# UNIVERSITY OF TORONTO
# STUDIES

## PAPERS FROM THE PHYSICAL LABORATORIES

No. 49: ON THE INFRA-RED EMISSION SPECTRUM OF THE MERCURY ARC, by Professor J. C. McLennan and Raymond C. Dearle

# University of Toronto Studies

## COMMITTEE OF MANAGEMENT

*On the Infra-Red Emission Spectrum of the Mercury Arc.*

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(Read May Meeting, 1915.)

## 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[1], McLennan and Edwards[2] and others in the region between $\lambda = 6,000$ A°.U. and $\lambda = 1,800$ A°.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 $\lambda = 1,849$ A°.U., a moderately strong non-symmetrical one at $\lambda = 2,536 \cdot 72$ A°.U. and one still less marked and consisting of three narrow bands at $\lambda = 2,338$ A°.U.

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

[1] R. W. Wood. Physical Optics, p. 431.
[2] McLennan and Edwards, Proc. Roy. Soc. of Canada, 1915.

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[1] who worked with a rock salt prism spectrometer and a radiometer and found three definite lines between $0 \cdot 97\mu$ and $1 \cdot 285\mu$.   In addition to these they were able to identify six lines in the neighbourhood of $5 \cdot 0\mu$ and possibly one other near $3 \cdot 0\mu$.   Coblentz[2] repeated this work a couple of years later and announced that there are no important lines beyond $1 \cdot 3\mu$ except those near $5 \cdot 0\mu$.   W. J. H. Moll[3] somewhat later using a rock salt spectrometer and thermopile in connection with an automatic recording device identified five lines between $1 \cdot 0\mu$ and $1 \cdot 7\mu$.   In direct opposition to the results of Coblentz and Geer, Moll states that there is no measurable emission above $1 \cdot 7\mu$.   Probably the most accurate measurements on the infra-red spectrum of the mercury arc are those made by Paschen[4] 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 $1 \cdot 0\mu$ and $1 \cdot 7\mu$ and he confirmed the statement by Moll that there are no lines beyond $1 \cdot 7\mu$.   He[5] subsequently repeated his measurements and found a maximum at $4 \cdot 0\mu$; but inasmuch as this maximum came out in the arc spectrum 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[6] have succeeded in showing that the mercury arc emits a radiation of wavelength about $313\mu$.   They succeeded in isolating this radiation by the method of focal separation previously used by Rubens and Wood[7] 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[8] by them on this radiation

[1]W. Coblentz and W. C. Geer, Phys. Rev., 16 pp. 279-286, 1903.

[2]Coblentz, Phys. Rev., 20 pp. 122-124, 1905.

[3]Moll. Kon. Akad. Wet. Amsterdam.   Proc. 9 pp. 544-548, 1907.

[4]Paschen, Ann. der Phys. 27, 3, pp. 537-570, 1907.

[5]Paschen, Ann. der. Phys. 33, 4, pp 717-738, 1910.

[6]H. Rubens and O. von Baeyer, Phil. Mag., 21 pp. 689-695, 1911.

[7]H. Rubens and R. W. Wood, Preuss. Akad. Wiss. Berlin, Sitz. Ber. 52. pp. 1122-1137,  1910.

[8]H. Rubens and O. von Baeyer, Preuss. Akad. Wiss. Berlin, Sitz. Ber. 30 pp. 666-667, 1911.

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.[1] He used the phosphoro-photographic method of Bergmann[2] and found four lines corresponding to those of Paschen and in addition a new line at $1\cdot46\mu$.

In the present investigation a careful survey was made of the infra-red spectrum of the mercury arc in the region beyond $1\cdot0\mu$ 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 $3\cdot0\mu$ 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 $3\cdot0$ to $3\cdot2$ amperes, with a striking potential of 110 volts. A suitable resistance was of course inserted in series with the lamp. It was found 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. show the variation of the current with the elapse of time in a typical case:
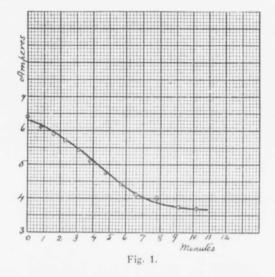
| Time | | | Current |
|---|---|---|---|
| 0 min. | | | $6\cdot4$ amps |
| 0 min. | 50 secs. | | $6\cdot1$ " |
| 1 " | 35 " | | $5\cdot9$ " |
| 2 " | 20 " | | $5\cdot7$ " |
| 3 " | 10 " | | $5\cdot45$ " |
| 3 " | 45 " | | $5\cdot1$ " |
| 4 " | 45 " | | $4\cdot75$ " |
| 5 " | 40 " | | $4\cdot4$ " |
| 6 " | 35 " | | $4\cdot13$ " |
| 7 " | 50 " | | $4\cdot00$ " |
| 9 " | 10 " | | $3\cdot75$ " |
| 10 " | 10 " | | $3\cdot72$ " |
| 11 " | — | | $3\cdot7$ " |

[1]H. Lehmann. Ann. der. Phys. 39, 1, pp. 76-77, 1912.
[2]Bergmann, Zeitschr. Wiss. Phot. 6 pp. 113-130 and pp. 145-169, 1908.

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.



Fig. 1.

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
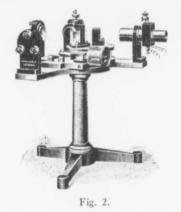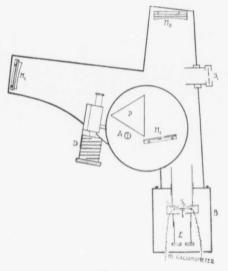


Fig. 2.

Fig. 3.  The energy measurements were made with a senstitive Rubens thermopile shown in Fig. 4 in conjunction with a very delicate Paschen galvanometer made by the Cambridge Scientific Instrument

Company.   The radiation from the lamp was allowed to fall upon a large concave mirror having a diameter of 19 cms and a focal length of 30 cms which brought it to a focus on the slit $S_1$.   From this slit the
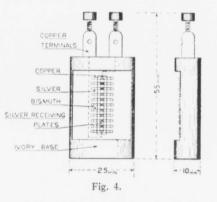


Fig. 3.

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[1] and others.

An eye-piece 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 $S_3$ was in agreement with the reading on the drum.   The prism had faces $3 \cdot 2$ cms by $4 \cdot 2$ cms 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.

[1]Paschen, Ann. d. Phys. 26. 1. pp. 120-138; 5 pp. 1029-1030, 1908.

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
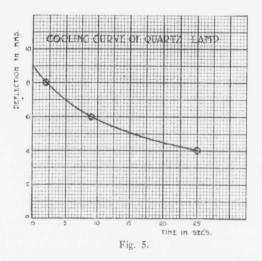


Fig. 4.

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[1] for radiometry 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 deflection of 1 mm. on a scale at a distance of one metre was produced by a current of ·00025 micro ampères.

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

[1]Paschen, Ann. der. Phys. 27, 3. pp., 537-570, 1908.

wooden box lined with absorbent cotton and all the free space between
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 deflection,
when it was again closed. This was repeated from six to ten times and
the mean value of the deflection was taken as a measure of the energy
in the particular wave-length selected. Zero drift was always con-
siderable, 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 deflection 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 special 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 con-
nected 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 deflection was read and the
time noted on a stop-watch. The shutter was again closed and after
an interval re-opened. The deflection produced and the time corres-
ponding 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 conrtibuted 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.

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 com-



Fig. 5.

pared with the deflection produced by the radiation from the green line $\lambda = 5,461$ A°.U. This line which was of strong intensity possessed the advantage of being practically outside the region of the hot quartz radiation.
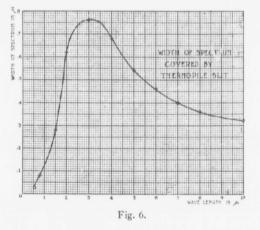
### III. ACCURACY OF MEASUREMENTS.

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 a 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 A°.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 spectroscope 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.

| Wave-length | Width of spectrum. |
|---|---|
| $0 \cdot 54$ $\mu$ | $0 \cdot 02$ $\mu$ |
| $0 \cdot 58$ " | $0 \cdot 03$ " |
| $0 \cdot 82$ " | $0 \cdot 08$ " |
| $1 \cdot 50$ " | $0 \cdot 28$ " |
| $2 \cdot 00$ " | $0 \cdot 62$ " |
| $3 \cdot 00$ " | $0 \cdot 76$ " |
| $4 \cdot 00$ " | $0 \cdot 68$ " |
| $5 \cdot 00$ " | $0 \cdot 54$ " |
| $6 \cdot 00$ " | $0 \cdot 46$ " |
| $7 \cdot 00$ " | $0 \cdot 40$ " |
| $8 \cdot 00$ " | $0 \cdot 36$ " |
| $10 \cdot 00$ " | $0 \cdot 32$ " |

These results are also shown graphically in Fig. 6.   Although from this table there seems to be a considerable width of spectrum



Fig. 6.
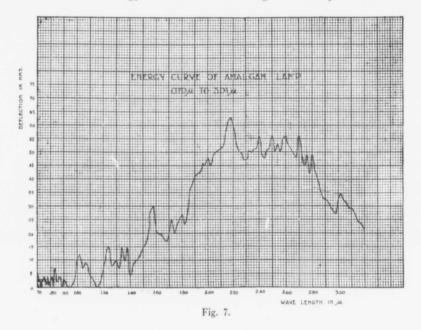
covered by the slit, still it must be remembered that since in all our measurements readings were taken at intervals of $0 \cdot 1\mu$, the energy curves could be filled in between these readings and the wave-lengths

could be assigned to the various lines with an accuracy of probably $\pm 0\cdot01\mu$.

## 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[1] amalgam lamp.  The amalgam in this lamp consisted of about 60% Hg, 20% Pb, 20% Bi, $\frac{1}{2}$% Zn and $\frac{1}{2}$% 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.  Thirty-six distinct



Fig. 7.

maxima were observed in all between wave-lengths $0\cdot70\mu$ and $3\cdot0\mu$. 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

[1]Arons, Ann. d. Phys.   Band 23, 1906.

position of each maximum as closely as possible.   In the same region
as that investigated by Paschen,[1] the positions of nine lines were deter-
mined 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 line observed by H. Lehmann[2] at $1 \cdot 464\mu$, a maximum was
found which appeared to vary slightly from $1 \cdot 46\mu$ to $1 \cdot 50\mu$.   The
mean wave-length of all the readings taken on this line was $1 \cdot 483\mu$.
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
$1 \cdot 045\mu$ while in ours it was found to be at $1 \cdot 038\mu$.   Close to the line
we also found two others at $1 \cdot 067\mu$ and $1 \cdot 090\mu$ respectively.   The
presence of these lines was evidently suspected by Coblentz and Geer[3]
since they state that certain observations were repeated "to learn
whether another line exists between $1 \cdot 06\mu$ and $1 \cdot 12\mu$ where the curve
is very asymmetrical."   Their instruments, however, were not suffi-
ciently sensitive to detect these lines.   Beyond $1 \cdot 7\mu$ only one line
was found which was at $3 \cdot 2\mu$.   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 $3 \cdot 7\mu$ 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 inten-
sities 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 re-
corded in their communications.   In the last column the frequencies
of all the lines are given, reduced to a vacuum.

[1]Paschen, *loc. cit.*
[2]Lehmann, *loc. cit.*
[3]Coblentz and Geer.   Phys. Rev. 16 p. 284, 1903.

　　THE ROYAL SOCIETY OF CANADA

*Table I.*

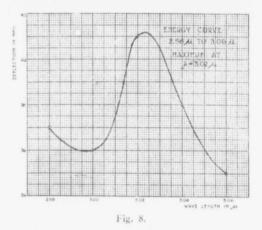| Authors | I | Paschen | I | Lehmann | I | Moll | Coblentz and Geer. | Frequency in vacua |
|---|---|---|---|---|---|---|---|---|
| $\mu$ | | | | | | | $\mu$ | |
| 3·02 | 6 | — | — | — | — | — | — | 3310·3 |
| — | — | — | — | — | — | — | 3·00 (?) | 3332·4 |
| 1·72 | 5 | — | — | — | — | — | — | 5812·4 |
| — | — | 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 |

## 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 the lines nearest to $1·329\mu$ are that noted by Paschen at $1·3517\mu$ and that given by Coblentz and Geer at $1·285$. The line at $1·270\mu$ appears to be a new one, unless it be the same as that given by Coblentz and Geer at $1·285\mu$. That at $1·205\mu$ very likely represents a combination of the

lines given by Paschen at $1\cdot207\mu$ and $1\cdot202\mu$. The line at $1\cdot170\mu$ probably represents the same one as Paschen's at $1\cdot188\mu$. The maximum observed at $1\cdot128\mu$ was also found by Paschen and Lehmann but the maxima at $1\cdot090\mu$ and $1\cdot067\mu$ are new. As mentioned before, the maxima at $1\cdot038\mu$ and $1\cdot045\mu$ probably refer to the same line. The line at $1\cdot01\mu$ was also observed by Paschen and by Lehmann at $1\cdot015\mu$.

An energy curve showing the maximum at $3\cdot02\mu$ is given in Fig. 8 and others showing the new lines at $1\cdot27\mu$, $1\cdot090\mu$, and $1\cdot067\mu$ are



Fig. 8.

given in Figs. 9 and 10. It will be noted that the maxima at $1\cdot27\mu$ and $3\cdot02\mu$ are fairly sharp while those shown in Fig. 10 are somewhat broader.
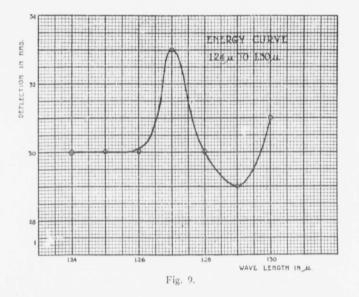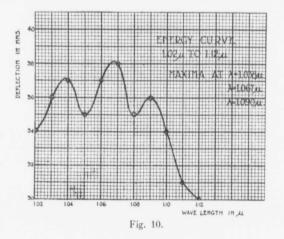
A comparison of the intensities assigned to the various lines by the different investigators affords an interesting study. Paschen says in his paper that he found the line at $1\cdot014\mu$ was the most intense in the whole mercury spectrum and that on the same relative scale, as that recorded in Table I., he found the mercury green line at $\lambda = 5461$ A°U. was represented by an intensity of 42, i.e., rather more than one-half of the intensity of the line $1\cdot014\mu$. In the measurements of the writers it was found that if the energy in the line at $1\cdot014\mu$ be represented by 30 that in the line at $\lambda = 5461$ A°U. was found to be represented by 40, or one-third more than that of the line $1\cdot014\mu$. 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 $1\cdot015\mu$ 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



Fig. 9.

visible spectrum than any of the others recorded, would not have as strong an effect as waves of longer length. As regards the relative intensities of the lines $1·014\mu$ and 5461 A°U., it was noted by



Fig. 10.

Paschen[1] that if the vapour pressure in his lamp was increased, the relative intensity of the line $1 \cdot 014\mu$ 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.

*Table II.*

| Wave-length. | Frequency | Difference. |
|---|---|---|
| First subordinate triplet series. | | |
| r = 2, p—m, d. m = 3. | | |
| 3663·05 A°. U. | 27292·06 | 4630·92 |
| 3131·66 " " | 31922·98 | 1767·36 |
| 2967·37 " " | 33690·34 | |
| Second subordinate triplet series. | | |
| = 2, p—m, s. m = 1·5. | | |
| 5460·97 A°. U. | 18306·73 | 4631·31 |
| 4358·66 " " | 22937·04 | 1767·19 |
| 4046·78 " " | 24707·23 | |
| Triplet $1 \cdot 038\mu$ $1 \cdot 270\mu$ $3 \cdot 02\mu$. | | |
| 30200 A°.U. | 3310·3 | 4561·5 |
| 12700 " " | 7871·8 | 1759·6 |
| 10380 " " | 9631·4 | |
| Suggested triplet $1 \cdot 09\mu$ $1 \cdot 367\mu$ $3 \cdot 70\mu$ | | |
| 37000 A°. U. | 2702·7 | 4608·6 |
| 13670 " " | 7311·3 | 1860·4 |
| 10900 " " | 9171·7 | |

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 $1 \cdot 038\mu$, $1 \cdot 27\mu$ and $3 \cdot 02\mu$ are practically the same as those which characterise the subordinate series triplets in the mercury spectrum given by $\gamma = 2$, p—m, d and $\gamma = 2$, 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 $1 \cdot 09\mu$ and the one given by Paschen at $1 \cdot 367$ is equal to $1860 \cdot 4$, which approximates, as the table shows, to the frequency difference between the second and third numbers of the triplets of the two subordinate series mentioned above. If these two lines should turn out to be the second and third numbers of a triplet similar to the one

[1]Paschen, Ann. d. Phys. 27. 13. p. 559, 1908.

already noted, there would need to be a line at about $3 \cdot 70\mu$. A line in this position, however, was not observed in our investigation; but as already mentioned this portion of the infra-red spectrum was not examined as 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 $1 \cdot 00\mu$ and $3 \cdot 02\mu$.

II. The existence of the line near $1 \cdot 04\mu$ which was shown to exist by Coblentz and Geer but which was not found by later investigators, was confirmed by the finding of a line at $1 \cdot 038\mu$.

III. The existence of at least one line with a wave-length longer than $1 \cdot 70\mu$ was proved by the discovery of a line at $3 \cdot 02\mu$, which was also in confirmation of the work by Coblentz and Geer.

IV. Three new lines were discovered in the infra-red spectrum at $1 \cdot 067\mu$, $1 \cdot 090\mu$ and $1 \cdot 270\mu$.

V. It has been pointed out that the frequency differences for the lines $1 \cdot 038\mu$. $1 \cdot 270\mu$ and $3 \cdot 02\mu$ are the same as those which characterise the triplets in the subordinate series for the mercury arc spectrum given by $\gamma = 2$, p—m, d and $\gamma = 2$, p—m, s. It has also been suggested that possibly the lines at $1 \cdot 09\mu$ and $1 \cdot 367\mu$ are the third and second numbers of a similar triplet with its first number in the neighbourhood of $3 \cdot 70\mu$.