Uranium Glass and Its Scientific Uses

Paolo Brenni

Several years ago I saw for the first time some samples of uranium glass.[1] I was fascinated by their beautiful brilliant colour produced by fluorescence when exposed to sunlight. A friend, Stuart Talbot, who was aware of my interest, managed to find a pair of uranium glass candlesticks, which were kindly offered to me by the Scientific Instrument Society at the end of the Society dinner closing the excursion in Paris in 1997.

It happened that these two pieces were the first of a collection which now counts more than 50 artefacts. Uranium glass collecting has become quite fashionable in recent years. Today it is possible to find several books and websites[2] dedicated to uranium glass artefacts, while eBay and other on-line auction houses constantly advertise hundreds of vases, bottles, tableware, lamps, plates, necklaces, and various bibelots made of it.

But the use of uranium glass in decorative arts is not the focal point of my article. In the 19th and in the early 20th centuries not only did uranium glass play an important role in the pioneering studies of the phenomena of fluorescence, but it also was used in various scientific instruments. Here I will consider this aspect of the history of uranium glass.

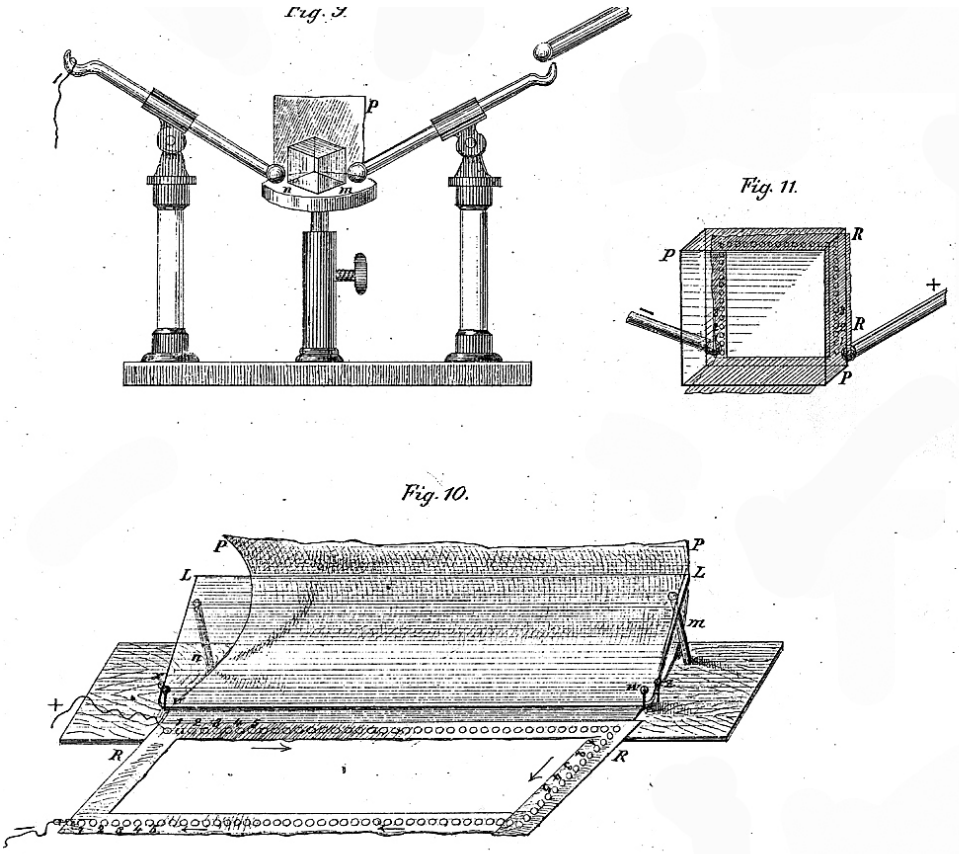

Fig. 1 *Experiments illustrating the fluorescence of uranium glass excited by electric sparks (see Pisko,* op. cit.*, note 18).*

Uranium and Uranium Glass

Today the strategic importance of uranium (atomic number 92, an heavy element of the actinide series with a silvery metallic appearance) as fuel for nuclear power plants and for the production of weapons is too well known. But until the discovery of radioactivity by Antoine Henri Becquerel (1852-1908) in 1898 it was just an element among many others, which was used for colouring glass and glazing ceramics and earthenware.

In 1789 the German pharmacist Martin Heinrich Klaproth (1743-1817) investigated pitchblende, a brownish-black mineral consisting mainly of uranium oxide (UO_2), obtained a yellow compound (probably sodium diuranate). From it, he was able to produce a black powder, which he believed to be a new element. He named it Uranium remembering that the planet Uranus had been discovered 8 years before by the astronomer William Herschel (1738-1822). In fact Klaproth only obtained uranium oxide and not the pure element. Metallic uranium was isolated only in 1841 by the French chemist Eugène Melchior Peligot (1811-1890).[3] Klaproth mentioned the property of uranium compounds for colouring glass, but the history of uranium glass between the end of the 18th century and the late 1830s is quite fragmented. Various German and English authors mentioned the use of uranium salts for colouring glass since the beginning of the 19th century, but due to the secrecy maintained by glass manufacturers about their recipes, little is known about this period.[4] The first dated artefacts made of uranium glass which survive are from the years 1835-1840, but certainly others were made in previous decades. In the 1840s the production of uranium glass began to boom owing to the introduction of better methods of extracting uranium salts from ore. Large- scale production of uranium glass is strictly connected to the story of Riedel, a glassmaking dynasty of Neuschloss in northern Bohemia[5], which started its activity in the late 17th century. Franz Anton Riedel (1786-1844) began the production of uranium glass in the 1830s and Josef Riedel (1816-1894)[6], who transformed the family business into a large industrial activity, became one of the most important manufacturers of glass jewels. Joseph Riedel personally developed the composition of beautiful yellow and green uranium glasses, which he baptised '*Annagelb*' and '*Annagrün*' in honour of his wife Anna. Around the same time similar uranium glasses were produced in England and in France under the name '*canary glass*' and '*verre canari*'. In France uranium coloured glass (which was produced at the glass making factories of Clichy and Choisi-le-Roi) was also named '*verre dichroïde*'.

In the second half of the 19th century uranium glass was used for an incredible number of objects: lamps, jewels, plates, bottles, drinking glasses, tankards, jars, buttons, necklaces, vases, inkwells, cups, etc. The most expensive artefacts were made of cut glass, while the cheapest objects were made with the press down technique. The popularity of uranium glass continued during the 'Art Nouveau' period, when it was appreciated by many artists and decorators. Its peak, however, came in the first half of the 20th century, especially in the 1920s and 1930s, when it was widely used for 'Art Deco' glassware. Between 1943 and 1958 the American government banned uranium salts from any commercial use because of its strategic importance during WWII and during part of the Cold War. After the ban was lifted several American manufacturers resumed production. It has to be pointed out that following the 1950s, uranium glass was produced with depleted uranium and therefore its radioactivity was reduced compared to older glasses.[7] Generally uranium was normally added into the glass

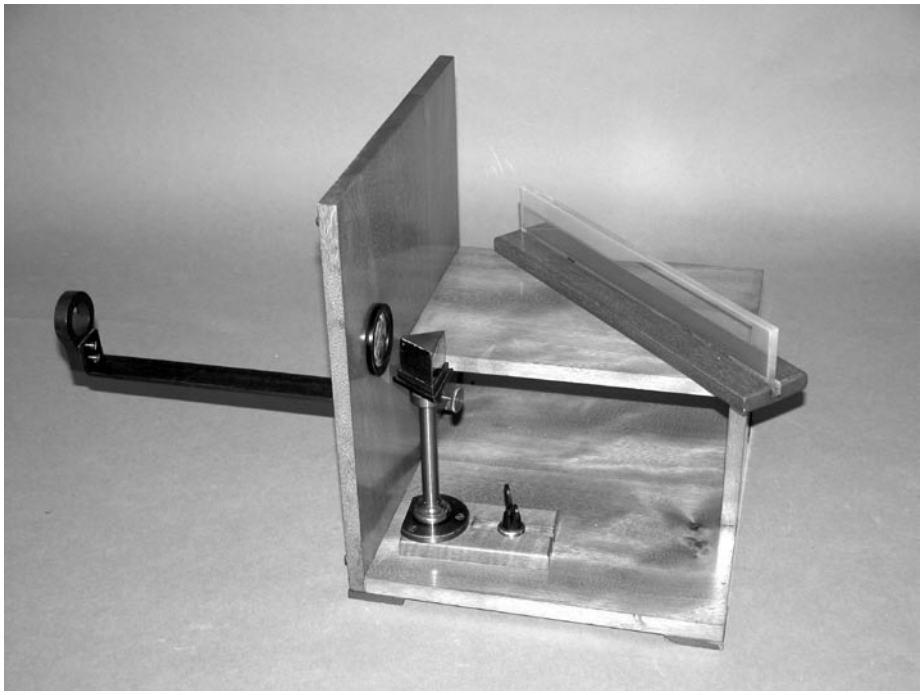

Fig. 2 *Müller's apparatus for showing the flourescence spectra of electric sparks. The instrument is preserved in the collection of the museum of physics of the University of Coimbra. (see Müller,* op. cit.*, note 21).*

compositions in the form of yellow oxide (sodium diuranate $Na_2U_2O_7{\cdot}6H_2O$). The salt dissolves easily into the silica matrix of the glass during the firing of the initial melt. Many recipes for different types of uranium glass can be found in technical treatises on glass making and several others, which were never published, remain in archives of glass factories. Extensive analysis has shown that generally uranium content in glass varies between 0,1 and 1,5 % even if sometimes higher percentages were used. Yellow glass contains more uranium than greenish glass (often including small amounts of copper) and generally the fluorescence of the former is stronger than the latter.

Fluorescence of Uranium Glass

Fluorescence is a kind of luminescence of cold bodies and it is a complex phenomenon.[8] Simply speaking, one can say that in fluorescence the molecular absorption of a photon produces the emission of another photon of longer wavelength (Stokes's law, see below). The energy difference between the absorbed and emitted photon is dispersed in molecular vibrations or heat. Usually the absorbed photon is in the range of ultraviolet light while the emitted is in visible light and the duration of the transition is in the range of about 0,5-20 10^{-9} sec. The brilliant greenish fluorescence of uranium glass is particularly strong when it is illuminated with long UV light around 360 nanometers; A common black light lamp (which also produces some violet light) is also excellent for exciting its fluorescence.

The first observations related to what we now call fluorescence goes back to the 16th century.[9] The Spanish physician and botanist Nicolas Monardes (1493-1588) noticed that an infusion of *lignum nephriticum*[10] displayed a peculiar bluish colour. Other physicians reported similar observations, and the property of the same wood attracted the attention of the polymath Atanasius Kircher (1601-1680), who in 1646 remarked that its infusion changed its colour depending on the condition under which it was observed. Other authors such as Boyle, Grimaldi, Newton and Hooke correctly recognized that the tincture was blue by reflected light and yellow by transmitted light. In the 18th century various philosophers repeated the same experiences and also found that other liquids (such as petroleum, as well as the tinctures of sandalwood, quassia wood and horse-chestnut bark) showed similarly peculiar phenomenon. But no real progress was made in explaining the phenomenon. At the beginning of the 19th century the famous French mineralogist René Just Haüy (1743-1822) observed that the colour fluorspar[11] was different by reflected and transmitted light. Haüy as well as John Herschel (1792-1871) tried to explain this phenomenon in terms of the colours of thin films. Around the same time, the Scottish physicist David Brewster (1781-1868) became interested in these phenomena and studied the behaviour of an alcohol chlorophyll (leaves) solution, and of fluorspar traversed by a beam of light. Herschel continued his observations with quinine solution and lignum nephriticum and in 1845 proposed the term '*epopolic dispersion*'[12] for the blue colour seen at the surface of these liquids. He also observed that the blue rays of the spectrum were responsible for the production this kind of dispersion. Brewster, stimulated by the paper of Herschel, extended the observations and showed that the so-called epipolic dispersion was merely a particular case of internal dispersion, peculiar only in this respect, and that the rays capable of dispersion were absorbed with unusual rapidity. He also remarked, probably for the first time, that uranium glass showed this kind of dispersion.

All these phenomena were reconsidered and carefully studied by the Irish mathematician and physicist George Gabriel Stokes (1820-1903) at the beginning of the 1850s. In a long and epochal paper of 1852 in which he coined the term 'fluorescence', Stokes offered a comprehensive description of the phenomena.[13] After having repeated the experiences of Herschel and Brewster, he proposed various systems for detecting and observing fluorescence; he introduced the cross-prism method for producing and studying the fluorescence spectra; he tested the action of different light sources on several substances; and he studied the polarization of fluorescent light in solids and solutions. Stokes came to the conclusion that incident light with greater refrangibility was always transformed into light with lesser refrangibility. That is in fact (in 19th century terms) the essence of the abovementioned Stoke's law. In a second article of 1862 Stokes extended the observations of florescent spectra produced by electric light produced by sparks or arcs between metallic electrodes, which were extremely rich in ultraviolet light. For these researches he used prisms and lenses of quartz and a plate of uranium glass (and a screen coated with uranium salts) and discovered that these fluorescence spectra extended '*no less than six or eight times the length of visible spectrum...*'.[14] Without entering in further details we can affirm that Stokes's research set the fundamentals of modern fluorescence.

In the second half of the 19th century, fluorescence was intensively investigated, and an increasing number of substances were tested under the action of various light sources. In the 20th century fluorescent phenomena began to play an ever-increasing role in an extremely wide range of scientific disciplines and techniques. Today they are among of the most powerful research and investigation tools in chemistry, biochemistry, medicine, mineralogy, gemmology, forensics, environmental sciences, history of art and are used in many practical applications in lighting, electronics, etc.

The Use of Uranium Glass in Scientific Instruments

Probably the first scientific observation of uranium glass fluorescence is due to

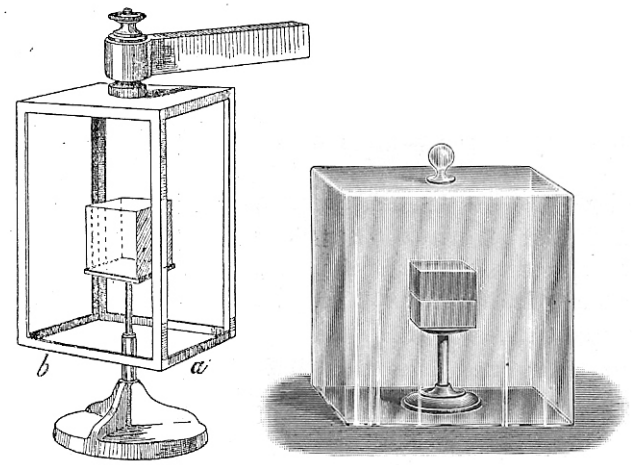

Fig. 3 *Two versions of the apparatus with coloured glass windows for demonstrating the flourescence of uranium glass. (see Mach,* op. cit., *note 24).*

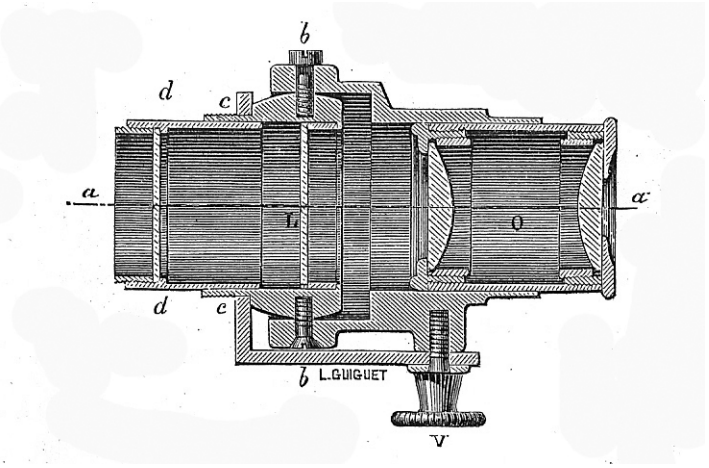

Fig. 4 *Soret's flourescent ocular The uranium glass plate is indicated with an 'L' (see Soret,* op. cit., *note 25).*

Brewster in the mid-1840s: '*Sir John Herschel mentions that the green flour-spar of Aston Moor is the only solid in which he observed an epipolic tint. It is the only mineral in which I have found an internal dispersion; but I have found several glasses which possess it, one in particular of a yellow colour, which disperses a brilliant green light.*[15] In his fundamental paper of 1852, Stokes dedicated about four pages to uranium glass, which at the time was commonly available. '*Among the media which posses the propriety of internal dispersion in a high degree, Sir David Brewster mentions yellow Bohemian glass, which dispersed a brilliant green light. This led me to seek for such a glass, and it proved to be very pretty common in ornamental bottles and other articles. The colour of the glass by transmitted light is pale yellow. Its ornamental character depends in a great measure upon internal dispersion, which occasions a beautiful and unusual appearance in the article made of it. The commercial name of the glass is canary glass. The following observations were made with a bottle of English manufacture.*[16]

Because of its strong fluorescence uranium glass was one the ideal substances for studying and demonstrating the phenomena of fluorescence. In 1861 the Austrian physicist Franz Joseph Pisko (1828-1888) published a booklet, which represented the state of the art of florescence studies and described several experiments with uranium glass.[17] Fours years later he presented a series of demonstrations concerning the phenomena of fluorescence excited by the light of electric sparks.[18] One of the most spectacular was made using a cube of uranium glass. A series of tiny disks of tin foil were glued to its surface so that they could form an interrupted line (exactly like in a sparkling tube). With a powerful electrical machine connected to the extremities of the line it was possible to produce a series of sparks bridging the gaps. The cube glowed with the typical vivid greenish light. A similar experiment was done using a long flat bar of uranium glass. (Fig. 1) In 1867 the French physicist Edmond Becquerel (1820-1891) in his famous treatise on light, extensively illustrated the phenomena of fluorescence and described various experiments with uranium glass.[19] But Becquerel never mentioned the term fluorescence, for him it was just a short lasting phosphorescence.[20]

From the second half of the 19th until the first decades of the 20th century most optical instrument makers offered blocks, plates and prisms of uranium glass which were utilized for demonstrating fluorescence (see cover). But it is not rare to find in physics cabinets decorative uranium glassware used for the same purpose (see cover). Many of them are still preserved today in museums and scientific collections. In 1867 the German physicist Johan Heinrich Müller (1809-1875)[21] conceived a compact apparatus for producing the fluorescent spectra of electric light and for repeating the above mentioned observations made by Stokes in 1862. It was composed of a wooden frame with a lens and a prism made of quartz (Fig. 2). On the frame, which also screened the observer from the light source, there was a plate of uranium glass. With this apparatus it was possible to see that using electric light across the length of the uranium plate produced much more fluorescence than with sun light. Various German firms such as Ferdinand Ernecke and Max Kohl offered this apparatus in their catalogues[22], and a similar device, composed by two moveable prisms and a lens on a stand, was produced by the Parisian maker Jules Duboscq.[23]

The Austrian physicist and philosopher Ernst Mach (1838-1916) described another didactic apparatus for showing fluorescence. (Fig. 3) It consisted of a rectangular box with pairs of opposite sides made of yellow and blue glass respectively.[24] In it there was a stand with a cube of uranium glass partially covered by paper. If sunlight illuminated the cube through the blue glass, the cube appeared brilliant yellow-green seen through the yellow glass. If the box was rotated 90 degrees, the cube appeared dark brown as the papers appeared in both cases. With this simple device it was possible to demonstrate that uranium glass transformed the blue (and violet) light into yellow-green (which is transmitted by the yellow glass) while in the reverse case the cube appears dark because it does not transform yellow light to blue (which would be transmitted by the blue glass).

Uranium glass proved to be useful not only for demonstration devices but also in the field of spectroscopy. In 1874 the Swiss chemist Jacques Louis Soret (1827-1890) used uranium glass in a 'fluorescent eyepiece' to be adapted to spectroscopes for observing the ultraviolet portion of the spectra (Fig. 4). Soret subsequently improved his eyepiece and used it in a series of extensive researches using various types of spectroscopes with prisms and lenses made of quartz (or Island spar). A definitive description of his eyepiece was published in 1874.[25] Essentially it was composed of a thin plate of uranium glass (about 1 mm) on which the florescence spectrum was formed.[26] The plate was observed with a moveable positive eyepiece, which could be oriented to avoid the disturbing effect of diffused light. With a suitable orientation of the eyepiece, the spectrum appeared clearly on the blackened wall of the tube. For example, at the end of the 19th century this device was one of the accessories of

Schumann's quartz spectrograph manufactured by the German firm Fuess of Berlin and offered by the French firm Ph. & F. Pellin in its catalogue.[27] Soret's eyepiece, which was often used for adjusting the position of photographic plates in UV spectrographs, remained quite popular in the 20th century.[28]

Uranium glass also found some use in microscopy. The first but not very successful application in this field, was described in 1857 by the German physiologist Ernst Wilhelm von Brücke (1819-1892).[29] He believed that the vivid light of the clear blue sky disturbed his microscopical observations. It could tire the eye and also generate an (at the time) undesired fluorescence in organic objects. For avoiding such disturbances and improving the quality of observations, Brücke proposed to use thick uranium glass slides (2 to 4 mm thick) for the preparation. Later and until at least the end of the 20th century, uranium glass blocks were sometimes used for visualising the paths of rays in microscopes and for teaching the principles of microscope optics and illumination.[30] When the block is placed above the condenser (or the illuminator) the light coming from it appears as a brilliant yellowish cone in the uranium glass (Fig. 5). The block can also be used for demonstrating the angular aperture and the working distance of the microscope objectives. (In this case one has to remove the eyepiece and direct light down the tube so that it comes out of the objective.) Finally uranium glass block were also used for calibrating various fluorescence apparatus.

As I mentioned before, uranium glass fluorescence is strongly excited by electrical discharges and this fact was exploited in electric eggs and Geissler tubes. Electric eggs, which derived from 18th century aurora flasks, were spherical or elliptical glass vessels mounted on a brass stand with a stopcock and having a brass collar with a sliding electrode on the top. The 'eggs' were evacuated with a pump and connected to the poles of an electrostatic machine or an induction coil. The appearance of the electric discharge depended on the type of gas or vapour and its pressure. If electric eggs were not made of coloured glass, a few of them were made of uranium glass (see cover). Studying this phenomenon, the British wealthy wine merchant and amateur scientist John Peter Gassiot (1797-1877) proposed a very spectacular demonstration in the early 1850s.[31] He placed a goblet (sometimes partially covered in foil) in a glass bell jar on the plate of a vacuum pump. An electrode, connected with the negative pole of an induction coil, penetrated into the bell with its lower terminal entering the goblet, which was made of uranium glass. He connected the second electrode to the plate of the pump. With a suitable vacuum, the discharge between the electrode and the plate appeared as an effluvium flowing along the external wall of the goblet like a luminous cascade. The discharges excited the fluorescence of the uranium goblet which glowed a brilliant greenish light. Sometimes the luminous phenomena were increased by putting the goblet on a small base coated with quinine sulphate which showed a blue fluorescence (Fig. 6).

The famous German instrument maker Heinrich Geissler (1814-1879), after having learned the art of glass blowing and after having travelled in various places, opened his own workshop in the early 1850s in Bonn and began his collaboration with several leading scientists. In the second half of the 1850s, Geissler developed his famous discharge tubes (with platinum electrodes), a mercury vacuum pump and many other glass laboratory apparatus. In the following decades Geissler produced an enormous number of tubes with an incredible variety of forms, dimensions and characteristics (different gases, pressures etc.).[32] Many of them were partially made of uranium glass. The use of this type of glass had essentially two purposes, scientific and aesthetic (see cover). On one hand it demonstrated that fluorescence could be excited by electrical discharge, while on the other hand it produced very brilliant and spectacular luminous effects.[33] In fact some Geissler tubes which came in the form of crowns, crosses, spirals did not have any special scientific purpose. They were simply used for attractive classroom demonstrations. It has to be remembered that some Geissler tubes presented a compact version of the abovementioned Gassiot's demonstration. The small uranium glass goblet was included in a sealed and evacuated bulb and there was no need of an additional pneumatic pump for producing the phenomenon known as 'Gassiot cascade' (see cover).

But Geissler tubes with uranium glass also found quite a successful technical application for a few years. In 1863 the Frenchmen Dumas and Benoît (an engineer and doctor from Privas) proposed a miner's safety electric lamp (Fig.7).[34] The device (which weighted about 5,5 Kg!) was composed of an electric battery, an induction coil and a Geissler tube protected by a thick glass cylinder. For increasing the intensity of the light and for limiting the dimensions of the lamp, the Geissler tube was formed by a long capillary tube coiled into a spiral. In the first trials the tube (made of normal glass) was filled with carbon dioxide which produced quite an intensive white light. But due to the chemical decomposition of the gas it was soon preferred to use nitrogen in a capillary tube of uranium glass. The reddish light generated by the discharge in nitrogen was 'corrected' by the florescence of uranium which produced a strong greenish light. For their invention of a safety lamp, Dumas and Benoît were awarded a 1000 Francs for the '*Prix Montyon pour les arts insalubres*' by the Académie des Sciences in 1864.[35] Similar lamps were also developed for submarine lighting. Again at the end of the 19th century the inventor and scientist Nikola Tesla (1856-1943) widely used uranium glass vacuum tubes for some experimental lamps working with his high frequency and high voltage currents (see cover).[36]

Prof. J.G.Delly (in a personal communication) pointed out another curious application of uranium glass. I quote his comment: *'When making, for example, glass electrolysis apparatus, metal electrical leads needed to go through the glass, and even*

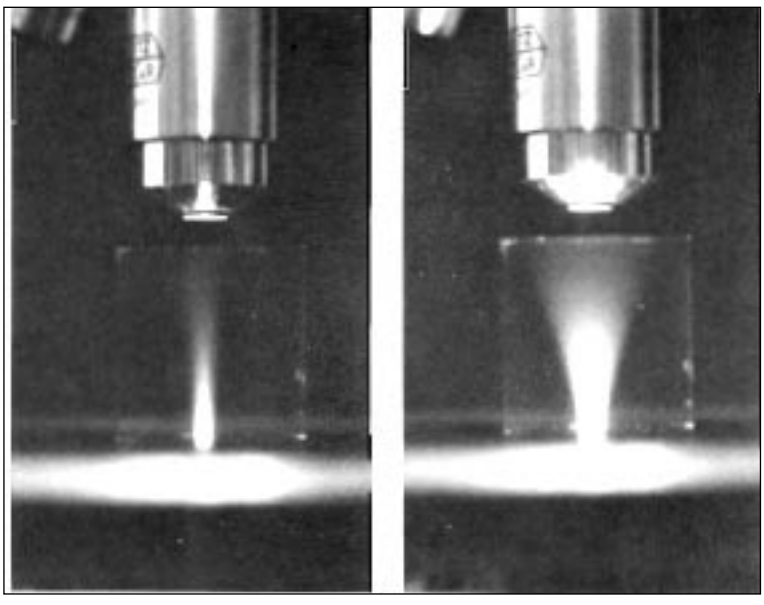

Fig. 5 *A uranium glass cube being used to demonstrate the light rays through a Zeiss Aplanat 1.4 Condenser with the aperture diaphragm set for, respectively, axial illumination and moderate angle illumination (see Delly,* op. cit., *note 30).*

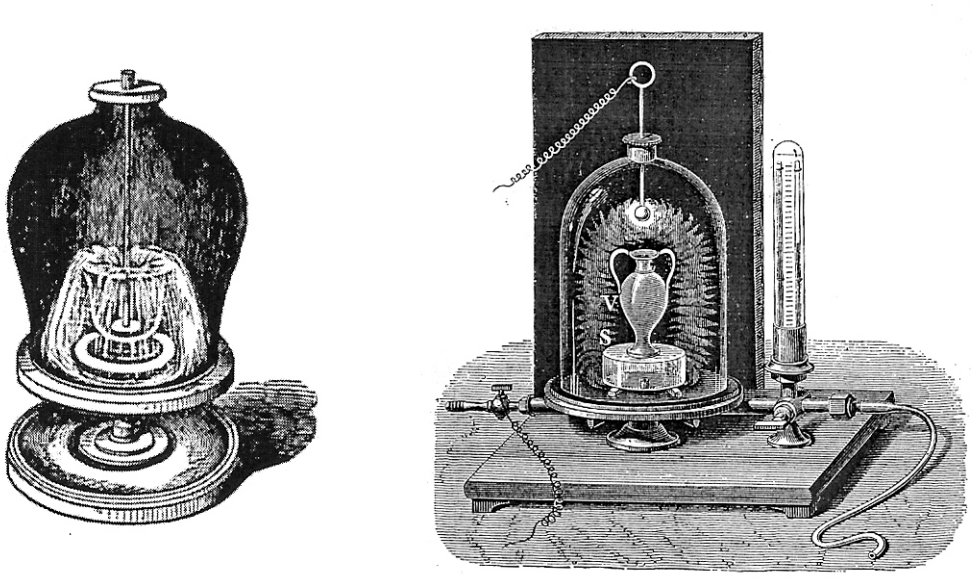

Fig. 6 *Two versions of the experiment known as 'Gassiot's cascade' (see Noad* op. cit.*, note 32 and Becquerel* op. cit.*, note 19).*

borosilicate glass could not be fused directly to the glass, but had to go through "graded seals" employing uranium glass'.

Finally uranium glass was also used in some scientific or technical apparatus just for its beautiful colour and its decorative effects and not specifically because of its fluorescence. For example, I have seen a beautiful Volta's electric lighter with uranium coloured glass vessels, while apothecary bottles of the same material were relatively common.

Is Uranium Glass Dangerous?

When I show my collection of uranium glass to friends, I always hear the same inevitable question. Is it dangerous? The harmful effects of radiation are too well known. Natural uranium consists of 3 radioactive isotopes with very different proportions: U^{238} (99.285%), U^{235} (0.711%) and U^{234} (0.005%). Uranium atoms break down spontaneously through a multistep process forming a series of radioactive products. Over a long period of time, these products break down forming non-radioactive lead atoms. The U^{283} to Pb^{206} half life is about 4.5 10^9 years. Uranium decays emitting alpha and beta particles and gamma rays. The former are rapidly absorbed in air but gamma radiation travels much farther. The greatest hazard is from internal exposure to alpha and beta radiation emission coming from uranium and its progeny products which enter the body via inhalation or ingestion.

In the recent years several specialized studies have been made on uranium glassware and several measurements have been done.[37] Many uranium glass artefacts have been measured using Geiger counters and other instruments. Without entering in the details which can be found in the mentioned bibliography, we can state that generally radioactivity of uranium glass artefacts is remarkably low. For example, a series of measurement made on about 30 different artefacts showed that apart from two exceptions, at a distance of about 60 cm no radiation at all could be detected considering that the background radiation is 0,02 mrem/h. At a much shorter distance (about 1 cm) the highest level of radiation was 4mrem/h Working for 5 hours with artefacts that measure 0,02 mrem/h produces less radiation exposure than a normal dental X-ray.

Finally one can say:

a) From recent researches it appears that radiation exposure from normal handling of individual uranium glass artefacts (and uranium glazed or enamelled art object) is very low. It is in the order of normal background radiation. It does not represent a danger nor require any special care. Nevertheless it would be better to avoid storing large numbers of such objects together or at least to check their global radioactivity.

b) Internal exposure through ingestion or inhalation can be more important, also considering that uranium salts not only are radioactive but toxic. Therefore it is better to avoid uranium tableware (drinking glasses, plates, etc.) for storing or serving food. Uranium can leak from glassware (and especially from glazed ceramics) when submitted to the action of acids or bases.

c) Restoration work involving smoothing, polishing or drilling uranium glass or uranium colorants can produce uranium containing dust, whose inhalation can be hazardous. In such case a dust mask and gloves are recommended.

Acknowledgements

I would like to thank all those who through the electronic mailing list 'Rete' sent me several important pieces of information. A special thank you to my friend David Pantalony, who for a long time has carefully corrected and improved the English in my articles.

Notes and References

1. Uranium glass has several names. The term 'vaseline glass' was probably introduced in the mid-20th century and is widely used in the USA for decorative artefacts. It seems that at the beginning it indicated a particular kind of opaque-white uranium glass tempered at high temperature and similar in appearance to petroleum jelly. Uranium glass, which was also called 'canary glass' or 'yellow Bohemian glass' is translated in French as 'verre à l'uranium', 'uraline', 'verre canari' or 'verre dichroïde', and in German as 'Uranglas', 'Annagelb' or 'Annagrün', and in Italian as 'vetro all'uranio'.

2. As far as I know the best book about uranium glass history, technology and decorative use is: H. von Philipsborn, R. Geipel (and others), *Uranfarben, Urangläser, Uranglasuren –radiometrisch, technisch. Historisch-, Schriftenrehie des Bergbau- und Industriemuseums Ostbayer*, Band 46 (Schloss Theuern, Kümmersbruck, 2005). See also R. Schwanker, *Uran in Glas* (available at: http://www.stmwfk.bayern.de/downloads/aviso/2001_3_aviso_22-29.pdf). Several other books are more dedicated to collectors of decorative artefacts. See for example: C. Davies Sue, *The Picture Book of Vaseline Glass* (Atglen, PA, 1999). See also: http://en.wikipedia.org/wiki/Uranium_glass, http://www.glassassociation.org.uk/Journal/uranium.htm, http://www.glass.co.nz/uranium.htm.

3. Uranium is not a very rare element. The Earth crust contains an average of about 0,27% of uranium which it is the same concentration of tin. Silver is much scarcer (0,0006 %).

4. Uranium salts were also widely used for glazing decorative ceramic artefacts, earthenware, etc.

5. Today *Nový zámek* in Tschechische Republik.

6. About the Riedel dynasty see: http://www.riedelcrystal.co.at/page21.htm.

7. Depleted uranium is obtained by extracting from natural uranium part of its content of U^{235} . Depleted uranium

contains only 0,2-0,3 % of this isotope instead of about 0,7% of natural uranium.

8. For a more detailed description of the phenomena of florescence see the specialised textbooks or websites.

9. For a detailed history of fluorescence see E. Newton Harvey, *A History of Luminescence* (Philadelphia, 1957).

10. This tree, which was supposed to cure kidney diseases, is the *Eysenhardtia polystachia* (palu dulce) from Mexico.

11. Fluorspar is a mineral composed of calcium fluoride (CaF_2). The term fluorescence comes in fact from it.

12. Epipolic dispersion means superficial dispersion. The term 'epipolic' derives from Greek word 'επιπολη'.

13. G. Stokes, 'On the Change of Refrangibility of Light', *Philosophical Transaction of the Royal Society*, **143**, Part 2 (1852), pp. 463-562.

14. G. Stokes, 'On the Long Spectrum of Electric Light', *Philosophical Transactions of the Royal Society*, **152**, Part 3 (1863), pp. 599-619.

15. D. Brewster, 'On the Decomposition and Dispersion of Light with Solid and Fluid Bodies', *The London Edinburgh and Dublin Philosophical Magazine and Journal of Sciences*, 3rd series, **32** (1848), pp. 401-402.

16. See note 13.

17. J. Pisko, *Die Flourescenz des Lichtes* (Wien, 1861).

18. J. Pisko, ,Beitrag zur Flourescenz des Lichtes', *Annalen der Physik und Chemie*, V Reihe, IV Band, 1865, pp. 471-476.

19. E. Becquerel, *La lumière ses causes et ses effets* (Paris, 1867), Tome I, pp. 178, 316-334.

20. In the past the difference between fluorescence and phosphorescence was just determined by the duration of the phenomenon. In the fluorescence the emission of light stops almost immediately after the excitation, while in the phosphorescence the emission can continue for a quite long time. Today a much more precise distinction is made from the different mechanisms involved in the electronic transitions of these phenomena.

21. J. Müller, ,Das Florescenz-Spectrum des elektrischen Lichtes', *Annalen der Physik und Chemie*, V Rehie, 10 Band, 1867, pp. 137-140. See also: *Müller-Pouillet's Lehrbuch der Physik und Meteorologie* (umgearbeitet un vermehrte Auflage von L. Pfaundler), II Band, Erste Abtheilung (Braunschweig, 1897), pp. 370-372.

22. See for example F. Ernecke, *Physikalische Apparate, Chemische Instrumente und Gerätschaften Preisliste 11* (Berlin, 1887), p. 74 or Max Kohl, *Physikalische Apparate Preisliste N.21* (Chemnitz, 190-), p. 392.

23. J. Duboscq, *Catalogue systématique des appareils d'optique* (Paris, 1870), p. 20.

24. E. Mach, *The Principles of Physical Optics an historical and philosophical treatment* (London, 1926), pp. 129-130, see also J. Frick, O. Lehmann, *Physikalische Technik*, II Band, 2 Abteilung (Braunschweig, 1909), p. 1048. See also Fürsten von Salm-Horstmar, 'Beobachtungen über Flourescenz', *Annalen der Physik und Chemie*, IV Rehie, 8 Band (1856), pp. 343-345.

25. J.L. Soret, 'Spectroscope à oculaire fluorescent', *Annales de Chimie et de Physique*, V Série, Tome XI, pp. 72-86.

26. Instead of the plate of uranium glass it was possible to use also a cell containing a fluorescent solution.

27. C. Leiss, *Die optische Instrumente der Firma R. Fuess dener Beschreibung, Justierung und Anwendung* (Leipzig, 1899), p. 67, Pellin Ph. & F. *Instruments d'optique de précision, VI Fascicule, Spectroscopie, Phosphorescence, Fluorescence* (Paris, 1913), p. 27.

28. B.K. Johnson, *Optics and Optical Instruments* (New York, 1960), pp. 102-103.

29. E. Brücke, ,Ueber Objectträger aus Canarienglas', *Dingler's Polytechnisches Journal*, **144** (1857), pp. 438-440.

30. See for example J.G. Delly, 'Uranium Glass in Microscopy', *The Microscope*, **38**/1 (1990), pp. 109-116 and also E.M. Chamot, C.W. Clyde Walter Mason, *Handbook of Chemical Microscopy* (New York, London, 1938), pp. 10, 47, 89 and also S. Inoué, K.R. Spring, *Video Microscopy: the fundamentals* (New York, 1997), pp. 123-124. Recently these uranium glass blocks tend to be replaced by fluorescent plastics.

31. See T.B. Greenslade, 'Nineteenth Century Textbook Illustrations XXXV/ Gassiot's cascade', *The Physics Teacher*, **8** (1980), pp. 296-297. This experiment is illustrated in many physics treatises, see for example E. Becquerel (*op.cit.*, note 19), pp. 333-334 or H. Noad, *The Improved Induction Coil* (London 1861), p. 42.

32. Many tubes can be seen in the 19th century instrument makers catalogues and in several websites. See for example: http://www.infogr.ch/roehren/roehren.htm or http://www.jogis-roehrenbude.de/Roehren-Geschichtliches/Glimmroehren/Geissler-Roehren.htm and http://members.chello.nl/~h.dijkstra19/page6.html.

33. Fluorescent minerals and solutions were also enclosed in certain types of Geissler tubes.

34. Dumas, Note descriptive de la lampe photo-électrique', *Bulletin de la Société d l'Industrie Minérale*, Tome IX (1863-1864), pp. 5-14 and 'Lampe Dumas', *ibid.*, pp. 113-117 ;'Note sur la lampe électrique de

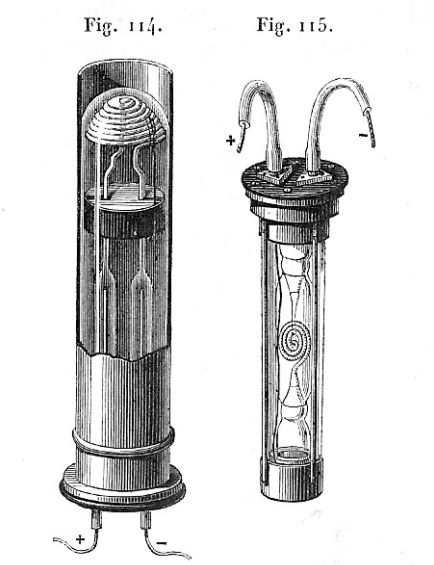

Fig. 7 *The electric miner lamp invented by Dumas and Benoît (see Dumas* op.cit., *note 35).*

Dumas et Benoît', *ibid.*, pp. 118-120. See also T. Du Monchel, *Notice sur l'appareil électrique e Ruhmkorff* (Paris, 1867), pp. 394-398.

35. See 'Prix dit des arts insalubres', *Comptes Rendus de l'Académie des Sciences*, **60** (1864), p. 273.

36. N. Tesla, 'Experiments with Alternating Currents of Very High Frequency and their application to methods of artificial illumination', A lecture delivered at the American Institute of Electrical Engineers at Columbia College, May 20, 1891, in *Nikola Tesla, Lectures,* edited by Vojin Popovic (Beograd, 1999), pp. pp. 41-83.

37. See D. Strahan, 'Uranium Glass, Glazes and Enamels Identification and Handling', *Studies in Conservation*, **46**, No. 3 (2001), pp. 181-195, and also the above mentioned book by H. von Philipsborn, R. Geipel, *op.cit.*, note 2.

Author's address:
Via Motta 27
CH-6850 Mendrisio, Switzerland
e-mail: pbrenni@imss.fi.it