



XXII. Note on the construction and attachment of thin galvanometer mirrors

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the calculated values of X are represented, the scale being the same as in fig. 2.

The constant B varies nearly as the pressure, while C increases rapidly with diminishing pressure. If X_m is the maximum value of the intensity, then $X_m^2 = B$, so that X_m varies as \sqrt{p} .

C is equal to $\frac{\lambda e k_2 p}{A \beta}$ and $B = \frac{\lambda}{A}$, consequently, since C increases as the pressure diminishes, it follows that β the coefficient of recombination must rise with increasing pressure. This result is in agreement with Langevin's measurements* of the coefficient of recombination of the ions produced in air by Röntgen rays at low pressures.

The experiments described in this paper were done at the Cavendish Laboratory, and I wish to say that my best thanks are due to Prof. J. J. Thomson for his kindly interest and advice given during the course of the work.

XXII. *Note on the Construction and Attachment of Thin Galvanometer Mirrors.* By W. WATSON, D.Sc., F.R.S., Assistant Professor of Physics, Royal College of Science, London†.

AS has been pointed out by several persons (Rayleigh, Phil. Mag. xx. p. 360, 1885; Threlfall, Proc. Phys. Soc. xvi. p. 205, 1898) there are distinct advantages in increasing the sensitiveness of the optical arrangements used to measure the rotation of a galvanometer needle rather than increasing the electrical sensitiveness, *i. e.* the angular deflexion produced by a given small current. Excessive electrical sensitiveness implies a very weak controlling force. Such a weak controlling force involves a long period, and also disturbances produced by convection currents in the air and tremors in the supports of the instrument.

In order to increase the optical sensitiveness of a galvanometer it is necessary to increase the diameter of the mirror, while, to allow of its being carried by a fine suspension and to keep the period low, the weight of the mirror must be made as small as possible, yet at the same time its figure must remain good. With the ordinary form of mirror, consisting of a disk of glass silvered on the back, it is almost impossible to obtain a really thin mirror with a good figure unless the area of the mirror is excessively small. In the first place, the grinding and polishing of a very thin slip of glass is an

* *Thèses présentées à la Faculté des Sciences*, Paris, pp. 150-152.

† Communicated by the Physical Society: read May 8, 1903.

operation which taxes the skill of the optician to the utmost. More important, however, is the fact that the silver backing of the mirror has to be coated with some kind of varnish to protect the silver from the action of the impurities in the air. Although numberless kinds of varnish have been tried for this purpose none has yet been discovered which does not distort the mirror to some extent. A further difficulty in the case of the glass mirror is the attachment of the mirror to the stem which carries the magnets, the cement employed almost always producing some distortion. While designing a special form of mirror for use in a magnetograph I have been led to a method of constructing galvanometer mirrors which I believe entirely obviates the difficulties mentioned above.

Prof. Threlfall has already pointed out the advantages of quartz as a material from which to construct galvanometer mirrors, but he, I believe, employed silvered mirrors, and hence had to use some form of varnish, and also he cemented the mirrors to the rod which carried the magnets. He tried both crystalline quartz and fused silica, and states he found them equally suitable. In my case I was obliged to use fused silica, and when I attempted to use thin slices silvered on the back I found that there was a very considerable loss of light owing to the small bubbles which are always present in any but the smallest pieces of fused silica. It then occurred to me to try and use some material for the reflecting surface which would be unaffected by the air. Platinum naturally was the material first tried, and after testing practically all the methods of which I could hear for giving a bright film of platinum, I obtained from Messrs. Johnson and Matthey a platinizing solution which is entirely satisfactory, and gives without any polishing a perfectly bright surface of platinum. The film of platinum obtained is bright on the surface turned away from the silica, so that the reflexion takes place at the air-platinum surface, and hence the silica disk requires polishing on one surface only, a circumstance which, as will be seen, very much simplifies the construction of thin mirrors.

The method I adopt for making the mirrors is as follows:—A stick of fused silica is prepared having a diameter equal to the diameter of the mirror it is wished to prepare. This stick is cemented to a small piece of wood by means of pitch. A disk of tinned iron (No. 28, s.w.g.) about 12 centimetres in diameter is mounted on a mandrel and the edge turned true. A little diamond-dust mixed with thick oil is then spread round the edge of the disk, and while rotating the

disk at the rate of about five turns a minute a piece of flint is pressed firmly against the edge. In this way the diamond particles are driven into the iron and, at any rate after an attempt or two, the disk will be satisfactorily armed. A horizontal plate with a guide at one edge is attached to the slide-rest of the lathe and the wooden base to which the silica is attached is placed on this plate, and the silica pressed firmly against the edge of the disk which is rapidly rotated. Soap and water must be used as a lubricant, being supplied by means of a brush. In this way a disk having a diameter of one centimetre can be cut in a minute.

A small rod of fused silica is then fused to the edge of the disk by means of a small oxyhydrogen flame, and all but the last two or three millimetres cut off, so as to leave a small tab of silica. The disk is then roughly ground flat on either side by rubbing it on a flat plate of brass freely supplied with powdered carborundum (of such a size as to pass through a sieve of 250 threads to the inch) and water. The disk is then annealed by being heated to a bright red in a small scoop of platinum or thin sheet-iron over a Bunsen flame for about 5 hours. That surface of the disk which, on inspection, appears most free from bubbles is ground on a plate of thick plate-glass with water and emery of gradually increasing fineness. The disk is moved round and round in circular sweeps, the end of the finger pressing it lightly down on the surface of the glass. About ten minutes' grinding with each of three grades of washed emery, finishing with the finest which can be obtained, will generally be sufficient. The grades of emery I use are such that the emery is deposited from water in the following times:—No. 1 settles in 1 minute, No. 2 settles in 10 minutes, No. 3 settles in between 20 minutes and 60 minutes.

The surface is polished with rouge on a pitch form. It is essential to obtain opticians' rouge, which has been well washed, and not jewellers' rouge. The proper quality of rouge I have obtained from Messrs. Cooke of York. To form the pitch surface some pitch is melted, and when thoroughly liquid is poured over the surface of a piece of plate-glass and a second piece of plate-glass, the surface of which has been thinly coated with dilute glycerine, is pressed down on the top of the pitch. Weights are placed on the upper glass till the pitch is cold, when the glass can be slid off. The polishing is continued till on examining the surface with a low-power microscope no pitting can be seen. Quite a light pressure of the tip of the finger must be used during the polishing, which will take from 10 to 30 minutes.

To give the polished surface its reflecting coating a very thin layer of the platinizing liquid is uniformly painted over the surface with a clean brush, and the disk is placed on a metal plate over a water-bath. When the coating is quite dry the disk is heated in a small muffle made by bending a sheet of thin sheet-iron and placing it over a large Bunsen flame. The heating must be continued till a fairly bright red is attained. It is an advantage to raise the temperature of the disk to a red heat as quickly as possible, for if the heating is slow the platinizing compound tends to volatilize before it decomposes. The surface thus obtained will be very bright and will not require polishing. If the film of platinum is too thin a second coating of the platinizing liquid can be given.

In this way a mirror is obtained which, however, is about a millimetre thick. To reduce it to a more suitable thickness the platinum surface is temporarily protected with a coating of pitch or some other varnish, and the other surface of the disk is ground away on the brass-surface plate with carborundum till the desired thickness is obtained. It will be found quite easy to prepare a mirror having a diameter of one centimetre and a thickness of two-tenths of a millimetre. Such a mirror will weigh about .045 gram.

In order to support the mirror the tag is fused, by means of a small oxyhydrogen flame, to a thin rod of fused silica and the magnets are cemented to this rod.

The above method of constructing galvanometer mirrors avoids the necessity of grinding and polishing the surface of a very thin disk, an operation of great difficulty, and is only rendered possible by using a non-corrodible reflecting surface so that the light has not to traverse the quartz disk. Also the excessively small coefficient of thermal expansion of quartz enables us to obtain a disk of the material which is so free from internal strains that when we grind away one side the form of the other side is not appreciably altered. Lastly, the method of attachment of the mirror to the stem, since it avoids all cements, entirely does away with the risk of distortion due to the contraction of the cement.

Platinum surfaces prepared as above described have not quite such a large reflecting power as glass backed with silver. A comparison between a platinum surface which had been exposed quite unprotected to the air of the laboratory for a month and a silver on glass mirror made by Hilger showed that the reflecting power of the platinum was about seven-tenths of that of the silver. Any difficulty due to this

smaller reflecting power can be got over by using a transparent scale with opaque lines backed by a flame, in place of the ordinary opaque scale illuminated by diffuse light.

Platinum mirrors appear as if they might be of considerable use where a metallic mirror is required, and where silver would be likely to tarnish. When glass is used considerable care has to be used, in the first place not to increase the temperature so quickly as to crack the glass, and secondly not to raise the temperature to such a height as to alter the figure of the glass by softening. When crystalline quartz is used no softening is to be feared. The temperature has, however, to be altered *very slowly* or the quartz will crack. With care, however, very perfect mirrors have been obtained on quartz.

Platinum deposited in this way forms a very good coating for producing "half-silvered" mirrors for use in interference experiments and such instruments as those recently described by Sir Howard Grubb (*Sci. Trans. R. Dublin Soc.* vii. p. 385, 1902). The preparation of a surface having a given reflecting power is much easier in the case of platinum than in the case of silver, and once such a surface has been obtained it seems to be practically unalterable.

XXIII. *Notices respecting New Books.*

International Catalogue of Scientific Literature. First Annual Issue.

C. PHYSICS. Part I. London: Harrison and Sons. 1902. Pp. xiv + 239.

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Subject List of Works on General Science, Physics, Sound, Music, Light, Microscopy, and Philosophical Instruments, in the Library of the Patent Office. London: Patent Office. 1903. Pp. 183.

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