On the first patents, key inventions and research manuscripts about glass science & technology

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ABSTRACT

The objective is to describe the first patents, key inventions and scientific papers related to glass science & technology. According to the literature and the Guinness Book of Records, the first English recorded patent was granted to John Utynam in England in 1449 and a second in 1552. Regarding publications, the first two papers on glass production were published in 1665 in Le Journal des Sçavans in France and the Philosophical Transactions of the Royal Society in England. We illustrate our points using landmarks that cover half a millennia and constitute advancements in modern life that are substantially connected to and dependent on glass technology.

1. Introduction

1.1. Patents

An early historical landmark in glass technology monopolisation occurred when King Henry VI of England (1421–1471) issued a special grant to the Flemish glassmaker John Utynam in 1449 to produce stained glass windows at Eton and King’s Colleges, Cambridge [1]. Utynam was also obliged to teach and instruct his art and technique to English apprentices at these two institutions. Science historians learned that the technology of glass windows, in which the transparency of glass is exploited, had developed at approximately the time of the birth of Christ and attained new heights of artistry, such as the use of different colours by the Christian church in the Middle Ages [1–5].

The English monarch awarded him exclusive rights to arrange, prepare, produce and manufacture stained glass. John Utynam claimed to have invented a new technological process for producing this special glass [1]. An imperial order was signed on April 3, 1449, and John was granted this right for a twenty-year monopoly because he knew a method for preparing colored glass that had not been introduced in England at that time. Fig. 1 illustrates the Court of King’s Bench at work around 1460.

Currently, this equivalent function of transmitting knowledge is rewarded by patent specification publications. This register of Utynam’s grant is probably one of the world’s first formally recorded patents in England, as noted by the librarian of the British Patent Office and researcher and historian of technology Arthur Allan Gomme (1882–1955) [1].

Therefore, Utynam can be considered to be the first recognized inventor of a recorded technical patent in the world. He obtained patent letters from King Henry VI of England, from France (only indirect documents exist on this subject), and for restricted
technological development in the province of Murano, which is located near the Italian city of Venice [2]. Murano has a long history of glassmaking — approximately 25 centuries [3]. This particular case illustrates that ideas about globalization or the internationalization of intellectual property are not new. Historians affirmed with some certainty that the old Republic of Venice had started issuing patents by indirect references to glassmakers in approximately the 1420s [4] (no documents are available to prove this claim and to verify possible technical improvements). However, patents were regularly awarded beginning in the 1450s [5]. According to Zarzycki, the glass industry flourished due to the development of glass technology that ensued after the invention of glass blowing in the first century before Christ by Syrian craftsmen and was disseminated by Phoenicians over the Mediterranean Sea [3]. This particular technique that modified glass production and the use of glass, as well as the cost of glass, became very popular.
New glass centers appeared in Cyprus, Rhodes, Greece, and the Italian peninsula. The Italians were the main developers of glass vessels, containers, vases and tableware, starting with the Romans and subsequently the Venetians. A major category was “glass for hygienics, cosmetics and health”, i.e., small flasks, sprinklers, dishes, boxes and medical bottles [4]. Vessels and windows, as well as mirrors, were produced by glass blowing, which was perfected by Rome and its colonies [3]. In particular, the use of silvered glass became widespread throughout Europe but also appeared in the Middle East and Asia. The ‘specialization’ in window glass developed two methods for producing a sheet of glass – the cylinder and the crown methods. In the first method, a glassmaker blows a large bubble of glass, which is spun until centrifugal force caused the molten glass to spin outwards and flatten. The disc was subsequently cut into different sizes. In the second method, a glassmaker blows molten glass into a cylinder and cuts off the ends and the cylinder lengthways. The glass is subsequently reheated and rolled flat.

After the fall of the Roman Empire, glass manufacturing did not change until 12th century and was distributed throughout isolated sites in Western Europe. From approximately 14th century, the Venetian provinces were predominant centers of a resurgent glass manufacturing companies. The Venetian glassblowers who tried to practice their art abroad, because it can be employed in many vessel forms. For these reasons, many Venetian artists were tempted to establish their work abroad by emigrating. Knowing the Venetian patenting system, they obtain a monopoly due to their knowledge about the new processes and methods that they introduced to foreign territories. For some Venetian glassblowers who tried to practice their art abroad, however, a death penalty existed. At this time, glassmakers had an extraordinarily high reputation; however, to retain a monopoly, they were strictly forbidden by governments to leave the country. For example, in France, a special glass industry was created in 1665 to produce the large mirrors for the Palace of Versailles. Many glass artisans were assassinated by hired killers, including two glassmakers who were hired to create a flat glass industry for the famous Hall of Mirrors in Versailles [10]. After this work, the ‘Manufacture Royale des Glaces de France’ was founded by King Louis XIV; it surpassed Venice as an exporting country for mirrors. This company subsequently became the worldwide famous Saint-Gobain [3].

The diffusion of patent systems of other countries began in this manner and motivated glass specialists, such as John Utnam, to provide other places with improved security, special rights and advantages. However, the origin of patents for invention remains obscure; however, Britain has one of the longest continuous patent traditions in the world, according to the Intellectual Patent Office (www.ipo.gov.uk). Its history dates to the 15th century, when the Crown began to issue specific grants of privilege to inventors, traders and manufacturers. Since this time, patents have been considered to be a form of intellectual property.

One hundred years after Utnam’s first patent in 1449, no additional patents were granted in England. According to B. Spear [11], the second technical patent that was granted for glassmaking, in a series of English patents with twenty-year monopolies granted by King Edward VI (1537–1553), was granted to Henry Smyth on April 26, 1552 [12].

Granting patents was allowed as a royal prerogative in absolutist England. Unfortunately, minimal information exists about Utnam and Smyth or their works, with the exception that they were master glassmakers, as indicated in historical documents.

1.2. Scientific articles

Approximately one century after the second glass patent was granted, scientific printed discourses started to appear in “Le Journal des Scavans” [13] and the “Philosophical Transactions of the Royal Society” [14]. Both journals were founded in 1665: the first journal was founded by the French writer and lawyer Denis de Sallo (1626–1669), and the second journal was founded by the German theologian, diplomat and natural philosopher Heinrich Oldenburg (c.1619–1677). De Sallo used the pen name Sieur d’Hedouville, and Oldenburg signed as Henry. Both men were excellent writers. Maintaining contact with numerous persons around the world was an enormous responsibility. Oldenburg was a linguist — he was fluent in English, Dutch, French, German, Italian and Latin [15,16].

The French journal imposed a new writing style and original methods for disseminating technological and scientific knowledge; everything was initiated by de Sallo hands. This journal also helped to disseminate Cartesianism since the first issue [13], and
consequently, the scientific method. Regarding the English journal, Oldenburg is cited as the creator of the scientific peer review process. He began the practice of sending submitted manuscripts to experts who could judge their quality and recommend improvements prior to publication. The word “philosophical” in the journal title referred to “natural philosophy”, which was the equivalent of the term “science”.

These journals intended to encompass a broad range of topics of human knowledge. However, the first scientific publications in both journals were related to glass and astronomy, such as the improvements and findings of the Italian optician and astronomer Giuseppe Campani (1635–1715). Campani made special glass lenses for astronomical observations, his telescopes were famous at that time [17]. According to Trier and Gaulke [18], Campani was one of Europe’s foremost telescope makers and opticians in 17th century due to his skill at grinding and polishing objective lenses with long focus. Some of these lenses were ordered by the Italian mathematician, astronomer and engineer Giovanni Domenico Cassini (1625–1712).

2. The first patents on glass: litterae patentes

According to K. W. Dobyns [19], the beginning of specific letters that were referred to as patents in England was a privilege of the monarch. The English King issued patent letters for many functions. Originally, patent letters comprised open manuscripts from the King to anyone who wished to read them. Privileges were established by patents when the monarch and his staff were convinced that inventions should be protected.

The word patent is derived from the Latin “litterae patentes”, in
the context of an open letter. R. A. Klitzike [20] noted that this name was addressed not to particular persons but “to all to whom these presents shall come.” The papers were traditionally sealed by the King to prevent them from being read without rupturing the seals. These letters were employed by medieval royals to confer exclusive rights and privileges to individuals. With an imperial seal, the letters provided public proof of these rights.

According to Comme [12], the word patent originates from the Latin patere, which means “to lay open”: to make accessible for public examination, which predates the modern patent system. A grant of Patent Letters was a personal and direct award of a dignity, office, monopoly, franchise or other benefit by the English monarch via the exercise of the royal sanction and was registered on the Patent Rolls in the Record Office. According to the Intellectual Property Office of the UK, the term patent usually refers to the right granted to anyone who invents any original, functional, and innovative process, machine, article of manufacture, or composition of matter.

The King Henry VI letter, as presented in the Calendar of the Patent Rolls preserved in the Public Record Office [21] (in public domain), is shown as follows:

April 3. Westminster

“Licence for life for John Utynam, born in Flanders, who has returned, of late to England at the king’s command, to stay in the realm with his wife and children, sons and daughters, and servants, as any liege of the king, and protection for the same; grant also to him for life that he may engage in all acts, works and sciences lawful and liberal without impediment, and since he has come to make glass of all colours for the windows of Eton college and the college of St. Mary and St. Nicholas, Cambridge, appointment of him to take artificers, workmen and labourers and to set them to work at the king’s wages, and wood, clay (lutum), stones, ashes, metals and carriage therefor, and to commit to prison all rebellious herein to stay until they find security to serve faithfully; and grant that all glass made at his own costs and not for the use of the colleges may be exposed by him for sale without payment of customs or subsidies thereon; and because the said art has never been used in England and John intends to instruct divers lieges of the king in many other arts never used in the realm beside the said art of making glass, the king retains him therefor for life at his wages and fees and grants that no liege of the king learned in such arts shall use them for a term of twenty years against the will and assent of John, under a penalty of 200l., whereof two parts shall be rendered to the king and one part to John, any liege who cannot levy that sum to suffer imprisonment without delivery save by the king’s special command”. By K. etc.

Utynam’s letter was usually stamped with the King’s Great Seal. In this letter, Utynam would produce his own glasses for sale but was obliged to pay a penalty of £200 if he did not complete the arrangement.

According to Klitzike [20], the English Crown was not the first entity to grant patents to inventors; however, they were the first entity to develop a lasting patent law. In 1552, Edward VI granted another patent of invention to Henry Smyth, who was a London merchant, as presented in the Calendar of the Patent Rolls preserved in the Public Record Office, Edward VI [22] (in public domain):

26 April. Westminster

“Whereas Henry Smyth of London, merchant, intends to bring certain strangers into the realm expert in making “brode glasse” such as is commonly called “Normandy glasse”, whereby divers of the king’s subjects “may be set to worke and gett their lyyyng and in tyme learne and be hable to make the said glasse them selves” and instruct others:

Licence to the said Henry Smyth to bring from beyond seas such persons as are expedient for making the said “grasse” (sic); and for twenty years to make the said “Normandy glasse” anywhere within the realm; and no person without his authority “shall attempte or presume to make any kynde of the said brode glasse commonly wount to be called Normandy glasse or any other fytte for wyndowes”, on pain of forfeiture of all glass so made.”

By p.s.

These patent grants can be considered to be the first and second of the relatively numerous patent grants from the 15th century onward. Smyth promised to train, instruct and educate persons about his new technology to ensure that the industry was capable when the award finished.

Other patent privileges to individuals had not granted monopolies but only privileges to practice their innovations in England. Prior to this time, organizations had been the exclusive recipients of monopolies; however, individual inventors and persons who introduced new industries from abroad obtained monopoly concessions that were similar to the concessions received by the guilds. Although the patent of John Utynam antecedes the Smyth patent by a hundred years, intervening documents were not available. Thus, John’s patent remains unaccompanied in the 15th century; the English system of monopoly patents to inventors for innovations started as a regular practice after the Smyth patent [23]. Therefore, the English patent system derived from its previous medieval origins into the first modern patent system, which recognized intellectual property to motivate innovation and invention; this legal foundation upon which the Industrial Revolution (1760–1850) emerges and flourishes in subsequent centuries, starting with Utynam’s and Smyth’s patent letters.

3. The first papers on glass

Another historical landmark in the history of science, specifically in glass science and technology, comprised the first publications in the primary scientific journals in 1665: both “Le Journal des Scavans” (subsequently renamed Journal des Savants) and the Philosophical Transactions of the Royal Society unveiled the same discovery by the Italian astronomer Giuseppe Campani, who related to his first observations using special optical glasses. In 1665, one of the largest and most important industrial glass companies of the world was created: Saint Gobain.

Despite the fact that the “Le Journal des Scavans” can be treated as the first publication, which was followed in a few weeks by the
Royal Society periodical [16,24], the English journal is likely the longest-running journal because the French publication was interrupted for almost a quarter century (between 1792 and 1816 due to the French Revolution) [24]. Concerning the form, the table of contents, the lexicographic sorting, the pagination, the citation mode, and even the use of italic style are identical in both journals, as presented in contemporary magazines. The English journal was restricted to “natural philosophy” subjects [24], whereas the French journal presented a broader viewpoint.

The readers were informed from the first volume about the purpose of the French journal: “the design of this journal is to make known all that is new in the Republic of Letters” (“le dessein de ce journal estant de faire sçavoir ce qui se passe de nouveau dans la Republique des lettres”, as shown in “L’imprimeur au lecteur” [13]). According to the editor notes, one of the goals was to keep the reader informed about new books published in Europe. However, this feature did not consist of writing simple booknote lists; however, every report was expected to include a short description of the book content and its subject area. According to Banks [24], the term “sçavans” was based on the incorrect belief that the word was derived from the Latin scire rather than saper. Note that this citation procedure was common during this time: books were the main source of knowledge. The first scientific article on “Le Journal des Sciences” was anticipated by two notes: the first note was about the printed book “Victoris Vitensis et Vigilii Tapsensis, provinciae Bizacanae episcoporum Opera” (“Victor of Vita, and Vigile de Thapse, on the assistance of the province of Byzacena”) by the French Jesuit Pierre-François Chifflet (or Petrus Franciscus Chiffletius, 1592–1682) on page 1; the second note was about “Henrici Spelman Glossarium, continens Latinobarbara, peregrina, obsoleta, et novaeae significations vocabula” (briefly, “Henry Spelman’s Dictionary”) by the English antiquary Sir Henry Spelman of Congham (1562–1641) on page 2. The third note is assumed to be a scientific paper because its content presents observations, experiments and discoveries. These first notes and articles had no authorship indication but one would presume that they were written by Sieur d’Hédouville. Pages 3–5 [13] (now in public domain) read as follows:

The article is separated into three parts. The first observation is related to the excellence of Campani’s instruments; however, the author made three minor comments: on size, differences using small and large telescopes, and the last comment referred to the large telescopes that could be used with three eyepieces and superior focusing. Campani invented the composite lens eyepiece. He was an exceptional artisan who was able to construct a telescope with four lenses, which consisted of a triple ocular and an objective [17]. The second observation was related to Saturn’s new findings, which confirmed the discoveries of 1659 by the Dutch astronomer and mathematician Christiaan Huygens (1629–1695). The third observation was related to Jupiter’s satellites. According to the article, the observations were in accordance with the Copernican system, primarily due to Campani’s telescopes.

Campani completed noteworthy observations with his instruments, as cited by Murara [17]. His astronomical annotations and descriptions about his telescopes were detailed in the communication cited in the previously cited text: “Ragguaglio di Due Nuove Osservazioni, una Celeste in Ordone Allia Stella di Saturno, e Terrestre l’Altra in Ordone agli‘Instrumenti” (“Report on Two New Observations, the One Heavenly about Saturn, the Other Earthly about Instruments”), published in Rome in 1664 and 1665 [25].

According to Murara [17], due to the influence of Cassini, Campani’s instruments were commonly employed at the Royal Observatory in Paris and all of Cassini’s discoveries were made using Campani’s telescopes. Campani also wrote to Cassini in a second communication in 1666: “Lettere di G. C. al Sig. Giovanni Domenico Cassini Intorno alle Ombre della Stelle Medicee nel Volto di Giove, ed altri Nuovi Fenomeni Celesti Scoperti Co’ suoi Occhiali” (“G. C.’s Letters to Mr. Giovanni Domenico Cassini about Medicean Stars’ Shadows on the Face of Jupiter, and other New Heavenly Phenomena Discovered with His own Telescopes”), which were also announced in Rome.

The same discoveries and notes using the special lenses that are employed in large telescopes had been published a few weeks in advance in an English periodical. The complete title of the English journal, as given by its first secretary, Oldenburg, was “Philosophical Transactions, Giving some Account of the present Undertakings, Studies, and Labours of the Ingenious in many considerable parts of the World”.

In the Introduction on page 1, the journal intention was “helping the Society in its stated aim of ‘promoting Natural Knowledge’, bringing natural philosophers into communication with one another, and keeping the Society’s correspondents abreast of news from the world of experimental learning”. In the first volume
An account of the improvement of Optick Glasses.

"There came lately from Paris a Relation, concerning the Improvement of Optick Glasses, not long since attempted at Rome by Signor Giuseppe Campani, and by him discoursed of, in a Book, Entituled Ragguaglio di Nuove Osservazione, lately printed in the said City, but not yet transmitted into these parts; wherein these following particulars, according to the Intelligence, which was sent hither, are contained.

The First regardeth the excellency of the long Telescopes, made by the said Campani, who pretends to have found a way to work great Optick Glasses with a Turne-tool, without any Mould: And whereas hitherto it hath been found by Experience, that small Glasses are in proportion better to see with upon the Earth, than the great ones; that Author affirms, that his are equally good for the Earth, and for making Observations in the Heavens. Besides, he useth three Eye-Glasses for his great Telescopes, without finding any Iris, or such Rain-bow colours, as do usually appear in ordinary Glasses, and prove an impediment to Observations.

The Second concerns the Circle of Saturn, in which he hath observed nothing, but what confirms Monsieur Christian Huygens de Zulichem his Systeme of that Planet, published by that worthy Gentleman in the year, 1659.

The Third respects Jupiter, wherein Campani affirms he hath observed by the goodness of his Glasses, certain protuberancies and inequalities, much greater than those that have been seen therein hitherto. He addeth, that he is now observing, whether those sallies in the said Planet do not change their situation, which if they should be found to do, he judgeth, that Jupiter might then be said to turn upon his Axe; which, in his opinion, would serve much to confirm the opinion of Copernicus. Besides this, he affirms, he hath remarked in the Belts of Jupiter, the shadows of this satellites, and followed them, and at length seen them emerge out of his Disk."

The first part of the English article relates to Campani's masterpiece and his incredible lenses, which were produced without mould. Murara [17] affirmed that Campani elaborated a lens-grinding machine the previous year; however, whether it was able to grid and polish lenses without moulds was controversial. Additionally, he improved telescope tubes by constructing them with wood rather than cardboard covered with leather. Even if this design was somewhat difficult to handle, control, or address because it was large and heavy, it proved durable. Another interesting aspect was related to the lens effects (the rainbow image). In the second part, the article presents findings about Saturn, which confirms Huygens' proposal. The third part is related to Jupiter's belts and satellites.

A comparative discourse analysis of the first issues was performed by Banks [24]. He observed that two methods for disseminating new information and knowledge existed in the 17th century. The first method involved books, which was a lengthy and expensive process. The second method involved letters. Although these letters were sent from person to person, they were not really individual letters in the present day sense. These letters could be copied, sent, or even read at meetings of intellectual societies in many cases. Networks of correspondence were constructed based on this method. In this context, the first two academic journals were created.

Both articles have a structure that is similar to a letter in the sense explained by Banks [24]. However, they were not signed, had the same origin — Campani's book — and their arguments were divided into three parts. The majority of the existing basic aspects of professional and scientific writing, regarding form and content, were implemented since these two articles were published. Open questions remain: the first issue is related to the origin of the term "news from Paris". Reports may be obtained from the Royal Observatory in Paris or a Royal Society's fellow in England. Oldenburg had been contacted by the authors of the French journal and invited to supply accounts of new books and other scientific discoveries by Englishmen. He brought a copy of the first French issue and 'a sample' of a similar project 'but much more philosophical in nature' to a meeting of the Royal Society. This sample may comprise a sketch or draft of the first issue of the Philosophical Transactions magazine [16]. The second question is about the possible receiver(s) of this note. The first short article on page 3 invokes findings of "the Ingenious Mr. Hook" about "A Spot in one of the Belts of Jupiter". A third name would be Huygens, who was active in both English and French academies of that period. Because he was one of the most important natural philosophers of this time, he also published contributions to both journals. The quiet and young genius Isaac Newton (1642–1727) was a student during this period; he had just started correspondence with Oldenburg in 1672 (the topic was Newton's telescope) [15]. Bluhm [15] affirmed that the majority of the early volumes were written by Oldenburg, who summarizes in his own words all information he gathered from the letters that he received. Fig. 3 shows an illustration of a meeting of the Royal Society in Crane Court, showing possibly Isaac Newton as president.

4. Some landmarks on glass inventions (patents and papers)

Macfarlane and Martin [4,6] suggested that glass has an enormous relevance in the history of science because it changed the conditions of everyday life and promoted explorations in science and technology.

We agree with Macfarlane and Martin [4] because is not a mere coincidence that titans of science, such as Galileo Galilei (1564–1642), René Descartes (1596–1650), Christian Huygens (1629–1695), Antonj van Leeuwenhoek (1632–1723), Robert Hooke (1635–1703), Giuseppe Campani (1635–1715), Isaac Newton (1642–1727), Mikhail Vasilyevich Lomonosov (1711–1765), Joseph Fraunhofer (1787–1826) and Michael Faraday (1791–1867), had a strong interest in glass making (some of these scientists were glass grinders). All used glass instruments in their discoveries and innovations and extended their sights to new levels of comprehension.

To cite some of the key milestones in glass science and technology after the first and second glass patents, the inventions of the microscope (approximately 1595–1609 [26]) and telescope (approximately 1608 [27,28]), which altered all dimensions of the world, must be included. The German-Dutch Hans Lippershey (or Johannes Lippershey, c. 1570–1619), a master lens grinder and spectacle maker, applied for the first telescope patent in October 2, 1608, which he named “kijker” ("looker") and offered to the Dutch government and for which he requested a thirty-year exclusive

"Philosophical Transactions" (currently in public domain), pages 2–3 [14] read as follows:
patent [29]. His invention was successfully tested but his application was rejected because the same claim for invention had also been made by at least two other Dutch spectacle-makers [30] — Jacob Metius (1572–1628) and Zacharias Janssen (c. 1585 – c.1632).

As in the case of the telescope, the idea of combining lenses for a magnifying device independently occurred at approximately the same time to more than one person. This case also applied to the microscope, which was proposed between 1595 and 1609 by Zacharias Janssen and his father, Hans. Their microscope had two lenses joined in a tube, in which the magnification could be varied by altering the distance between the lenses. However, no work by the Janssens about observations using the microscope were published; instead, the two names associated with the origin of microscopy are Hooke and van Leeuwenhoek [26].

Some glassmakers had been practicing Neri’s suggestions from the “Art of Fire” [8] and began to note that glass can be crystallized in a controlled manner by adequate heat treatment. However, the French polymath René-Antoine Ferchault de Réaumur (1683–1757, Fig. 4) was the first person to produce and publish results about his attempts to crystallize a glass after heat-treating soda-lime-silica glass bottles in a bed of sand and gypsum during several days [31]. Réaumur almost discovered the first glass-ceramic because he could not control the final product, which was deformed. His intention was to manufacture new materials by changing “verre en porcelaine” but he only managed to crystallize his bottle on the external surface (not in the interior as in a real glass-ceramic).

Extensive studies on the chemistry of colored glasses were made in Russia in approximately the 1750s. The Russian polymath Mikhail Vasilyevich Lomonosov (1711–1765, Fig. 5) performed the first detailed investigation of the influence of the components and the composition of glass on their properties. He synthesized more than a 1,000 glass compositions [32].

In 1814, the German optician Joseph Fraunhofer (1787–1826, Fig. 6) invented the spectroscope, which is an instrument used to measure the properties of light over a specific portion of the electromagnetic spectrum [33]. In the course of his experiments using prisms and lenses with the highest quality, he discovered the bright fixed line, which appears in the orange region of the light spectra when it is produced by fire. This line enabled him to determine the absolute power of refraction in different substances. Experiments to establish whether the solar spectrum contained the same bright line in the orange region as the bright line provided by fire led him to the discovery of hundreds of dark fixed lines in the solar spectrum. His results and discoveries opened new branches in astronomy and served as the basis for the quantum theory in the 20th century.

Another landmark was related to the invention of the refractometer in 1871 by the German physicist and optician Ernst Karl Abbe (1840–1905, Fig. 7). The refractometer is a bench-top device for the high-precision measurement of the refraction index, which was published in 1874 [34]. With the German industrial Carl Zeiss (1816–1888) and the German chemist Friedrich Otto Schott (1851–1935), Abbe laid the foundation of modern optics in the medieval city of Jena, Germany. Abbe was a co-owner of Carl Zeiss AG (founded in 1846), which was the first industrial optical glass company that produced high-quality astronomical telescopes, microscopes, planetariums, cameras and other optical systems for military, medical and commercial devices. Another landmark in glass technology was the foundation by Otto, Abbe and Zeiss of the Glastechnische Laboratorium Schott & Genossen (“Schott & Associates Glass Technology Laboratory”) in 1884.

In 1884, the French Francois Barthelemy Alfred Royer de la Bastie (1830–1901) developed a method of tempering glass [35] by quenching almost molten glass in a heated bath of oil or grease,
which created the first toughened glass. The first contemporary patent on an entire process to make tempered glass was held by the American chemist of Austrian origin Rudolph Abraham Seiden (1900–1965) [36].

In 1898, the Russian chemist Gustav Heinrich Johann Apollon Tammann (1861–1938, Fig. 8) [37] proposed and published the first "modern" scientific paper, which describes the behavior of glass-ceramic production by controlling the nucleation and growth rate processes. Tammann investigated the crystallization of organic liquids and suggested a systematic procedure, which is now known as the Tammann or "development" method.

Laminated (or safety) glass, which was invented and named tripex by the French chemist Edouard Benedictus (1878–1930) in 1903, applied for a patent in 1910 and published it in 1912 [38]. His discovery was a serendipitous invention: he was on a ladder looking for something on an elevated shelf when he knocked a glass container to the floor. He heard the glass shatter; when he looked down he discovered that the broken pieces of glass were stuck together. Benedictus observed that the container housed a type of plastic liquid that had evaporated and left a thin film inside [39].

The British chemist William Ernest Stephen Turner (1881–1963), who joined the University College of Sheffield, UK as a lecturer in 1904, established the Department of Glass Technology a century ago, in 1916. It was the first academic department in the world to address all aspects of glass science and technology, including art, history, design, and manufacture, as well as R&D applications. He was also the first Professor of Glass Technology and founded the Society of Glass Technology (www.sgt.org) in the same year. The SGT is celebrating its 100th anniversary this year!

The first accurate and concise atomic picture of glass structure by X-ray was prepared by the Norwegian-American physicist Fredrik William Houlder Zachariasen (1906–1979) in 1932 [40]. A new method of producing glass wool was established by the American engineer and inventor Russell Games Slayter (1896–1964) from Owens Illinois Glass Co. He applied for the first patent on fiberglass on November 11, 1933 and published the patent on October 11, 1938 [41].

Two new glass innovations transformed modern life in the 1940’s and 1950’s — they are two of the most extensively reported methods for special glass manufacturing. Both were discovered by the same prolific inventor — the American chemist Stanley Donald Stookey (1915–2014) at Corning Glass. The first method refers to special glass that contain atomic elements that are capable of forming stable photographic figures or images into a transparent glass when exposed to light; it is referred to as photosensitive glass (patent US 2,515,937 applied on December 8, 1943 [42] and published in July 8, 1950). The second discovery occurred in 1953, when Stookey inserted a piece of a transparent glass based on lithium disilicate into a muffle furnace. This special glass was mistakenly heated to a temperature of 900 °C, which is 300 °C higher than he intended. After the heat treatment, the astonished Stookey noted a dense and white (crystalline) material that had not deformed instead of a melted pool of glass. He also accidentally dropped the piece on the ground; however, it did not shatter into small pieces, as expected. He also heard a metallic sound [43]. Probably surprised by the unusual toughness, Stookey had discovered by simple thermal treatment a new fine-grained crystalline material that was stronger, harder and higher in electrical resistivity. This innovation
was patented under number US 2,920,971, which was applied on June 4, 1956 and published on January 12, 1960 [44]. He had accidentally created the first glass-ceramic — Fotoceram® — by rediscovering in an independent manner the procedure invented by Réaumur during the two previous centuries [43]. In this case, however, the metallic silver particles that were dispersed in the glass acted as nucleating agents for the internal crystallization.

Another multimillion dollar glass innovation subsequent to Stookey’s accidental discovery was achieved by the British engineers Lionel Alexander Bethune Pilkington (1920–1995) and Kenneth Bickerstaff (c. 1922–1987): the Float process [45]. Pilkington and Bickerstaff developed the world’s first commercially successful manufacture of high-quality flat glass using their float glass process [46]. In 1952, Pilkington conceived the idea of forming a ribbon of glass by floating the molten raw materials at elevated temperature over a bath of melted tin. One evening in 1952, Pilkington conceptualized the idea of float glass when he was washing dishes at home [47]. He was fascinated by the view of oil droplets and bubbles suspended in water and wondered whether the principle could be applied to glass making. Thus, he daydreamed as he observed a bar of soap float in the slippery water and visualized glass floating like a bar of soap.

According to US patent 2,911,759 [48], which he applied for the next year, the ribbon is held in a chemically controlled atmosphere at a sufficiently high temperature and time to enable the irregularities to melt out and the surfaces to become flat and parallel [46]. Because the surface of molten tin is flat (melting point 231.9 °C), the glass is also flat and operates from its molten state near 1200 °C–600 °C when it is a supercooled liquid, which converts glass at approximately 550 °C. The ribbon is continuously cooled while advancing across the molten tin until the surfaces are sufficiently hard to be removed from the tin bath (without the typical rollers in contact with the bottom surface). Therefore, a uniform thickness and bright, fire-polished surfaces that do not require polishing or gridding are formed [47]. Pilkington’s invention substituted the twin polishing and grinding process for making plate glass.

In 1969, the American materials engineer Larry Leroy Hench (1938–2015) et al. was credited with another outstanding invention when he discovered the first bioactive glass composition named Bioglass® [49]. His discovery was published as a peer reviewed paper in 1971 [49]. His paper includes a description of the composition of the glass and an indication of its capability of bonding to bone by transmission electron microscopy (TEM). The results indicate that the bonded interface created a layer of growing bone mineral that has interlaced with collagen fibrils generated by osteoblasts growing at the interface. This invention was disclosed as a patent in 1980 [50] and has remained in clinical use since 1985.

Another multimillion dollar patent on self-cleaning glass was granted in 1997 and subsequently published [51]. This glass is a soda-lime-silica glass with a surface coating that eliminates dirt and grime. It has been in industrial production since 2001. The first composition was based on a thin-film titania coating [52].

In 2009, the Chinese electrical engineer and physicist Charles Kuen Kao (b. 1933) received a Nobel Prize in Physics for “ground-breaking achievements concerning the transmission of light in fibers for optical communication” in a work done with George Alfred Hockham [53]. In 1977, the Swedish Academy awarded the English physicist Nevill Francis Mott (1905–1996), the American physicists Philip Warren Anderson (b. 1923) and John Hasbrouck Van Vleck...
would likely be fascinated by the technical and legal complexity of the present patent system. The days when the King simply awarded monopoly rights to an invention using his seal have passed. The current patents process in the UK is regulated by the Patents Act of 1977. This specific legislation has been restructured over the years by the Copyright, Designs and Patents Act of 1988. The bureaucratic details of the patent system are restricted by the Patents Rules of 1995 and subsequent revisions.

Fig. 11 shows a similar trend for scientific publications in periodicals. An exponential enhancement has occurred in this type of publication. Searching for titles using the term glass, 165,624 articles were published since 1856 according to the Scopus database. The limit of a hundred papers per year was surpassed in 1930s, and a thousand papers were published in the 1970s. If the same keywords are considered in the title or abstract, the number of papers increases to 478,933 papers prior to 2015. Mauro and Zanotto have recently conducted a data analysis concerning the last two hundred years of glass science and technology [54].

Approximately 30 thousand scientific periodicals [16] exist; this number is increasing. The number of patents issued worldwide exceeds the number of published scientific articles, which may be attributed to the high level of activity in industries. In 2015, science celebrated 350 years of scientific discussions in academic journals due to the ingenious work of de Sallo and Oldenburg in disseminating knowledge worldwide as pioneers of editing science papers. However, advancements in modern science and technology can be attributed to innovations in glass [55].

5. Conclusions

The first English patent for invention was granted on April 3, 1449, to John Utynam, who attended a specific call from the reigning King. The crown issued him a Patent Letter that was sealed with the King’s Great Seal to guarantee John’s privileges. Utynam’s triumphant mission to protect his technological innovations gave birth to a system that gave people official sanction to enjoy the economic benefits of their own knowledge.

The second English patent was granted to Henry Smyth by King Edward VI on April 26, 1552. It is important to note that patents (i.e., monopolies) were granted for all types of things apart from technical innovation, so the King could raise money or reward his associates. The English Statute of Monopolies established in 1624 ended this abuse and limited patents only to technical innovation.

Since these two English patents, the Intellectual Property Office of the UK has granted more than 2,500,000 patents. A landmark publication patent was issued on September 11, 2013, under patent number GB 2,500,000. Since the 15th century, patent protection began when the English Crown granted monopolies to manufacturers, inventors and traders.

The USA celebrated the 225th Anniversary of the Patent Act Celebration in 2015 and has issued more than 9 million patents since 1790. The European Patent Office has published over 3 million patent applications, and presents a database, Espacenet, which contains over 90 million patents from many countries: Espacenet (www.epo.org) prior to 2016. A specific search with the keyword “glass” yielded results in this database (see Fig. 10). Fig. 10 shows the exponential enhancement in patents since the first registered claims. Searching for titles using the term glass, 250,589 patents were issued since 1859. If the same keywords are considered in the title or abstract, the number of patents increases to 827,643 patents prior to 2015. Since this database was developed in the 1850s, more than a hundred patents were published per year culminating in a thousand patents in the 1930s.

Fig. 8. Gustav Heinrich Johann Apollon Tammann (1861–1938) by the German photographer August Schmidt (1877–1934) around 1913. Source: Voit Collection, now in public domain.

King Henry VI, John Utynam, King Edward VI and Henry Smyth (1899–1980) with the Nobel Prize in Physics “for their fundamental theoretical investigations of the electronic structure of magnetic and disordered systems”. Fig. 9 summarizes some landmarks of glass science and technology [54].
ceramics by Donald Stookey, the float process by Pilkington and Bickerstaff, bioactive glass by Larry Hench and optical fibers as a practical communication medium by Charles Kao and George Hockham. These discoveries are some of the greatest revolutionary inventions that changed the mass production of the twentieth century.

Regarding scientific manuscripts, the first volumes of the first scientific journals differed from the scientific journals of present times; however, they served the same function: to inform scientists and other interested readers of the latest scientific discoveries that promoted the dissemination of knowledge. These publications initiated an entirely new genre — the scientific journal — and are
the oldest publications in print. The Philosophical Transactions started the peer review process, which has become the central foundation of scientific journals. This system proved to be an interesting approach to guaranteeing methodological rigor, excellence in practice and bona fide (good faith) in science.

We suggest that all inventors are Utnym and Smyth’s heirs and that all scientists are de Sallo and Oldenburg’s heirs. As a fascinating, versatile and extraordinary substance, glass is central to most aspects of modern science and technology. As a “true fruit of the art of fire” but neither a true solid nor a true liquid, glass is a frozen fluid that shaped our world!

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