *Venetian Frosted Glass* or *Anglo-Venetian Glass*. In 2007, Bonhams auctioned a 19th century colourless Overshot Glass pitcher for $ 240.

Crackle Glass was sometimes further decorated by being rolled onto threads of coloured glass and then reheated so that these glass filaments got firmly attached to the main body of glass. Since the main glass piece was usually opaque white or transparent and coloured; the contrasting glass filaments give it a stunningly delicate look. The process was patented in 1880 by Wilhelm Kralik who first made the so-called *Peloton Glass*, which is also called *Spaghetti Glass* or *Shredded Coconut Glass*.

Custard Glass: Custard Glass is an opalescent, opaque glass. It is the colour of egg-custard, i.e. slightly yellow or rich creamy in colour; hence the name. Regardless of intensity, the hue was originally called ivory and described in superlative terms such as *Ivorina Verde* and *Carnelian*. Custard Glass was made by adding various combinations and amounts of Uranium and Sulphur into the glass mix before it was melted.

Cut Glass: The term refers to glassware adorned with facets, grooves, and depressions made by cutting with rotating wheels. The pattern needs to be polished after it has been cut.

Cut Velvet Glass: This Victorian–era glass is made with two layers of blown glass. It used acid-etching which left the glass feeling 'velvety' smooth to the touch; hence the name Cut Velvet.

Depression Glass: This machine-made, inexpensive glassware with the sad name was made during 1920s to 1930s in USA...a time of great economic hardship. Depression Glass was made in pink, green, amber, red, blue, yellow and white colours. Sometimes, tiny items made using this type of glass were given as gifts to motivate sales. In 2009, Bonhams auctioned a set of nine Depression Glass goblets for $207.

End-of-Day Glass: This was a glass made by glassblowers at the end of the day's work to use up the scraps of glass left over. However, it is unlikely that odd motley of discarded glass could be shaped into the beautiful objects that are known as End-of-Day Glass. This term is also used for marbleized glass in several colours. The term Spatter Glass is also used for multi-coloured glass made from many small pieces of different coloured glass. End-of-Day Glass is also called Friggers and even, Whimsey Glass. By definition, Friggers were never mass produced.

Feathered Glass: Feathering or combing was done by applying threads of opaque glass to a layer of molten glass. The threads were rolled into the glass and the hot surface was combed to give a feathery effect that was quite decorative.

Filigree Glass: Filigree Glass has internal decorations of twisted threads.

Flake Glass: Flake Glass was first developed in 1938 by Russell Games Slayter of Owens-Corning Fiberglas Corporation, USA, but was not commercially utilized till much later.

Flash Glass: Flash Glass is made by applying a thin coating of molten glass over another glass object. Flash Glass can be applied within or inside a thicker glass object. Flash Glass is also called Plating.

Flint Glass: Flint Glass is a heavy and durable glass characterized by brilliance, clarity and high refractive index. It was developed by George Ravenscroft in 1675. Most Flint Glass formulas called for 33 per cent Lead as compared to 24-28 percent Lead in modern crystals. Pressed Flint Glass has superior light refraction and produces a resonant bell- like sound when struck. It is heavier as compared to standard glass of similar size. Flint Glass is also a generic term for any highly refractive Lead-containing glass used to make lenses and prisms. It absorbs most the ultraviolet light but comparatively little visible light, so it is also used for making telescope lenses. In 2003, Bonhams sold an 1874 Flint Glass paperweight for

£199 and in 2007; it sold a 20th century blue Flint Glass covered jar for $ 6,600.

Frit Glass: This is a fine crushed glass that is applied to piece of glass as part of the latter's manufacturing process. Frit Glass can also be ground into a fine powder then mixed with oil and chemicals to make enamel. The frit added to this combination aids in fusing colour onto a piece of glass.

Gold Ruby Glass: Gold Ruby Glass is a deep red glass made with gold chloride. It is also called Cranberry Glass or *Rubino Oro*. It was originally made by the ancient Romans. The story goes that a nobleman tossed a gold coin into a pot of melting glass and that is how this beautiful colour resulted. Wonderful as the legend is, scientifically it does not hold water....the gold must be dissolved in *Aqua regia* before being added to the molten glass.

It is believed that either German chemist Johann Kunckel rediscovered the process in the mid-1600 or that Florentine glassmaker Antonio Neri did. However, it took the acumen of Nobel laureate Richard Adolf Zsigmondy to figure out that colloidal Gold was responsible for the stunning colour. Another form of Ruby Glass is called Selenium Ruby. Nicholas Kopp, Chief Scientist, Pittsburgh Lamp, Brass and Glass Co., USA, who developed the Selenium Glass process in the 1890s; gets credit for creating this type of glass. Selenium Ruby Glass was used in railway signal lights.

Goofus Glass: Goofus Glass is mass-produced and cheap pressed or mould-blown glass on which cold, unfired paint was used. It was produced in USA from 1897-1920. The most common colours used were gold, red and green. These colours soon flaked off, particularly if the glass was handled roughly or washed vigorously. Reportedly people thought they had been 'goofed' or fooled. Others thought that someone had 'goofed up' or made a mistake. Hence, the name. It was also called Mexican ware possibly because of its resemblance to the colours of the flag of Mexico. It was also referred to as *Hooligan Hoolies*, Bridal Glass and Gypsy Glass. This type of glass was often given away free at promotional events. Today it is sold at auctions. The paradoxical fact about this type of glass is that any attempt at restoring the flaking paint diminishes its value in the eyes of the collector.

Grotesque Glass: Steuben Glass Works Glass Works, USA, was founded in 1903 by English artist and glassmaker Frederick C. Carder and Irish-American glassmaker Thomas Gibbons Hawkes. Frederick Carder produced many different forms of coloured art glass from 1903-1933. One of his favourite types of glass was free-form vases, supported by ribs, which he jokingly named Grotesque Glass. All coloured Grotesque Glass was made before 1933. Grotesque Glass items are unique because these were all individually handcrafted.

Historismus Glass: This is German 19th century glass made in the style of 17th century and earlier periods. Historismus Glass is also called Historical Revival Glass. Historimus Glass, despite its pretentions, is not considered a fake or an imitation but a type of glass in its own right. On 2012, a transparent German Beer mug decorated with celestial and royal figures and made of Historimus Glass was sold by Bonhams for £375.

Hobnail Glass: Hobnail Glass has a regular, pattern of raised dots all over its body. This gives it a bumpy texture. This type of glass was very popular during Victorian times. It was usually hand-blown, translucent and coloured. It is also called Dew Drop Glass. Hobnail glass was first made by the Fenton Art Glass Works. Initially, opalescent perfume bottles were made, but milk glass hobnail items, introduced in 1939, truly topped the sales charts. Even today, antique Fenton Hobnail Glass is auctioned for considerable sums.

Iridescent Glass: Iridescent Glass is also called Iris Glass, perhaps because of the rainbow colours shimmering on its surface. After all to the ancient Greeks, the Goddess Iris was the personification of the rainbow. Iridescent glass can be made by either adding metallic compounds to the glass or by spraying the surface with stannous chloride or lead chloride and reheating it under low oxygen or reducing conditions. Originally, iridescence on glass was a result of corrosion after centuries of being buried underground. The Victorians fell in love with the interplay of colours on the surface of glass and contemporary entrepreneurs rushedto profit from this.

In 1904, Steuben Glass Works patented a thick iridescent glass called Aurene. Later came the clear glass with a silvery iridescence known as *Verre Soie*. In the 1920s, a new iridescent glass called *Ivrene* was introduced. At about the same time, Frederick Carder introduced Alabaster Glass. It had an iridescent finish that was obtained by spraying the item with stannous chloride and then reheating it.

Favrile Glass is a type of iridescent art glass designed by Louis Comfort Tiffany with the help of expert chemists and glassworkers who managed to produce the exact shade of colour desired. *Favrile Glass* was patented in 1894 and first produced in 1896. It differs from most iridescent glasses in that the colour is ingrained in the glass itself. Carnival Glass is a sort of iridescent glass too.

Jacobite Glass: This is 18th century English drinkware, created for toasting Bonnie Prince Charlie or Prince Charles Edward Stuart. Jacobites were the supporters of the exiled King James II and of his descendants including Prince Charles Edward Stuart (the Young Pretender). Before the defeat of the Young Pretender in 1746, Jacobite glasses were usually engraved with the English rose, representing the Crown, and an optimistic motto such as *Redeat*, which in Latin means "May he return."

Jade Glass: Jade is a gemstone in pleasing shades of green. In the 1930s, a lot of glass was made by various glassmakers and sold under the name 'Jade.' It varied substantially in colour as it was a difficult process to control precisely. Because of the difficulty in making this colour, Jade Glass was produced only in limited quantities and that too only from 1931-1934. No wonder, it is now eagerly sought after by glass aficionados.

Knitted Glass: Knitted Glass is a technique developed by artist Carol Milne in 2006. Basically, it involves pouring glass into empty designer moulds made with thin and flexible wax candles. UK designer Catherine Carr also crochets and knits with glass.

Lutz Glass: Lutz Glass is a striped glass made in the 19th century by French glassmaker Nicholas Lutz.

Moss Agate Glass: Moss Agate Glass was developed in 1888 by glassmaker John Northwood, with the assistance of Will Bridges, Manager of the glasshouse Stevens & Williams. This sophisticated stripe-patterned glass is also called 'Stone Glass'. The coloured stripes resemble those of natural agate; hence the name. This effect was created by mixing molten glass of different colours. In 2006, Bonhams auctioned a vase made of Moss Agate Glass for $896. In 2011, they auctioned a snuff bottle made during 1800-1860 out of Moss Agate Glass and embellished with mother-of-pearl for $7,930.

Mary Gregory Glass: Mary Gregory Glass is a variety of glass produced in USA in imitation of English cameo glass. This is a term for a specific decorative style of glass enamelling. Mary Gregory Glass is divided into two types depending on its vintage. Old Mary Gregory Glass was made during 1879-1939. It came primarily from central Europe. New Mary Gregory Glass was made after the Second World War.

Mary Gregory Glass usually depicts white enamel paintings of a child playing with butterfly nets, blowing bubbles, using fishing rods, or running with hoops. The foliage is usually executed in a feathered style.

The Westmoreland Glass Company, USA, marketed their glasswork as Mary Gregory in the 1920s. Interestingly enough, Mary Gregory was an artist who was well known for her artwork showing playful Victorian-era kids. She worked for the Boston and Sandwich Glass Company during 1880-1884 and had absolutely nothing to do with this type of glass.

The predecessor to this glass is thought to have been the 'Quarkman' or 'White People'. In this decorative technique of Central Europe, white enamel figures of children were hand painted on coloured or crystal glass. Friedrich Egermann is credited with developing this style during the early 1800s. The story goes that he was fascinated by the quality of porcelain decoration being done in the German town of Meissen. Posing as a deaf-mute, he secured employment there and learnt the tricks of the trade. He then returned as an expert in mixing and firing enamel and soon developed new methods of staining glass. In 1815 or thereabouts, he started using tiny white dots, called *bisque pearls*, to accentuate his decorations. This became an instant hit and soon other glassmakers began to copy his style. *Lithyalin* (from Greek *lithos* meaning stone) is a type of glass he developed. It is opaque and has a marbled surface resembling semiprecious stones. It was often used for making scent bottles and had gilded ornamentation on the body. In 2013, Bonhams sold a 1830-made, rich chestnut-coloured Bohemian Lithyalin Glass scent bottle and stopper for £625.

Milk Glass: Milk Glass is an opaque white glass that looks like white porcelain. It was first made in Venice. This sort of Milk Glass is usually made with tin oxide. Milk Glass with a semi-opaque white appearance is made with ashes of calcined bones. It is sometimes called Opal Glass, Opaline Glass or Milk-and- Water Glass. In 2013, Bonhams auctioned a tear-drop shaped, enamelled Milk Glass snuff bottle made during 1800-1870 for $ 6,875. The same year it sold another Milk Glass snuff bottle made during 1770-1799 for $10,625.

Mother of Pearl (MOP) Glass: Mother of Pearl Glass is also called Pearl Satin Glass or Air Trap Glass. It was first patented in England in 1857-58 by British glassmaker Benjamin Richardson; although some believe that the technique was known to the ancient Venetians. Joseph Webb of the Phoenix Glass Works was granted an US patent in 1886. MOP Glass is made by blowing molten glass into a mould which has a pattern of projections built inside it. This leads to air bubbles being trapped in the glass when it is removed from the mould. For a satin finish, the glass is dipped in acid.

Opalescent Glass: Opalescent Glass is a translucent glass that resembles the semi-precious gem Opal. This glass originated in England in the 1870s. It is often found as pressed glassware made in Victorian times. Opalescent glass can be one solid colour, or a mixture of two or more, with streaks and swirls. Opalescent stained glass may be translucent or even, almost opaque. It reflects as well as refracts light.

In USA, the Opalescent era lasted from 1880-1920. American painter and stained glass window-maker John La Farge and American artist Louis Comfort Tiffany each patented a type of opalescent glass. John La Farge received a patent in February 1880 and L.C. Tiffany in November the same year. John La Farge was the first designer to use opalescent glass in a window. This has been called, "... a uniquely American phenomenon that proved to be among the most important advances in decorative windows since the Middle Ages." In 2013, a mounted Butterfly in Opalescent Glass was sold by Bonham's for $ 2,250. It was made in 1932.

Peach Blow Glass: This is an American glass made in the latter part of the 19th century. The name is derived from a Chinese porcelain glaze called 'peach-bloom,' a colour described as that of crushed strawberries. Peach Blow Glass shows graduated colours which shade from red or rose to yellow or pale blue or white on the outside and white inside. Most Peach Blow items were given acid treatment to produce a plush finish.

Apparently, the craze for this colour began in March 1886 when an 18thcentury Chinese porcelain 'Peach Blow' vase was sold at an auction for $18,000.

Pigeon Blood Glass: Pigeon Blood Glass is a brilliant ruby glass with brown highlights. The term is usually applied to old pressed glass that has a solid deep red colour.

Pulled Glass: Pulling is a glass manufacturing technique. It is also called 'swung'. Many varieties of old glass were subject to this technique. Swung vases, for example, may be found in Carnival Glass, Opalescent Glass and even Stretch Glass. These vases generally ranged in height from small 18 cm bud vases to the bigger versions that were sometimes over a meter in height. These vases were hand-blown and then hand-swung to lengthen and to produce the neck. Not very expensive, swung vases are collector's items.

Rubina Verde Glass: In Italian, *Rubina* means ruby or red and *Verde* means green. It refers to glass that shades from red at the top to green at the bottom. It was first made by Hobbs, Brockunier and Company in USA. In the 1880s, glassmakers in USA added uranium oxide as a colourant in *Rubina Verde*. This gave a lovely yellow colour known as 'Canary', or 'Vaseline'.

Sandwich Glass: Sandwich Glass is any glass made by the Boston and Sandwich Glass Works in Sandwich, Massachusetts, USA, between 1825-1888. It is greatly prized by collectors today. In 2010, Bonhams auctioneers valued a Sandwich Glass paperweight decorated with pink flowers on a blue and white jasper background at £400 - £500.

Satin Glass: Satin Glass is the name for any glass that has been chemically treated to give it a satin finish. The satin finish is usually produced by immersing the glass in hydrofluoric acid or exposing it to hydrofluoric acid fumes.

Sea Glass: Sea glass is weathered glass found washed up on beaches. There is an online journal at http://www.seaglassjournal.com dedicated to the Sea Glass. Sea Glass festivals are held in many parts of the world. Sea Glass in unusual colours and shapes are used in modern jewellery and objets d'art.

Slag Glass: Common name for an opaque pressed glass which contains white or cream coloured streaks. When this type of glass was originally produced it was called *Marble Glass, Brown Malachite* or *Brown Marble Vitro-Porcelain*. Slag Glass is commonly found in purple, blue, brown, green colours; sometimes in red and orange too. Plenty of this glass was produced in England during the late 1800s. In 2005, Bonhams auctioned an early 20th century table lamp made of brass and Slag Glass for $ 323.

Spangle Glass: Spangle glass is a multi-coloured glass that contains mica or metallic flakes of Gold, Silver, Nickel or Copper. Spangle Glass is usually cased with a thin layer of clear glass over the multi-coloured layer.

Spatter Glass: Spatter Glass is Spangle Glass without metallic inclusions. It is so-called because it looks as if it has been spotted or splashed with coloured glass. *Tortoiseshell Glass* is a sort of Spatter Glass since it consists of two transparent layers of glass encapsulating core pieces of brown glass. Spatter Glass has been produced intermittently since Roman times. In Europe and in USA, it was mostly made during 1880-1900s.

Stained Glass: Stained Glass is a glass to which a chemical coating was applied such that the glass developed its colour during heating. The cooled glass was painted and fired so that the colours were fixed.

Stretch Glass: Stretch Glass is a glass which was reheated after the iridizing process. After reheating the glass was either crimped, flared or cupped, i.e. it was 'worked' in some way. This 'stretched' the iridescent surface and produced fine striations or stretch-marks on the surface of the glass. Stretch Glass was made in USA from about 1916 to the early 1930s. It differs from Carnival Glass in that Carnival Glass was worked first and later, iridized; it was also heavily patterned. Stretch Glass has little or no pattern. Lovers of Stretch Glass even have a Stretch Glass Society that was formed in 1974. (http://www.stretchglasssociety.org/). In 2009, Bonhams auctioneers sold two 20th century bowls and drip pans for $366.

Threaded Glass: The Corning Museum of Glass defines threading as "...the process of winding a thin trail (strand) of glass around an object to create the appearance of parallel lines." Threaded Glass, therefore, is a glass decorated with a pattern produced by variegated glass filaments. In 1876, W. J. Hodgetts of England, patented a machine that produced regular and closely-spaced glass threading. Very soon, other glassworks came up with moulds that mimicked the threading pattern on the final product. In 2010, Bonhams sold a pair of threaded glass and metal lamps made in 1923 for $ 2,196.

Tortoiseshell Glass: Tortoiseshell Glass is a glass in which two layers of blown glass have pieces of brown glass between them. The brown glass is usually in two colours, light and dark brown. The blotchy apparently resembles the marking on a tortoise shell; hence the name. German chemist Francis Pohl and English glass merchant S. A. Wittman patented this glass in 1880. Tortoiseshell Glass may be thought of as a type of Spatter

Glass. Tortoiseshell was also a name sometimes used for pressed glass with an amber background and darker brown streaks. In 2013, a 19th century brass and Tortoiseshell Glass table clock were sold for £2,500 by Bonhams.

Uranium Glass: This is a brilliant yellow-green glass coloured with uranium oxide which was first made in the 1830s. Uranium glass fluoresces a lurid green when exposed to a UV black light. When Radium was first discovered, its radioactive properties were not fully understood. Radium was sometimes consumed as an elixir and sold in containers made of Uranium Glass. Similarly, until Antoine Henri Becquerel figured out the radioactivity, Uranium was considered an element with potential for use to colour glass and glaze ceramic objects. Thankfully, Uranium Glass is typically not radioactive enough to pose a danger, although the use of a Geiger counter can detect emission of gamma rays. Uranium Glass was used to make lamps, plates, bottles, drinking glasses, tankards, jars, buttons, jewellery, vases, inkwells, cups, etc. However, what effect Uranium had on the health of the glassworkers who 'blew' many of these beautiful glass objects will perhaps never be fully known.

Interestingly, some important scientific instruments were made with Uranium Glass. In 1874, the Swiss chemist Jacques Louis Soret used it in a 'fluorescent eye-piece' to be adapted to spectroscopes for observing the ultraviolet portion of the spectra. Between 1943-1958, because of its strategic importance, the American government banned the use of Uranium salts for commercial use. Production resumed after the ban was lifted. In 2011, a set of three cylindrical Uranium Glass decanters made in 1840 were sold for £600 by Bonhams.

Vasa Murrhina Glass: The term *Vasa Murrhina* means 'Vessels of Gems.' It has a transparent overlay of glass in which pieces of coloured glass and mica flakes are embedded. *Vasa Murrhina* Glass is sometime confused with Aventurine Glass.

Vaseline Glass: Vaseline Glass is pressed glass coloured with a small amount of Uranium. It was made in USA. The name derives from its greasy appearance. Vaseline Glass appears to be yellow-green in daylight and fluoresces bright green under UV light. In 2005, Bonhams sold a Vaseline Glass *bon bon* dish for £88; the next year it sold an oval 26 cm long Vaseline Glass bowl for £211.

Williamite Glass: Late 17th century English drinkware engraved with a portrait of King William III or a toast/symbol/motto supporting him. In 2008, Bonhams sold an engraved Williamite plain-stemmed wine glass for £600. The bowl was inscribed with the words *The Glorious Memory of King William* within a pair of spiralling orange branches. In 2009, Bonhams auctioned an enamelled Williamite wine glass dated 1750- 60 for £4,560. The trumpet-shaped bowl had the words 'THE GLORIOUS MEMORY OF KING WILLIAM' inscribed on it in opaque-white colour. Many Williamite Glass items have been found to be 19th century fakes.

Woven Glass: Woven Glass was developed at the turn of the 21st century by American artists Eric Markow and Thom Norris. The product looks like a fabric right down to the warp and weft but is actually made of glass. These two artists have created structures that include a series of life-size Woven Glass kimonos and an impeccably detailed 1.5 m long crimson dragonfly made of Woven Glass.

With so many types of artistic expressions in glass, it is fairly obvious that gorgeous glass can only evolve further...and indeed from art glass we now have smart glass... or glass coated with different substances that make it react to outside stimuli. In its new avatar as smart glass, age-old glass has debuted in an entirely new field altogether.

10

ARCHITECTURAL WONDERS IN GLASS

Glass is extraordinary in the sense that it effortlessly displays contrary qualities. For example, it can be transparent or opaque; sometimes, even translucent. It can be coloured or colourless. It is malleable enough to be shaped yet brittle enough to shatter into smithereens if dropped. It is suitable for making items of daily use and also for being fashioned into one-of-a-kind work of art.

Glass and artists have always had a love affair that has resulted in sublime creations. Delicate flowers in glass rival their natural counterparts; abstract sculptures in glass brighten landscapes and public spaces. And now, incredibly designed houses of glass are serving as places of residence, worship and work.

Glass used in architecture is called architectural glass. A greenhouse, used for growing plants in protected or controlled conditions is also sometimes called a glass house because it is mostly made of glass. Yet are these the only houses of glass that have graced the landscape? No, not really! Innovative use of glass in buildings has always been a hallmark of architecture; it has simply become more sophisticated with the advance in available technology. With smart glass, beauty has simply married efficiency!

Royal palaces and temples to the divine shimmer and sparkle brilliantly under the Sun, all thanks to glass. Modern malls and high rises are draped in glass...awe inspiring sights indeed for all to look at and marvel.

But modern technology has ensured that not all structures made of glass are visible to the eye! It is reported that Korea will soon have a glass-clad invisible skyscraper named *Tower Infinity*. The glass-encased, 450m tall *Tower Infinity* has been designed by architect Charles Wee. Basically, images of the background scenery will be recorded and light-emitting diodes will project that image onto the skyscraper so that it blends into its surroundings and is so perfectly camouflaged as to be invisible. *Tower Infinity* is a rarity because glass has usually always been used to make the structure stand out; not to make it blend in or disappear.

Throughout history, tiny bits of glass have been used to great decorative effect. Glass tiles reflect the light and the *Bhunga* mud cottages of the Kutch regions are not only painted brightly but also have tiny glass bits embedded to sparkle and shine. In India, as across the world, there are buildings that have been beautified by using glass in innovative ways.

Shīshe is the Persian word for glass and closely resembles the Hindi word *Sheesha,* which also refers to glass. Palaces and mansions decorated in this style have earned the sobriquet *Sheesh Mahal*. The word *Mahal* means Palace or Mansion. There are many *Sheesh Mahals* in India.

Amber Fort near Jaipur, Rajasthan, India was built in 1592. It is still a tourist destination. Thousands of tiny mirrors cover the four walls and the ceiling of the *Sheesh Mahal* in Amber Fort. Local guides make tourists gasp in wonder when they light just one match. Its reflection in the innumerable bits of studded glass multiplies the effect a thousand times. By moving a lit candle in an arc, the movements of the constellations in the skies are also mimicked to perfection. It is almost as if the seasons pass before the amazed eyes of the visitors.

There is a *Sheesh Mahal* in Lahore, Pakistan too. This Palace of Mirrors was built by Emperor Shahjahan who also built another one at Agra Fort, India. The mosaic mirror work or *aina kari* on the walls is exquisite. Unfortunately, the similarly named palace at Lucknow has not escaped unscathed from the ravages of time. Built by Nawab Asaf-ud-Daula, the palace was once decorated with mirrors.

The *Sheesh Mahal* at Mehrangarh Fort (built in 1459), Jodhpur, has been preserved well. It is a fine example of a typical Rajput *Sheesh Mahal*. The difference between the *aina-bandi* here and the *aina-kari* of the other *Sheesh Mahals* is that large, regular pieces of mirrors have been used for the decorations instead of the fragments used elsewhere. Additionally, there is the superimposition over the mirror-work of the brightly painted plaster religious figures. Mehrangarh Fort also has a *Moti Mahal* (Pearl Palace) where the King used to hold court. Its ceiling is decorated with gold filigree and innumerable pieces of mirrors. Some rooms have huge panels of brilliantly coloured glass that throw lovely shadows keeping pace with the Sun's diurnal movements.

Although sometimes called *Sheesh Mahal*, this building at Indore, was the home of the Cotton Prince of India; Sir Seth Hukumchand Jain—a philanthropist who passed away in 1959. He also built the *Kanch Ka Mandir* which literally means Temple of Glass in 1903. This Jain temple has mind-blowing interiors richly decorated with glass in all colours. The walls, ceiling, floors, pillars and doors are all covered in glittering glass. There are delicately defined glass paintings and glass inlays too. It is said that Sir Hukumchand Jain brought artisans from Jaipur and even faraway Iran to give shape to his dream. The statue of Lord Mahavira is flanked by large mirrors giving rise to an infinite number of reflections. Chinese lantern-type glass lamps and cut glass chandeliers further enhance the beauty of this temple.

There are other temples in India, which are also known as *Kanch Ka Mandir*. These include *Kanch Ka Mandir* at Kanpur; at Champanery; at Chamatkarji; at Shivpuri and at Vrindavan. Build in 1867 by Seth Badridas, the *Kanchwala* Jain Temple (Parshwanath/Paresnath Temple) at Kolkata is another example of a Jain temple where the building is embellished with ornate mirror work and coloured glass. The splendid artistry of its pillars decorated with inlaid mirror work and stained-glass windows dazzles all viewers. This temple is celebrated as '*the Temple of a million mirrors*' and it attracts tourists from across the world.

Although not called *Kanch Ka Mandir* there are quite a few other glass temples in India. For example, the glass temple at Koottamundu, Kerala.

The use of glass to decorate temples is not restricted to India. The *Arulmigu Sri Rajakaliamman Glass Temple* in Johor Bahru, Malaysia is a stunning example of how glass can transform the appearance of a structure. About 90 per cent of the temple is embellished by 300,000 pieces of red, blue, yellow, green, purple and white glass.

The *Crystal Mosque* or *Masjid Kristal* in Kuala Terengganu, Terengganu, Malaysia is a lovely building made of steel, glass and crystal. The mosque was officially inaugurated in February 2008 by the 13th Yang di-Pertuan Agong, Sultan Mizan Zainal Abidin of Terengganu. Interestingly, India too has a glass mosque. This one, named *Madina Masjid* is located in Shillong, Meghalaya.

The glass decorations in *Gurudwara Data Bandi Chhod*, Gwalior have merited great appreciation from all who have seen it.

The Brahmo-Samaj *Upasana Griha* or hall for prayers at Shanti Niketan, was constructed by Maharshi Debendranath Tagore in 1863. The *Upasana Griha* is made of coloured Belgian glass and locally it is also known as *Kanch Ghar*.

The *La Estancia Glass Chapel* of Cuernavaca, Mexico is a chapel with frosted and latticed glass walls. The end wall contains a cross set into the glass. It is serene and beautiful; also a very popular location for weddings. The Crystal Cathedral is a church building in California, USA. This glass building was designed by American architect Philip Johnson. It was completed in 1981.

In 2016, Taiwan inaugurated a church building that was designed to look like a high-heel slipper. Made of glass, this beautiful blue structure uses over 320 tinted glass panels. The Cinderella's slipper lookalike building is over 10m wide. It cost about US$ 686,000 to build. However, it was announced that the building will not be used for regular services, but only for pre-wedding photo shoots and wedding ceremonies.

Although not made entirely of glass, many churches have brilliant stained-glass windows. A stained-glass window consists of pieces of coloured glass held together in a latticed web of Lead. Stained glass flourished in England until the 1540s and continued to be made in the 17th and 18th centuries. Then the craft declined. In the 19th century, there was a serious attempt to rediscover the lost techniques of the art.

Fabulous examples of stained glass can be seen in many historic abbeys, churches and cathedrals of Europe. Yet, few tourists are aware of the extraordinary measures taken to preserve these irreplaceable works of art during the Second World War and just how much was irretrievably lost.

Construction of the *Cologne Cathedral*, Germany, was begun in 1248 and completed in the 1880. The Cathedral's stained glass windows are world famous. Unfortunately, not all the coloured glass that originally decorated this Cathedral has survived unscathed the passage of time. In the 18th century some stained glass was removed in the course of a redecoration programme and replaced with white glass. Then, during the Second World War, the Cathedral was bombed at least fourteen times. Precious glass artwork was reduced to smithereens and lost forever. Plain, unadorned glass was put up in the southern window to replace the priceless stained-glass window destroyed during World War II.

A UNESCO World Heritage Site since 1996, the Cathedral is a much-loved heritage building. In 2007, German artist Gerhard Richter designed a 20 m tall work to replace the plain glass window. He used 11,500 squares of glass in 72 colours; much like pixels, to gift the Cathedral, a "window for eternity." He waived his fee but even then, the entire cost came to around €370,000.

In England too, bombings during the Second World War destroyed many historic examples of stained glass. Such shattered ancient stained-glass windows in *Westminster Abbey* were replaced with new windows by the British artist to mark the 60th anniversary of the coronation of Queen Elizabeth II. The blue and gold coloured windows incorporated designs of stars and lilies. These windows were the first to be commissioned by

Westminster Abbey in more than a decade. The new windows were installed in the 16th century *Lady Chapel*.

Restoration efforts are also needed to reverse the effects of time; sometimes previous restoration efforts call for interventions using modern techniques. Twenty-four metre tall and about the size of a tennis court, the 311-panelled Great East Window at *York Minster*, is the largest expanse of medieval stained glass in Britain. It showcases the master-piece of the 15th century master glazier and stained glass artist, John Thornton which has enthralled visitors for six centuries. During recent restoration attempts it was found that over the years, extra Lead had been used to stabilize the glass panels that were coming loose. Restorers removed the extra Lead that had obscured the coloured glass. Now more light passes through and the paintings appear brighter than ever.

The *Basilica of San Vitale*, Ravenna, Italy, is today on the UNESCO World Heritage List. This was where a clear glass roundel with a depiction of Christ was discovered. It was dated to the 6th century. This is thought to be the world's first find of ecclesiastical stained glass.

In India too, glass has been used with great decorative effect. Tourists flock to see the *Aina Mahal*, built in 1752, in Bhuj, Gujarat, India. *Aina* means Mirror and *Mahal* means Mansion... descriptive terms that define its appearance. The white marble walls of the palace are covered with mirrors, gilded ornaments and Venetian glass. Not many know that the chief architect and designer of *Aina Mahal* was Ramsingh Malam. Malam's life was an adventurous one. Shipwrecked; he was lucky enough to be rescued by a Dutch ship that took him to the Netherlands where he learnt to work glass. He soon became an expert in tile work, glass blowing and enamel work. On his return, after 18 years in Europe, he was fortunate again, to have the patronage of the Ruler, Maharao Lakpatji. One of Malam's first tasks was to create a hall of mirrors in the old *Darbargarh* (royal enclosure).

Almost a century after *Aina Mahal* came into existence; Great Britain stunned the world by building a huge pavilion of glass named the *Crystal Palace*. In 1851, Great Britain wanted to celebrate its role as an industrial leader and so organized a huge exhibition of products which had to be displayed attractively. A huge cast iron and plate glass building was built to house all the exhibits. It was the largest glass structure the world had ever seen till then. Sir Joseph Paxton was the architect who designed the *Crystal Palace*.

The *Crystal Palace* had many windows. Some believe that technology had advanced enough to make this possible. Others think this was not so much because of an advance in technology but because of the repealing of the tax on windows and window glass. This tax was a sort of proxy income tax because only the very-rich could afford to have many windows and glass panes and so, only they had to pay this tax.

The repeal of this tax meant that the *Crystal Palace* did not cost quite as much! While this may be true, it is also pertinent that advances in technology allowed large-sized glass panes to be made. According to Wikipedia, the shape and size of the entire building was directly based around the size of the panes of glass made by the supplier, Chance Brothers of Birmingham. These were the largest available at the time, and were 25.4 cm wide and 125 cm long. The entire building was scaled around those dimensions. Almost the entire outer surface was glazed using millions of identical pane; at drastically reduced production cost. Serendipitously, the Bessemer process of steel making facilitated the incorporation of steel into architectural structures. A Chicago engineer named William Jenney devised a method of steel framing towards the end of the 19th century that gave birth to the technology of high-rise buildings. Steel frames, and not the walls, supported the weight of the buildings. So, various non-structural materials could be used to cover the building and give it an artistic appearance. This came to be known as curtain-wall because the non-load-bearing material was simply hung from the structure like a curtain. The advantage of using glass as curtain-wall is that it allows natural light to enter. The glass walls on the external facade, gave the modern buildings an entirely new look; something the world had not seen previously...and people everywhere fell in love with the look.

An heirloom example of glass curtain architecture is the Mexican hothouse at the Jardin des Plantes. It was built by Charles Rohault de Fleury in 1836. In 1864, Architect Peter Ellis designed the *Oriel Chambers* in Liverpool, UK. It was the world's first building featuring a metal framed glass curtain-wall. It was not well-received at the time but history has been kind to it. Today, the *Oriel Chambers* is preserved as part of UK's heritage.

The *Glass Pavilion* was a pineapple-shaped, multi-faceted structure built in 1914 for the *Deutscher Werkbund* Exhibition held in Cologne, Germany. It had a fourteen-sided base constructed of thick glass bricks and a metal staircase with glass treads. The interior was studded with prisms that gave rise to coloured rays when sunlight streamed through these. The floor- to-ceiling coloured glass walls were mosaics. The *Glass Pavilion* was designed by the German architect Bruno Julius Florian Taut. Even at that early date, the purpose of this building was to demonstrate the potential that different types of glass had in architecture.

In 1918, American architect Willis Jefferson Polk designed a seven-story glass façade for the *Hallidie Building* in USA. The façade consisted of glass panes suspended in a steel grid. Concrete sills supported by anchors carried the weight of the glass skin. It has been recently restored. Even today, people look at with wonder.

The *Louvre Pyramid* is a large glass and metal pyramid, surrounded by three smaller pyramids, situated in the main courtyard of the Louvre Palace in Paris, France. The large pyramid serves as the main entrance to the Louvre Museum. The *Louvre Glass pyramid* was designed by the Chinese-American architect Ieoh Ming Pei. It is made of unusually clear and colourless glass made to order by St. Gobains. It is one of the most iconic of all modern glass structures.

Another modern building which immediately made it to the top of the news was the house designed by Croatian-

Czech architect Vlado Milunić, in collaboration with Canadian-American architect Frank Gehry. This glass-fronted house in Prague, Czech Republic looks like a couple dancing. Its design was a tribute to the dancing stars Fred Astaire and Ginger Rogers. *The Dancing House* was also, for a while, called 'Fred and Ginger.'

The Gherkin is the nickname of a 180 metre tall office building that was inaugurated in London in 2004. It was designed by Norman Foster. The building has a steel frame and a glass facade with diamond-shaped panels. Most of the panes of glass are completely flat - the only curved glass is the 'Lens': a structure at the very top of the building. *The Gherkin* makes maximal use of natural sunlight. Wind pressure differentials generated by *the Gherkin's* especial design assist natural ventilation and reduce the need for air conditioning. It uses energy efficient methods; consuming half the amount of power that similar sized buildings would use.

The *Giant Egg* or the National Centre for the Performing Arts, in Bejing, China was designed by the French architect Paul Andreu in 2007. This building used over 18,000 Titanium plates and more than 1,000 sheets of ultra-white, low-Iron glass with a high rate of light transmission. It is surrounded by an artificial lake. The ellipsoid Titanium shell is divided in two parts by a segment of curved glass. The glass ceiling throws light that shimmers in the lake. The *Giant Egg* is connected to the shore by a 60-meter long transparent underpass that goes under the lake.

Another example of contemporary architecture that incorporates the use of glass is the *Great Glass House*, housed in the National Botanic Garden, Wales. It resembles a giant raindrop and was built in 2000. This building was designed by Norman Foster and Partners. It is the largest single span glass house in the world; being 110m long and 60m wide. The dome consists of 785 panes of glass. Each glass plane has two 9mm thick sheets of glass with a laminated film in between making a 19. 5 mm glass sandwich.

The glass *Reichstag dome* constructed on top of the rebuilt Reichstag building in Berlin provides a 360-degree view over the city. It was designed by architect Norman Foster and built to symbolize the reunification of Germany.

One of the iconic buildings in Montréal, Canada is the *Palais des Congrès*. It has a striking glass exterior made up of 332 glass panels in different colours and 58 transparent glass panels in the interior. Visitors have likened its pink, orange, yellow, green, and blue facade to a kaleidoscope and on sunny days, to psychedelic rainbows!

City Hall is an onion-shaped glass building in central London. It is the headquarters for the Greater London Authority. City Hall was designed by Norman Foster and it threw open its doors in 2002. *City Hall* uses 3,844 panels (7,300 sq m) of triple- glazed, low-emissivity coated clear glass. Each glass panel is unique and was cut by laser to give its exact shape and size. The unusual design of City Hall has earned it the love of admirers and the ire of detractors alike. Those who dislike its unconventional sideways egg-like shape have derisively called it the *Glass Gonad* or even the *Glass Testicles*. However, those who admire it have hailed it as an example of modern architecture that will stand the test of time.

The *Ciudad de las Artes y las Ciencias* (City of Arts and Sciences) is a cultural complex and tourist destination in Valencia, Spain. The complex features three glass buildings, including a cinema, planetarium and a museum. The building is designed to resemble a giant eye with an eyelid that opens to access the water pool. The bottom of the pool is glass which deepens the illusion. The *Health Department's Building* in Bilbao, Spain, has been described as an origami-like folded glass building. The folded facade has two layers. The outer one is a glazed skin made of glass set in tubular frames. The inner layer contains the windows. There are two major benefits to the design: noise reduction and energy efficiency. The third of Spain's celebrated glass buildings is the *Hotel W* also known as *Hotel Vela (Sail)* in Barcelona, which was opened in 2009. It looks like a gigantic sail-boat and was designed by Catalan architect Ricardo Bofill. Its real beauty lies in the manner in which the sea is reflected by the Hotel's facade.

The Sage Gateshead on the bank of the River Tyne, UK, is a landmark centre for hosting musical performances. Not only does *The Sage* boast of superb acoustics, but it is a stunning piece of architecture as well. Designed by Foster and Associates in partnership with Arup Acoustics, the building was completed in 2004. It has a spectacular curved steel roof that uses 3,000 stainless steel and 250 glass panels. The 200 metre long, coloured glass balustrade at *The Sage* follows the curves of the building's roof. It was designed by London-based architectural glass artist Kate Maestri.

John Hancock Tower, or *The Hancock*, is one of Boston, USA's most significant landmarks. Designed by American architect Henry N. Cobb of I.M. Pei and partners, *The Hancock* is an all-glass skyscraper that provides a breathtaking 360-degree panoramic view. It was built in 1976. Since minimalism was the goal, this building used the largest glass panes available. In the early days, the building was plagued with the problem of falling glass panes due to high winds. However, later this issue was resolved albeit exceeding the budget in the process.

There are quite a few houses that have maximized the use of glass to such an extent as to qualify for the term glass house. For example, Farnsworth House, USA; Bloch Building (The Nelson-Atkins Museum of Art), USA; Glass Pavilion House, USA; House Cafe Kanyon, Istanbul, Turkey; Leonardo Glass Cube, Germany; Neo Solar Power Corporation, Hsinchu Science Park, Taiwan; Dune House, England; The floating Watervilla de Omval, Amsterdam, The Netherlands; Villa Kogelhof, Noord-Beveland, The Netherlands; Glass Concept Home, Milan, Italy and the colour-changing Opera House, Reykjavik, Iceland, to name just a few.

Sometimes the interiors of houses are decorated with luminescent glass tiles that absorb light and then give off a glow for 6 to 8 hours. These tiles are often incorporated into the walls, especially in bathrooms and in nurseries.

Glass staircases have been installed in many glass houses but most of these use glass plates at the sides of the steps to support the entire structure. Then there are glass staircases that use tempered glass steps and stainless steel banisters or else structural glass and wooden steps. The more sophisticated glass staircases even have LED lighting built into the glass treads. Now, Asahi Glass (AGC) has created the world's first glass spiral staircase, using a suspension structure. The spiral staircase is transparent and the glass steps appear to be floating in the air.

A glass floor is a transparent section of a floor. Glass floors are usually seen in the airports and in the observation decks or in boats in order to facilitate direct viewing of what lies beneath. Glass floors allow light to pass through and this reduces the need for artificial lighting; reducing energy demand. However, care has to be exercised to prevent users from slipping. An etched or textured surface improves grip and protects against this danger. Super-hi-tech gyms have glass floors with LED lighting to define 'boundaries' for better viewing by players. Other potential uses of such floors include illuminated escape routes during emergencies, programmable dance floors and mood lighting.

For those afraid that a glass floor may crack or break, the *CN Tower*, Toronto, Canada assures visitors that their glass floor is five times stronger than the required weight-bearing standard for commercial floors and that it can actually withstand the weight of 14 large hippos. The *CN Tower's* glass floor was the first of its kind in the world. It allows visitors to stand 113 storeys above the ground. The Sky Pod is 33 storeys above this and visitors can get a 360-degree view of Toronto's skyline from here. Finally, it has the Edge Walk: the world's highest full circle hands-free walk. This is on a 1.5 m ledge that encircles the main pod: 356 m above the ground. In 1995, the American Society of Civil Engineers recognized the *CN Tower* as one of the Seven Wonders of the Modern World.

From floors to bridges is quite a jump but one that glass appears to have bridged quite easily. The *Chihuly Bridge of Glass* is a 150 m covered footbridge in Washington, USA. It was opened in 2002. Aptly named, this bridge links the Museum of Glass to one of the busiest areas of the city. Arthur Andersson designed the bridge in close collaboration with glass artist Dale Chihuly, whose artistic idea it was. The Seaform Pavilion is part of the *Chihuly Bridge of Glass*. It comprises a ceiling made of 2,364 glass objects suspended in midair. At the far end of the *Chihuly Bridge of Glass* is the Venetian Wall. This displays 109 Chihuly glass sculptures and boasts of some of the largest blown-glass works ever executed.

An elevated bridge-like walkway that is used to cross a large space, a street or one that links two buildings is called a sky-bridge or a skywalk. Skywalks are excellent as observation decks too. *The Grand Canyon Skywalk* in USA which was inaugurated in 2007 is an example. This Skywalk has a deck built using four layers of St. Gobain Diamant low Iron glass with DuPont SentryGlas interlayer. The glass railings, built to withstand high wind pressures, are made with the same glass as the deck, but are bent to follow the curvature of the skywalk. The foundation of the Skywalk can support the equivalent of 71 loaded Boeing 747 planes or an 8.0 magnitude earthquake within 80 km.

Step into the Void, a five-sided glass skywalk on top of the Aiguille du Midi peak, near Chamonix, France is billed as 'the tallest attraction in Europe.' It gets its name from the fact that when visitors step into the minimalistic glass cube there is literally nothing between them and the one kilometre sheer drop; other than the 12 mm platform of glass enforced by steel frames. Definitely not for those suffering from vertigo!

And if that is not enough, China has designed a skywalk 1432 m above sea level on the side of the Tianmen Mountain in Zhangjiajie. On one side is a sheer rock face and on the other a straight plunging drop. Tourists, even those who wish to experience *walking on air* find it dizzying to look down through the transparent glass. However, the cleaners routinely dangle below the skywalk as they work to keep the glass clean. Other equally fabulous skywalks in China are: *Sky Arena 94, Sky Walk 97* and *SkyWalk 100*.

The *Willis Tower* (formerly the Sears Tower) in USA welcomes about 1.3 million visitors annually to *The Ledge*; a series of glass bays on *The Skydeck* that allow visitors to stand 103 floors over the road below.

However, the innovative uses of glass in buildings do not end with facades, interiors and skywalks. Maverick artists across the world are stretching the boundaries of the possible to create the fantastic.

Built out of 1.5 million glass bottles, the Wat Pa Maha Chedi Kaew Buddhist temple in Thailand has surely earned its title *Temple of Million Bottles*. Glass bottles were used to not only build the main structure of the temple, but also a crematorium, shelters and toilets. The caps on the bottles were used to make lovely mosaics on the walls. The best part is that once word got out, contributions of coloured glass bottles began to arrive in a steady stream, so there was no dearth of raw material.

Interestingly, in 1952, David H. Brown had built a clover-leaf shaped *Glass House* out of 500,000 empty embalming fluid bottles. He had headed a funeral business and decided to use all the empty embalming fluid bottles to build a Glass House on the shore of Kootenay Lake in Canada. It was built by orienting a single layer of bottles with the short neck towards the inside. Strips of wood were wired between the necks and reinforced with cement. A similar building is the *Bottle House*, in Ganja, Azerbaijan. Decorations include a portrait in poignant memory of a family member missing since the Second World War.

Another house of bottles was built in Michigan, USA, by John J. Makinen who was the owner of Northwestern Bottling Works. He used over 60,000 glass bottles to create this stunning piece of art in 1941. Although the words 'Happy Home' are spelled out using brown bottles surrounded by a border of green; John Makinen died before he could move in. It now houses the exhibits of the Kaleva Historical Museum.

Another house built of bottles is the *Six-Gabled House* on Prince Edward Island, Canada. It is made up of about 12,000 bottles cemented together. It was built by 66 year old Edouard

Arsenault who went on to build the Tavern (8,000 bottles) and the Chapel (10,000 bottles). The Chapel also has pews and an altar. These three buildings were built during 1981-1984.

However, Grandma Prisbrey's Bottle Village in California, USA perhaps takes the cake as far as bottle houses are concerned. It is a wonderland of recycling, primarily of glass bottles and consists of shrines, wishing wells, mosaic walks, and myriad other structures such as Leaning Tower of Bottle Village, the Dolls Head Shrine, Cleopatra's Bedroom, and the Round House. Tressa Prisbrey or "Grandma" began working on this project in 1956 when she was 60 years old. Apparently, she had a very large collection of commemorative pencils and wanted to house these safely but could not afford construction material. She soon realized that discarded bottles could be used innovatively and artistically and that these could be procured free from local dumps. In February, 1981, the *Bottle Village* was declared a California State Historical Landmark. In 1994, the *Bottle Village* was badly damaged by an earthquake but has been reconstructed and is now open to visitors.

The *Morrow Royal Pavilion*, Las Vegas, USA was built by entrepreneur Scott McCombs, founder of Realm of Design, using more than 500,000 beer bottles. The glass bottles were crushed, mixed with flyash and formed into a concrete-substitute called Green Stone, which was used to build the structure. The project saved landfill space calculated to be equal to eight to ten football fields piled to the top of the goal post. This re-used glass building is a replica of the English castle *Swarkestone Manor*.

However, with more and more glass being used in buildings, concern has been voiced about birds dying in large numbers after dashing into architectural glass. Environmentalists are alarmed about that fact that birds dash into glass, often with instantaneous fatal results. Apparently, in USA alone, millions of birds die directly because of collisions with glass. After colliding with a glass surface, most injured birds fall prey to scavengers. Glass researchers have now introduced patterned, UV reflective coating which acts as visual markers for birds but remain virtually invisible to the human eye. Hopefully, bird-friendly glass will have a positive effect on the urban avian population.

Apart from the need to be friendly to avifauna, there are two other issues that keep popping up when glass is discussed in the context of architecture. The first is energy efficiency and the second is the cost of upkeep.

John Straube, building science consultant and Professor at the Department of Civil Engineering and School of Architecture at the University of Waterloo, Canada, has sounded another alarm. According to him, maintenance costs will shoot up as the buildings age. The windows will fog up, and the cost of replacing entire walls of glass will be prohibitive on high-rise structures.

Non-existent or inefficient insulation is the main cause of excessive energy use in buildings. In glass-clad buildings, a lot of attention has to be paid to the glazing, caulkings, sealants and the glass itself to make the building energy-efficient.

Glass wool solutions are available for efficient insulation in different parts of the house. Innovations in window and door glass coatings and insulated glazing provide energy efficiency. Two of the most important innovations are double-glazing and Low emissivity glass. Double-glazing uses two thicknesses of glass separated by an air space to improve insulation. Most double- glazed windows are good insulators that do not allow the interior to fog. In triple-glazing, a third layer of glass is used. Low emissivity glass, or low-E glass is specifically designed to keep interiors more comfortable in winter. Emissivity is a measure of a surface's ability to absorb/ reflect radiant energy. The lower the emissivity, the better is the insulation effect in regard to heat loss. A clear window coating is applied to one side of the glass in dual-pane windows.

Then there is Smart Glass. When activated, this type of glass changes from transparent to translucent, blocking some or all wavelengths of light. For example, SPD Smart Glass uses the suspended particle device to adjust transparency to the level desired in the blink of an eye, regardless of the window size. Basically, such windows are made up of two panes of glass with freely-floating nanoparticles in between. A conductive film is applied to the glass. When no electric current is applied the nanoparticles are randomly oriented due to Brownian motion and absorb over 99 per cent of the visible light hitting the window. When electric current is passed via the conductive film, the nanoparticles align in a straight line and allow light to flow through. Once the electricity is taken away, they move back into a random pattern and block light.

Not only does glass make a building look beautiful, but specialized glass can also be used to introduce desired features. For example, glass such as Pilkington Optiphon™ or ViridianVLam Hush™ range can be used to cut down noise from sources such as traffic, aircraft, trains, factories or even, neighbours.

Then, there are glasses which have special coatings that allow them to be self-cleaning. The first of such glasses was developed by Pilkington in 2001 (Pilkington Activ™) but other companies released similar products shortly. According to the company, Pilkington Activ™ works in two stages. The first stage is 'photo-catalytic.' The term 'photo' indicates that sunlight is the agent that reacts with the coating to break down organic dirt. The second stage is 'hydro-philic.' The term 'hydro' indicates that water plays an active role. When rainwater hits the glass, it does not form drops. Instead, it forms an even sheet of water that runs off taking the dirt with it. The wet glass dries quickly and evenly with no apparent streak marks.

An issue holding centre-stage today is safety; especially in these intolerant times. Window glass, in particular, has come in for scrutiny because it is known that flying shards of glass following an explosion add substantially to injuries. So, bomb-resistance and bullet-resistance seem to be the two additional parameters that scientists are seeking to engineer into glass.

When an explosion is set off, there is an enormous rise in air pressure; albeit briefly. The explosion typically gives rise to a wave that rises almost instantaneously to a very high peak pressure but falls back to zero in a few milliseconds. Bomb-resistant glass can resist buckling and shattering when the air pressure peaks instantaneously. Instead of breaking, the glass absorbs the impact. It does not shatter. Multiple layers of plastic film lamination in the glass stop objects thrown up or out by the blast. However, repeated explosions will finally cause the glass to collapse, no doubt.

Bullet resistant glass can resist penetration by a specified type of bullet. It also restricts the flying shards of glass leaving the rear-face so that injury to the person standing behind such glass is minimized. However, such glass will eventually be penetrated by bullets so it is advised that the person move away before the glass is finally breached.

That toughened, laminated glass is a good choice to provide a certain level of safety is well-recognized. However, such glass can be notoriously thick. For example, according to Wikipedia, US President Obama's new Presidential car (nicknamed *The Beast*) has bomb-proof glass that is 12.7-cm thick...that is far thicker than an average paperback novel and more like a telephone directory. Not all cars can use such thick glass.

It is definitely good news that Indian-origin scientist Sanjeev Khanna, working at the University of Missouri College of Engineering, USA, is developing and testing a new type of blast-resistant glass that will be thinner, lighter and less vulnerable to small-scale explosions. The aim is to develop glass that will be less than 13 mm thick. This type of glass sandwiches long glass fibres between two thin sheets of glass. This is as strong as the thick glass, but definitely more convenient to install in normal buildings and cars. The researchers hope that this glass may provide added protection during earthquakes and cyclones, etc.

There is more good news for architectural glass. A team from the Wyss Institute for Biologically Inspired Engineering at Harvard University and Harvard School of Engineering and Applied Sciences has reported a new transparent, bio-inspired coating that makes ordinary glass tough, self-cleaning, and incredibly slippery. The new coating could be used to create self-cleaning windows and improved solar panels not to mention better contact lenses and new medical diagnostic devices. The new coating improved upon the technology known as Slippery Liquid-Infused Porous Surfaces (SLIPS).

SLIPS was inspired by the carnivorous pitcher plant, which has ultra-slippery leaves that lead to a 'pitcher' where insects fail to get a grip and slide into the pitcher to drown in enzyme-rich fluids. So, SLIPS is a Bio-inspired technology. SLIPS's thin layer of liquid lubricant allows liquids to flow easily over the surface. SLIPS also repels oil, sticky liquids and resists ice formation and bacterial bio-films as well.

SEVASA makes CriSamar® STEP Slip-resistant floor glass that can also be used for pretty and pretty safe flooring. Accidents arising from slips and falls, particularly when the floor is wet, are very common. This is because of a phenomenon called aquaplaning, which happens when there is a loss of traction because of the layer of water that is present between the feet and the surface. Slip-resistant glass can be used on floors that can get very wet, for example, the perimeter of swimming pools or bathing areas. The German ramp-testing method tests the safe angle for a person to walk on a ramp covered with a soapy solution without slipping. According to the angle obtained, the glass is classified into three ratings: A, B and C.

According to the manufacturers, CriSamar® STEP has specific textured designs for excellent drainage which channels the water. It also prevents aquaplaning, thanks to the texture that increases grip when the surface becomes soaked. LITE-FLOOR is another slip-resistant safety glass made by Saint Gobain. Walker Textures™ is acid-etched anti-slip glass manufactured by Walker Glass. Acid-etching eats away the glass to varying depths giving rise to beautiful translucent designs as well as facilitating 'grip' on the surface. There are many other manufacturers producing glass with anti-slip properties.

Glass is also being explored as a way to generating electricity. Such type of glass can be used to generate electricity from light. Many companies and researchers are working in this field.

One such is Victor Rosenberg, founder of Tropiglas Technologies, Perth, Australia, who along with Professor Kamal

Alameh and team at the Electron Science Research Institute, Edith Cowan University, Australia, are developing and testing Photovoltaic Glass. Currently, they have been able to produce about 50 watts per square metre from the glass, capturing just the infrared and UV part of the light.

It does appear that the traditional uses of glass are being replaced by newer and more innovative ones. The rules of the game of architecture are being changed and glass is emerging in bold avatars. Till recently, one piece of advice seems to have come through time almost unmutated. It is the saying, "Those who live in glass houses should not throw stones." Perhaps it should be revised, as posts on the Internet suggest, to: "Those who live in glass houses should use reinforced glass!"

11

FUN FACTS AND FUTURISTIC FIRSTS

Glass pops up in pretty interesting reports on Earth and the Moon. It also makes headlines in scientific papers on extra-solar planets. It unites Kings and commoners and is equally at home in the hands of easily-pleased kids, the connoisseurs of art, dedicated scientists, computer geeks, great beauties and the ugly rich. From Australian Aborigines whose traditional lifestyle is in stark contrast to that of sophisticated scientists who have the resources and ability to use even the vast reaches of space as a laboratory, no one is immune to the spell cast by glass.

Archaeologists at the Australian National University think that Australian Aborigines used European glass beads as currency. Apparently, Maccasans, from the Indonesian island of Sulawesi, used to sail to Australian waters to harvest sea cucumbers. The Aborigines took these beads as payments in return for allowing the Maccasans to fish in their traditional fishing grounds. Radiocarbon dating traces these beads to the 18^{th} century. Glass beads were used for trading in Africa too.

As European glassmaking technology developed; brightly coloured beads became easy to produce. Europeans saw glass beads as cheap and inexpensive trinkets made of blobs of melted glass. To them, the 'value' of these beads would have been just the cost of the raw material and labour. However, to the indigenous populations elsewhere these beads had symbolic 'value'. So, they greatly prized these beads.

The crafty European explorers gifted glass and ceramic beads to native Americans and also used beads for trade with them. On 12 October 1492, Christopher Columbus not only gave the natives of San Salvador Island some glass beads but also recorded it in the logbook. This is the earliest written record of glass beads in the Americas. In reciprocation of rich gifts received, the Spanish explorer Hernán Cortés de Monroy y Pizarro gifted glass beads and other paltry stuff to the Aztec Emperor. Spanish conquistadors and explorers Pánfilo de Narváez in 1527 and Hernando De Soto in 1539 used glass beads for trade with the native inhabitants of Florida, USA.

A special type of bead made for gifting to the natives was the Venetian chevron bead in red, blue and white; rarely also in green, black and yellow. Venetian chevron beads have been traded throughout the world, most heavily in West Africa, where they were first introduced by Dutch merchants in the late 15th century. These beads were a rarity in Africa and were avidly sought after. The indigenous people often used these glass beads to make decorative art objects, for the elite. Aggry beads are a type of decorated glass bead from Ghana. British envoy, T. E. Bowditch, who visited Kumasi in South Ghana in 1817, reported that those at court were richly adorned, "The sun was reflected ... from the massy gold ornaments...some wore necklaces reaching to the navel... entirely of aggry beads..." The Krobo tribe of Ghana still tie a multicoloured string of ancient Venetian glass trade beads around the waist of a new-born to ward off disease and the evil-eye.

Many tribes in Africa practice the traditional art of making different types of beads using recycled or powdered glass, although glass beads have had a dark past. Trade beads used in Africa are also called 'slave beads' because these were exchanged for slaves. Outbound ships carried beads as ballast and on the return journey, they carried human cargo plus ivory and Gold.

Glass effortlessly bridges the distance between slaves and Emperors. The terrestrial triumphs of Alexander the Great are well known; his under-sea exploits are not! *Alexander Romance*, probably written in the 3rd century AD, is a partly fictionalized account of his reign. Many such 'romances' were written over time. In one such illustrated manuscript from the early Middle

Ages, Alexander the Great has been painted sitting inside a glass diving bell lowered into the sea. The denizens of the deep look at him with the same curiosity with which he surveys them. Alexander's subjects would no doubt argue the fish and other aquatic creatures had gathered to pay homage to the great conqueror.

Most historians believe that Alexander the Great did not actually make such a trip. However, his Guru Aristotle was greatly interested in diving bells: the great-grand daddy of the modern submarines. He describes in verse the diving bell that his protégé used. It was "...a very fine barrel made entirely of white glass..." which was towed out to sea and lowered into the water. Another story regarding Alexander the Great's ventures underwater was published in 1886 in France. This claims that Alexander, then aged just eleven years, entered a glass case, reinforced by metal bands and was lowered into the sea by a chain.

From India comes the story of *Mahabharata* in which a fabulous palace has been described as having been built at Indraprastha. The palace had walls made of glass so transparent that Duryodhana, the eldest Kaurava Prince walked right into it. Mistaking a glass pool for a pool of real water, Duryodhana even rolled up his clothes least it get wet. Apparently, Draupadi had a good laugh over all this and her laughter spurred Duryodhana to exact vengeance; ergo the Kurukshetra War. The blame game is a bit hard to swallow but perhaps not for those who suffer from the pathological disorder named Hyalophagia.

Hyalophagia or hyalophagy refers to the eating of glass. The term is derived from the Greek words *yalos* meaning glass and *phagein* meaning to eat. Eating glass is dangerous as the sharp fragments may perforate the gastro-intestinal tract with fatal consequences. However, despite the inherent dangers of the practice, some people have been known to eat glass regularly, chomping light bulbs and tubelights with aplomb. This does not mean, however, that their displays need to be imitated because glass is not meant to be eaten. However, the culinary experts may try making glass potato chips, which are made of deep-fried potato starch and look amazingly akin to flat coin-shaped bits of glass. Recipes are freely available on the Internet.

Of course, bacteria have been living off glass for ages... although it is only recently that science has discovered the fact. About 5 per cent of the oceanic crust is made up of volcanic glass, long ignored as a hospitable habitat. A report was published in 2001 about the characteristics of *glassy* Silica rock created from lava ejected from deep-water volcanic vents. It is called *glassy* because it resembles Obsidian. Photomicrographs showed that this glass exhibited thin and irregular as well as smooth and broad channels. These are thought to have been made by microorganisms that have been *eating* the glass, using it as an energy source. The researchers explained that as bacteria *ate* the glass, the metabolic processes released acid that corroded the glass, creating pits, granular texture, and tiny tunnels. Although the interpretations of the results are still being debated, the prospect of glass–eating microbes and others of their ilk, i.e., microbes that derive their energy from inorganic chemical reactions raise the hope that life may be found in space after all. While the search for microbial life in space occupies scientists studying glass-eating microbes, British artist Luke Jerram has created huge glass sculptures of viruses, bacteria and other microbes. Stunning, not just because of the scale to which these have been sculpted, the sculptures are scientifically accurate too; revealing details that till now had needed an electron microscope to be seen. Jerram's artwork has graced the cover of *Nature* and been given pride of place within the covers of *The Lancet* and *The New York Times*, etc.

Polish artist Marta Klonowska does not just sculpt glass; she carefully assembles innumerable needle-like shards of glass into beautiful animals frozen in dynamic movement. Then she uses a metal frame and a net mesh to create an outline; adding the shards one by one. Her meticulous insertions of the individual shards give rise to textures reminiscent of fur. She derives inspiration from paintings by artists such as Peter Paul Rubens and Francisco de Goya.

Earth-bound glass artists would no doubt line up to visit, if that were possible, the second blue dot in space: a planet where it rains glass. Earth has been called "...pale blue dot" by astronomers who have seen it from space. Now, the Hubble Space Telescope has discovered another blue dot of a planet orbiting the star HD 189733, about 60-63 light-years from Earth. However, unlike on Earth where it rains pure aqua, rainstorms of glass are the hallmark of the new planet. Incidentally, it also has a surface temperature of almost 1000°C and wind-speeds here can reach 7000 k/h. Scientists say that the lovely deep azure hue is the result of Silicate (glass) rain in the atmosphere, which scatters blue light.

And since visiting this planet is not on the cards immediately, perhaps they would like to turn their gaze to our nearest celestial neighbour, the Moon. Innumerable micro-meteorites impact the Moon every day. Scientists have found that tiny bubbles of glass form on the lunar surface when micro-meteorites hit it. In this context, it is pertinent to remember that the Moon has no atmosphere to slow down or burn up the meteorites on entry. Thus, the strikes are pretty violent; generating tremendous heat that melts lunar rocks leading to ejection of the melted material from the crater. Small bits of the melt solidify before they fall back on the lunar surface again. These are usually spherical in shape and quite small.

Marek Zbik of the Queensland University of Technology, Australia has discovered that there is a highly porous network of nano-glassy particles inside these glassy bubbles. When these bubbles face further bombardment by meteorites on the Moon's surface these release the nano-glassy particles, which mix with the lunar soil. Marek Zbik says that, "This continuous pulverising of rocks on the lunar surface and constant mixing develop a type of soil which is unknown on Earth."

A visit to the Moon or even the planet where it rains glass would be memorable no doubt but if memory is the objective then the so-called 'Superman memory crystal' may be used instead. Scientists from the University of Southampton, UK, have developed a new type of nano-structured glass technology and experimentally demonstrated the recording and retrieval processes of five dimensional digital data by femto-second laser writing. It is called 5-D because it takes into account the size and orientation, in addition to the three-dimensional position of the nanostructures. The storage allows unprecedented parameters including 360 TB/disc data capacity, thermal stability up to 1000°C and practically unlimited lifetime. It does seem that science is on the verge of ushering in the era of total data security where data will be protected forever.

Protection, of course, has many facets. Cancer treatment would, no doubt, play an important role in the protection of health. Samuel Achilefu and his team at the Washington University School of Medicine in St. Louis, USA have developed hi-tech glasses that help doctors 'see' cancer cells during surgery. This technology was successfully demonstrated for the first time in February 2014. For the technology to work, a molecular agent is used to target the cancer cells. This 'marker agent' attaches to the cancer cells, making them glow when viewed through the glasses. In a study published in the Journal of Biomedical Optics, researchers announced that tumours as small as 1 mm in diameter (equal to the thickness of about out 10 sheets of paper) could be detected. Better detection means that surgeons can be sure about having taken out every last tumour cell.

Taking care of one's natural beauty is also a sort of protection. Hair-care, for example, has spewed a multi-billion dollar business globally. The latest in luxury hair-care is the use of liquid glass on a nano scale to coat the hair from root to tip. The product is being advertised as being able to protect hair from damage from dust, dirt and even ultra-violet.

Security too has many dimensions. The space and aviation industries are known to insist on extremely high standards. The lenses used in Space telescopes are of exceptionally good quality. The Hubble's Primary and Secondary mirrors are made of Ultra-Low Expansion Glass (ULE). Turning glass into a mirror polished and coated to serve the Hubble Space Telescope took more than two years. A slurry made of abrasive material was used to polish the mirror surface. At every step light-beams and laser blemish detectors were used to check that the polishing was proceeding on course. As the glass approached its desired shape, finer abrasives were used for grinding and polishing. Eventually, the highly polished mirrors were given a coating of Aluminum overlaid with magnesium fluoride. This covering was one-thousandth the thickness of a human hair. The Project-leaders announced that the mirrors were so smooth that no point deviated more than a millionth of 0.0254 m from a perfect surface.

In 2013, newspapers reported that the third primary mirror of the ground-based Giant Magellan Telescope (GMT) slated for completion by 2020, had been cast in a custom-built rotating furnace heated at about 1150° C. It was unveiled at the University of Arizona's Steward Observatory Mirror Laboratory with suitable fanfare. GMT-3 as it is known, measures 7.6 m in diameter and is made of 20 tons of molten borosilicate glass. It was melted in a furnace that is also capable of being spun. Rotating the furnace as the glass begins to melt, causes the glass to take a natural parabolic shape. The furnace was spun for two whole days; then the glass was allowed to cool at the rate of one degree a day. Thus, just the cooling process took about four months. This regulated cooling prevented stresses from developing in the glass that could lead to cracks later on.

GMT-3 has a boring immediate future. Before it can begin to snoop on the secrets of space, it will have to spend an inordinately long time—till 2018 to be exact—on a slowly moving carousel even as computer-controlled devices polish it exceedingly fine. According to an estimate, once the polishing is over the mirror will be so smooth that even it is blown up to the size of continental America, its tallest 'hill' would still be just about 2.5 cm tall. When fully operational, the Giant Magellan Telescope located in Chile's Atacama Desert will boast of seven such mirrors.

Additionally, a new class of materials called 'Bulk Metallic Glasses' may be used to make shields to protect spacecrafts from the impact of small projectiles, protect electronics and secure hull integrity. Metallic glasses are alloys that have amorphous or glassy structures. This means their atomic structures are not orderly. Interestingly, these 'amorphous metals' often better the properties exhibited by 'crystalline metals' and prove to be much stronger too. Unfortunately, Bulk Metallic Glasses are highly susceptible to fatigue, which rather limit their use as structural materials. Ever since the first commercial jetliner or the de Havilland DH 106 Comet met with accidents caused by catastrophic metal fatigue in the airframes; metal fatigue has been the bugbear of the aviation industry.

It is good news therefore that susceptibility to fatigue appears to have been overcome in amorphous (glassy) metals. Researchers at the U.S. Department of Energy's Lawrence Berkeley National Laboratory, USA, University of California, USA and the California Institute of Technology (CalTech), USA, have studied this issue closely. CalTech has already commercially introduced amorphous metals under the names *Liquid metal* and *Vitreloy*. Metallic glasses could be suitable for a whole range of products that need to be flexible; including aircraft wings, golf clubs and engine parts.

The aviation industry and space research depend on computer technology. This is another field where advanced types of glasses are catalyzing a revolution. Today, computer screens, television screens, water-resistant, scratch-proof high end watches and even the display panels of mobile phones have opened up new markets for specialized glass. Corning Lotus™ Glass platform enables crisp resolutions, fast refresh rates, and bright pictures as demanded by high-performance displays. Lotus™ glass has facilitated the development of thin, portable display devices that use less power but deliver great picture quality. Corning Incorporated recently launched Jade™ to address the technical needs of high-performance mobile devices. Jade™ glass is thermally stable, which allows it to perform extremely well even at high temperatures. It is also more resistant to mechanical stress as compared to ordinary glass.

And then, there is Google Glass: a wearable computer with an optical head-mounted display that is being developed by Google. Not only are Google maps incorporated into it but the glass also responds to voice commands to find information on the Internet; this includes sending and receiving emails and accessing social media sites. Of course, Google Glass still has a long way to go but the road ahead just got smoother...literally so, for the surface transport system.

Asphalt containing glass cullet as an aggregate is called *glassphalt*. It has been in use since the 1960s. In Australia, broken glass from households, which are difficult to recycle using conventional methods, is crushed into sand-sized fragments and mixed with asphalt. Pulverized glass does not have sharp edges and is then used to reseal, repair or build roads. A simple calculation will show why glasphalt is good economics. Currently, more than 130,000 tonnes of beverage container glass is disposed of in landfills across Australia every year, with three times this amount stockpiled pending a suitable use being found. The present rate of asphalt use is nine million tonnes of asphalt annually for road construction. Thus, just 10 per cent use of glass in the asphalt mix will easily use up current stockpiles...the equation will not change even as the numbers go up over the years. Two Australian councils have recently launched construction initiatives using recycled glass in road and path. The first was in Bondi, Sydney, where the first recycled glass road was designed and approved by the NSW Road Traffic Authority and the second in Victoria. Together, the projects used up nearly 100 tonnes of recycled glass that would have ultimately ended up in landfills.

Tasmania looked to recycled crushed glass to make up for sand shortage and discovered eco-friendly alternatives to repair a highway. The city of Abilene, Texas, USA, has been extensively using pulverized glass in golf course sand traps, sand filters, pipe bedding markers, around pipes in the ground, in leachate fields, swimming pool bases, sand filtration systems to clean swimming pool water and septic system liners. The added advantage is excellent drainage provided by crushed glass.

Besides pulverizing glass, companies are also turning used glass into foam glass sheets for multifarious uses, including road-stabilization, insulation of buildings, reinforcement of slopes and building of embankments. It has been reported that recycled glass has qualities equal or superior to those of traditional abrasive media, including walnut shells, aluminium oxide, hematite, nickel slag or Silica sand. Therefore, recycled glass can replace these materials. Glass is also being used to landscape gardens; leading to the term 'green-scaping.' Pulverized glass in colour(s) of the customer's choice is offered to make lovely garden walkways, and fish tank or aquarium liners instead of the previously used gravel. Clear blue pulverized glass is also used to create faux ponds or water-bodies to beautify a garden. A word of caution may be necessary though. A few sharp-edged glass shards have been known to escape the process of pulverization and to remain successfully hidden beneath their more rounded companions.

Glass cullet can be used as an additive to clay for making good bricks. It can also be used to make *glasscrete*—a cement-based composite material and foam glass. To make foam glass, cullet is packed into moulds and mixed with chemical agents such as carbon or limestone. It is then heated. As the glass softens, the gas given off by the additive gets entrapped within the glass. The result is a 'closed-cell' structure that retains its shape after cooling. Foam glass is light enough to float in water and has been used as a substitute for cork. It is usually used for thermal and sound insulation. It is impervious to moisture, most fumes, and vermin. Cullet along with marble dust and binder resin is used to make what is known as synthetic or artificial or cultured marble. Creative uses of cullet include using these to make innovative table tops and attractive gift items. It is also used as utility bedding and laid beneath underground pipes and cables. This works as a sort of 'bedding' for the pipes, etc.

While glass made and used on Earth is finding new avatars, scientists are exploring ways and means to make glass in space and further investigate what new properties such glass can have.

ZBLAN is an exotic glass containing fluorides of zirconium, barium, lanthanum, aluminium, and sodium (**Z**r, **B**a, **L**a, **A**l, **N**a, hence the name). It is most commonly used to make optical fibre. It has been found that thin fibres of ZBLAN glass are clearer when made in near weightlessness than when made on Earth because of the effects of gravity. Now, Queensland University of Technology's (QUT) Science and Engineering Faculty has partnered with the United States Air Force to fund world-first research into the development of ZBLAN glass in space. It is believed that space-made ZBALN glass could revolutionise the way fibres are made for telecommunications and medical imaging tools.

And while some scientists are looking spacewards to create glass with more-desirable qualities; still others are looking deeper into terrestrial resources to turn waste substances into glass. Researchers at the Colorado School of Mines have patented a method to transform organic wastes such as eggshells, rice husk, wheat husk, groundnut shells and even banana peels into glass. The project began when Prof. Ivan Cornejo heard a radio broadcast about how mining for calcium carbonate posed a threat for a forest. This galvanized him, engineer Ivar Reimanis and postdoctoral researcher Subramanian Ramalingam into action. They believe that their process has the potential to meet growing global demands for Silica to make glass and other ingredients essential to industrial growth without mining the Earth anymore. The team hypothesizes that volumes of food waste worldwide may be sufficient to sustain the booming global demand for glass — requiring at least 36 million tons of Silica. The team intends to catalogue minerals that could be mined from cafeteria, hotels, restaurants and farm waste. As Prof. Cornejo says, "This opens a new way of thinking about food waste...you allow people to eat what they have to eat. Then you use their waste to make unique materials...There's no reason to continue mining, destroying the environment, when we can find many of the materials we need from waste."

And even Mother Nature seems to be enthused by the prospect of not being cut up, dug up or drilled because she is sending a slow-moving lava flow made of Obsidian glass inching its way down Chile's Puyehue-Cordón Caulle volcano, nearly a year after it first erupted in April 2012.

Puyehue-Cordón Caulle's massive rhyolite lava explosion in June 2011, and then intermittent outbursts till April 2012, made headlines. Initially, the lava advanced several metres per day, then as its thick rocky crust cooled, it slowed. The rhyolite was very thick, dry and viscous, and incredibly sticky. It solidified much like window glass... in a disorderly manner. This type of lava, rich in Silica, forms a natural glass called Obsidian when it cools and solidifies. Scientists are fascinated by the fact that the volcanic-glass lava is still creeping down the volcano's slopes at a rate of 1.5m-3m per day; a year after the volcano stopped spewing. Interestingly, this lava flow bears no resemblance to the red hot, glowing molten mass tumbling down the sides of an active volcano; devouring all in its path. This lava is more a thick, rubble-strewn mass of rock. The fact that this was the first time scientist had actually *seen* an Obsidian flow moving made it worthy of a scientific cover story.

And although none of us have seen this as yet, researchers in USA are seriously considering the creation of roads made of solar powered panels. These roads will be paved with glass panels encasing photovoltaics and LEDs and would double as a national power grid. Glass suitable for use in intelligent solar roadways will need to be strong and textured to allow tyres to grip it and for rainwater to run off. It will also need to be embedded with heating elements to melt snow, if required. In addition, it will need to be self-cleaning so that highway dust and dirt does not get in the way of its functioning. Although glass with these specifications does not exist yet, Scott and Julie Brusaw inventors of Solar Roadways are convinced that the concept will work. Glass thus is very much a part of futuristic plans of infrastructure development and sustainable generation of energy. No wonder researchers everywhere are agog with a sense of anticipation.

And if glass can fascinate scientists, can artists neglect it as a medium to explore their creative instincts?

Georgie Eva Cayvan was a stage actress in the later part of the 19th century who died young. It is doubtful that anyone in the 21st century would have a reason to remember her, had it not been for the fact that in 1893 she had become the first person in the world to ever wear a glass dress.

A contemporary description of Cayvan in her glass dress paints a fabulous picture. It says the dress was "...resplendent with softest sheen, no further ornamentations (were) requisite to the melee of harmonious glitter and lustre into which the foot lights pour(ed) their sparkling rays." This romantic and magical dress was made by the Libbey Glass Company. This unique glass garment, too brittle for everyday use, was exhibited at the World's Columbian Exposition in the Chicago World Fair in 1893...where each of the two million visitors to the pavilion was given a small spun glass bow on a stick- pin as a souvenir by the Libbey Glass Company.

Apparently, the story behind the creation of this fairytale dress in white was not all dedication to art. It also had an economic angle to it. Edward Libbey had invested $200,000 to build a glass furnace at the Chicago World Fair, but the crowds stayed away from the stifling heat of the furnace. So, Edward Libbey ordered his team to create the world's first glass dress. When Georgia Cayvan, then a top Broadway actress, became associated with the dress, the crowd made a beeline for Libbey's stall.

But it was Edward Libbey's next coup that made every fashionista of the time crave a glass garment of her own. Spanish Princess Infanta Eulalia who was a Royal visitor was interested in a gown of finely spun glass "as fine as silk, soft, white, pliable, and lustrous." When Edward Libbey presented one to her, she appointed the Libbey Glass Company, glassmakers to his Royal Highness the King of Spain. Framed for posterity, the declaration read, "Royal House of H. R. H. Infante Don Antonio de Orleans H. R. H. Infante Antonio de Orleans appoints Messrs. Libbey and Company of Toledo, Ohio, cut-glass makers to his royal house, with the use of his royal coat-of-arms for signs, bills and labels. In fulfillment of the command of His Royal Highness I present this certificate, signed in Madrid, July 15th, 1893," and is signed Pedro Jover Fovar, Superintendent of His Royal Highness's Household.

In 1713, physician and naturalist Rene-Antoine de Reaumur had commented, "If they succeed in making glass threads as fine as those of spiders' webs, they will have glass threads of which woven stuffs may be made." He would, no doubt, have been happy to have seen his prediction come true. Edward Libbey had apparently stumbled onto the secret of making glass wearable. Weaving uses threads that interlace both vertically and horizontally (warp and weft). In the glass dresses, only the weft used glass fibres. The warp was made of silk.

With both Royalty and Broadway divas being the proud possessors of glass garments, there was no holding back widespread feminine interest. According to the *New York Times*, women were in ecstasies over glass dresses and despite the expense, there was great demand for these frail fashion fabrics. Later that year, the *New York Times* declared that glass garments would become fashion fads...despite the fact that there were reports that the Infanta Eulalia never wore the dress because, "...the glass strands were apparently so fragile that the slightest effort to bend them would cause them to snap and splinter into a thousand pieces."

Interest in glass dresses continued to grow as is evident from the feature in England's *Strand Magazine* in 1902, which was dedicated to "*the most marvellous and beautiful dress in the world*," a glass dress that could actually be worn. Miss Ellene Jaqua, American opera singer acquired this dress at a cost of $1,250... an exorbitant sum in those days. The 74 yards of glass needed to weave this creation was spun in Dresden, Germany, and cut in Paris. The Strand Magazine gushed about the magical material whose "...shimmering folds dazzle the eyes and bewilder the brain of all who gaze upon the creation." It went on with its lyrical description, "Delicate shades of pale green, blue, and silver-white blend into each other with bewildering rapidity as the light falls upon the folds,...scintillates in the light."

Perhaps one of the most romantic items made of glass is the blue glass wedding dress made for Helen Nairn Munroe, a leading glass artist in Edinburgh, when she married British glass technologist William Ernest Stephen Turner in 1943. The ensemble came complete with matching hat, glass purse and glass slippers, all of which were used by the bride on the wedding day. The glass dress feels smooth to the touch, changes colour depending on the angle of light but is a trifle heavy for everyday use. The dress was made by Glass Fibres Ltd., Glasgow. However, fairytale Princess Cinderella need not feel jealous of Helen's glass slippers as these cracked and cut the bride's feet unlike the magical one which led Prince Charming to his bride! The Turner Museum of Glass at Sheffield University's Department of Engineering Materials is today, the proud custodian of this unique wedding dress.

Yet, the fad faded away...if only to show hints of re-surfacing in modern times. In 2013, Bailey's Irish Cream (Canada) recruited fashion designer Lucian Matis to create a one-of-a-kind dress inspired by its newly launched taller and thinner bottle design. Lucian Matis incorporated multi-faceted beads, flat glass, and shards of broken glass from the old Baileys bottles into his design. The elegant and sophisticated dress took a team of three skilled workers 125 hours to complete. It debuted at Toronto Fashion Week in 2013.

Earlier, designer Joseph Helmer had created glass dresses that had turned heads at the 2011 Spring Fashion Shows in Montreal. Working with master glass blower Jean-Marie Giguere, the talented designer showcased not just stunningly embellished dresses but also hosiery, bags and bodices with glass baubles.

In 2010, University of Delaware, USA, student Kelsey Pushkarewicz shook the fashion fraternity by designing a turquoise and white off-shoulder cocktail dress made of silicon-mounted glass beads. The dress was featured at Synergy Fashion

Show held at the Trabant University Center Theatre where it wowed the spectators.

Interestingly, also in 2010, artist Diana Dias-Leão exhibited her work entitled *Dare to Wear* at the Walker Art Gallery, UK. The exhibits were beautiful garments made of glass, ceramics and textiles but strictly, only for display. Although these creations cannot be worn, the artist intended the exhibits to catalyze discussion and debate about issues around beauty and body image. She believes that anorexia, bulimia, other body dysmorphic disorders are connected with issues relating to image and lack of confidence. Her message? "Even though the image is glittering, it is the person inside who is priceless."

As if taking the message one step further are the works of American artist Karen LaMonte. She is well-known for her life-size cast glass dresses. Karen LaMonte's sculptures feature just the glass dresses; no human/glass models are used. Her work is technically complex yet simply brilliant in its visual appeal. Art critics have praised her probing of the "...disparity between our natural skin and our social skin: clothing which is used to obscure and conceal, to protect the individual and to project a persona."

How glass can intrigue royalty and commoners alike is best exemplified by the glass objects created when molten glass is dropped into cold water. These tadpole-shaped objects with a bulbous head and a thin elongated tail are called King (or Prince) Rupert's drops after Prince Rupert of Bavaria who first introduced these to Britain, in 1660 as a gift for his Uncle, the King.

The cold water rapidly cools the glass on the outside of the drop but the molten glass inside takes longer to cool. Finally, when the molten glass on the inside eventually cools, it contracts inside the already-solid outer part. This gives rise to all sorts of stresses on the surface as well as inside the object. It also gives it unusual qualities, such as the ability to withstand a blow from a hammer on the bulbous end without breaking. However, even minor damage to the tail makes it disintegrate explosively.

King Rupert's drops were made in Mecklenburg, Germany, as early as 1625. However, in the 17th century it was often referred to as Dutch tears (*Larmes Bataviques* or *Lacrymae Batavicae*) because people believed these were made in Holland. These are also called Greatricks (Great-tricks) Glass, apparently because King Charles II make his subjects hold the bulb end in their palms, and then he would break off the tip. It really was a great trick to play.

King Rupert's drops successfully spanned the divide between royal amusement and scientific observation. Charles II, the Founder and Patron of the Royal Society asked its members to explain why the *chymical glasses* exploded and the scientists took up the challenge. With such intensity did they carry out their research that in 1663, a satirist composed a ballad about it :

"And that which makes their Fame ring louder
With much adoe they shew'd the King
To make glasse Buttons turn to powder,
If off the[m] their tayles you doe but wring. How
this was donne by soe small Force Did cost the
Colledg a Month's discourse."

Robert Hooke, the Society's Curator of Experiments, did the first detailed examinations of the drops. He coated them with transparent glue, wrapped them in leather, broke off their tails, and then viewed the glass fissures under his microscope. However, science had to wait for technology to catch up before an answer could be provided.

It was not until 1994 that high-speed photographic analyses of the drops showed the cracks accelerating from the drop's tail towards the head at almost 6500 km per hour. Modern scientists video-recorded the phenomenon at 130,000 frames per second. Replayed in slow-motion, the movie revealed how the glass actually explodes into fine powder even if the tail is merely scratched.

The acceleration in the pace at which technology has developed has led to many other interesting experiments. Researchers at the University of Leeds, UK, are trying to create an artificial liver made of tiny hexagonal glass plates with channels running from their edges to the centre. It will be lined with liver cells which are designed to mimic some of the functions of the liver. It will be used in the same way that a dialysis machine is used to work like a natural kidney does. Initially, the researchers want to replicate the way the real organ is constructed. Once this is achieved, they intend to study how the constituent cells function.

Of course, anatomically correct models of the organs made out of glass have long been appreciated by those in academia. For example, Gary Farlow's Scientific Glassblowing Inc can provide customized glass models to suit a customer's requirement. It has been said admiringly about Gary Fralow that he can "*make art out of arteries.*" In these models, arteries, veins and capillaries are shaped and fused together, individually, one at a time. Indeed his borosilicate glass model of the body's blood vessels is not just anatomically accurate; but also an ornate piece of art in its own right. The model can be used to simulate blood flow, demonstrate placement of catheters/angioplasty devices etc., and even test new surgical ideas.

Perhaps in a way, glass artists creating such life-like models of the organs and organ-systems of the body are taking forward the long-lost art of renowned 19th century glass artists Leopold Blaschka and his son, Rudolf Blaschka.

After a brief apprenticeship with jewellers and metal-workers, the young Leopold Blaschka joined his family's business of making glass ornaments and glass eyes. On an extended sea voyage to America, he had the opportunity to see a variety of marine life that he had never encountered before. When he returned home, he began to make impressively accurate and beautiful replicas of these creatures. Luckily for him, the Curator at the Staatliches Museum für Tierkunde, Dresden, was struggling at that time to effectively display animals without backbones. Invertebrates tended to collapse at the bottom of jars making it difficult to display them properly. Leopold Blaschka not only managed to create life-like replicas but his creations were made in dynamic stances as if the creature were alive! He began to selling models of marine invertebrates to museums, aquaria, universities and other educational institutions and soon earned a name for himself. In 1876, his son Rudolph joined him. Together they created a veritable Noah's Ark of marine invertebrates; even marine microbes. They were helped in their mission by inputs of renowned scientists such as Philip Henry Gosse and Ernst Haeckel. They studied marine creatures from the North Sea, Baltic Sea and Mediterranean Sea and also maintained aquaria at home to study the minutiae of marine specimens.

Leopold and Rudolf Blaschka were approached in 1886 by Harvard University and commissioned to create an entire botanical garden of glass plants. A most unusual clause in the agreement was that some flowers were to be shown being pollinated and some other flowers had to look realistically diseased. The work began in 1886, and took fifty years to be completed. A mixture of clear and coloured glass was used. Sometimes wire was used to hold the flower or leaf in place. Other models were given a thin wash of coloured ground glass or metal oxide(s) and heated until the material fused to the model. The final collection of 3000 models represents 847 plant species. The glass the Blaschka's used came from Thuringia, Germany and from Gablonz in Bohemia. Amazingly, when in the early 20th century Rudolph Blaschka realized that he was unable to procure glass of the quality that he needed, he simply began to produce such glass. His is indeed a unique legacy in glass.

Today, the lifelike appearance of the sculptures, impeccable attention to delicate details and the fragile nature of the art still excite curiosity. Unfortunately, the father-son duo trained no apprentices and so their art died with them.

Yet even as a technique dies; advances in another add another feather to the hat of glass...like it happened when serendipitously scientists discovered the art of making glass just two atoms thick. This makes it 'more bendable' as compared to ordinary glass. The accidental breakthrough happened when scientists at Cornell University and University of Ulm, Germany, were trying to make graphene. Apparently, there was an air leak in the quartz furnace they were using. This caused the copper foils to react with the quartz and give rise to what the scientists dismissed as 'muck' on top of the much-awaited graphene. Electron microscopy of the muck revealed it to be a 2D sheet of common glass, made up of silicon and oxygen atoms that closely resembled theoretical models proposed for the structure of glass in the 1930s. David Muller, Professor of Applied and Engineering Physics at Cornell University was delighted by the discovery. "This is the work that, when I look back at my career, I will be most proud of,..It's the first time that anyone has been able to see the arrangement of atoms in a glass," he said.

In 2012, Sadanand Singh of the University of Wisconsin, USA and his colleagues reported results of experiments that showed that glasses prepared by vapour deposition onto a substrate exhibits remarkable stability. Such stability could have only been expected from , glasses aged for thousands of years. Thus, technologically valuable ultra-stable glasses can now be swiftly produced.

More futuristically, astronomer Roger Angel, USA, thinks that putting a sunshade 100,000 km wide and placed in orbit about 1.5 million km away from Earth can limit some of the Sun's energy reaching Earth and thus combat global warming. The proposed giant sunshade will have 16 trillion glass discs. There is no doubt the 'Age of Glass' extends from ancient times to now as an unbroken and sparkling link!

12

IDIOMS INSPIRED BY GLASS

Crawl on hands and knees over broken glass to ...: Do anything to achieve wish.

Don't tap the glass: Don't scare away someone by your superior knowledge.

Edible Glass, Candy Glass, Sugar Glass and ***Breakaway Glass:*** Sugar or synthetic resin which has been made transparent and brittle. It is used to simulate glass in movies.

Glass axe/Glass hammer/Glass magnet: Objects to send someone on a Fools' errand.

Glass blower's bench: A chair with iron arms which allows the blower to roll the blow pipe back and forth spinning molten glass; the centrifugal force of the spinning maintains the shape of the glass while it is being worked.

Glass blower's soap: Term used for the decolourizing agent.

Glass bombs: Shower of glass from shoddily maintained skyscrapers. In 2011, Shanghai residents were instructed to watch out for glass bombs during an exceptionally hot summer. ***Glass bones:*** A congenital disorder known as *Osteogenesis imperfecta* or brittle bone disease.

Glass cancer: A result of nickel sulphide crystals forming in the glass during manufacture. The crystals exist in two different sizes depending on the temperature of the glass. The crystals initially take on the smaller shape, but over time these revert to the larger shape. The expansion causes the glass to crack.

Glass cannon: A person, weapon, or vehicle which has a high output, but is low on durability, etc.

Glass ceiling: An invisible barrier that keeps someone (usually women) from getting a better career position.

Glass chin/ jaw: Boxers who can be knocked out with one blow to the jaw.

Glass cloth: Textile that filters ultraviolet rays but allows visible light through to plants in greenhouses. It was invented and first manufactured in 1916 by Alfred Turner, USA.

Glass delusion: An unusual psychiatric disorder that appeared in Europe during the late Medieval period. Many people came to believe they were made of glass.

Glass dog: 3-D Anatomy software programme for veterinarians.

Glass floats: Hollow glass balls or cylinders containing air to give them buoyancy were once used by fishermen to keep their nets afloat. Large groups of fishnets strung together, were set adrift in the ocean and supported near the surface by glass floats. The first glass floats were made in the 1840s. Christopher Faye of Norway is credited as the inventor. These are considered to be collectibles.

Glass gene: A gene required for normal development of cells that sense light (photo-receptors).

Glass harmonica: Musical instrument that uses a series of glass bowls or goblets graduated in size to produce musical tones by means of friction.

Glass harp: Musical instrument made of upright wine glasses. It is played by rubbing a powdered finger around the rim. It was invented in 1741 by Richard Pockrich; the world's first guru of musical glass.

Glass ionomer cement: A dental restorative material.

Glass it in: To enclose something in glass.

Glass King: Charles VI of France (1368-1422); also called Charles the Mad and Charles the Well-Beloved. He suffered from Glass delusion or hallucinations that he was made of glass and that if people came too near him he would break. He reinforced his clothing with iron rods to protect himself from crumbling. According to *Wikipedia*, glass delusion has disappeared from contemporary society.

Glass noodles: Transparent noodles made of starch.

Glass pocket: Financial transparency.

Glass shit: Particularly painful bowel movement.

Glass sickness: A cloudy condition issue caused by wear and washing, especially with automatic dishwashing detergents, that irreversibly damages glassware by dulling its finish.

Glassy-eyed: Having a dull, dazed, or uncomprehending expression.

Ground Glass hepatocyte: Liver cell with a flat hazy and uniformly dull cytoplasm.

Heart of glass: Easily affected emotionally.

Juggling glass balls: Fragile and precious, most important things in life… not to be dropped.

Like drinking a glass of water: Easy task.

Raise one's glass to someone or something: Propose a toast.

See life through rose-coloured/tinted glasses: Be optimistic or see only the pleasant parts of things/situations.

See the glass as half empty: Being pessimistic; believing that a situation is worse than good.

See the glass as half full: Being optimistic; believing that a situation is more good than bad.

Smooth as glass: Used to describe calm bodies of water.

Spun-glass hair: A medical condition also known as Uncombable hair syndrome, *Pili trianguli et canaliculi* and *Cheveux incoiffables*. Because of a structural anomaly, the hair cannot be combed down flat. The hair is usually silvery-blonde or straw-like in colour, dry, curly and brittle. Eventually, it looks 'spangled' or shimmery maybe because light reflects off the irregular surface of the hairshaft. This is why it is called spun-glass hair.

Talk a glass eye to sleep: Be extremely boring.

To lose oneself in a glass of water/ To drown in a glass of water: To be easily discouraged.

Walk on glass: To handle someone carefully because they get upset easily.

The Glass Menagerie

Clasping Venus's Looking Glass: *Triodanis perfoliata*. A flowering herb native to America.

Glass Anemone: Marine invertebrate belonging to the species *Aiptasia pallida or A. pulchella.*

Glass Barb: Fishes belonging to the species *Puntius guganio* and *Parachela oxygastroides*.

Glass Blenny: Fish belonging to the species *Emblemariopsis diaphana.*

Glass Blue-eye: Freshwater fish belonging to the species *Kiunga ballochi.*

Glass Butterfly: *Greta oto.* Also called Glass-winged butterfly in English and *espejitos*, meaning 'Little mirrors"' in Spanish because it has translucent wings.

Glass Catfish: *Kryptopterus bicirrhis.* Also called Ghost catfish, Indian Ghosts, Ghost Fish, or Glass Cats. These transparent aquarium fish like to stay in groups and single specimens pine away.

Glass Eel: An intermediary stage in the life cycle of the American Eel, *Anguilla rostrata*.

Glass Eye/Glass Big Eye/Glass Eye Squirrelfish: Fish belonging to the species *Heteropriacanthus cruentatus*.

Glass Eye: The common name of the birds belonging to the species *Turdus jamaicensis* and *Camaroptera brachyura.* Also refers to artificial eye.

Glass Fin/Glass Bloodfin Tetra: Fish belonging to the species *Prionobrama filigera*.

Glass Fish: *Parambassis ranga.* Also known as Indian Glassy fish. It gets its name because it has a transparent body that reveals its skeleton and internal organs. It is a popular freshwater aquarium fish. See-through Zebra fish (*Danio rerio*) have been created to serve as models that allow scientists to observe abnormal growth of tissue. Normally, these fish are transparent as embryos but the laboratory-bred Casper variety retains transparency as an adult trait.

Glass Frogs: Mostly arboreal frogs belonging to Family Centrolenidae. Most have translucent abdominal skin. The Giant Glass Frog belongs to the species *Centrolene antioquiense*. Not so surprisingly perhaps one species of Glass Frog goes by the name *Hyalinobatrachium fragilis*...Fragile Glass Frog.

Glass Goby: Marine fish belonging to the species *Coryphopterus hyalinus*.

Glass Headstander: Fish belonging to the species *Charax gibbosus*.

Glass Jellyfish: A marine invertebrate scientifically named *Aglantha digitale*. Also known as Pink helmet.

Glass Knifefishes: Thirty or so species of fishes belonging to the Family Sternopygidae.

Glass Lizard/Glass Snake: Legless lizards belonging to the genus *Ophisaurus*. The name comes from their glassy-looking tails. The tail can be shed to distract the predator's attention if the Glass lizard feels threatened. The deep sea fish *Nemichthys scolopaceus* is also called Glass Snake.

Glass Minnow: Tiny fish used as bait to catch larger fish. Usually *Anchoa mitchilli* but the term is applied indiscriminately to other small and transparent fishes.

Glass Octopus: Octopus belonging to the species *Vitreledonella richardi*. Not much is known about this transparent octopus found in tropical and sub-tropical seas. It has no known close relatives and is the sole member listed under the Family Vitreledonellidae. The name bears reference to the word vitreous, meaning glass.

***Glass Rope*:** Sponge belonging to the species *Hyalonema apertum*.

Glass Sardine: Fish belonging to the species *Roeboides dayi*.

Glass Schilbid: Fish belonging to the species *Parailia pellucida*.

Glass Shrimp: *Paratya australiensis*. Common freshwater shrimp found in Australia. Also *Palaemonetes paludosus*.

Glass Slug: *Cyerce cristallina*. Mollusc that is also called Harlequin glass slug.

Glass Snails: (Garlic glass snail and Cellar glass snail). Molluscs of the genus *Oxychilus*. The name comes from their glassy translucent and fragile shells.

Glass Sponges: These marine animals are classified under the phylum Porifera. Their tissues contain glass-like structural particles made of Silica.

Glass Squids: About 60 species are listed under Family Cranchiidae. These squids are also called cockatoo squids, cranchiid squids, cranch squids, or bathyscaphoid squids. Most Glass Squids have a distended body with very short arms and are bio-luminescent meaning they can produce their own light.

Glass Tetra: Freshwater fish belonging to the species *Moenkhausia oligolepis.* .

Glass Worm: Transparent larva of the insect named *Chaoborus sp*. These are sometimes sold as fish food.

Glassy Bombay Duck: Fish belonging to the species *Harpadon translucens.* This fish is also called the Ghost Grinner!

Glassy Cardinalfish: Fishes belonging to the species *Cercamia eremia* and *Rhabdamia spilota.*

Glassy Darter: Fish belonging to the species *Etheostoma vitreum*.

Glassy Flathead: Fish belonging to the species *Hoplichthys haswelli.*

Glassy Perchlet: Fishes belonging to the species *Ambassis agassizii, Chanda nama* and *Ambassis gymnocephalus.*

Glassy Sandy Sprat: Fish belonging to the species *Hyperlophus vittatus*. Sometimes it is simply called Glassy.

Glassy Sprat: Fish belonging to the species *Hyperlophus translucidus.*

Glassy Sweeper: Fish belonging to the species *Pempheris schomburgkii.*

Large-leaved Looking Glass tree: *Heritiera macrophylla.* A Mangrove tree found in India.

Mermaid's Wineglass: *Acetabularia crenulata,* an algal species typically found in sub-tropical waters.

Poor Man's Weather Glass: Flowering plant belonging to the species *Anagallis arvensis*. It gets its name from the fact that its petals fold up when skies darken; be it before storms or when evening falls. They do not open again until morning.

Proverbs from across the World

- A blind man will not thank you for a looking-glass – English Proverb
- A diamond daughter turns to glass as a wife – American Proverb
- A friend's eye is a good looking-glass – Scottish Gaelic Proverb
- A storm in a glass of water –Hungarian Proverb
- Caution is the parent of delicate beer-glasses – Dutch Proverb
- Credit lost is like a broken looking-glass – Italian Proverb
- Do not shoot a glass arrow into a painted deer –Moroccan Proverb
- Fame is a magnifying glass – English Proverb
- Fortune and glass break easily – Dutch Proverb
- Happiness and glass break easily – Danish Proverb
- He pays for the glasses who breaks them – French Proverb
- He that has a head of glass must not throw stones at another – Romanian Proverb
- If a person shaves you with a razor, do not shave him with broken glass – Surinam Proverb
- If the eye does not want to see, neither light nor glasses will help – German Proverb
- Lasses and glasses are always in danger – Italian Proverb
- People who live in glass houses shouldn't throw stones at others
- Sometimes people who live in glass houses throw stones because their windows are painted – English Proverb
- The looking glass is the enemy of ugly women – Romanian Proverb
- The same hammer that breaks the glass forges the steel – Traditional Proverb
- There never was a looking-glass that told a woman she was ugly – French Proverb
- Three glasses of wine end a hundred quarrels – Chinese Proverb

- Vinegar that is too sour even taints the glass it is kept in – Turkish Proverb
- What good serve candle and glasses, if the owl does not want to see? – Dutch Proverb
- Women and glasses are always in danger – Portuguese Proverb
- When a stone hits glass, the glass breaks. When glass hits a stone, the glass breaks –Persian Proverb

Fear of Glass

Hyelophobia is the abnormal and persistentfear of glass or crystal. It is also called Hyalophobia, Nelophobiaand Crystallophobia. It is usually seen in people who have been involved in some traumatic accident involvingglass.

Well Said

"People are like stained glass windows, they sparkle and shine when the sun is out, but when darkness sets in their true beauty is revealed only if there is a light from within."

– Elisabeth Kubler-Ross

"I want my prose to be as clear as a pane of glass." – Tracy Kidder

"The formation of glass from the melting is like starting a clock. It resets the time for us to determine billions of years later."

– Robert Duncan

"Our house is made of glass...and our lives are made of glass; and there is nothing we can do to protect ourselves."

– Joyce Carol Oates

"The intellect of the wise is like glass; it admits the light of heaven and reflects it."

– Augustus Hare

"It is no use blaming the looking glass if your face is awry."

– Nikolai Gogol

"It has been common knowledge to informed collectors that many times the finest and rarest art glass is found unsigned."

– James Lafferty

Prizes to bewon

- ***The Glass Prize*** is awarded annually by Warm Glass, UK, to inspire innovation in kiln formed glass and to encourage Glass Artists throughout the world to share their work and express their passion.
- ***The Ranamok Glass Prize*** is an annual award for glass artists who are resident in Australia and New Zealand. The Prize was founded in 1994 by Andy Plummer and Maureen Cahill as a way to promote glass as an art form to the public.
- ***The International Glass Prize*** is a triennial international glass competition for arts, design and crafts.
- ***The Stevens Architectural Glass Competition***, UK, is an annual competition open to students and glass artists who have completed their training within the last five years.
- The International Commission on Glass (ICG) gives four awards for advancement of glass science and technology.
  - ***The Gottardi Prize*** in memory of Prof. V. Gottardi was initiated in 1987 and is awarded annually to young people with outstanding achievements in the field of glass in research and development, teaching, writing, management or commerce.
  - ***Woldemar A. Weyl International Glass Science Award*** in memory of Prof. W.A. Weyl was initiated in 1976 and is awarded once every three years to an outstanding young scientist working in glass research.
  - ***The ICG President's Award*** was initiated in 1995 to recognise outstanding lifetime contributions to the international glass community in areas such as scientific discoveries, engineering developments, artistic accomplishments, leadership and communications.
  - ***The Turner Award*** in memory of Prof. W.E.S. Turner was initiated in 2002 and is awarded to those who have made a noteworthy contribution to the ICG Technical Committees.

Take a Glass Break

If the lack of a passport, Visa hassles or the rising cost of travel are deterrents, a fast browser can be a good substitute for the armchair tourist...the list is by no means an exhaustive one though.

China

- Shanghai Museum of Glass, http://en.shmog.org/index.php

Croatia

- Museum of Arts and Crafts, Croatia, http://www.muo.hr/ (Croatian Biedermeier glass)

Denmark

- Glasmuseum, Denmark, http://www.glasmuseet.dk/ (The Museum for International Contemporary Glass, Denmark)

Egypt

- Glass Art Museum, Giza, Cairo, Egypt, www.glassartmuseum.com/

England

- Ashmolean Museum, http://www.ashmolean.org/ (Antiquities collection and Western Art collection)
- British Museum, http://www.britishmuseum.org/, information@brisitshmuseum.org (Extensive collection of glass from all periods)
- Broadfield House Glass Museum, http://www.glassmuseum.org.uk/ (Large glass collection spanning 17th century to present day, focusing on StourbridgeGlass Industry)
- Fitzwilliam Museum, http://www.fitzmuseum.cam.ac.uk (Large glass collection, especially pre-Medieval and 18th century)
- The Glass Art Gallery, http://www.londonglassblowing.co.uk (Contemporary gallery.)

- Haworth Art Gallery, www.hyndburnbc.gov.uk/hag (Good collection of Tiffany glass in Europe)
- Laing Art Gallery, www.twmuseums.org.uk/laing/ (Historic glass)
- Manchester Art Gallery, http://www.manchestergalleries.org/ (Large collection of 18th century English drinking glasses)
- National Glass Centre, http://www.nationalglasscentre.com/. (Permanent display on properties of glass, plus the University of Sunderland's Glass Department and glass blowing demonstrations)
- New Walk Museum & Art Gallery, www.leicester.gov.uk/museums (Decorative arts collection including glass from all periods)
- Shipley Art Gallery, www.twmuseums.org.uk/shipley/ (Decorative arts collection including historic, pressed and contemporary glass)
- Stained Glass Museum, http://www.stainedglassmuseum.com/, info@stainedglassmuseum.com (British stained glass)
- The Turner Museum of Glass, University of Sheffield, Department of Engineering Materials, http://www.turnermuseum.group.shef.ac.uk/ (19th and 20th century glass from Europe and America, plus Helen Munro Turner's wedding dress)
- Victoria and Albert Museum, http://www.vam.ac.uk/ (The National Museum of Art and Design, permanent exhibitions include glass galleries)
- Victoria Art Gallery, http://www.victoriagal.org.uk/ (Large collection of 18th century drinking glasses)
- The World of Glass, http://www.worldofglass.com/ (Exhibitions and glassblowing demonstrations)
- Yelverton Paperweight Centre, www.paperweightcentre.co.uk (Permanent display of the Broughton Collection of paperweights)
- Zest Gallery, Roxby Place, London, SW6 1RS, www.zestgallery.com

Germany

- Deutsches Glasmalerei-museum, Linnich, Germany, www.glasmalereimuseum.de (German Stained Glass Museum)
- Glasmuseum Passau, Germany, http://www.glasmuseum. de The Optical Museum Jena at Carl-Zeiß-Platz shows the history of optical instruments like glasses, microscopes, cameras and telescopes.

Iran

- Glassware and Ceramic Museum of Iran, http://www.glasswaremuseum.ir/

Italy

- Museo del Vetro, Murano http://museovetro.visitmuve.it/en/home/

Japan

- Hakone Garasunomori Museum, http://www.ciao3.com/info/english/ (Venetian Glass exhibits)
- Notojima Art Glass Museum, http://www.hot-ishikawa.jp/kanko/english/20016.html
- Hida Takayama Museum of Art, https://www.jnto.go.jp/eng/location/spot/museum/hidatakayamaart.html

Korea

- Jeju Glass Museum, www.jejuglasscastle.com

New Zealand

- Glass Museum, New Zealand, http://www.glass.co.nz/ (A virtual museum)

Northern Ireland

- Ulster Museum, Botanic Gardens, Belfast, Northern Ireland, www.nmni.com/um (Good collection of Irish glass.)

Scotland

- Burrell Collection, Glasgow, museums@csglasgow.org

(Comprehensive collection of Western European tableware.)

- Kelvingrove Art Gallery and Museum, Glasgow, (Large collection, especially Roman and pre-Roman, 18th century and glass from Cyprus.)
- Royal Museum and National Museum of Scotland, Edinburgh, www.nms.ac.uk (Extensive collection from pre-Roman to 21st century.)

Spain

- The Barcelona Glass Centre, Spain

USA

- Corning Museum of Glass, New York, www.cmog.org
- Museum of Glass, Tacoma, USA, http://www.museumofglass.org/
- Sandwich Glass Museum, Massachusetts, www.sandwichglassmuseum.org
- The New Bedford Museum of Glass, http://www.nbmog.org/index.html

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Index

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An infant's first introduction to glass is perhaps via the feeding bottle much before coherent thoughts arise. After that glass fires childish imagination when a Prince finds a glass slipper belonging to his mysterious dance-partner who leaves the ball at midnight. As a teenager, the mirror is often an inseparable companion. A little later in life, the debate moves to the nature of glass: is it a super- cooled liquid or an amorphous solid? What makes its structure so interesting and its properties such an amalgam of opposites?

Primitive man mined Obsidian—a naturally formed volcanic glass of sorts. The ancients taxed it even as they created enduring works of art that command astounding prices at auctions today. Modern humans value glass no less. To an artist, glass is a perfectly malleable medium; colourful or colourless; transparent, translucent or opaque as fancy demands. To a scientist, glass is the perfect medium too; enabling the creation of spectacles, microscopes, binoculars, telescopes and cameras. To an architect, glass is the perfect medium to clad state-of-the art- buildings. The environmentalist is happy because glass can be recycled eternally.

Glass is a conglomerate of contrasting characteristics...it shatters if dropped but can stop bullets. This book explains the 'hows' and the 'whys' of glass, in an extremely lucid way. From fantasy to fantastic facts, this book reveals all about gorgeous glass.

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