THE DEVELOPMENT OF THE MERCURY LAMP

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Introduction

The mercury (vapor) lamp (1) is an evacuated tube, usually of quartz, with electrodes sealed in at the ends and containing a quantity of liquid mercury. Variation of size, shape, amount of mercury, and electrical system can produce a small, low intensity lamp suitable for detecting spots on a thin layer chromatogram (2) or a lamp of output in the hundreds of watts appropriate for outdoor lighting. These are but two of the great variety of uses of such lamps. Their long history began with Humphrey Davy, 19 years after he had discovered the carbon arc lamp (3). Described here is the early development of the mercury lamp .

Humphry Davy: The Discovery

The first connection of electricity to mercury was reported to the Royal Society of London by Davy in 1821 (4). Earlier workers had argued that electricity could not be transmitted through a vacuum, the "ether" being required as a medium. Davy was interested in testing the validity of this hypothesis. He chose to use mercury as an electrode material, apparently on a suggestion of Berzelius. Fig. 1 is a reproduction of the simple apparatus he constructed as described in his 1822 paper: a bent tube containing an amount of mercury with an electrode cemented in at one end and a stopcock at the other. The lamp was filled to any desired level with mercury and degassed by evacuation with an air pump followed by repeated boiling of the mercury.

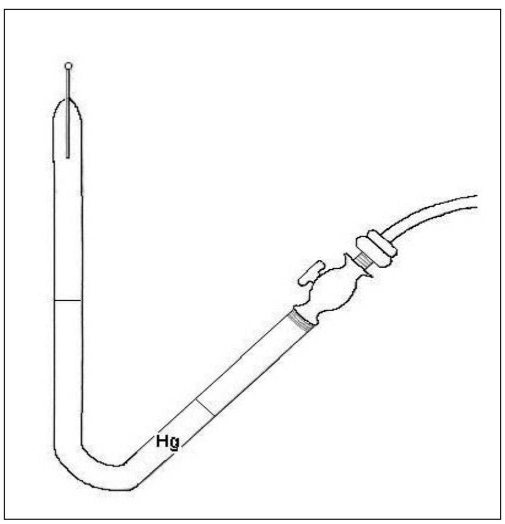

Figure 1. *Sir Humphry Davy's Mercury Lamp*

A remarkably bright light was observed when the electric current from a battery was applied. Davy investigated various effects, such as temperature, on the behavior of the system. Satisfied that he had established the fact that current could be transmitted through a vacuum, he turned his attention in other directions.

Three scientific papers using mercury light sources for study of the emission spectrum of mercury vapor appeared during the remainder of the 19th century until the report of Arons in 1892 (see below) when the study of mercury lamps returned to the realm of science. The first of these in 1835 was due to Wheatstone (5), who obtained emission spectra of mercury and of the molten metals zinc, cadmium, tin, bismuth, and lead. The action of an electric spark on mercury gave "seven definite rays separated from one other by dark intervals." Emission spectra were also obtained by the same procedure from the metals listed above. "The appearances are so different that, by this mode of examination, the metals may be readily distinguished from each other"(5). This was suggested as a superior method for analysis, but Wheatstone's interests lay in other very productive directions involving mainly electrical apparatus. He did no further work nor did he evince any interest in application of mercury lamps for illumination. He did anticipate the work of Bunsen and Kirchoff over a decade later.

Ångstrom (6) reported an extensive study of emission spectra of many substances in 1855. He used Geissler (7) tubes to obtain the emitted light and included mercury among the substances investigated. This was followed by a study of mercury by Gladstone, who used a lamp he obtained from Way (8) (see below). There was good agreement between the results of the latter two investigators.

Wiedemann, using Geissler tubes, studied emissions of mercury with a variety of other substances also (9). Fig. 2 presents an idealized emission spectrum of mercury vapor. As will be discussed, the relative intensities vary with the pressure of mercury. To be noted is the large number of well-spaced emission lines.

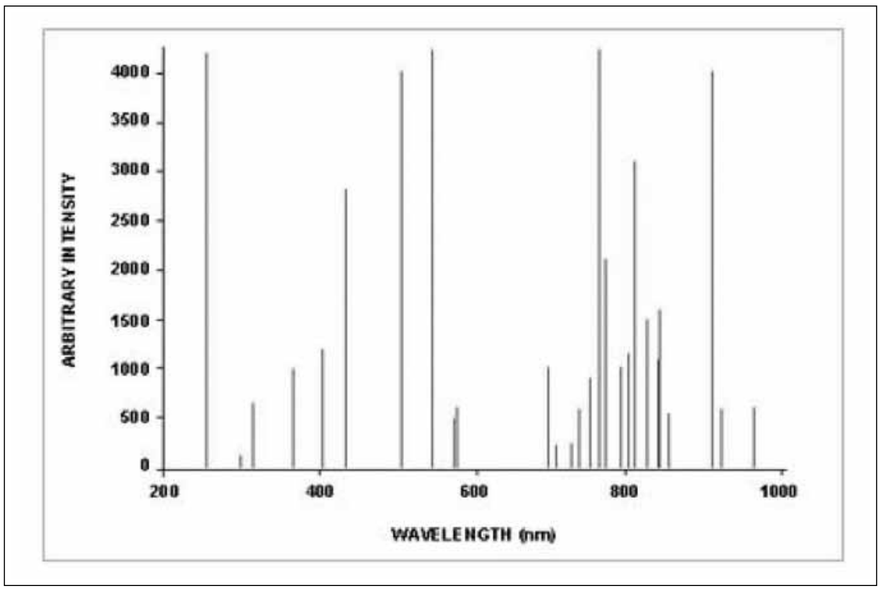

Figure 2. *Idealized Version of Mercury Emission Spectrum*

19th-Century Patents

Except for work relating to the emission spectrum of mercury described above, activity in the area of mercury lamps was concentrated exclusively in the field of patents for lighting applications until Arons' paper (see below) in 1892. A few of those patents, listed below, were discussed and summarized by Recklinghausen (10) and by Perkin (11). There are undoubtedly more; the middle of the 19th century was a time when street lighting came into popular use.

1852. E. H. Jackson of Soho patented a lamp based on carbon electrodes, one electrode with a recess containing a quantity of mercury.

1857. J. T. Way Brit. Pat. No. 1258, 4 May 1857, "Improvements in Obtaining Light by Electricity, and in Employing light so Obtained for lighthouses and for Giving Signals," No. 2841m, 10 Nov., 1857, "Improvements in Obtaining Light by Electricity." For details see below.

1857 Charles W. Harrison patented a lamp with a carbon rod suspended over a cup of mercury.

1867. Sir W. Siemens (UK) developed a lamp with a vibrating electrode dipping into a mercury cup which gave intermittent light. Proposed for lighting buoys at sea.

1879. J. Rapieff, Brit. Pat.. 211, 18 Jan., 1879, "Producing and Applying Electric Currents for Lighting &c". Two mercury poles in U-tube, started by shaking or tilting the U tube, either *in vacuo* or air.

1887. Rudolph Langhans, German Pat. 45880, 24 Nov. 1887, Klasse 21, described a U-tube filled with metal or metalloid.

1889. Rizet French Pat. 132426, 27 Aug., 1889, similar to that of Rapieff but filled with nitrogen.

These devices quietly faded into obscurity, but the lamp of J. T. Way caused much excitement in its time. A long article in the London *Times* of Aug. 3, 1860 (12) ecstatically described a night time boat trip in the English channel illuminated by a Way lamp and including a run by the Queen's channel residence (Osborne House), so that she could see the new marvel. This was also reported in other publications (13). Quoting the *Times*: "The strongest and purest light in the known world, and the nearest approach to sunlight…"

For a discussion of the ignition of Way's lamp, see the later section on lamp ignition. The lamp itself was not closed to the atmosphere; and Monasch reported (14) that because of the exposure to mercury vapor, Way paid with his life for the experiments with his lamp. This was an exaggeration, since he continued an active career in agricultural and environmental science into his later years and died in 1883 at age 63. In any event, nothing was heard of his lamp after 1860; nor was it mentioned in his obituary (15) in the *Journal of the Chemical Society*.

Arons' Lamp

The development of the mercury lamp began in earnest with the work of Arons published in 1892 (16); he is sometimes given credit (17) for its invention, although he cites the work of Way in the first footnote to his second paper (18) and the use of Geissler tubes by Wiedemann (9) to obtain the mercury spectrum. His lamp design follows that of Rapieff by using a U-tube.

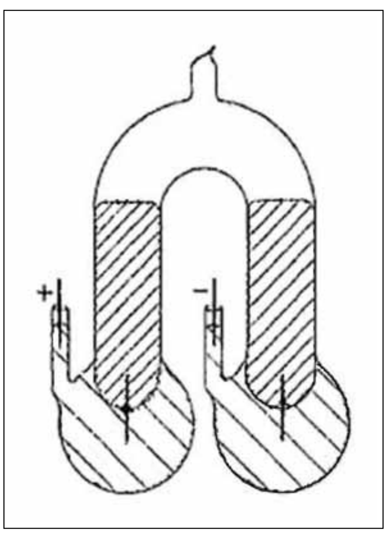

***Figure 3**. Aron's Mercury Lamp*

The simple construction of Arons' lamp is shown in Fig. 3. It consisted of an inverted U-tube (2-cm diameter tubing) with 6-cm arms and a side tube at the top for connection to a vacuum pump, etc. Platinum electrodes were sealed into the closed ends of the two arms with cement, and the whole apparatus filled with mercury nearly up to the bend, exhaustively evacuated, and sealed off. The apparatus shown in the figure is a modification with additional mercury reservoirs at the bottom for dissipation of the heat; these could be further cooled in water. Exhaustive evacuation and good sealing were key elements in successful lamp preparation. Current for the lamp was provided by a battery or by the municipal electrical supply (105-110 v DC) with suitable regulator. The lamp was ignited by connecting the current supply followed by tapping or tilting to create a temporary metallic circuit. This led to the vaporization of some mercury; and after a very short interval the lamp, returned to the vertical position, ignited to give a remarkably intense, stable, grayish-white light.

Table. Current-voltage relationships in Arons' mercury lamp

Amp	11	9	7	5.5	3	2	1.4	0.8	0.5
Volt	17.5	17	16.5	16	15.3	14	20	28	40

The Table gives the current-voltage relationships Arons found. At currents of 1.4 amp or less, ignition was not possible. It was necessary to ignite the lamp at a higher current and then reduce it to the desired value. In contrast to the carbon arc, the cathode of the mercury lamp was appreciably hotter than the anode. Arons, using a grating apparatus, observed 33 lines in the emission spectrum of his lamp. It should be noted that ordinary glass was used, for lack of an alternative, eliminating emission below about 300 nm.

The considerable amount of heat generated was the major problem with Arons' design, affecting the seals and resulting in deposition of mercury on cooler walls of the apparatus.

Detailed studies of the inverted U-tube lamp including results with a variety of amalgams were reported by Arons in 1896 (18). Major factors in the construction of stable, long-lived lamps were temperature control, high vacuum, and good quality sealing of the electrodes. A modified lamp housing which allowed more efficient utilization of the light produced by avoiding condensation of mercury drops on the light-transmitting part of the apparatus was described by Lummer (19), who arranged for commercial production of this lamp with a water-cooled housing, as illustrated in

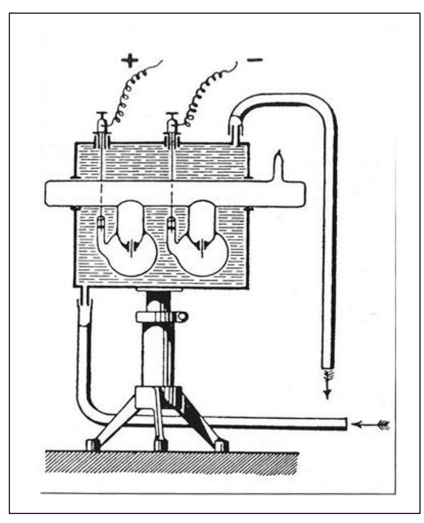

***Figure 4**. Lummer's Commercial Water-Cooled Mercury Lamp*

Fig. 4. The mercury lamp was on its way to becoming an important tool in science. For example, Fischer and Braehmer (20) in 1905 used a home made mercury lamp for a detailed study of the photochemical formation of ozone from oxygen.

Cooper Hewitt's Street Lamp

The first practical mercury lamp was developed by Peter Cooper Hewitt. Cooper Hewitt made a detailed study of the factors involved in operation of a lamp, such as geometry, electrical characteristics, amount of mercury, etc. A simplified drawing from his 1901 patent (21) is shown in Fig. 5. The bulb at the top of the lamp was introduced to optimize the cooling of the lamp; similar bulbs grace many mercury lamps produced over 100 years later. Ignition was achieved by a solenoid arrangement, which tilted the lamp so as to close a circuit and vaporize some mercury, whereupon the lamp was returned to the vertical position (22). Recklinghausen (10) has discussed Cooper Hewitt's design in some detail.

Cooper Hewitt's lamp had a long lifetime and a light output far in excess of tungsten lamps of comparable wattage. Its main drawback was the light itself, which made objects appear an unnatural chalky color. This did not interfere with some uses such as outdoor lighting or use as a projection lamp. Much work was done to improve the quality of the light. Cooper Hewitt and George Westinghouse established a company to market the lamps; this was taken over by Westinghouse Electric in 1902 and changed to a joint arrangement with General Electric (GE) in 1913. Westinghouse subsidiaries in a number of European countries marketed the lamp in Europe (23). GE took over the lamp operation upon George Westinghouse's death in 1914. The Cooper Hewitt lamp served as a model for lamps produced by other companies.

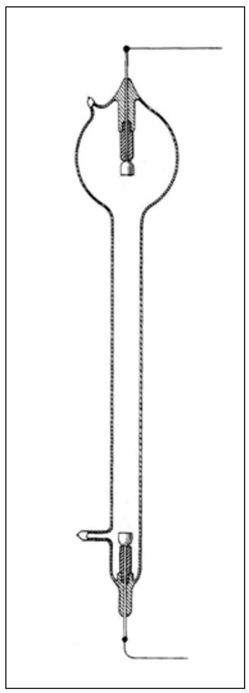

Figure 5. *Cooper Hewitt's Gas-Vapor Lamp*

Quartz Lamps.

The next advance in mercury lamps was the result of developments in quartz technology, which came at the beginning of the 20th century (24). The lamps described earlier were all constructed from ordinary glass. The development of quartz with high transparency in the ultraviolet allowed construction of lamps with improved optical properties and much greater heat resistance (24). The higher temperatures that could be tolerated by quartz resulted in higher efficiency of the lamps.

It should be noted that the much improved ultraviolet transparency requires great care in avoiding exposure of skin and particularly eyes to the light produced. In 1905 Schott (25) described a commercial lamp, called the Uviol lamp, which transmitted light down to 253 nm. He stated that Heraeus quartz was transparent to 220 nm. The efficiency of the mercury lamp improved sufficiently at higher pressure, so that it was economical to construct lamps for street lighting of quartz and enclose them in an envelope of ordinary glass for protection of passers-by.

Ignition

If the usual working current is applied to a cold mercury lamp, nothing will normally happen. The early workers with U-tubes found that their lamps would ignite if a temporary circuit were closed by tilting or tapping the mercury. After brief flow of current, the lamp would ignite as soon as the circuit was interrupted. It was assumed that this was necessary because of the low vapor pressure of mercury at ambient temperature. Weintraub speculated that formation of ions or local arcs was necessary for ignition. As noted above, temporary tilting was an integral part of Cooper Hewitt's and the Uviol lamps. Way (26) had an ingenious method for ignition using flowing streams of mercury to close the circuit; ignition occurred when the flow was interrupted. Intermittent flashing light could be generated by adjusting flows to have periodic breaks. With systems under high vacuum, ignition could also be initiated by an external Tesla coil.

A simple, practical solution to the ignition problem was discovered by Weintraub (27), who introduced a third, metallic electrode close to the cathode. Initial application of current between the two proximate electrodes led to some activity at the main cathode, and this in turn initiated interaction between the two main electrodes. Many present day commercial mercury lamps incorporate Cooper Hewitt's bulb and Weintraub's third electrode.

Final Remarks

An idealized emission spectrum of the mercury lamp is shown in Fig 2, where it can be seen to consist of a series of lines covering the range from 187-254 nm and through the UV and the visible spectrum. Individual lines or narrow groups of lines can be isolated with commercially available filters, making the lamps particularly useful for photochemical studies. They became available at a time when much attention was being paid to photochemical reactions because of the Einstein postulate relating the number of photons absorbed to the number of molecules absorbing. Mercury lamps continue to be extremely valuable in photochemical investigations up to the present day.

The output of mercury lamps is partly dependent on the operating conditions of the lamp. When the amount of mercury involved is very small, the emission spectrum of the resulting low pressure lamp is concentrated in the ultraviolet (on the order of 90% at 187 and 254 nm). This wavelength range was shown to be very efficient in destroying undesirable bacteria, and sterilization lamps were available commercially before 1911. The fluorescent lamp, developed in the 1930s (28), is also a low pressure mercury lamp contained in a tube which has an inner coating of a material that absorbs the short wavelengths and emits in a useful region of the spectrum.

Increasing the amount of mercury in the lamp leads to medium-, high-, and superpressure lamps. Self absorption by excess mercury vapor present results in disappearance of the 254-nm emission in higher pressure lamps and some broadening of the remaining emissions. By the time of these developments, progress in mercury lamps had been largely concentrated in the hands of the industrial producers of lamps, so that much of the information is proprietary or in the form of patents. Almost anywhere light is required, the mercury lamp can be found in the appropriate configuration. High and super-pressure lamps (1-2 mm i.d., 2 cm length) can approximate point sources and be used in optical systems.

Mercury sensitization is a special case in which a solution containing traces of dissolved mercury is irradiated with a mercury lamp. The resulting excited mercury may transfer its energy by collision with other molecules present, resulting in reaction of the excited state which is formed.

Present demands for nonpolluting, high-efficiency light sources promise an interesting period in lamp development in the near future. Minimum efficiency for ordinary domestic lamps has been legislated in various parts of the world, including the U. S. The leading candidate at the time of preparing this article is the "long life" compact fluorescent lamp, another mercury-derived lamp. Vigorous research is in progress to improve the efficiency of the classic tungsten lamp as well as development of new types of lamps such as the sulfur lamp.

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REFERENCES AND NOTES

1. The term mercury lamp and mercury vapor lamp are often used interchangeably, but they may be indexed separately. The correct usage (IUPAC) is mercury lamp, deuterium lamp, hydrogen lamp, etc.
2. An extremely useful technique for analysis and separation of mixtures. The most convenient method for visualizing the separated materials after migration of a solvent on an adsorbent layer is shining light from a mercury lamp on the dried plate.
3. An anonymous referee, whose erudition we admire and to whom our thanks are due, has brought to our attention the "barometric light" discovered by Picard in 1675 and reported in detail by Francis Hauksbee in 1709. When a tube containing mercury under a modest vacuum is shaken, a glow is observed, presumably the effect of static electricity on the mercury. See Wikipedia or any edition of the *Encyclopedia Brittanica* under the heading barometric light.
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Mordecai B. Rubin (chrubin@tx.technion.ac.il) has been emeritus professor of chemistry, Schulich Faculty of Chemistry Technion since 1994. It has become difficult to remember when he was not retired. This work on the mercury lamp originated from investigation of the early photochemistry of ozone, where mercury lamps played an important role— thus showing that his historical research is still dominated by the history of ozone.