



LXXI. On the infra-red emission spectrum of the mercury arc

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To cite this article: Professor J.C. McLennan F.R.S. & Raymond C. Dearle M.A. (1915) LXXI. On the infra-red emission spectrum of the mercury arc, Philosophical Magazine Series 6, 30:179, 683-695, DOI: [10.1080/14786441108635444](https://doi.org/10.1080/14786441108635444)

To link to this article: <http://dx.doi.org/10.1080/14786441108635444>



Published online: 08 Apr 2009.



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that apart from the crooks at the ends of the alpha-ray tracks, the "scattering" is due to single deflexions through considerable angles.

4. The experiments failed to bring out evidence in support of ionization by the nuclei of hydrogen atoms projected from the latter when alpha particles collide with the atoms.

5. The experiments go to show that when alpha particles are projected through hydrogen or through hydrogen containing traces of air exceedingly few collisions occur which result in the ejection of a hydrogen nucleus.

The Physical Laboratory,
University of Toronto.
May 1st, 1915.

LXXI. *On the Infra-red Emission Spectrum of the Mercury Arc.* By Professor J. C. McLENNAN, F.R.S., and RAYMOND C. DEARLE, M.A., *The University of Toronto* *.

[Plates XIV. & XV.]

I. Introduction.

AT the present time when efforts are being directed towards the establishment of relationships between the atomic structure of an element and special features of its spectra, it is desirable to ascertain as fully as possible the frequencies which are associated with the atoms of the element in definite and determinate physical states. The frequencies associated with mercury atoms in the neutral, or supposed neutral, state have been carefully investigated by R. W. Wood†, McLennan and Edwards‡, and others in the region between $\lambda=6000$ Å.U. and $\lambda=1800$ Å.U. In the experiments in which this was done, it has been found that if light of wave-lengths lying within the limits mentioned be passed through non-luminous mercury vapour, there is a strong symmetrical absorption band at $\lambda=1849$ Å.U., a moderately strong non-symmetrical one at $\lambda=2536.72$ Å.U., and one still less marked, and consisting of four narrow bands, at $\lambda=2338$ Å.U.

From this it has been concluded that within the limits mentioned there are three groups of frequencies which characterize the atoms or groups of atoms present in the vapour

* Communicated by the Authors. Read before the Royal Society of Canada, May 26th, 1915.

† R. W. Wood, 'Physical Optics,' p. 431.

‡ McLennan and Edwards, Proc. Roy. Soc. of Canada, 1915.

of mercury in the non-luminous state. It is desirable, however, that a wider range of frequencies should be investigated, especially on the side of the infra-red where but little work on absorption appears to have been done as yet.

With a view to proceeding in this direction, some preliminary work has been done by the writers in that region on the emission lines in the spectrum of the mercury arc. It is evident that a knowledge of the lines which characterize this spectrum in the infra-red region, as well as of their exact wave-lengths, would be of great assistance in deciding where to look for absorption by mercury vapour.

It was found, on examining the work of those who have already investigated the emission spectrum of the mercury arc in the infra-red region, that considerable divergence exists in their results. The first recorded investigations were somewhat cursory attempts by Snow and by Drew, and it was not until 1903 that we have any results in which confidence can be placed.

These are due to Coblentz and Geer*, who worked with a rock-salt prism spectrometer and a radiometer, and found three definite lines between $0.97\ \mu$ and $1.285\ \mu$. In addition to these they were able to identify six lines in the neighbourhood of $5.0\ \mu$, and possibly one other near $3.0\ \mu$. Coblentz† repeated this work a couple of years later, and announced that there are no important lines beyond $1.3\ \mu$ except those near $5.0\ \mu$. W. J. H. Moll‡ somewhat later, using a rock-salt spectrometer and thermopile in connexion with an automatic recording device, identified five lines between $1.0\ \mu$ and $1.7\ \mu$. In direct opposition to the results of Coblentz and Geer, Moll states that there is no measurable emission above $1.7\ \mu$. Probably the most accurate measurements on the infra-red spectrum of the mercury arc are those made by Paschen§ with a concave grating and a Rubens thermopile. By means of the better definition and the higher dispersion afforded by the grating, Paschen was able to separate maxima which had previously been recorded as single lines. In all he identified fourteen lines between $1.0\ \mu$ and $1.7\ \mu$, and he confirmed the statement by Moll that there are no lines beyond $1.7\ \mu$. He|| subsequently repeated his measurements and found a maximum at $4.0\ \mu$, but inasmuch as this maximum came out in the arc spectrum

* W. Coblentz and W. C. Geer, *Phys. Rev.* xvi. pp. 279-286 (1903).

† Coblentz, *Phys. Rev.* xx. pp. 122-124 (1905).

‡ Moll, *Kon. Akad. Wet. Amsterdam, Proc.* ix. pp. 544-548 (1907).

§ Paschen, *Ann. d. Phys.* xxvii. 3. pp. 537-570 (1907).

|| Paschen, *Ann. d. Phys.* xxxiii. 4. pp. 717-738 (1910).

of a number of the elements, he concluded that it was due to the presence of hydrogen. In these later measurements a bolometer was used in combination with a grating. More recently still H. Rubens and O. von Baeyer* have succeeded in showing that the mercury arc emits a radiation of wave-length about $313\ \mu$. They succeeded in isolating this radiation by the method of focal separation previously used by Rubens and Wood†, and in measuring its wave-length by means of a Fabry and Perot interferometer of a special type in combination with a Rubens microradiometer. Subsequent measurements‡ by them on this radiation showed that it consisted of two wave-lengths, the one at about $218\ \mu$ and the other in the neighbourhood of $343\ \mu$.

The only noteworthy measurements by photographic methods in the infra-red spectrum of the mercury arc were made in 1912 by H. Lehmann§. He used the phosphorographic method of Bergmann||, and found four lines corresponding to those of Paschen and in addition a new line at $1.46\ \mu$.

In the present investigation a careful survey was made of the infra-red spectrum of the mercury arc in the region beyond $1.0\ \mu$ with the object of confirming, if possible, the existence of the lines identified by Paschen, and of seeing whether the lines found by Coblentz and Geer in the neighbourhood of $3\ \mu$ had a real existence. In this examination a number of the lines noted by Paschen were identified, the existence of a line near $3.0\ \mu$ was confirmed, and in addition a number of new lines were observed.

II. Apparatus.

In this work a number of different forms of mercury arc-lamps were used as sources of the radiation, but a quartz mercury-lamp constructed by W. C. Heraeus was found to be the most satisfactory. This lamp gave a very powerful and quite concentrated arc. When in operation it was driven with a direct current of from 3.0 to 3.2 amperes with a striking potential of 110 volts. A suitable resistance was of course inserted in series with the lamp. It was found

* H. Rubens and O. von Baeyer, *Phil. Mag.* xxi. pp. 689-695 (1911).

† H. Rubens and R. W. Wood, *Preuss. Akad. Wiss. Berlin, Sitz.-Ber.* lii. pp. 1122-1137 (1910).

‡ H. Rubens and O. von Baeyer, *Preuss. Akad. Wiss. Berlin, Sitz.-Ber.* xxx. pp. 666-667 (1911).

§ H. Lehmann, *Ann. d. Phys.* xxxix. 1. pp. 76-77 (1912).

|| Bergmann, *Zeitschr. Wiss. Phot.* vi. pp. 113-130 and pp. 145-169 (1908).

that even with this lamp the current through it steadily decreased for the first ten minutes after the arc was struck. This was brought about by an increase which took place in the resistance of the mercury vapour when the temperature of the lamp was rising. The following table and the curve in fig. 1 (Pl. XV.) show the variation of the current with the elapse of time in a typical case:—

| Time. | | Current. |
|--------|----------|-----------|
| 0 min. | | 6.4 amps. |
| 0 min. | 50 secs. | 6.1 " |
| 1 " | 35 " | 5.9 " |
| 2 " | 20 " | 5.7 " |
| 3 " | 10 " | 5.45 " |
| 3 " | 45 " | 5.1 " |
| 4 " | 45 " | 4.75 " |
| 5 " | 40 " | 4.4 " |
| 6 " | 35 " | 4.13 " |
| 7 " | 50 " | 4.00 " |
| 9 " | 10 " | 3.75 " |
| 10 " | 10 " | 3.72 " |
| 11 " | — | 3.7 " |

In all experiments care was taken to see that the lamp was in the steady state before measurements were made on the intensity of the radiation.

The form of spectrometer used was one designed and constructed by the Adam Hilger Co. It is shown in fig. 2 and in diagram in fig. 3 (Pl. XIV.). The energy measurements were made with a sensitive Rubens thermopile shown in fig. 4, in conjunction with a very delicate Paschen galvanometer made by the Cambridge Scientific Instrument Co. The radiation from the lamp was allowed to fall upon a large concave mirror having a diameter of 19 cm. and a focal length of 30 cm., which brought it to a focus on the slit S_1 . From this slit the rays passed to the nickel-steel concave mirror M_1 , thence through the rock-salt prism P to the plane nickel-steel mirror M_2 . From this they were reflected to the concave nickel-steel mirror M_3 , and by it they were brought to a focus on the linear junctions of the thermopile at T , which was placed immediately behind the slit S_2 . The prism and plane mirror were mounted on a table which rotated about the point A . By turning this table through a small angle, any desired part of the spectrum could be brought to a focus at S_2 . The rotation was produced by the motion of a helical drum attached at D , which was calibrated in wave-lengths

up to $10\ \mu$ from data on the dispersion of rock-salt as given by Paschen* and others.

An eyepiece E was attachable behind the slit S_2 for the purpose of focussing lines in the visible part of the spectrum on the thermopile, and of adjusting the prism so that the radiation brought to a focus at S_2 was in agreement with the reading on the drum. The prism had faces 3.2 cm. by 4.2 cm., and was ground to an angle of approximately 55° . Judging by the visible spectrum, there was very little curvature in the spectral lines produced by this prism.

The thermopile (fig. 4) consisted of 10 junctions of bismuth-silver joined by silver solder and flattened out into rectangular plates at the exposed junctions, which were blackened. The sensitive area was 20 mm. long and 1.5 mm. wide, or a total of 30 sq. mm. As the slit-width used in all the experiments was only 1 mm., the effective area of the exposed junctions was only 20 sq. mm.

The galvanometer used was a modified form of the Thomson galvanometer, and was specially designed by Paschen† for radiometric measurements. The magnet system consisted of two groups of thirteen magnets arranged alternately on opposite sides of a fine glass stem and supported by a fine quartz fibre. The coils were elliptical in shape, and were wound with six different sizes of wire with the object of producing a maximum field for a given resistance of copper. The period could be controlled by means of a magnet, and it was adjusted to have a full period of 5 secs. It was found that while a longer period did not materially increase the sensibility, it made the zero drift considerably greater. The resistance of the thermopile was 2.93 ohms and that of the galvanometer, with the coils connected in multiple series, which was the arrangement always adopted, was 3.0 ohms. The sensitiveness of the instrument was such that a deflexion of 1 mm. on a scale at the distance of one metre was produced by a current of 0.0025 microampere.

One of the greatest difficulties met with in the work was the variation produced by temperature changes and by stray air currents. To overcome these the thermopile and slit were enclosed in a nickelled box, shown at B in fig. 3, which was both packed inside and surrounded outside with cotton-waste. The whole spectrometer was enclosed in a wooden box lined with absorbent cotton, and all the free space between

* Paschen, *Ann. d. Phys.* xxvi. 1. pp. 120-138; 5. pp. 1029-1030 (1908).

† Paschen, *Ann. d. Phys.* xxvii. 3. pp. 537-570 (1908).

the spectrometer-stand and the box was also filled with cotton-waste. The box had a window at S_1 , covered by a shutter, and a second window as well, through which to read the wave-lengths on the drum. As an additional precaution an asbestos screen was always placed between the lamp and the spectrometer. The lamp itself gave rise to certain errors due to variations in the current, and to the occasional deposit of a drop of mercury on the face of the tube from which the radiation was taken. These latter errors were sufficient at times to produce false maxima of considerable magnitude. In taking all readings, the drum was set at the desired wave-lengths and the shutter was opened until the galvanometer reached its maximum deflexion, when it was again closed. This was repeated from six to ten times, and the mean value of the deflexions was taken as a measure of the energy in the particular wave-length selected. Zero drift was always considerable, on some days amounting to as much as 140 mm. in readings extending over the space of an hour. To eliminate the effect of this drift the amount of deflexion on opening the shutter was read, and also the distance which the spot of light returned on closing the shutter. The mean of these two was then taken as the correct reading. When every imaginable precaution was taken, it was still found that maxima appeared in the energy curves which apparently did not represent spectral lines. However, it was possible, by repeating the readings over any given portion of the spectrum on different days, to differentiate between true and false maxima and so to identify the spectral lines. In taking the measurements, it was necessary to distinguish between the energy which was contributed by a spectral line and that which was contributed by the continuous spectrum due to the radiation from the heated quartz of the lamp itself. To do this, a circuit breaker was connected in series with the lamp, the drum was adjusted to give the wave-length of the desired line, and the shutter was opened immediately after the circuit was broken. The ensuing deflexion was read and the time noted on a stop-watch. The shutter was again closed and after an interval reopened. The deflexion produced and the time corresponding to it were again noted. In this way several readings were taken, and a cooling curve was plotted from them. This curve was then extended backwards to zero time, and from the point where it cut the ordinate axis the energy contributed by the radiation from the hot quartz of the wave-length under investigation was ascertained. This reading was subtracted from the reading taken when the lamp was in operation, and the difference

gave the energy contributed by the spectral line. A cooling curve of the type just mentioned is shown in fig. 5 (Pl. XV.).

The intensity of the radiation of any particular wave-length as measured by the spectrometer was found to vary with small displacements of the lamp or scale, and so all measurements were compared with the deflexion produced by the radiation from the green line $\lambda = 5461 \text{ \AA.U.}$ This line, which was of strong intensity, possessed the advantage of being practically outside the region of the hot quartz radiation.

III. *Accuracy of Measurements.*

In work on infra-red spectra the means generally employed to produce the spectrum are the prism and the grating. The latter has the great advantage that it absorbs but little radiation and that it affords good definition in all parts of the spectrum. Against this, however, is the fact that the energy is divided up into several orders, that these orders often overlap in the infra-red, and that the distribution of energy in any one order does not always correspond with the true distribution in the spectrum. The prism, on the other hand, gives but one order, so that the maximum of energy is found in each and every wave-length. It limits the measurements, however, to the region where the radiation is transmitted without absorption. With prisms of rock-salt the radiation is transmitted up to wave-lengths of $60,000 \text{ \AA.U.}$, but it is difficult to secure good definition in the longer wave-lengths. This difficulty, moreover, is enhanced by the fact that in order to secure sufficient energy in the weaker lines, it is necessary to work with a fairly wide slit. On this account, one cannot expect in working with a rock-salt prism to reach the precision of wave-length measurement attainable with a grating spectro-scope, or to differentiate between lines very close together with the same facility as with a grating. The prism, however, enables one to obtain a reliable register of the maxima in the energy spectrum, and these can be used as a guide for finer measurements with an instrument such as a grating. The following table shows the width of spectrum covered in the different ranges by the thermopile slit for a slit-width of 1 mm.

These results are also shown graphically in fig. 6. Although from this table there seems to be a considerable width of spectrum covered by the slit, still it must be remembered that since in all our measurements readings were taken at intervals of 0.1μ , the energy curves could be filled in

| Wave-length. | Width of spectrum. |
|--------------|--------------------|
| 0.54 μ | 0.02 μ |
| 0.58 „ | 0.03 „ |
| 0.82 „ | 0.08 „ |
| 1.50 „ | 0.28 „ |
| 2.00 „ | 0.62 „ |
| 3.00 „ | 0.76 „ |
| 4.00 „ | 0.68 „ |
| 5.00 „ | 0.54 „ |
| 6.00 „ | 0.46 „ |
| 7.00 „ | 0.40 „ |
| 8.00 „ | 0.36 „ |
| 10.00 „ | 0.32 „ |

between these readings, and the wave-lengths could be assigned to the various lines with an accuracy of probably $\pm 0.01 \mu$.

IV. Observations.

After the apparatus was carefully set up and found to be in good working order, a set of readings was taken on the energy spectrum of an Arons* amalgam lamp. The amalgam in this lamp consisted of about 60 per cent. Hg, 20 per cent. Pb, 20 per cent. Bi, $\frac{1}{2}$ per cent. Zn, and $\frac{1}{2}$ per cent. Cd. The lamp was run on the 110 volt direct-current circuit with a suitable resistance in series. The energy curve is shown in fig. 7 (Pl. XV.). Thirty-six distinct maxima were observed in all between wave-lengths 0.70μ and 3.0μ . Possibly as many more could have been distinguished by repeated observations, but as there was no way of distinguishing which were mercury lines and which were lines of the other metals, further work with this lamp was abandoned.

Readings were then taken, as stated above, with a lamp containing only pure mercury. The maxima from a large number of sets of readings were compared, and the regions which contained constantly recurring maxima were carefully examined so as to establish the exact position of each maximum as closely as possible. In the same region as that investigated by Paschen†, the positions of nine lines were determined, and these accorded fairly well with the wave-lengths given by him. As was expected, in regions where the latter gives two or three lines in close proximity, only one maximum, corresponding to the mean wave-length, was recorded in our measurements. Corresponding to the new

* Arons, *Ann. d. Phys.* Band xxiii. (1906).

† Paschen, *loc. cit.*

line observed by H. Lehmann* at $1.464\ \mu$, a maximum was found which appeared to vary slightly from $1.46\ \mu$ to $1.50\ \mu$. The mean wave-length of all the readings taken on this line was $1.483\ \mu$. In addition to these, four other lines were recorded, two of which had already been located by W. Coblentz and W. C. Geer, with slightly higher values for the wave-lengths. In their work a line is given at $1.045\ \mu$, while in ours it was found to be at $1.038\ \mu$. Close to this line we also found two others at $1.067\ \mu$ and $1.090\ \mu$ respectively. The presence of these lines was evidently suspected by Coblentz and Geer†, since they state that certain observations were repeated "to learn whether another line exists between $1.06\ \mu$ and $1.12\ \mu$ where the curve is very asymmetrical." Their instruments, however, were not sufficiently sensitive to detect these lines. Beyond $1.7\ \mu$ only one line was found, which was at $3.2\ \mu$. This confirmed the doubtful indications recorded by the above-named pair of investigators. This part of the spectrum was not as thoroughly examined as might be desired, and it is just possible that a closer examination might have revealed other maxima, particularly in the region of $3.7\ \mu$, where indications, as will be shown below, point to the possible existence of a new line.

In Table I., the wave-lengths of the lines isolated in the present investigation are given in the first column and their relative intensities in the second. Accompanying these are given in order the wave-lengths of the lines determined by other investigators, namely, Paschen, Lehmann, Moll, and Coblentz and Geer. The intensities are given for the first two, but in the case of the others no intensities are recorded in their communications. In the last column the frequencies of all the lines are given reduced to a vacuum.

V. Discussion of Results.

If the measurements made by the writers be compared with the others given in Table I., it will be seen that the line observed by us at $3.02\ \mu$ is probably the same as that given by Coblentz and Geer at $3.00\ \mu$, and the maximum at $1.72\ \mu$ doubtless corresponds to the group of four lines given by Paschen between $1.692\ \mu$ and $1.711\ \mu$. There is no line given by the others near 1.483 unless it be that given by Paschen at $1.529\ \mu$ and the one given by Moll at $1.52\ \mu$. The maximum noted at $1.377\ \mu$ represents probably a combination of Paschen's two lines at $1.395\ \mu$ and $1.367\ \mu$, and

* Lehmann, *loc. cit.*

† Coblentz and Geer, *Phys. Rev.* xvi. pp. 284, 903.

TABLE I.

| Authors: | I. | Paschen. | I. | Lehmann. | I. | Moll. | Coblentz and Geer. | Frequency in vacuo. |
|----------|-----|----------|-----|----------|-----|-------|--------------------|---------------------|
| μ | | μ | | μ | | μ | μ | |
| 3.02 | 6 | ... | .. | ... | ... | ... | ... | 3310.3 |
| ... | ... | ... | ... | ... | ... | ... | 3.00 (?) | 3332.4 |
| 1.72 | 5 | ... | ... | ... | ... | ... | ... | 5812.4 |
| ... | ... | 1.711 | 4 | ... | ... | ... | ... | 5843.1 |
| ... | ... | 1.707 | 5 | ... | ... | ... | ... | 5856.9 |
| ... | ... | ... | ... | ... | ... | 1.70 | ... | 5880.8 |
| ... | ... | 1.694 | 2.8 | ... | ... | ... | ... | 5900.8 |
| ... | ... | 1.692 | 4.6 | ... | ... | ... | ... | 5908.6 |
| ... | ... | 1.529 | 9 | ... | ... | ... | ... | 6514.4 |
| ... | ... | ... | ... | ... | ... | 1.52 | ... | 6577.1 |
| 1.483 | 3 | ... | ... | ... | ... | ... | ... | 6668.3 |
| ... | ... | ... | ... | 1.464 | 4 | ... | ... | 6828.5 |
| ... | ... | 1.395 | 6.5 | ... | ... | ... | ... | 7166.0 |
| 1.377 | 8 | ... | ... | ... | ... | ... | ... | 7260.6 |
| ... | ... | ... | ... | 1.369 | 2 | ... | ... | 7300.2 |
| ... | ... | 1.367 | 17 | ... | ... | ... | ... | 7311.3 |
| ... | ... | ... | ... | 1.359 | 2 | ... | ... | 7352.2 |
| ... | ... | 1.357 | 12 | ... | ... | ... | ... | 7366.7 |
| 1.329 | 6 | ... | ... | ... | ... | ... | ... | 7522.4 |
| ... | ... | ... | ... | ... | ... | ... | 1.285 | 7778.4 |
| 1.270 | 4 | ... | ... | ... | ... | ... | ... | 7871.8 |
| ... | ... | 1.207 | 2.6 | ... | ... | ... | ... | 8282.2 |
| 1.205 | 2 | ... | ... | ... | ... | ... | ... | 8286.6 |
| ... | ... | 1.202 | 2.4 | ... | ... | ... | ... | 8316.4 |
| ... | ... | 1.188 | 2.6 | ... | ... | ... | ... | 8410.3 |
| 1.170 | 7 | ... | ... | ... | ... | ... | ... | 8544.9 |
| ... | ... | 1.129 | 31 | ... | ... | ... | ... | 8826.5 |
| 1.128 | 9 | ... | ... | 1.128 | 3 | ... | ... | 8863.0 |
| 1.090 | 5 | ... | ... | ... | ... | ... | ... | 9171.7 |
| 1.067 | 7 | ... | ... | ... | ... | ... | ... | 9369.7 |
| ... | ... | ... | ... | ... | ... | ... | 1.045 | 9567.2 |
| 1.038 | 6 | ... | ... | ... | ... | ... | ... | 9631.4 |
| ... | ... | ... | ... | 1.015 | 1 | ... | ... | 9851.2 |
| 1.014 | 30 | 1.014 | 71 | ... | ... | ... | ... | 9863.5 |

the lines nearest to 1.329μ are that noted by Paschen at 1.351μ and that given by Coblentz and Geer at 1.285 . The line at 1.270μ appears to be a new one, unless it be the same as that given by Coblentz and Geer at 1.285μ . That at 1.205μ very likely represents a combination of the lines given by Paschen at 1.207μ and 1.202μ . The line at 1.170μ probably represents the same one as Paschen's at 1.188μ . The maximum observed at 1.128μ was also found by Paschen and Lehmann, but the maxima at 1.090μ and 1.067μ are new. As mentioned before, the maxima at 1.038μ and 1.045μ probably refer to the same line. The line at 1.014μ was also observed by Paschen and by Lehmann at 1.015μ .

An energy curve showing the maximum at 3.02μ is given

in fig. 8, and others showing the new lines at $1.27\ \mu$, $1.090\ \mu$, and $1.067\ \mu$ are given in figs. 9 and 10. It will be noted that the maxima at $1.27\ \mu$ and $3.02\ \mu$ are fairly sharp, while those shown in fig. 10 are somewhat broader.

A comparison of the intensities assigned to the various lines by the different investigators affords an interesting study. Paschen says in his paper that he found the line at $1.014\ \mu$ was the most intense in the whole mercury spectrum, and that on the same relative scale as that recorded in Table I., he found the mercury green line at $\lambda = 5461\ \text{\AA.U.}$ was represented by an intensity of 42, *i. e.*, rather more than one-half of the intensity of the line $1.014\ \mu$. In the measurements of the writers it was found that if the energy in the line at $1.014\ \mu$ be represented by 30, that in the line at $\lambda = 5461\ \text{\AA.U.}$ was found to be represented by 40, or one-third more than that of the line $1.014\ \mu$. On looking at Lehmann's results it will be seen that though there is no value given for the intensity of the green line, that of the line $1.015\ \mu$ is given by him as the weakest in the infra-red spectrum. This was probably due to the method of registering the spectrum used by Lehmann, for it will be remembered that by it the lines were recorded by their inverting action on a phosphorescent screen. It is quite possible that the line $1.015\ \mu$, being nearer to the wave-lengths of the visible spectrum than any of the others recorded, would not have so strong an effect as waves of longer length. As regards the relative intensities of the lines $1.014\ \mu$ and $5461\ \text{\AA.U.}$, it was noted by Paschen* that if the vapour-pressure in his lamp was increased, the relative intensity of the line $1.014\ \mu$ came out still higher, while with a low vapour-pressure the intensity of the two lines was about equal. This may explain the values of the intensities found for these lines in the present investigation.

In looking for series relationships among the lines given in the first column of Table I., it was seen that the frequency differences for the lines $1.038\ \mu$, $1.27\ \mu$, and $3.02\ \mu$ are practically the same as those which characterize the subordinate series triplets in the mercury spectrum given by $\nu=2$, $p-m$, d , and $\nu=2$, $p-m$, s . This will be evident from the numbers given in Table II. It will be noted, too, that the frequency difference between the line given in our list at $1.09\ \mu$ and the one given by Paschen at 1.367 is equal to 1860.4 , which approximates, as the table shows, to the frequency difference between the second and third members of the triplets of the two subordinate series mentioned above.

* Paschen, *Ann. d. Phys.* xxvii. 3. p. 559 (1908).

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If these two lines should turn out to be the second and third members of a triplet similar to the one already noted, there would need to be a line at about $3.70\ \mu$. A line in this

TABLE II.

| Wave-length. | Frequency. | Difference. |
|---|------------|-------------|
| First subordinate triplet series. $\nu=2, p-m, d. m=3.$ | | |
| 3663.05 Å.U. | 27292.06 | 4630.92 |
| 3131.66 „ | 31922.98 | 1767.36 |
| 2967.37 „ | 33690.34 | |
| Second subordinate triplet series. $\nu=2, p-m, s. m=1.5.$ | | |
| 5460.97 Å.U. | 18306.73 | 4631.31 |
| 4358.66 „ | 22937.04 | 1767.19 |
| 4046.78 „ | 24704.23 | |
| Triplet $1.038\ \mu, 1.270\ \mu,$ $3.02\ \mu.$ | | |
| 30200 Å.U. | 3310.3 | 4561.5 |
| 12700 „ | 7871.8 | 1759.6 |
| 10380 „ | 9631.4 | |
| Suggested triplet $1.09\ \mu,$ $1.367\ \mu, 3.70\ \mu.$ | | |
| 37000 Å.U. | 2702.7 | 4608.6 |
| 13670 „ | 7311.3 | 1860.4 |
| 10900 „ | 9171.7 | |

position, however, was not observed in our investigation, but as already mentioned this portion of the infra-red spectrum was not examined so closely as the region of somewhat shorter wave-lengths.

VI. *Summary of Results.*

I. Thirteen lines have been recorded in the infra-red spectrum of the mercury arc between the wave-lengths $1.00\ \mu$ and $3.02\ \mu$.

II. The existence of the line near $1.04\ \mu$, which was shown to exist by Coblenz and Geer but which was not found by later investigators, was confirmed by the finding of a line at $1.038\ \mu$.

III. The existence of at least one line with a wave-length longer than $1.70\ \mu$ was proved by the discovery of a line at $3.02\ \mu$, which was also in confirmation of the work by Coblenz and Geer.

IV. Three new lines were discovered in the infra-red spectrum at $1\cdot067\ \mu$, $1\cdot090\ \mu$, and $1\cdot270\ \mu$.

V. It has been pointed out that the frequency differences for the lines $1\cdot038\ \mu$, $1\cdot270\ \mu$, and $3\cdot02\ \mu$ are the same as those which characterize the triplets in the subordinate series for the mercury arc spectrum given by $\nu=2$, $p-m$, d and $\nu=2$, $p-m$, s . It has also been suggested that possibly the lines at $1\cdot09\ \mu$ and $1\cdot367\ \mu$ are the third and second members of a similar triplet with its first member in the neighbourhood of $3\cdot70\ \mu$.

The Physical Laboratory,
University of Toronto.
May 1st, 1915.

LXXII. *On the Absorption Spectra of Mercury, Cadmium, and Zinc Vapours.* By Professor J. C. McLENNAN, F.R.S., and EVAN EDWARDS, M.A., B.Sc., University of Toronto*.

[Plate XVI.]

I. Introduction.

IN 1907 it was pointed out by Wood † that in the absorption spectrum of non-luminous mercury vapour there is a heavy band at $\lambda=2536\cdot72\ \text{\AA.U.}$, and a less sharply-defined one at $\lambda=2350\ \text{\AA.U.}$ In a later paper by Wood and Guthrie ‡ dealing with the same subject no mention is made of the absorption band at $\lambda=2350\ \text{\AA.U.}$, but it is stated that with dense mercury vapour there is a fairly strong band at $\lambda=2338\ \text{\AA.U.}$, and another very broad one at $\lambda=2140\ \text{\AA.U.}$ From the work of Kirschbaum § and others it is known that light of wave-length $\lambda=1849\cdot6\ \text{\AA.U.}$ is strongly absorbed by mercury vapour.

The absorption band at $\lambda=2536\cdot72\ \text{\AA.U.}$ has been shown by Wood to be asymmetrical. It is sharply defined on the shorter wave-length side, but with increasing vapour density it gradually spreads out towards the red end of the spectrum. With low vapour densities it consists of two bands, the one at $\lambda=2536\ \text{\AA.U.}$ and the other at $\lambda=2539\ \text{\AA.U.}$ The band at $\lambda=2338\ \text{\AA.U.}$, which is probably the same one as that originally given by Wood at $\lambda=2350\ \text{\AA.U.}$, does not appear

* Communicated by the Authors.

† Wood, *Astr. Phys. Journ.* vol. xxvi. p. 41 (1907).

‡ Wood and Guthrie, *Astr. Phys. Journ.* vol. xxxix. No. 1, p. 211 (1909).

§ Kirschbaum, *Electrician*, vol. lxxii. p. 1074 (1914).

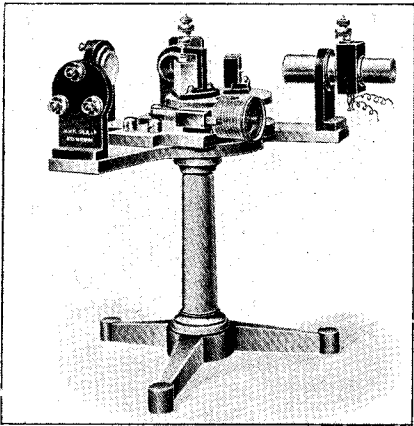


FIG. 2.

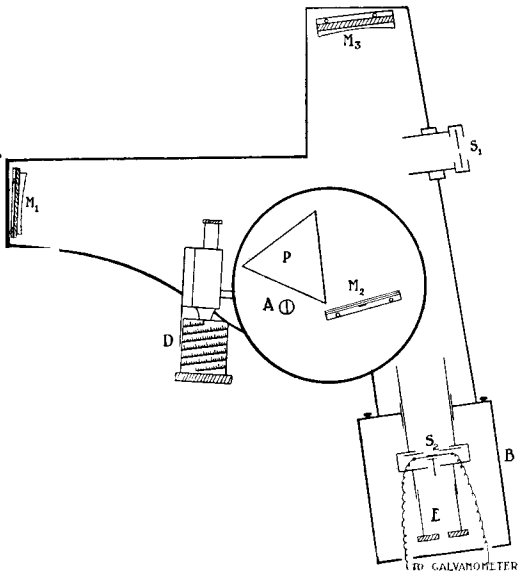


FIG. 3.

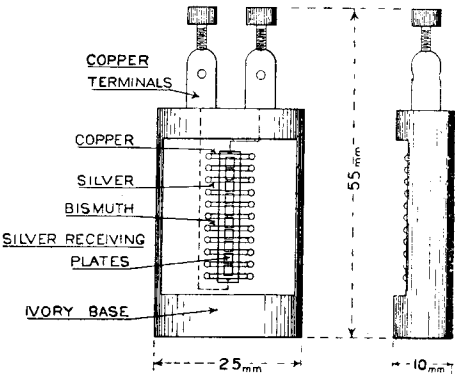


FIG. 4.

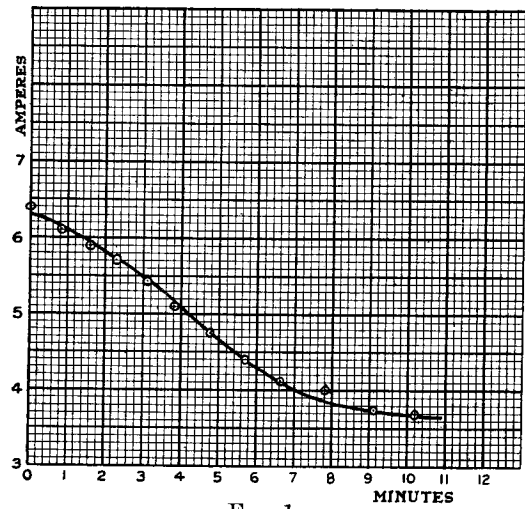


FIG. 1.

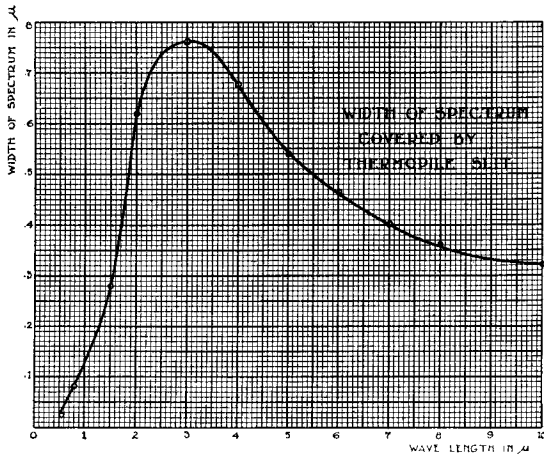


FIG. 6.

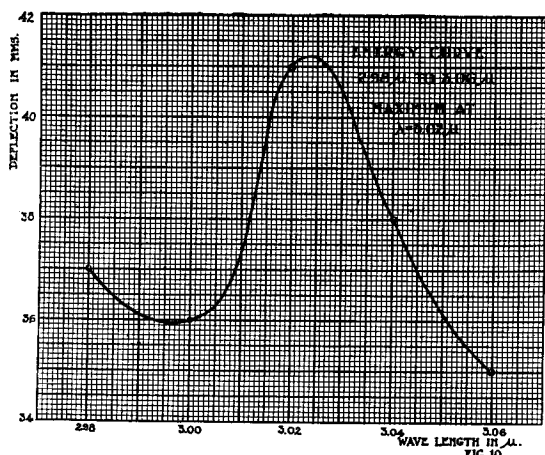


FIG. 8.

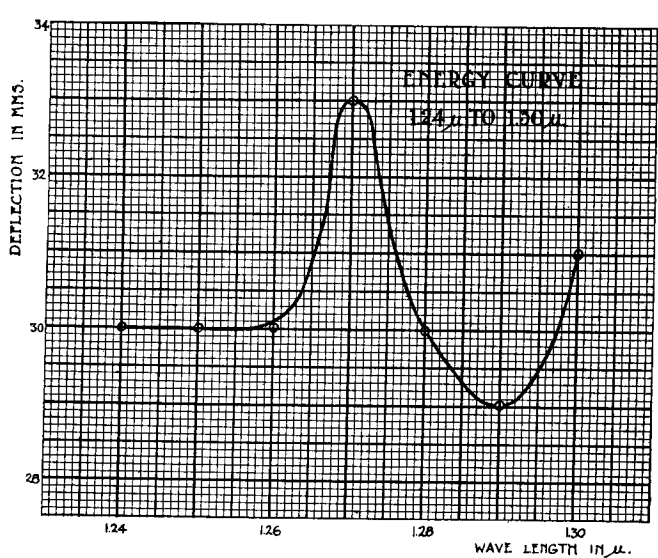


FIG. 9.

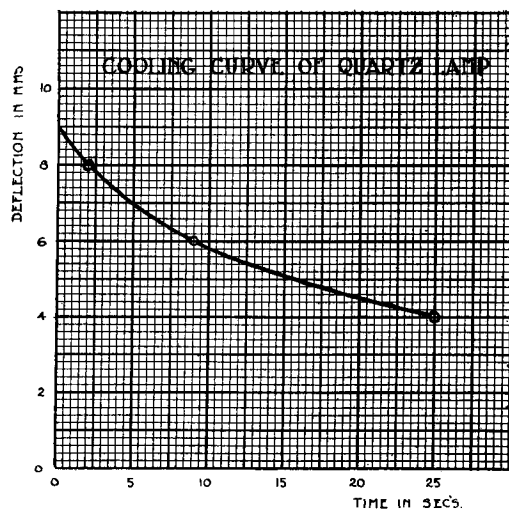


FIG. 5.

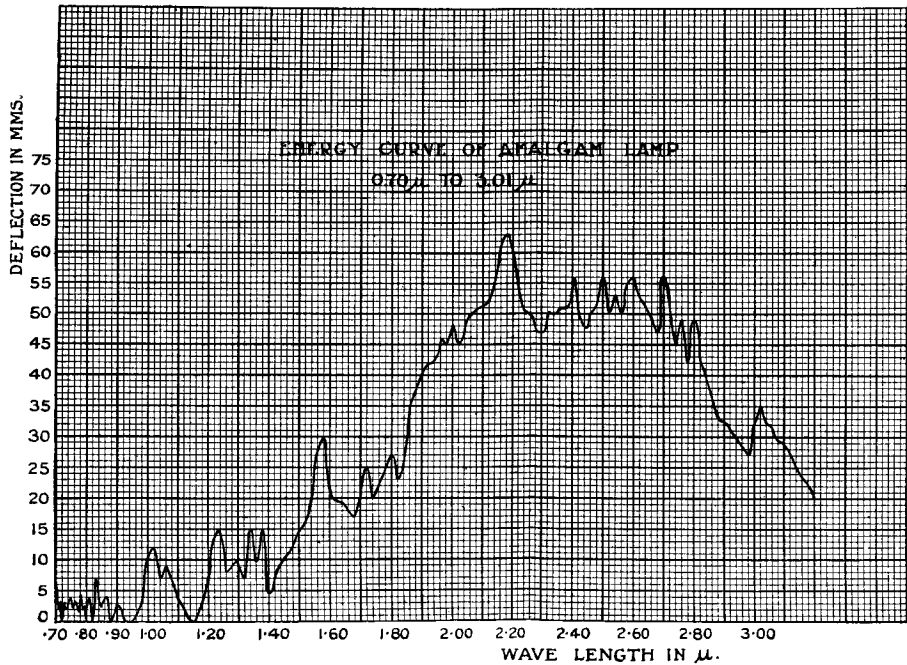


FIG. 7.

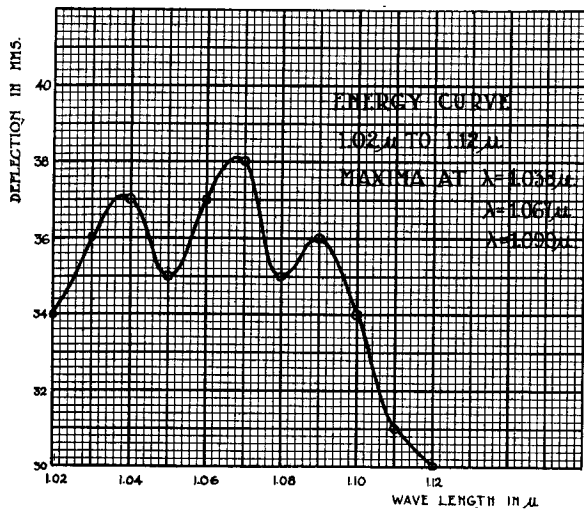


FIG. 10.