III. *The Effect of Pressure upon Arc Spectra.—No. 1. Iron.*

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Communicated by Professor A. SCHUSTER, *F.R.S.*

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As this paper is the first record of work undertaken with the large Rowland Grating in the Physical Laboratory of the University of Manchester, the occasion seems a fitting one for the description of the mounting of the instrument, which differs in several essential features from previously described systems.*

A detailed account of the scheme adopted for the adjustment of the apparatus is also given in the hope that it will be of service to those who may be confronted with a similar task. The papers of AMES and KAYSER† on the adjustment of their own systems of mounting have been consulted and detailed acknowledgment will be found in the text.

PART I.

THE MOUNTING OF THE LARGE ROWLAND CONCAVE GRATING.

The grating possesses 14,438 lines to the inch; the length of the ruled portion is 6 inches, its height 2 inches, and the radius of curvature of the concave metal surface upon which it is ruled 21 feet 6 inches.

ROWLAND'S original system of mounting has, in general, been followed, though several important modifications have been introduced by Professor SCHUSTER and by the constructor, Sir HOWARD GRUBB. Two carriages, DD, fig. 1, which run freely upon two heavy girders, A and B, placed at right angles to one another, carry the grating and camera and are connected by a cross-beam, C, which is of such a length that the centre of the curved photographic plate is at the centre of curvature of the mirror. The slit is placed at the point of intersection of the two girders, which are shown in plan in fig. 1.

As the camera is moved away from the slit the grating moves towards it, the method of attachment being such that both turn with the cross-beam, which remains normal to the curved surfaces of the mirror and the photographic plate. With this disposition the spectrum should be in focus for all positions of the carriages along their girders. The mounting has been specially designed to make the various adjustments independent of one another and to ensure the stability of the carriages and their freedom from any constraint due to a possible twisting or sagging of the cross-beam.

The Girder for the Grating Carriage. (Fig. 1, A.)

This is a heavy cast-iron girder of ⊔ section, 20 feet 6 inches long, $6\frac{1}{2}$ inches high, 8 inches wide, whose upper edges have been machined, one to form a Λ and the other flat. These carry the wheels of the grating carriage. KAYSER† had previously

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* AMES, 'Phil. Mag.' (5), 27, 369, 1889. KAYSER, 'Handbuch der Spectroscopie,' i., p. 473. BALY, "Spectroscopy," 'Textbook of Physical Chemistry Series,' p. 195. ADENEY and CARSON, 'Proc. Roy. Soc. Dublin' (1), 8, 711 (1898).

† 'Handbuch der Spectroscopie,' i., 473.

adopted a heavy carriage with four wheels, two of which were grooved to run on a rail, while a parallel wooden flat-topped beam served to support the other pair.

The Supports for the Grating Girder. (Fig. 1, F.)

Three cast-iron brackets are braced to the wall, and through their bases pass strong set-screws to afford a means for adjusting the plane of the girder and its height above the floor.

The Girder for the Camera Carriage. (Fig. 1, B.)

This is a heavy cast-iron girder of hollow rectangular section, 23 feet long, 18 inches high, and 8 inches wide, whose upper edges have been planed to form rails of the same shape and size as those of the grating girder.

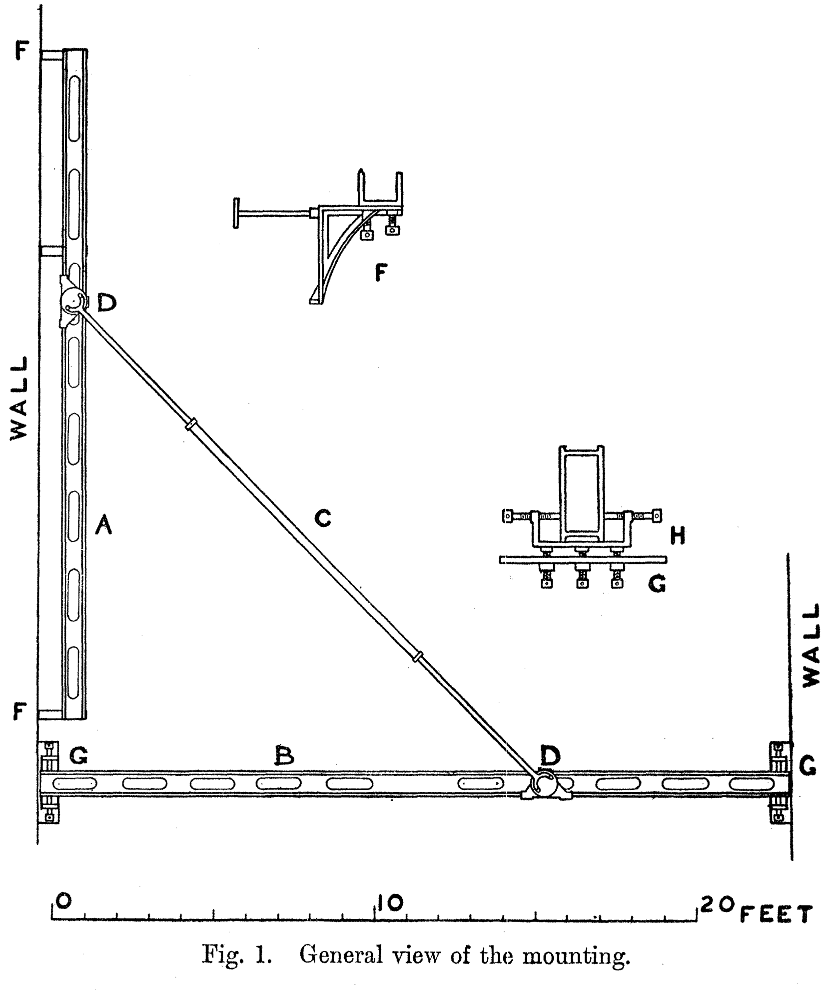

Fig. 1. General view of the mounting.

A. Grating girder.	F. Bracket for grating girder.
B. Camera girder.	G. Bracket for camera girder (built into the wall).
C. Cross-beam.	H. Cradle for camera girder.
D. Carriages.	

The Supports for the Camera Girder. (Fig. 1, G and H.)

This girder spans the room from wall to wall, each end resting in a cradle, which stands upon a strong metal bracket built into the wall. The cradles are of cast iron of the pattern shown in fig. 1, H, and are 18 inches long, 6 inches wide, and $\frac{3}{4}$ inch thick; their sides are thickened at the top to provide sufficient metal for the two stout screws which serve to adjust the girder in a horizontal plane. Three set-screws with "tommyholes" passing upwards through the bases of the brackets support the cradles and regulate the height of the girder and the plane of its surface.

The Cross-beam. (Fig. 1, C, and fig. 2.)

This is a 4-inch tubular girder of wrought iron, as in ROWLAND'S original arrangement,* but in this case constructed in three sections, of which the central portion is of slightly larger diameter than the ends, so that a telescopic adjustment of its length is possible. The sliding parts can be firmly secured by set-screws and by two flexible metal straps.

The method of attachment of the cross-beam to the grating and camera carriages, which is due to Sir HOWARD GRUBB, obviates many of the defects of the earlier systems, which were not free from the constraint resulting from a too rigid connection.

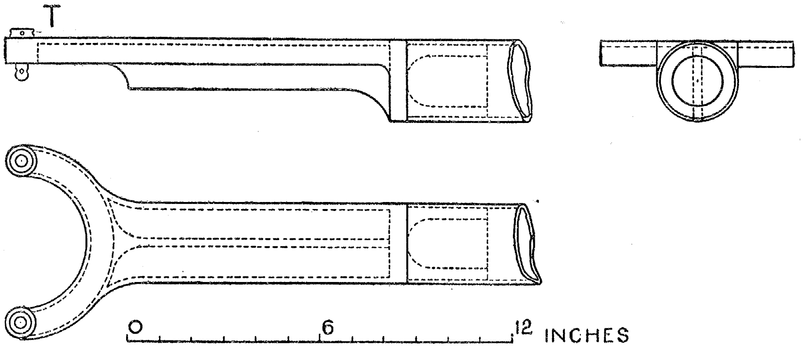

Fig. 2. The cross-beam ends.

Lugs were brazed on to the two ends of the cross-beam, fig. 2, and parallelism was obtained by turning them relatively to one another within the central tube. A second and more delicate means for obviating any constraint is provided by the set-screws T, which pass through the U ends of the lugs; these have rounded ends, and are turned until all four rest evenly in the hemispherical sockets VV, fig. 5, in the carriage mounting, and they are then held firmly in position by means of lock-nuts. This feature, combined with the stable form of the carriages, secures freedom from tilting of the grating and from any change of focus due to the sagging or twisting of the cross-beam.

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* AMES, 'Phil. Mag.' (5), 27, 369 (1889).

The Carriages for the Grating and Camera. (Fig. 3.)

Each carriage consists essentially of a heavy triangular casting supported upon three wheels, two of which are grooved to run upon the rail of the girder, while the third is flat. The whole is heavy, and stability is assured by the distance apart of the grooved wheels, which is 15 inches.

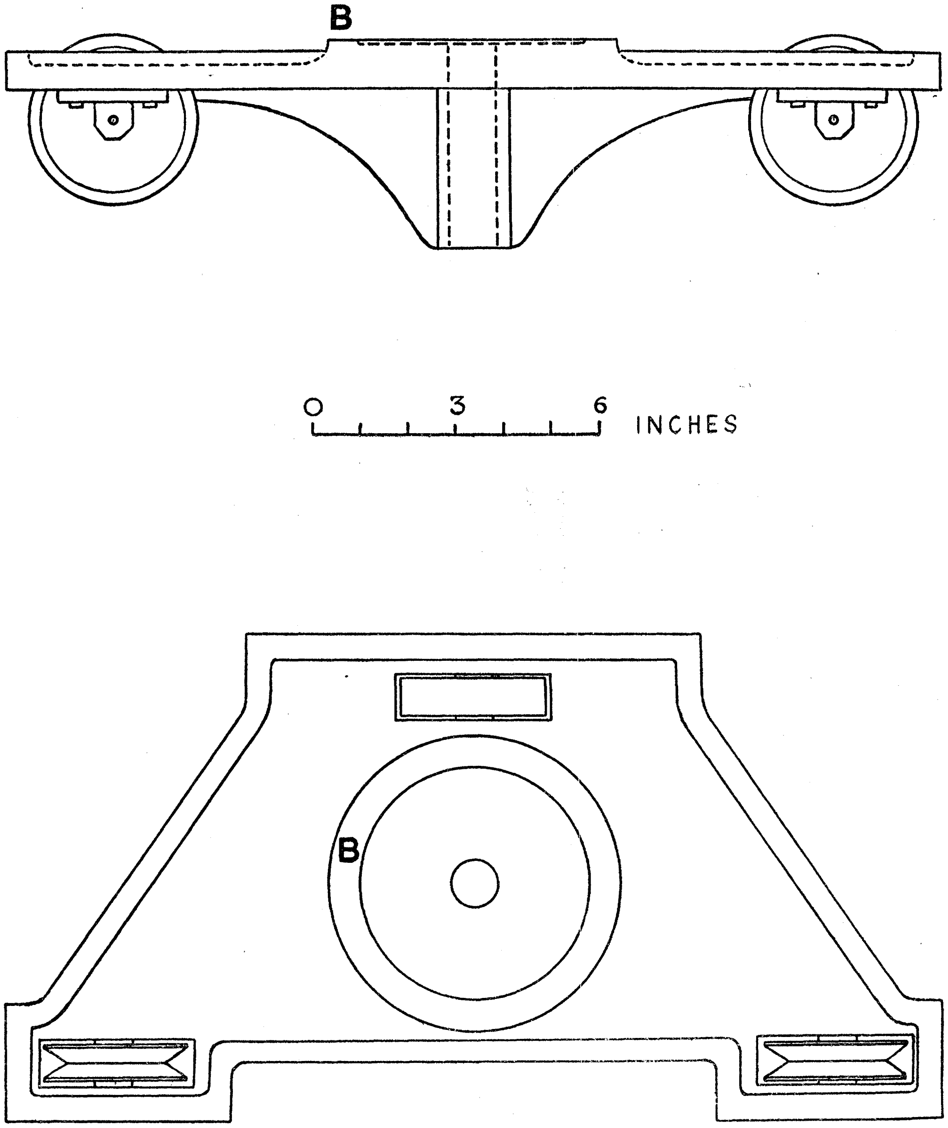

Fig. 3. The carriages for grating and camera.

Each end of the cross-beam, fig. 2, rests upon a casting (figs. 4 and 5, A), which turns upon a raised annular bearing surface (fig. 3, B) on the top of the carriage, and which has a solid steel pin, C, figs. 4, 5, to fit in a vertical hole drilled in the carriage itself. A cast-iron plate (F, fig. 4, E, fig. 5) furnished with a collar fitting over the top of this casting, to which it is firmly fixed by means of a set-screw, forms a table upon which rests either the grating holder or the camera box. The holes to receive the ends of the cross-beam are at opposite extremities of a diameter of the lower circular plate, and this provides that the distribution of the weight of the cross-beam upon the carriage is not altered when the cross beam is moved.

The Grating Holder. (Fig. 4.)

The grating itself is held in a metal box, the front of which has been cut away, and against this frame it is gently pressed by light springs, SS. The whole is mounted upon a circular brass plate $7\frac{1}{2}$ inches diameter, with a $\frac{3}{4}$-inch hole drilled at its centre, through which passes a short pivot fixed to a cast-iron plate, shaded in the diagram, to which the base plate can then be clamped—a fine adjustment, G, consisting of a flange attached to the upper plate held between two screws attached to the lower plate, allowing the correct angular position of the grating about its vertical axis to be accurately determined.

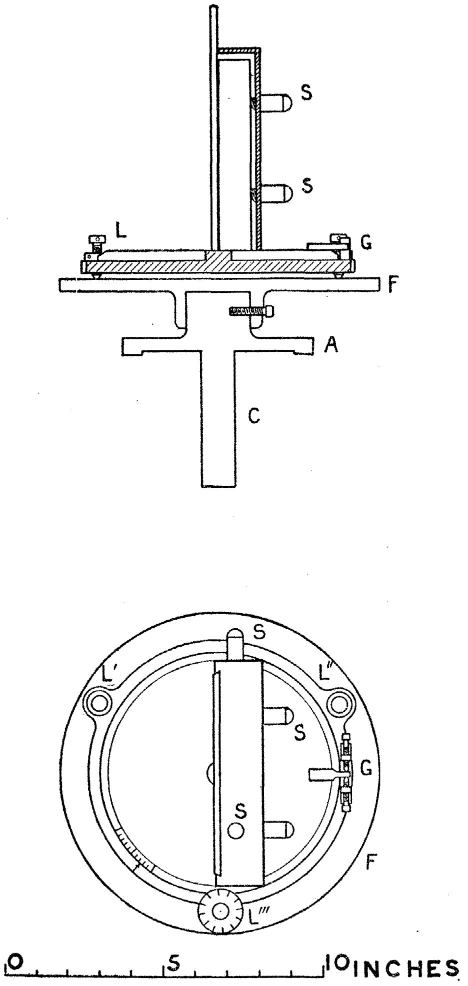

Fig. 4. The grating holder and grating table.

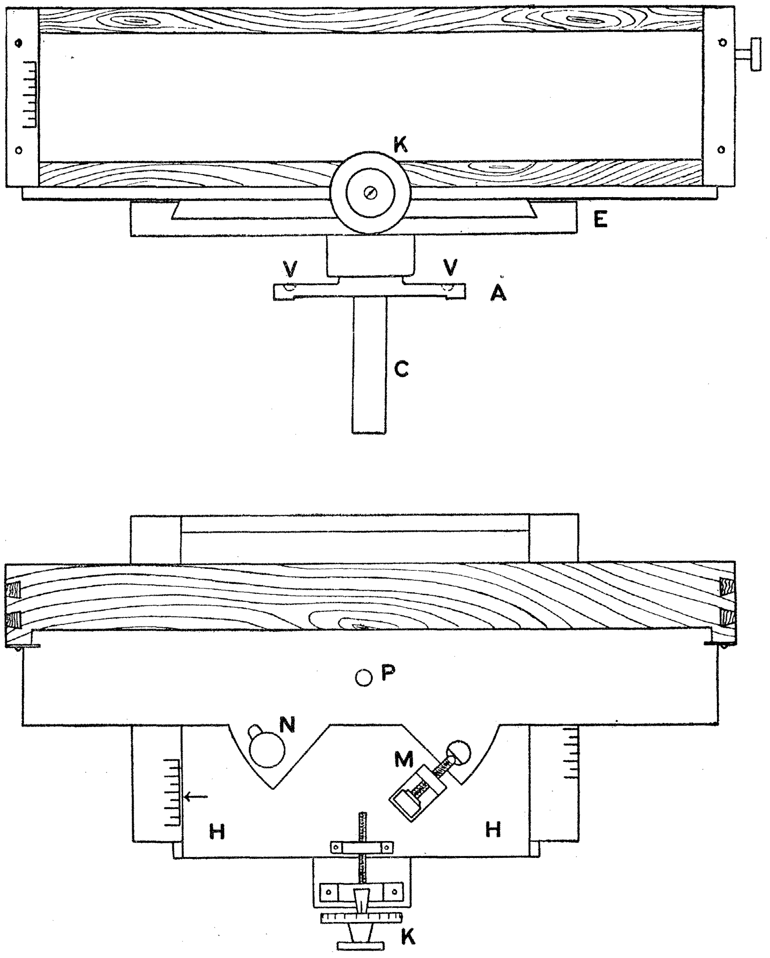

Fig. 5. The camera and its mounting.

Three levelling screws, L, on the lower plate fit into a hole-slot-plane system on the top of the grating table F, and by their means the height of the grating, its rotation about its normal through its centre and about a horizontal axis in its plane can be regulated. A divided head attached to these screws allows a record to be kept of their correct positions.

When not in use, the grating is protected by a glass plate which slides in vertical grooves in front of the ruled surface—this is replaced at other times by a black mask to cover the unruled portion of the mirror.

The Camera. (Fig. 5.)

The mounting of the camera box differs from that of the grating in having a rectangular metal plate, E, with grooves in which the base of the camera can slide, instead of the circular plate, F, to take the grating holder. The base of the camera is of brass and is capable of rotation about the pivot P in the sliding plate H, which is exactly below the centre of the photographic plate when that is in position in its dark slide.* The position of the pivot with reference to the camera carriage can be regulated by means of the screw K, which moves the sliding plate in its grooves.

M is a fine adjustment for turning the photographic plate about the pivot P, and when the correct angular position has been found the base plate may be fixed in position by means of the clamp N. M and N are not shown in elevation.

The dark slide moves in vertical grooves on the camera, so that several photographs may be taken upon the same plate. The plate, which is usually 20 inches by $2\frac{1}{2}$ inches, is pressed against rubber stops, which impart to it the necessary curvature.

The Comparison-shutter. (Fig. 6.)

This is now mounted apart from the camera box and is separately supported upon the grating girder to obviate any displacement of the spectra on the plate due to the operation of the shutter.* In the figure, R is a wooden block, heavily weighted with lead, to which is clamped the wooden grooved arm U, whose end carries a short length

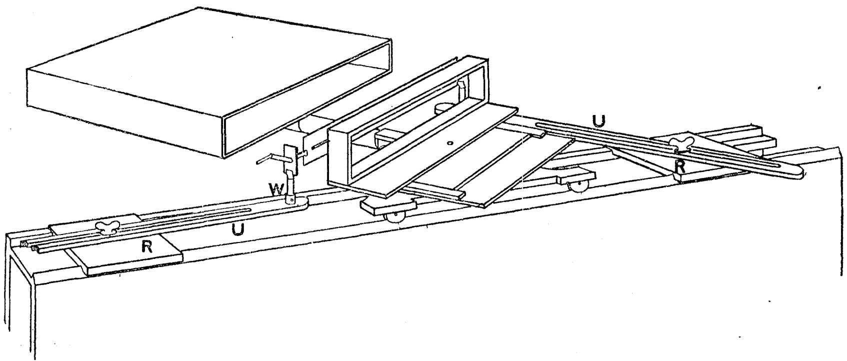

Fig. 6. The comparison-shutter and its support.

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* The writer is responsible for these and a few other minor modifications of the original design.

of $\frac{1}{2}$-inch brass tubing, W, into which fits a second tube of slightly smaller diameter, fixed to one end of the shutter, whose height is then capable of adjustment by sliding the tube up or down. It is then held in position by means of a set-screw.

The shutter itself is of the ordinary pattern, consisting in this case of two steel rules $\frac{1}{8}$ inch apart, soldered into end-pieces which are shaped to form the pivots about which it may be turned. It is placed as close as possible to the photographic plate; in fig. 6 for clearness it is shown some distance away. To screen the plate from diffused light, a light wooden box is supported on the cross-beam, and dark cloths attached to its sides are drawn over the camera box when the dark slide is in its place.

The Slit. (Fig. 7.)

This was designed by Sir Howard Grubb and made at the works of the Cambridge Scientific Instrument Company.

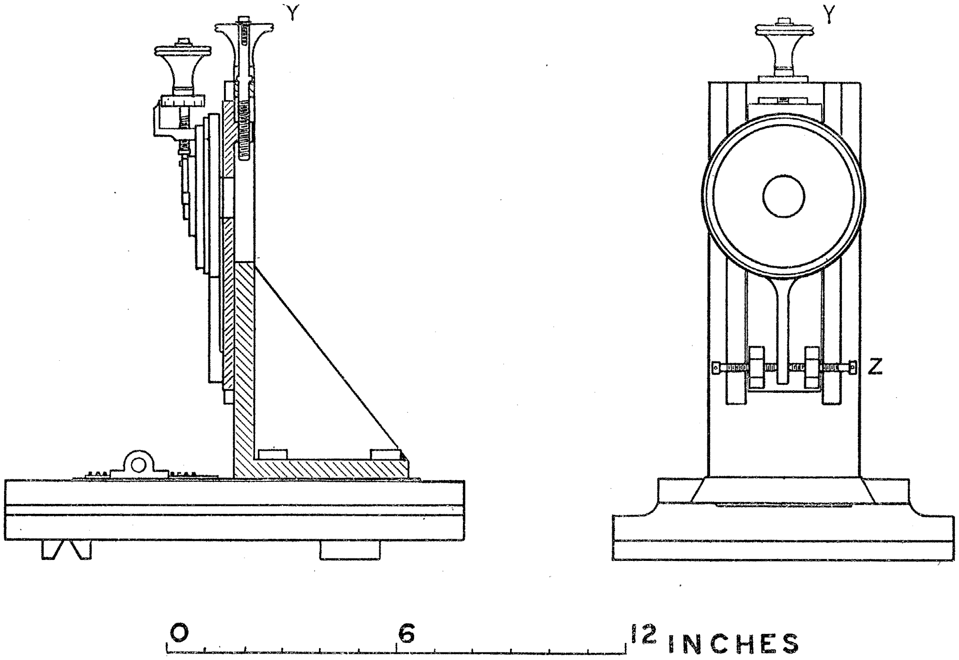

Fig. 7. The slit.

The requirements of a slit for use with a concave grating are that it be movable both along, and perpendicular to, the camera girder, that its height be adjustable, and that it be capable of rotation about its centre in its own plane.

The base of the mounting is grooved to rest evenly across the rails of the camera girder along which it may be moved, a scale and pointer indicating its position. Upon this base a plate carrying the slit slides in grooves, and the motion is controlled by a rack and pinion. The height of the slit is regulated by the screw Y, which passes through the top of the frame in which the slit itself slides. The jaws are held by a spring attachment to the circular metal plate, which can be turned in its own plane by the screws Z controlling the position of the lug attached to it.

Details of the mechanism by which the jaws are operated are not shown in the figure, but the system possesses the property of moving the knife-edges through equal distances as the width of the slit is altered, so that the position of its centre always remains the same.

The Grating Room.

The whole of the mounting is supported at such a level above the floor that it does not interfere with the floor space, which is therefore available for other purposes. At one end of the room a large platform has been erected, so that the camera can be easily manipulated, and a source of light placed in position and operated during the experiment.

Behind this platform are apertures in the wall through which sunlight can enter after reflexion from a heliostat. This can be placed on one of the ledges projecting from the outside wall, access to which is afforded by a balcony.

A ventilating chimney immediately over the source of light, usually an electric arc or spark, prevents obnoxious fumes from filling the room and injurious gases from reaching the grating surface. In addition, a screen of black cloth completely encloses this portion of the room and prevents stray light from affecting the plate. A hole in this screen permits the light to pass from the slit to the grating.

The room can be very perfectly darkened by means of blinds, and a double door permits access to or egress from it during the course of an experiment.

The electrical equipment of the platform consists of leads from the Corporation mains, from the storage batteries, and from the dynamo house, thus giving a wide range in the choice of voltage of both continuous and alternating current.

THE ADJUSTMENT OF THE LARGE ROWLAND CONCAVE GRATING.

The two carriages without their mountings were placed upon their respective girders and—

I. The grating girder* A, fig. 1, was so adjusted that the turned face of its carriage D remained horizontal for all positions along it. A spirit-level was laid upon the carriage, and the height of the four screws projecting upwards through the supporting brackets F altered.

II. The line of motion of the centre of the grating carriage was marked out.

A pianoforte wire, held at each end by a clamp, was stretched above the girder in

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* This girder was found to be considerably out of true alignment, so clamps were applied at intervals along its length to twist it until its edges were parallel and horizontal. The employment of a length of a lathe bed and saddle for the grating holder would obviate any twisting, and, I believe, possess many advantages over existing systems.

such a manner that as the carriage was moved the wire remained over the centre of the hole in which the pivot of the grating table turned.

III. and IV. Similar adjustments were made for the camera girder.

V. The line of motion of the centre of the camera carriage was adjusted perpendicular to the line of motion of the centre of the grating carriage.

KAYSER employed a theodolite to effect this, AMES the 3, 4, 5 method. The latter was adopted in the present case, and lengths of 4·5 m. and 6 m. were measured along the wires from their point of intersection, and a third wire, upon which a length of 7·5 m. was marked, was stretched across them, and the angle between the two girders altered by means of the cradle and side screws, fig. 1, G and H, until these marks coincided with those on the first two wires.

VI. The wires were removed and the slit placed at their point of intersection.

VII. An examination was made of the grating to ascertain on which side it threw the brighter spectrum of the second order; it was then placed in the grating holder, so that this spectrum should be employed.

VIII. The vertical bearing for the grating, ACF, fig. 4, was fitted into its carriage, and the grating in its holder placed in the hole-slot-plane system designed to receive it on the plate F. The base of the grating holder was made approximately horizontal by means of a spirit-level and the levelling screws L.

IX. The slit was moved vertically by turning the screw Y, fig. 7, until it was in the line of motion of the centre of the ruled space of the grating. The slit was illuminated by an arc and the light reflected from the grating received upon white paper surrounding the slit. The grating was moved to and fro along its girder, and the height of the slit altered until the centre of the reflected image remained upon the centre of the slit for all positions of the grating.

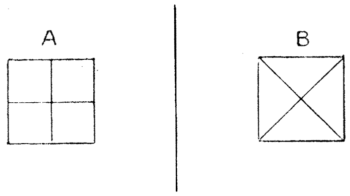
X. The vertical bearing for the camera, ACE, fig. 5, was fitted into its carriage and the camera fixed on it by means of the pin P. The spectrum was then adjusted horizontal and at the right height in the camera.

A piece of ground glass was placed in the dark slide in the camera, and by means of a scribing-block a mark was made on it at the height of the centre of the slit above the camera girder. The slit was illuminated and the spectrum observed on the plate. It was necessary to alter the screws $L' L''$, fig. 4, to bring the spectrum to the required position. The camera was then moved along the girder and, as a change in the level of the spectrum was noticed, the screw L''' was adjusted until the spectrum remained at the same height in the camera for all positions of the camera and grating on their girders.

The above operations insured the lines of the grating being vertical. The accuracy with which the face of the grating table had been turned was tested by rotating the grating about its axis and observing the position of the reflected image of the slit in the camera as it was moved along its girder. The centre of this image neither rose nor fell, so the mounting was considered satisfactory.

XI. The cross-beam was placed in position and (α) the grating was rotated until the pivot about which the centre of the plate turned was in the normal of the grating through its centre; (β) the length of the cross-beam was made equal to the radius of curvature of the grating mirror.

(α) was accomplished by the method described by Kayser of marking on a ground glass screen (a photographic plate which has been fixed for 10 minutes, without previous exposure, when it becomes almost transparent, is, after washing, a serviceable substitute) two small squares equidistant from a central line, and placing it in the camera with the central line directly above the pivot about which the camera box turns. A candle was held behind A, and its image observed with the magnifying glass in the square B while the grating was turned about its vertical axis by an assistant who operated the fine adjustment G. When the centres of the two crosses coincided, the central line lay in the normal to the grating.



(β) was effected by observing the image of A through the square B, as before, and racking the camera box backwards and forwards by means of the screw K, fig. 5, until all parallax disappeared and no motion of the eye caused the image of A to move within the square B. This determination was a matter of some difficulty and delicacy, and several independent observations were made by different observers. The adjustments of the mounting necessary for (β) require the displacement of the centre of the plate from its true position above the pivot, but the distance through which the plate holder was moved was noted, and the cross-beam was lengthened or shortened by the amount requisite to restore the plate to its correct position. The telescopic adjustment allows this to be easily performed.

XII. The slit was adjusted parallel to the lines of the grating.

The slit was rotated in its own plane about its centre by turning the screws Z, fig. 7, and with the usual method of illuminating the slit many photographs were taken on a small plate placed immediately over the pivot P, fig. 5. The spectrum of the iron arc was employed, and that disposition of the slit giving the best definition was chosen.

A simple test, due to Kayser, of the accuracy of this adjustment is to cover the middle of the slit to make it equivalent to two short slits separated by an opaque interval; a photograph taken with this disposition will show two spectra whose lines are drawn out by the astigmatic property of the grating to nearly meet in the centre. When the slit is parallel to the rulings, the two portions of the slit give a continuous line, otherwise the two lines are slightly displaced.

The fineness with which the ends of spectral lines (*e.g.*, those of the iron arc) are pointed, and the precise similarity of their two ends, is also a good gauge of the accuracy of this adjustment.

XIII. The camera was adjusted so that the centre of the grating lay in the normal to the plate through its centre.

The method adopted for accomplishing this was to take photographs of the iron arc spectrum in the usual way, on three small plates placed at the two ends and at the centre of the dark slide, between the exposure of each set the camera was turned slightly by means of the screw M, fig. 5, about the pivot P, and the disposition of the camera giving equally good definition for the ends as for the middle was selected. AMES describes a convenient method for obtaining a rough approximation: a piece of plate glass having been fixed to the face of the camera box, a candle is held on the girder near the grating, and the camera turned until the flame and its image come into line.

XIV. The adjustment necessary to correct for changes of temperature was made.

Changes of temperature prevent the spectrum from remaining in focus continually, since the focal length of the grating mirror and the length of the cross-beam are liable to alteration on this account.

The first care has been, therefore, to keep the temperature of the grating room as even as possible, and after this to move the slit towards or away from the grating, according as the temperature rose or fell, the best position at each temperature being found by trial photographs. A scale denoting the correct positions of the slit for different temperatures was in this way constructed and has been found to work well; the necessary motion of the slit is approximately 1 millim. for one degree Centigrade. Since the expansions of the grating and the cross-beam are unequal in their effects on the focus, at some temperatures the best definition is rather better than that attainable at others.

The expansion of the grating also affects the dispersion in the spectrum to an unsuspected extent. A simple calculation shows that $\delta\lambda/\lambda$ is equal to α, the coefficient of linear expansion of the grating. For $\lambda = 5000$ Å.U., and $\alpha = 0{\cdot}00002$ for speculum metal, $\delta\lambda = 0{\cdot}1$ Å.U. for a change in temperature of one degree Centigrade. The necessity for regulating the temperature of the grating room at once becomes apparent.

I have pleasure in acknowledging the services of Mr. T. ROYDS, B.Sc., who assisted me in making these adjustments. My indebtedness to the papers of AMES and KAYSER has already been expressed; to Professor KAYSER I am also grateful for his criticism of photographs obtained with this grating.

PART II.

THE EFFECT OF PRESSURE UPON THE SPECTRUM OF THE IRON ARC.

1. *Preliminary.*

Most intimately connected with the problem of the influence of pressure upon arc spectra are the names of HUMPHREYS and MOHLER,* who in 1897 published a full account of their investigations in this subject. They formed an arc between metal or cored carbon poles within a strong metal chamber furnished with a window, through which the arc was observed. Air or other gases could be pumped into the apparatus, and it was found that with an increase of pressure the spectrum underwent a change, the lines in general becoming broader and being slightly displaced towards the region of longer wave-lengths. Up to 14½ atmospheres, which was the highest pressure reached, the displacement of the lines for all the metals investigated was found to be directly proportional to the pressure, and a subsequent photograph of the spectrum of iron, which HUMPHREYS obtained at 37 atmospheres in 1905,† tended to confirm this.

MOHLER‡ extended the work to pressures lower than one atmosphere, and the linear relation was still found to hold. In 1906, ANDERSON§ obtained a photograph of the iron arc at a pressure of 30 atmospheres.

The present research was begun by the writer in November, 1904, with the object of extending the work of HUMPHREYS and MOHLER to still higher pressures, and two sets of photographs of the direct-current iron arc have now been obtained under pressures ranging from 1 to 100 atmospheres, the surrounding medium being in all cases air. This work was greatly facilitated by the preliminary work of HUTTON and PETAVEL,|| who in 1903 published the results of a research made with the same pressure apparatus and a 1-m. Rowland grating. The possibility of photographing the spectrum from an arc under pressures up to 100 atmospheres was demonstrated, as well as the probability of a successful use of the pressure apparatus in conjunction with a spectroscope of the highest dispersive power.

In August, 1906, the writer ¶ exhibited to the British Association photographs of the arc spectrum of iron taken with the 21½-feet grating under pressures varying from 1 to 101 atmospheres.

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* HUMPHREYS and MOHLER, 'Astrophysical Journal,' VI., 169, 1897; also 'Astrophysical Journal,' III., 114, 1896; IV., 175, 1896; IV., 249, 1896; for data published during the progress of their work.

† HUMPHREYS, 'Astrophysical Journal,' XXII., 217, 1905.

‡ MOHLER, 'Astrophysical Journal,' IV., 175, 1896.

§ ANDERSON, 'Astrophysical Journal,' XXIV., 221, 1906.

|| HUTTON and PETAVEL, 'Phil. Mag.,' 6, p. 569, 1903.

¶ DUFFIELD, 'Brit. Assoc. Report,' York, p. 481, 1906.

Of the results obtained by **HUMPHREYS** and **MOHLER**, the following are tabulated as being pertinent to the subject of this paper :—

(1) The Shift is proportional to the excess of pressure above one atmosphere, and takes place towards the red end of the spectrum.
(2) The Shift is different for different elements.
(3) The Shift differs for different groups of lines in the spectrum of any one element.
(4) The Shift of lines belonging to the Second Subordinate Series is twice the shift of those belonging to the First Subordinate Series, which is itself twice that of those belonging to the Principal Series, *i.e.*, the shifts are in the ratio 4 : 2 : 1.
(5) The Shift of some iron lines is three times the shift of other lines in the same Spectrum.
(6) The Shift is proportional to the wave-length for lines of the same series.
(7) A few lines showed no broadening.

The effect of pressure on the spark discharge in liquids and gases has now been investigated through a wide range by **HALE**,* **HALE** and **KENT**,† **LOCKYER**‡ and **ANDERSON**,§ and it has been shown that the effect of self-induction and capacity in the spark-circuit also affects the frequency of the vibrations ; it is not, therefore, possible to compare quantitatively the results of their investigations with those of **HUMPHREYS** and **MOHLER**, who used a direct-current arc.

2. *The Apparatus.*

The pressure cylinder, Plate 1, figs. 1 and 2, was designed by Mr. J. E. **PETAVEL**, F.R.S., and constructed by Mr. **CHAS. W. COOK**, of the Manchester University Engineering Works. This cylinder was used by **HUTTON** and **PETAVEL** for their 'Preliminary Note on the Effect of Pressure on Arc Spectra,' to which reference has already been made.

The pressure apparatus consists of a cylinder of drawn steel, fig. 8, 2 feet long, 3 inches internal and 5 inches external diameter, lined inside with brass $\frac{1}{16}$ inch thick ; to the top and bottom heavy flanges are screwed, and to these are bolted the covers which carry the arrangement for feeding the arc mechanically. The rods passing through the covers are screwed where they pass through the insulated plates at the top and bottom of the apparatus, and these are operated by the hand-wheels shown in the diagram. The current passes through the feed-rods to the electrodes which are attached to their extremities, and which form an electric arc opposite a

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* **HALE**, 'Astrophysical Journal,' XV., 132, 1902.

† **HALE** and **KENT**, 'Astrophysical Journal,' XVII., 154, 1903 ; and 'Publications of Yerkes Observatory,' Vol. III., Part II., 1907.

‡ **LOCKYER**, 'Roy. Soc. Proc.,' LXX., 31.

§ **ANDERSON**, 'Astrophysical Journal,' XXIV., 221, 1906.

window in the side of the cylinder, made of glass ground into the shape of a truncated cone, and so fitted into its seat in the cylinder that an increase of pressure tends to make the joint tighter. The whole cylinder is surrounded by a water-jacket through which water circulates and carries off the heat generated by the arc. Details of the design are described elsewhere,* and fig. 8 merely indicates diagrammatically the essential features of the apparatus. The stuffing-boxes in the covers perform the function of insulating the electrodes from the sides of the cylinder, besides that of permitting a vertical motion of the feed-rods without escape of gas.

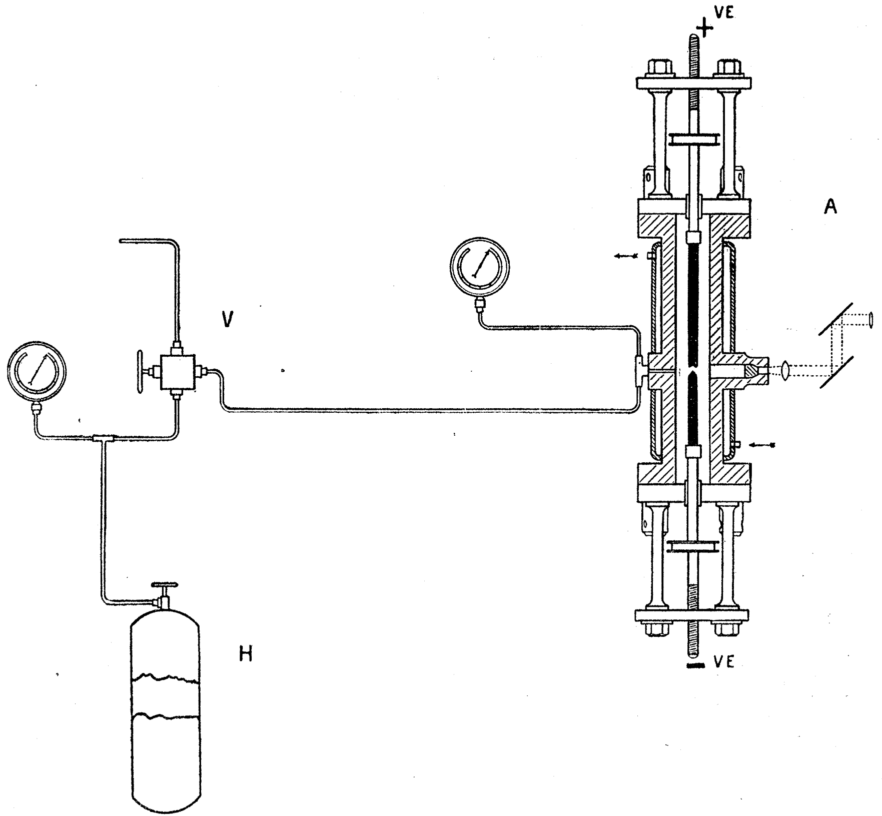

Fig. 8.

The maintenance of the highest pressures for long periods without appreciable leakage testifies to the excellence of Mr. PETAVEL's design. The writer here desires to express his indebtedness to Mr. PETAVEL for the use of the pressure cylinder and connections, and for valuable advice upon their management.

For the production of pressure within the cylinder the gas holder H, fig. 8, which was filled with air at a pressure of 120 atmospheres, was placed in communication with the pressure cylinder through the valve V, which could also afford a means for the escape of the gas from the pressure cylinder A to the outlet pipe. Pressure gauges indicated the pressures in the gas holder and in the cylinder.

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* HUTTON and PETAVEL, 'Electric Furnace Reactions under High Gas Pressures,' read Royal Society, March 7, 1907.

As there was a certain amount of risk of the window being blown out, it was usual to operate the feeding of the arc from a little distance by ropes passing round the pulleys on the covers; save, however, for some slight chipping of the inner surface, due to straining, the window has remained intact.

3. *The Illumination of the Slit.*

During the present research, in which the large dispersion of the 21-feet 6-inch Rowland grating was employed, it was found that extremely long exposures were required, and a number of unsuccessful attempts were made before a photograph of the spectrum under pressure was obtained. It became, therefore, most important to obtain the maximum illumination of the grating from the light passing through the window of the pressure cylinder.

The system of lenses employed is shown in the diagram: lenses K and L are at their focal distances from the arc and slit respectively.

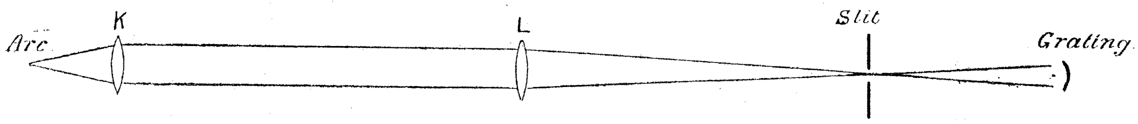

Fig. 9.

The cone of light from the lens L passes through the slit, and a little more than just fills the grating; this is not the usual arrangement, but the conditions differ from those contemplated by SCHUSTER,* who finds that the conditions for maximum uniform illumination are fulfilled when the angle subtended by the lens is four times that subtended by the grating at the slit. In the present instance the original cone of light is limited by the window in the cylinder, and the most efficient use is made of it by refracting it into the slit by a lens which subtends at the slit the same solid angle as the grating. The central maximum of the diffraction pattern for each ray then falls upon the grating, ensuring a sufficiently (but not perfectly) even illumination of its surface, and the loss of very little light.

Dealing with the concave grating, the size of the image of the arc on the slit is of some influence on the intensity of the spectral lines, because the astigmatic properties of the ruled surface serve to partially integrate the effects from different parts of the slit. In a prism spectroscope this is not the case, and the size of the slit does not affect the intensity of the lines. The lens K was therefore introduced in order that the image of the arc should just fill the slit; in this way the intensity of the illumination of the slit was not altered, since the angle subtended by the lens L at the slit remained constant, but the total quantity of light received over the area of the slit was then a maximum.

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* A. SCHUSTER, 'Astrophysical Journal,' XXI., p. 209, 1905.

4. *The System of Mirrors.*

It was found by some preliminary work that special means were essential for continually adjusting the image of the arc upon the slit; as soon as the air in the cylinder was compressed the arc became unsteady, and moved about the ends of the electrodes in an uncertain manner. Without a means of training the image on to the slit only a very small proportion of the length of exposure was effective, but with the apparatus to be described it was easy to follow the movements of the arc, and to ensure its almost continual focussing on the slit.

Two mirrors were silvered and polished on the surface, and fitted into frames which held them at an angle of 45° with the horizontal; the upper was fixed with its centre in the line joining the centre of the grating with the centre of the slit. The second was placed 4 inches below the first, opposite the window of the pressure cylinder, and could be moved parallel to itself by means of the rack and pinion shown in fig. 10.

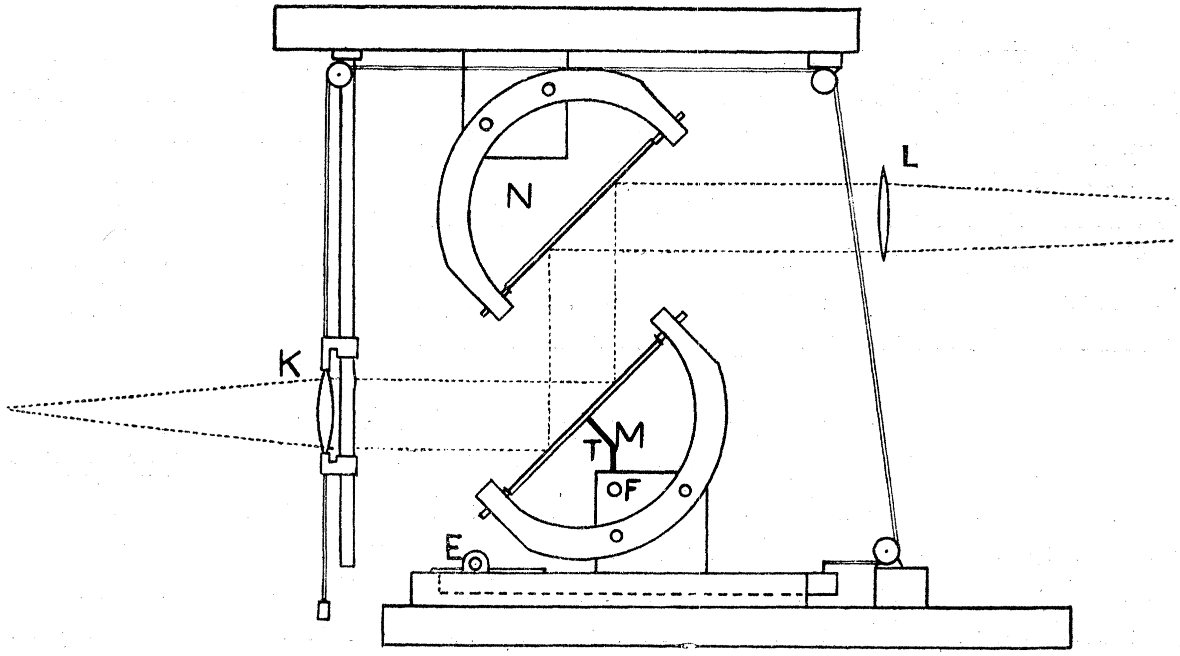

Fig. 10. Arrangement of mirrors.

Vertical displacements of the arc from its central position, caused by unequal consumption of the electrodes or unequal feeding, were counterbalanced by this motion. If we confine our attention to the bundle of rays symmetrical about a horizontal ray and for the moment neglect the lens K, we see that a lowering of the arc (which occasions a lowering of the position of the spot of light received upon the upper mirror) may be counterbalanced by moving the mirror M parallel to itself away from the arc. This restores the reflected beam to its original position on mirror N; similarly, when the arc is higher than usual, the re-adjustment is effected by moving the mirror M forward.

Without the lens K, the direction of the beam of light passing through the window would change as the arc shifted its position, and it would be necessary to alter the angles of the mirrors and the position of the lens L in order to keep the image in focus on the slit, but the lens K has been arranged to move up or down just as much as the arc moves up or down, by means of the system of pulleys shown in the diagram, which ensures the vertical motion of the lens being equal to the horizontal motion of the mirror M; when M moves towards the arc, L is pulled up, and *vice versâ*. The ray passing horizontally through the window thus always proceeds through the centres of the second lens, the slit and the grating, and all danger of a fictitious shift due to want of centrality is obviated. When the arc fluctuates horizontally round the poles the image is brought back upon the slit by turning the mirror M about its pivots; the motion required is very small and the adjustment can be made rapidly enough for an experienced operator to keep the image of the arc almost continually in position. Since the arc and slit are in the focal planes of their respective lenses the image is always in good focus.

The turning of the mirror about its long axis is effected by the screw F, which presses against a projection T from the back of the frame holding the mirror, a spring keeping F and T in close contact. Universal joints were attached to the ends of E and F, and long handles provided, fig. 2, Plate 3, so that the assistant whose duty it was to keep the image on the slit was not too close to the window.

This mirror system was designed by the writer and constructed by Mr. GRIFFITHS in the workshop of the Physical Laboratory. To it the success in photographing the spectrum of the arc under high pressures is largely due.

5. *General Arrangement of the Apparatus.*

Plate 3, fig. 2, shows the cylinder in position in front of the Rowland grating spectroscope, the slit of which is to be seen at the right of this photograph standing on the cast-iron girder along which the camera carriage runs. The cylinder is mounted on a swinging jib turning on the vertical axis at the left of the picture, so that it can be moved out of position when the grating is required for other work. A screw-jack at the base of the jib allows the cylinder a vertical range of adjustment of about 6 inches.

On a level with the window is the lens which slides in vertical grooves, and beyond it the arrangement of mirrors is to be seen. These were operated by an assistant who stood at some distance from the apparatus and worked them by means of the two wooden handles. The second lens is held in the clamp of the retort stand and was accurately adjusted in line with the centres of the slit and the grating.

The ropes for operating the mechanical feeding of the arc were not in position when the photograph was taken, nor is the auxiliary shutter shown; this latter was fixed beyond the slit, so that its operation caused no jarring to the mounting of the grating.

The rubber pipes for supplying the jackets with water may be seen, one in front at the bottom of the cylinder, and the other behind it at the top. Above the cylinder a ventilating chimney serves to carry off any noxious vapours which might otherwise escape into the room, and a block and tackle arrangement facilitates the removal of the cylinder covers.

6. *Precautions necessary in taking the Photographs.*

The object of the experiments was the direct comparison of the spectrum of the iron arc when subjected to high pressures with the spectrum emitted under ordinary conditions. To facilitate the examination of the relative positions of the lines in the two cases it was desirable to photograph the two spectra in as close proximity as possible, and for this purpose the usual form of comparison-shutter was adopted. This caused the central strip of the plate to be exposed to the arc under pressure, and above and below this strip the comparison spectrum to be photographed; or *vice versâ*. The shutter is described in Part I., p. 117. The dispersion of the second-order spectrum (1 millim. = 1·3 Å.U.) was employed in this research.

The following precautions were taken to insure the freedom of the photographs from any fictitious displacement of the lines :—

1. To prevent jarring of the camera when the shutter was operated, the latter, which was originally fixed to the camera box, was detached from it and separately supported, as already described.

2. To make sure that the conditions were the same for the two different positions of the shutter, some photographs were taken with the pressure spectrum within the central strip and others with the comparison spectrum in the centre. No systematic difference was found between the two.

3. To insure the absence of an apparent shift due to the illumination of the grating being different for the two exposures, the arrangement of mirrors and lenses already described was adopted. Since the mirror N and the lens L, fig. 10, were fixed, the light always passed through the lens L in the same direction when the image of the arc was in focus on the slit. This is the necessary condition for constant distribution of illumination over the grating. That no conditions might be different for the two exposures, the comparison spectrum was taken from the same metallic poles within the cylinder.

4. As a fictitious displacement of the lines might also be caused by a change in temperature of the grating (see Part I., p. 122), a careful watch was kept upon a thermometer placed near it. For some weeks it was found impossible to take photographs on account of the fluctuations of the temperature, of which complete records were kept, and, although one or two reliable photographs at low pressures were taken at night towards the end of 1905, it was not until the Spring of 1906 that the temperature of the room settled down sufficiently for long exposures to be made, a

long period of rainy weather proving of great service in the prosecution of this research.

5. To have a means of ascertaining whether the photographs taken were reliable, the comparison spectrum was invariably photographed by a divided exposure; the spectrum of iron arc at atmospheric pressure was taken immediately before and also immediately after the pressure exposure, and the positions of these two spectra were carefully examined. Any disturbance of the apparatus or continuous change in temperature during the experiment could thus be discovered, and all plates in which the lines were not accurately coincident were rejected.

7. *The Behaviour of the Iron Arc under High Pressure.*

Under ordinary conditions the iron arc was maintained almost as easily as the carbon arc, but an increase of the pressure of the air surrounding it caused its management to become more difficult. The disturbed area on the positive pole from which the arc sprang was in constant motion over the surface of the turbulent molten mass, and luminous metallic vapour was constantly expelled in all directions. These convection currents rendered the arc very unstable, and at a pressure of only 10 atmospheres it was difficult to maintain it for more than half a minute on account of the tendency of these flames to blow it out.

At higher pressures the life of the arc became shorter, and at 50 atmospheres the exposure consisted of a series of flashes of not much more than a second's duration, the maximum length of the arc being then about 2 millims. For the first pair of iron poles, between 300 and 400 flashes were required to affect a photographic plate, so it was necessary to prolong the process of striking the arc and withdrawing the poles for a period of from 40 minutes to one hour. Up to 50 atmospheres a workable scale of exposures was to open the shutter for the same number of minutes as the number of atmospheres employed, but for pressures between 50 and 100 atmospheres it was not necessary to increase the exposure beyond one hour.

A second set of photographs, Set B, was taken with another pair of iron poles, and these proved much more satisfactory, as the arc lasted much longer at all pressures, at the highest pressure only 8 to 12 minutes exposure being required, and this rendered the plates less liable to fogging from stray light in the room. The two sets of photographs are subsequently referred to as Sets A and B.

The specimens of iron bar were obtained from the same source in the two cases.

The length of the exposure necessitated the use of a wider slit than would otherwise have been employed; this was decided upon experimentally by taking a series of photographs of the iron arc at ordinary pressures with different widths of slit and choosing that aperture at which the definition just remained good—the series showed that the definition decreased gradually to a point at which it suddenly became bad; a reasonable margin for accidental alterations was allowed, and the slit width chosen gave a definition sufficiently good for the finely reversed portions of the lines *b*3, *b*4, *c*0, &c., Plate 4, to remain quite clear. The width was found to be 0·022 millim., a larger value than that required for perfect definition, viz., 0·007 millim.

W. E. WILSON* and WILSON and FITZGERALD† have observed the changes in the temperature and brightness of the carbon arc in different gases under pressures varying from 1 to 20 atmospheres. No very concordant results were obtained, as the absorption of the light by the vapour in the long observing tube was considerable and fluctuating, but the evidence tended to show that with the carbon arc there is no increase in the intensity of the light emitted from the crater when the pressure of the surrounding gases, whether oxygen, nitrogen, or hydrogen, is increased.

During the course of the present experiments notes were made of the apparent intensity of the light at each pressure, and, according to visual observations, the brilliance of the image thrown upon the jaws of the slit increased gradually with the pressure until at 100 atmospheres it became painful to the eyes to observe it, the brightness apparently increasing more rapidly after 50 atmospheres than between 1 and 50 atmospheres.

It is to be remarked that with this increase of brightness there is little concomitant decrease in the necessary time of exposure. As the pressure was increased the spectral lines became very much wider and more diffuse, and in some instances were spread out over 15 Ångström units; consequently, though there is an increase in the intrinsic brightness of the arc, the fact that the area over which the energy of vibration is spread is increased in a greater proportion, results in the intensity of the radiant energy received upon the photographic plate being less than that received when the total amount of light is less and the energy concentrated into narrow lines.

The city mains at 100 volts were used as the source of supply, a reduction being effected by a resistance frame. The current in the arc varied from 12 to 20 ampères; this could not be measured accurately on account of the intermittent nature of the arc, nor could a higher voltage than 50 be used across the terminals, because at the moment of striking it a short circuit through the molten metal was produced, and the wiring of the building was not capable of taking more than 30 ampères.

An interesting phenomenon, to which reference will be made later (p. 153), was observed in connection with the coating of the window with a black deposit derived from the arc; this was very troublesome between 1 and 20 atmospheres, and it necessitated the removal and cleaning of the window after each exposure, but between 20 and 30 atmospheres this ceased, and from 30 to 100 atmospheres the window remained perfectly clear. It may be that the particles shot off from the arc cannot, at high pressures, penetrate the dense envelope of air, or it may be that the hot vapours extend right from the arc to the window and consume the metallic particles. The former is the more acceptable hypothesis, since the latter condition can scarcely hold

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* WILSON, 'Astrophysical Journal,' II., 213, 1895; 'Roy. Soc. Proc.,' 58, 174, 1895.

† WILSON and FITZGERALD, 'Astrophysical Journal,' V., 101, 1897; 'Roy. Soc. Proc.,' 60, 377, 1896.

at pressures of 95 and 100 atmospheres when the arc is of too short duration for the formation of the necessary quantity of vapour.

8. *General Features of the Results.*

1. *The Broadening of the Lines.*—It will be seen from the photographs accompanying this paper that the first obvious effect of an increase of the pressure of the gas surrounding the arc is the *broadening of the lines.*

Under a pressure of three atmospheres, Plate 4, No. 1, the widths of all the lines are appreciably increased, and under higher pressures this becomes still more marked. The width is too dependent upon the length of the exposure and the nature of the photographic process* for more than a general idea of the broadening to be obtained from the photographs, but it will be seen that the lines widen and become more diffuse as the pressure is increased, and that *the amount of broadening is different for different lines;* those that reverse strongly are spread out over a large range (*e.g.*, lines marked *b*3, *b*4, *c*0, *d*0, *d*2, &c.), while others remain comparatively sharp (*b*1, *b*2, *c*1, *c*2, *c*3, *d*1, &c.), though these are not nearly as fine under high pressure as they are under one atmosphere. It is in general true that the lines that are originally strong are the ones that are most broadened under pressure.

The broadening of most lines is unsymmetrical, being greater towards the region of greater wave-length; the following lines illustrate this well: 2, 3, *d*3, *f*1, *f*2, Plates 4, 7 and 8. Those that reverse easily, *b*3, *b*4, *c*0, *d*0, *d*2, &c., however, appear to broaden almost symmetrically, and so do the lines already mentioned as remaining comparatively sharp at high pressure. In no instance has a line been found with a greater broadening on its more refrangible side. It should, however, be remarked that there is invariably some broadening towards the violet, but not always to the same extent as towards the red end of the spectrum. The phenomenon of broadening may be studied in Plate 5, fig. 1, in which, however, the exposures are not quite comparable.

2. *The Displacement of the Lines.*—A careful study of the photographs, Plate 4, reveals the fact, first discovered by HUMPHREYS and MOHLER, that there is a slight *displacement of the lines towards the red end of the spectrum as the pressure of the vapour about the arc is increased.* At low pressures it is not quite definite that this phenomenon is not due to an unsymmetrical widening of the line, but the photographs taken at high pressures dispose of this objection, because several lines are then displaced so much that they are quite clear of their comparison lines. The lines *f*1, *f*2, *f*3, at 100 atmospheres, No. 9, Plate 4, show this well, and it is emphasized in the enlargement, Plate 8, and in Plate 6, fig. 1, in which the shift of *d*3 at 100 atmospheres is specially remarkable; the lines 2, 3, *a*1, Plate 7, though not displaced quite as much, also testify that the displacement is a real phenomenon.

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* The photograph at 10 atmospheres (No. 2) is over-exposed in comparison with the other spectra.

The question of the magnitudes of the displacements are discussed under a separate heading.

3. *The Reversal of the Lines.*—In the region of the spectrum examined, several lines are reversed at ordinary atmospheric pressure, such are *b*3, *b*4, *c*0, *d*0, *d*2, &c., but under increased pressure the reversals become stronger and other lines originally unreversed exhibit the phenomenon; such are *b*1, *c*1, *d*1, *f*1. It thus follows that *the immediate effect of pressure is to increase the number and intensity of the reversals.* But at a pressure of about 25 atmospheres for Set A, the maximum tendency to reverse is reached, and *above* 25 *atmospheres the reversals decrease in number and generally in width.* For Set B, the maximum intensity of the reversals occurs at 20 atmospheres; it may also be seen from Table II. that the reversals are more numerous at 10 atmospheres than at 15 atmospheres. In Plate 5, fig. 1, in which the spectrum photographed at 100 atmospheres pressure is not exposed as much as the other spectra under pressure, the lines *b*3, *e*3, *e*4, are reversed most strongly at 25 atmospheres; a careful examination of the original negatives under a high magnifying power is, however, necessary for the detection of the fine reversals of *b*1, *c*1, &c. A few lines remain strongly reversed even at the highest pressures reached, *c*0, *d*0, *d*2, *e*1.

Some reversals are symmetrical, *i.e.*, the absorption line is in the centre of the bright emission line, see lines *d*0, *d*2, Plate 6, fig. 1; others are unsymmetrical, see line *e*3, Plate 6, fig. 2. A separate section, p. 152, is devoted to the discussion of this phenomenon.

9. *Measurement of the Photographs.*

The plates were measured on a KAYSER measuring machine in which they are firmly attached to a table which travels on a fine screw in front of a fixed eye-piece containing the cross-wires; depressing a key prints the reading of the scale on a tape and enables several measurements to be made without moving the eye from the instrument. The shifts were measured by causing the line under pressure and its comparison line to travel in succession past the double wire of the eye-piece, the key being depressed as the most intense portion of each spectral line came between the double threads; the setting on the broadened portion of the line was generally made first, because it was then found easier to decide upon its most intense portion. In some few cases in which the line was abnormally broad, the film was pricked under a low-power magnifying glass which enabled the position of maximum intensity to be more easily gauged, and the position of this dot was then measured. Some of the plates were taken with the pressure spectrum within the comparison spectrum, but most of them in the reverse manner; no important differences were found between the readings in the two cases. For pressures above 60 atmospheres the second method was alone adopted. The astigmatism of the grating was purposely left uncorrected, because it was an advantage to have the extremities of the lines drawn out into points, as these indicated their most intense portions and enabled a more accurate setting of the cross-wires to be made. Two parallel threads in the eye-piece gave more consistent results than cross-wires.

As has already been stated, two sets of photographs, A and B, have been taken at pressures varying from 1 to 101 atmospheres (absolute).

Set A was measured first by the writer, and then by two assistants. Each observer obtained six readings of the displacement, making the total number of readings for each line 18. This number was frequently exceeded. For a second plate taken at the same pressure, 12 readings of each line were usually considered sufficient. The mean value of the shift of each line at each pressure was therefore obtained from at least 30 readings of the displacement. For Set A, 20,000 determinations of the displacements have been made.

Set B was measured by the writer alone, except in a few cases when separate observation seemed desirable, and the figures given in the table are the means of ten measurements of each displacement. The plates used for this set were Imperial Flashlight, and the Developer the Imperial Pyro-Metol Standard—a combination which was more successful than that previously used for Set A; the photographs were free from developer-fog, and the lines consequently measurable with much greater ease. The total number of readings for the second set is about one-third of the number made for the first set, but for the reasons given above, and also because experience is essential for the accurate determination of the positions of the most intense portions of the lines under pressure, the results given for the second set are considered more satisfactory.

The following photographs constitute the two sets :—

Set A.			Set B.	
Pressure in atmospheres.	Number of photographs.		Pressure in atmospheres.	Number of photographs.
	Pressure spectrum inside.	Pressure spectrum outside.		Pressure spectrum outside.
5	3	—	3	1
10	2	—	4	1
15	—	2	5	1
20	1	2	10	1
25	—	2	15	2
30	1	2	20	1
40	2	—	25	2
60	1	1	30	1
80	—	1	40	3
95	—	1	50	2
100	—	1	60	1
			70	1
			80	1
			100	1

Two photographs were usually taken upon each plate.
The first set are numbered D1 to D19.
The second set are numbered D21 to D33.

10. *Description of the Tables of the Displacements.*

The results of the measurements of the two sets of plates are given in Tables I. and II.

The first columns contain a list of arbitrary letters and numbers assigned to the different lines to facilitate reference to them. Beginning at the red end they run 1, 2, 3, 4, 5, 6, *a*0, *a*1, *a*2, *a*3, *a*4, *b*0, *b*1, *b*2, *b*3, *b*4, *c*0, *c*1, *c*2, &c. Plate 4 contains photographs showing lines beginning with 2 and ending with *j*0.

The second columns give the wave-lengths of the lines according to KAYSER and RUNGE'S tables.

In the subsequent columns the displacements of the lines at different pressures are set forth in thousandths of an Ångström unit. The use of black figures, *e.g.*, **223**, for displacements indicates that the line is reversed at the corresponding pressure, italic figures, *e.g.*, *223*, denoting a faint reversal; the displacements are those of the centre of the reversal. An asterisk * indicates that the line is reversed, but that the measurements of the displacements were not consistent. Numbers in brackets have not been plotted in the diagrams.

When two values for the displacement are given, one is for the line when reversed and the other for the unreversed line (measured on different plates), the upper number referring to the latter.

In all cases the shifts are towards the side of greater wave-length.

The pressures are the excess above one atmosphere.

Table I.—Set A.

Atmospheres . .		5.	10.	15.	20.	25.	30.	40.	60.	80.	95.	100.
Line.	Wave-length.	Displacements in thousandths of an Ångström unit.										
1	(4531·25)†	35	46	—	100	—	108	116	160	240	280	289
2	4528·78	47	*75*	128	*103*	*231*	215	270	259	421	404	452
3	4494·67	46	62	103	213	274	185	172	241	371	403	323
4	4482·35	44	51	78	193	298	121	177	237	393	388	345
5	4476·20	21	22	60	62	129	90	73	103	139	190	177
6	4466·70	24	27	34	*41*	*118*	78	69	95	175	177	181
(*a*)	4461·75	25	24	37	**48**	*	82	69	82	148	95	194
1	4459·24	43	64	71	211	254	203	177	263	362	365	431
2	4447·85	38	64	92	187	246	185	203	259	366	(315)	362
3	4443·30	26	25	57	94	105	86	78	129	160	—	134
4	4442·46	34	63	93	172	204	172	172	211	306	—	323
(*b*)	4430·74	37	63	66	155	207	172	172	293	—	(277)	323
1	4427·44	23	16	49	**28**	*	73	78	86	148	181	—
2	4422·67	25	22	75	68	107	69	65	112	195	185	134
3	**4415·27**	**30**	**22**	**47**	**52**	**103**	**82**	**73**	**138**	**222**	**250**	**(121)**
4	**4404·88**	**25**	**22**	**50**	**64**	**110**	**82**	**69**	**142**	**190**	**(224)**	**(138)**
(*c*)	**4383·70**	**26**	**19**	**53**	**78**	**103**	**65**	**82**	**138**	**198**	**194**	**(121)**
1	4376·04	22	21	27	**30**	*	73	73	95	129	82	—
2	4369·89	26	16	39	69	95	65	69	95	194	147	—
3	4352·86	39	16	31	51	108	69	60	82	147	164	—
4	4337·14	28	26	37	**93**	**185**	95	103	116	220	181	—
(*d*)	**4325·19**	**22**	**25**	**57**	**75**	**102**	**69**	*	**129**	**211**	**207**	**151**
1	4315·21	19	—	*28*	**42**	**86**	**69**	—	86	151	125	108
2	**4307·96**	**23**	*	**38**	**65**	**86**	**91**	*	**138**	**198**	**198**	**155**
3	4299·42	64	*133*	*209*	**126**	**224**	474	—	474	603	582	646
4	4294·26	33	**31**	**29**	**47**	**101**	**73**	**99**	116	164	263	172
(*e*)	4282·58	18	**15**	**30**	**35**	**90**	**56**	**59**	90	125	159	121
1	**4271·93**	**22**	**30**	**93**	**94**	**99**	**82**	**95**	**142**	**215**	**237**	**172**
2	4271·30	68	—	*	**75**	*	—	—	—	—	—	—
3	**4260·64**	**31**	**54**	**71**	**84**	**183**	**159**	**198**	*323*	754	862	991
4	**4250·93**	**18**	**30**	**33**	**55**	**97**	**78**	**82**	*116*	211	—	181
(*f*)	4250·28	—	(104	—	**83**	**172)**	—	—	—	—	—	—
1	4236·09	83	147	355	**122**	**211**	517 **155**	733	625	776	776	948
2	4233·76	86	133	239	534 **107**	**190**	431	474	453	491	(431)	603
3	4227·60	119	105	452	440 **122**	**195**	560	582	582	—	—	—
4	4222·32	75	81	241	440	—	388	409	431	—	—	—
(*g*)	4219·47	26	29	63	**56**	**105**	78	108	134	185	241	(125)
1	(4210·48)†	67	72	157	345	323	259	241	362	297	375	—
2	4204·07	23	16	56	(121)	—	90	95	129	—	—	134
3	**4202·15**	**13**	**17**	**41**	**38**	**101**	**69**	**90**	**121**	**198**	**211**	**188**
4	4199·19	23	**36**	**42**	**40**	**116**	**69**	**82**	*150*	224	134	134
5	4198·42	(96	103	—	**127)**	*	*	—	—	—	—	—
(*h*)	4191·57	81	122	263	530	—	345	431	496	(388)	(388)	733
1	4187·92	(66	120	349	**94**	**215)**	*	—	—	—	—	—
2	4187·17	76	123	213	**128**	*	*	—	—	—	—	—

Asterisks and black figures indicate reversals. Italic figures indicate faint reversals.

† See note on p. 138.

TABLE I.—Set A (continued).

Atmospheres . .		5.	10.	15.	20.	25.	30.	40.	60.	80.	95.	100.
Line.	Wave-length.	Displacements in thousandths of an Ångström unit.										
3	4181·85	25	30	**55**	**42**	**90**	**69**	**78**	116	181	228	207
4	4175·71	26	27	47	68	116	86	103	129	181	259	186
(*i*)	4156·88	23	21	**41**	**52**	*	73	99	129	164	172	172
1	4154·57	27	21	**58**	**41**	*110*	78	99	151	168	151	155
2	**4143·96**	**19**	**22**	**71**	**76**	**103**	**99**	**78**	**129**	**181**	**233**	**233**
3	4143·50	18	21	*	**48**	**69**	**39**	78	—	—	—	—
4	4134·77	19	20	62	**32**	**77**	103	112	125	194	177	185
(*j*)	**4132·15**	**16**	**24**	**45**	**59**	**92**	**86**	**95**	**129**	**259**	*	**289**
1	4127·68	20	25	*	**107**	**130**	**90**	95	108	172	168	215
2	4118·62	21	29	**56**	**70**	**110**	**95**	95	103	194	164	198
3	**4071·79**	**19**	**23**	**37**	**75**	**95**	**82**	**82**	**142**	**185**	**241**	**220**
4	**4063·63**	**20**	**25**	**40**	**67**	**86**	**73**	**95**	**138**	**198**	**250**	**233**
(*k*)	4062·51	17	25	—	**44**	*	—	—	—	—	—	—
1	**4045·90**	**20**	**25**	**25**	**77**	**107**	**73**	**103**	**147**	**185**	**250**	**267**
2	4033·16	26	37	—	**58**	*	—	—	—	—	—	—

TABLE II.—Set B.

Atmospheres . .		3.	4.	10.	15.	20.	25.	40.	50.	70.	80.	100.
Line.	Wave-length.	Displacements in thousandths of an Ångström unit.										
1	(4531·25)†	21	—	32	—	—	56	78	99	142	—	—
2	4528·78	—	—	*	86	**108**	138	172	177	259	284	340
3	4494·67	46	47	73	99	129	129	168	172	259	276	349
4	4482·35	—	45	—	86	—	86	—	151	237	259	306
5	4476·20	14	22	26	36	51	39	42	56	86	125	151
6	4466·70	16	—	26	43	40	44	46	56	86	125	147
(*a*)	4461·75	20	—	23	37	41	37	39	43	86	112	124
1	4459·24	46	47	79	95	116	121	172	185	254	289	345
1α	4454·50	—	—	22	—	—	—	—	—	—	142	—
2	4447·85	43	46	77	86	121	121	172	181	263	297	336
3	4443·30	17	24	28	47	47	43	60	73	103	116	164
4	4442·46	48	49	71	99	101	112	164	177	228	271	319
(*b*)	4430·74	41	—	71	103	108	108	159	194	276	284	340
1	4427·44	18	—	*23*	36	52	(22)	43	37	65	108	95
2	4422·67	18	—	28	47	44	43	46	52	78	112	138
3	**4415·27**	**24**	*	**41**	**46**	**52**	**62**	**78**	**112**	**121**	**172**	**228**
4	**4404·88**	**17**	**19**	**54**	**47**	*	**60**	**56**	**125**	**116**	**194**	**194**
(*c*)	**4383·70**	**16**	**20**	*	**56**	**62**	**62**	**60**	**142**	**116**	**198**	**198**
1	4376·04	18	—	*21*	31	**34**	37	47	36	56	86	138

Asterisks and black figures indicate reversals. Italic figures indicate faint reversals.

† See note on p. 138.

TABLE II.—Set B (continued).

Atmospheres . .		3.	4.	10.	15.	20.	25.	40.	50.	70.	80.	100.
Line.	Wave-length.	Displacements in thousandths of an Ångström unit.										
2	4369·89	17	—	33	32	40	43	60	60	108	129	134
3	4352·86	21	—	25	34	45	35	56	56	(47)	106	(106)
4	4337·14	30	31	42	62	69	66	82	73	121	185	194
(*d*)	**4325·19**	**18**	**21**	**32**	**56**	**62**	**65**	**56**	**125**	**112**	**203**	**185**
1	4315·21	15	24	*16*	31	**39**	37	41	43	56	108	99
2	**4307·96**	**16**	**20**	**24**	**56**	**60**	**56**	**60**	**112**	**95**	**194**	**177**
3	4299·42	—	—	**60**	155	*	207	313	—	470	474	560
4	4294·26	*	**21**	**24**	**47**	**52**	61	*86*	*142*	116	116	151
(*e*)	4282·58	*	**24**	**22**	*	**29**	33	56	*39*	—	116	95
1	**4271·93**	**14**	**23**	**21**	**45**	**64**	**65**	**69**	**129**	**147**	**203**	**203**
3	**4260·64**	**27**	**34**	**64**	**95**	**124**	**90**	**177**	**263**	**320**	*293*	732
4	**4250·93**	*	**18**	**22**	**46**	**58**	**56**	**82**	**116**	**129**	177	190
*f*1	4236·09	**31**	*	**64**	*95*	**129**	223	405	444	(776)	552	776
2	4233·76	99	92	193	172	297	203	370	409	465	483	668
3	4227·60	113	90	145	155	326	246	431	—	—	—	—
4	4222·32	86	71	140	177	265	196	358	—	543	517	—
(*g*)	4219·47	24	25	24	39	75	40	78	78	155	142	181
1	(4210·48)†	60	—	107	129	142	142	157	181	362	259	474
2	4204·07	21	—	22	30	—	43	60	61	134	121	190
3	**4202·15**	**21**	*	**21**	**47**	**49**	**60**	**78**	**116**	**116**	**190**	**228**
4	4199·19	*	*	**24**	**37**	**47**	**67**	**65**	**100**	**104**	121	181
5	4198·42	—	—	—	(147)	—	—	—	—	—	—	—
6	4196·31‡	**(174**	**210**	293	260)	—	—	—	—	—	—	—
7	4195·46‡	**(138**	**187**	284	250)	—	—	—	—	—	—	—
(*h*)	4191·57	—	—	188	190	271	183	310	—	443	452	539
1	4187·92	122	—	—	177	—	228	431	—	—	—	—
2	4187·17	106	—	—	177	321	(168)	(190)	—	—	—	—
2α	4184·99	—	—	24	—	—	—	47	94	—	—	172
3	4181·85	20	—	**25**	40	**43**	60	—	—	95	138	181
4	4175·71	24	—	21	49	60	52	65	47	108	142	172
(*i*)	4156·88	27	—	21	43	56	62	65	(39)	99	134	151
1	4154·57	24	—	22	46	54	57	86	(36)	112	129	172
2	**4143·96**	**14**	*	**26**	**56**	**60**	**70**	**99**	**138**	**155**	**181**	**177**
3	4143·50	18	—	*	30	**48**	—	—	—	—	—	—
4	4134·77	28	—	21	53	(142)	57	86	78	116	138	164
(*j*)	**4132·15**	**12**	*	**26**	**47**	**68**	**59**	**108**	**134**	**129**	*172*	*177*
1	4127·68	16	—	41	47	—	56	82	73	125	125	164
2	4118·62	26	—	**21**	41	71	59	99	86	142	125	177
3	**4071·79**	**20**	*	*	**59**	**60**	**69**	**86**	**129**	**147**	**181**	**198**
4	**4063·63**	**21**	*	*	**53**	**56**	**73**	**82**	**129**	**151**	**185**	**194**
*k*1	**4045·90**	**21**	*	*	**69**	**65**	**73**	**82**	**138**	**168**	*	*

Asterisks and black figures indicate reversals. Italic figures indicate faint reversals.

[† *Note added December*, 1907.—From a private communication from Professor KAYSER I understand that the lines 1, λ = 4531·25, and *g*1, λ = 4210·48, are the only ones in the above table that are doubtfully due to iron, being possibly produced by Co and Sa respectively. These lines alone fail to fall into any of the groups of lines into which the iron spectrum is divisible. There is thus additional evidence that they may be due to impurities. They have not been included in the diagrams.]

‡ See p. 157.

11. *Mean Values of Displacements.*

Table III.—Set A.

	Displacements in thousandths of an Ångström unit.										
Atmospheres	5.	10.	15.	20.	25.	30.	40.	60.	80.	95.	100.
Group I., unreversed	24	23	52	54	102	80	72	101	161	183	164
Group I., reversed	**21**	**23**	**45**	**67**	**101**	**74**	**86**	**136**	**203**	**227**	**191**
Group II.	41	63	94	194	245	187	185	252	371	359	366
Group III., unreversed	82	118	310	490	—	452	475	510	620	680	730
Group III., reversed	**31**	**54**	**71**	**109**	**203**	**157**	**193**	**323**	—	—	—

Table IV.—Set B.

	Displacements in thousandths of an Ångström unit.										
Atmospheres	3.	4.	10.	15.	20.	25.	40.	50.	70.	80.	100.
Group I., unreversed	20	23	27	43	52	45	62	59	102	122	153
Group I., reversed	**18**	**20**	**26**	**51**	**59**	**55**	**81**	**124**	**129**	**186**	**194**
Group II.	45	47	74	95	116	120	168	181	256	283	338
Group III., unreversed	100	84	166	171	280	212	374	426	539	510	655
Group III., reversed	**29**	**34**	**64**	**95**	**137**	**90**	**177**	**263**	**388**	**293**	*

12. *Discussion of the Displacement Tables and Curves.*

Tables I. and II., Diagrams I., II., III., and IV.

The values for the shifts given in Tables I. and II. have been plotted in Diagrams I. and II., in which the abscissæ represent the excess of pressure over one atmosphere, and the ordinates the increase in wave-lengths of the lines in thousandths of an Ångström unit.

Each line on the diagram depicts the behaviour under pressure of one spectral line, which may be identified by the letter attached to it. The reversal of a spectral line is indicated by the dotting of the line on the diagram near the pressure at which reversal takes place. Small arrows indicate those pressures at which measurements have been made.

The Curves and Tables show that—

(1) No lines remain undisplaced.

(2) The displacement is always towards the red end of the spectrum, indicating a decrease in the frequency of the vibrating particle.

(3) The displacement of the lines increases as the pressure is increased.

(4) The relation between the pressure and displacement is in general, but not quite rigorously, a continuous and linear one. (See pp. 145, 146.)

(5) The rates of increase of the displacement with the pressure vary greatly for different lines.

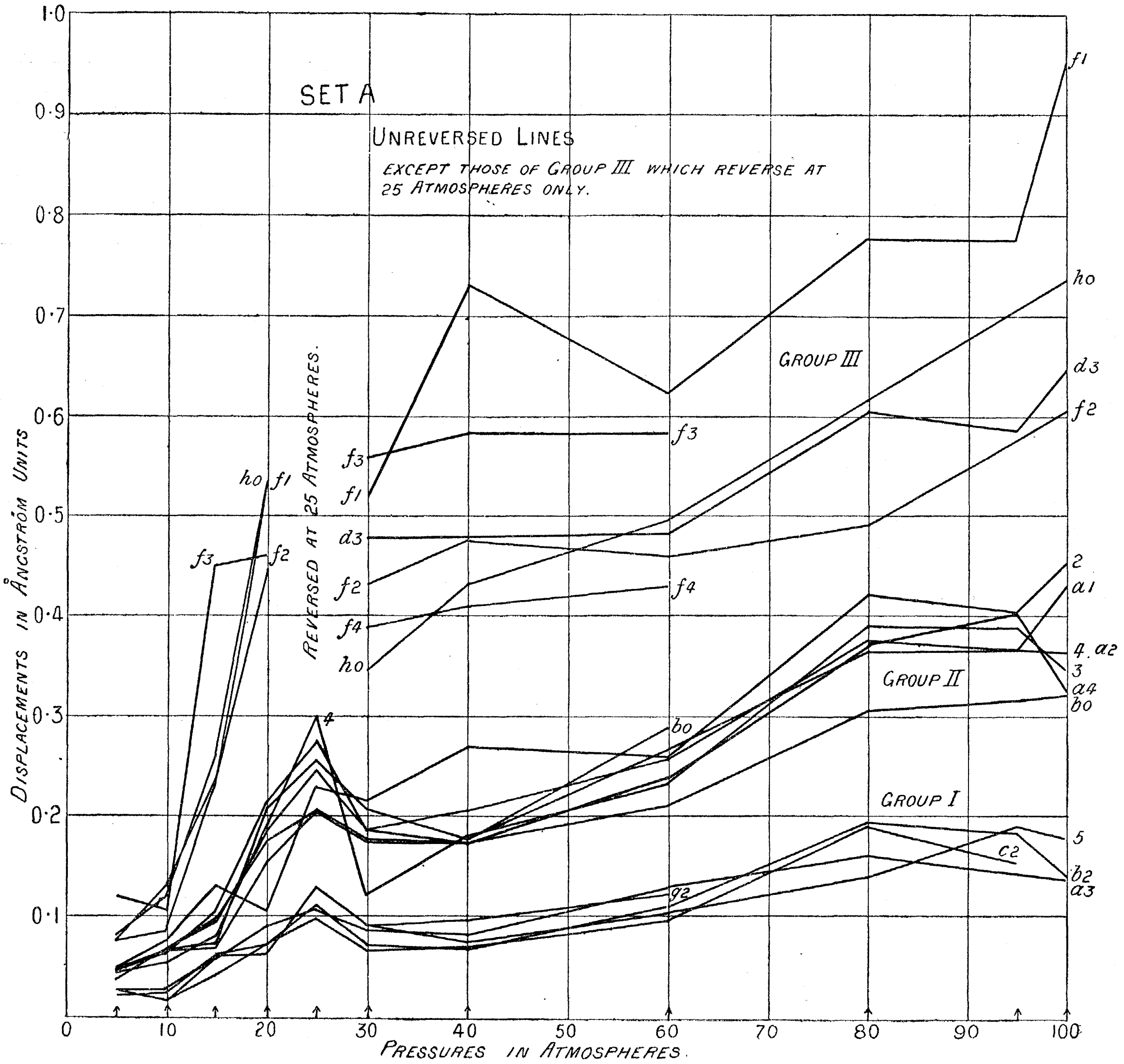


Diagram I.

No. 5 suggests a means for the classification of the lines: for example, the lines $f1$, $f2$, $h0$ always exhibit a much greater shift than do lines 2, 3, $a1$, whose displacements are themselves greater than those of the lines 5, 6, $a0$, &c. Three groups can in this way be definitely determined by the different values of the shifts of their several members.

In Group I. the lines are least shifted, and the wide range in the values of the shifts suggests that this group may be capable of resolution into simpler groups. The measurements of these lines were carefully repeated, but their diffuseness under pressure prevented great accuracy in the true setting of the lines, and all that could be definitely ascertained is that in both sets of photographs a few lines, *b*1, *c*1, *d*1, are less shifted than some others, for example the lines *c*4, *g*2, *h*3, *h*4, *j*1, *j*2. See Diagrams VII. and VIII., pp. 150 and 151, in which are plotted curves for the lines which reverse for a portion of the range of pressure.

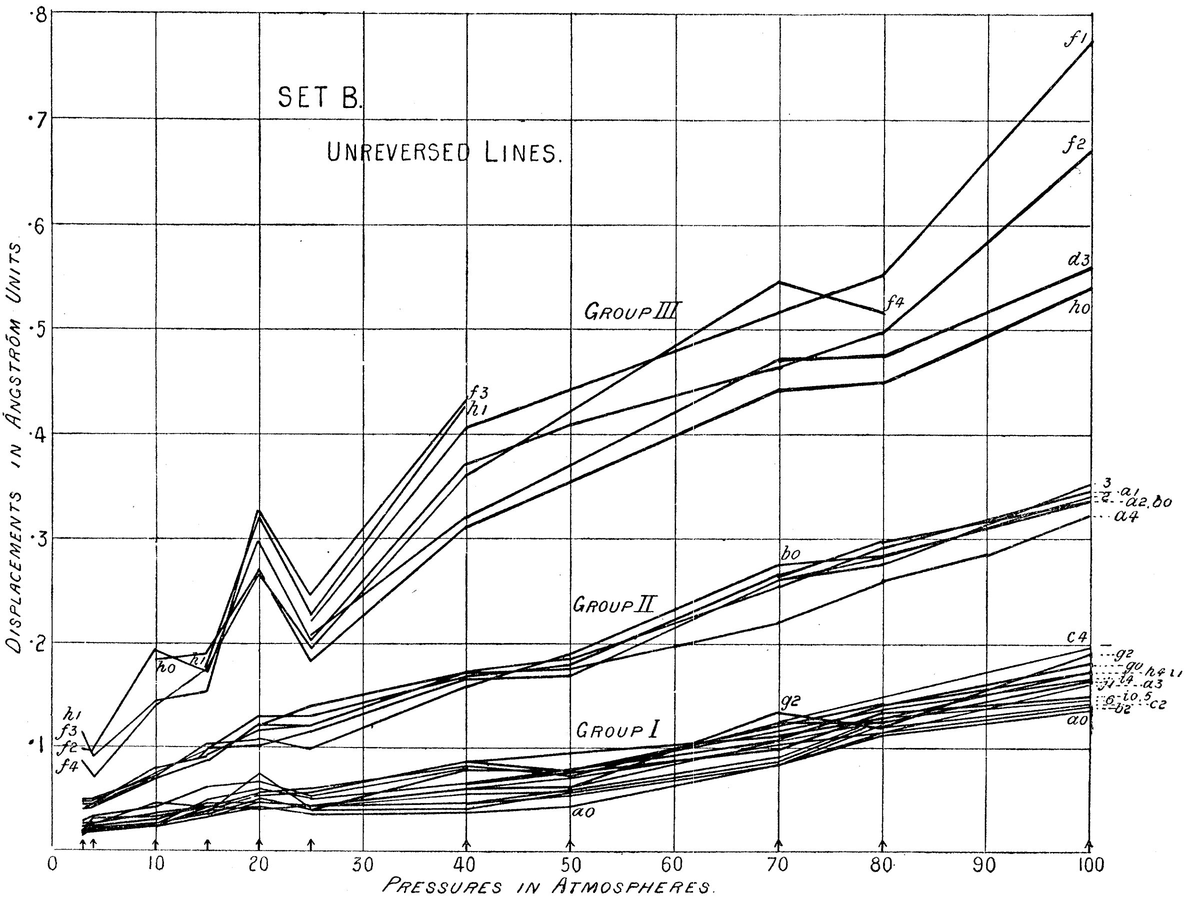


Diagram II.

The employment of poles not consisting entirely of iron, but of an alloy containing iron, or of an iron wire in a cored carbon, might facilitate the subdivision of this group, since it would decrease the widths of the lines and occasion greater accuracy in the measurements; still it is not yet clear that the presence of another element is without effect upon the displacement of the lines. This is at present under investigation; in the meantime it was considered advisable to avoid the use of an alloy.

The reversed lines of Group I. are plotted separately in Diagrams III. and IV.

Group II. contains fewer members and is more compact, all the lines showing remarkable agreement with one another. Diagrams I. and II. agree in assigning a low value to the shift of this line.

Line 4 also belongs to this group, but the presence of a faint line very close to it vitiated its measurements, which therefore have not been included in the diagram.

Group III. consists of lines which are invariably broad and diffuse under pressure, rendering their measurement a matter of great difficulty. As in the case of Group I., it is possible that two groups are united in Group III., but here again sub-division is

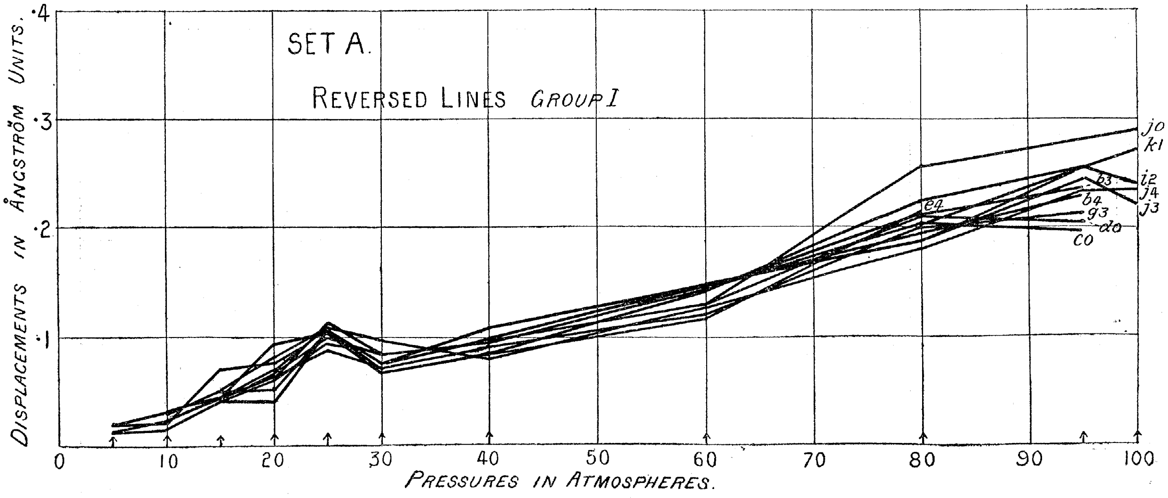


Diagram III.

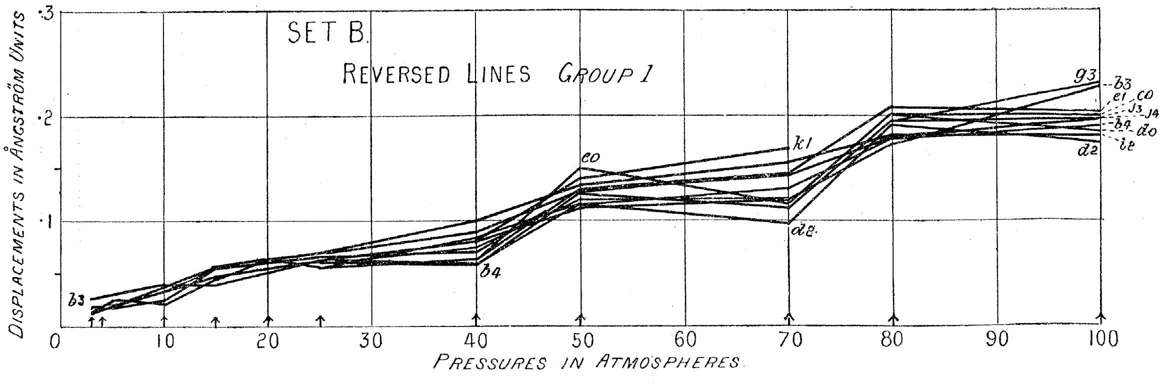


Diagram IV.

not at present feasible, though there is some indication that the lowest members—the two lines $d3$ and $h0$—are to be treated apart from those exhibiting the greatest shift—$f1$, $f2$, $f3$, Diagram II. The difficulty of determining the true position of these lines is accentuated by the shape of their intensity curves, which under pressure are nearly flat-topped.

Group IV.—The existence of a fourth group is suggested by the displacements of the lines $g6$, $g7$, but it is possible that their abnormal displacements are only apparent. (See p. 157.)

Tables III. and IV., Diagrams V. and VI.

The mean values of the displacements have been found for each group at each pressure, and the results for Set A are given in Table III., and those for Set B in Table IV.

For Groups I. and III. the reversed have been separated from the unreversed lines.

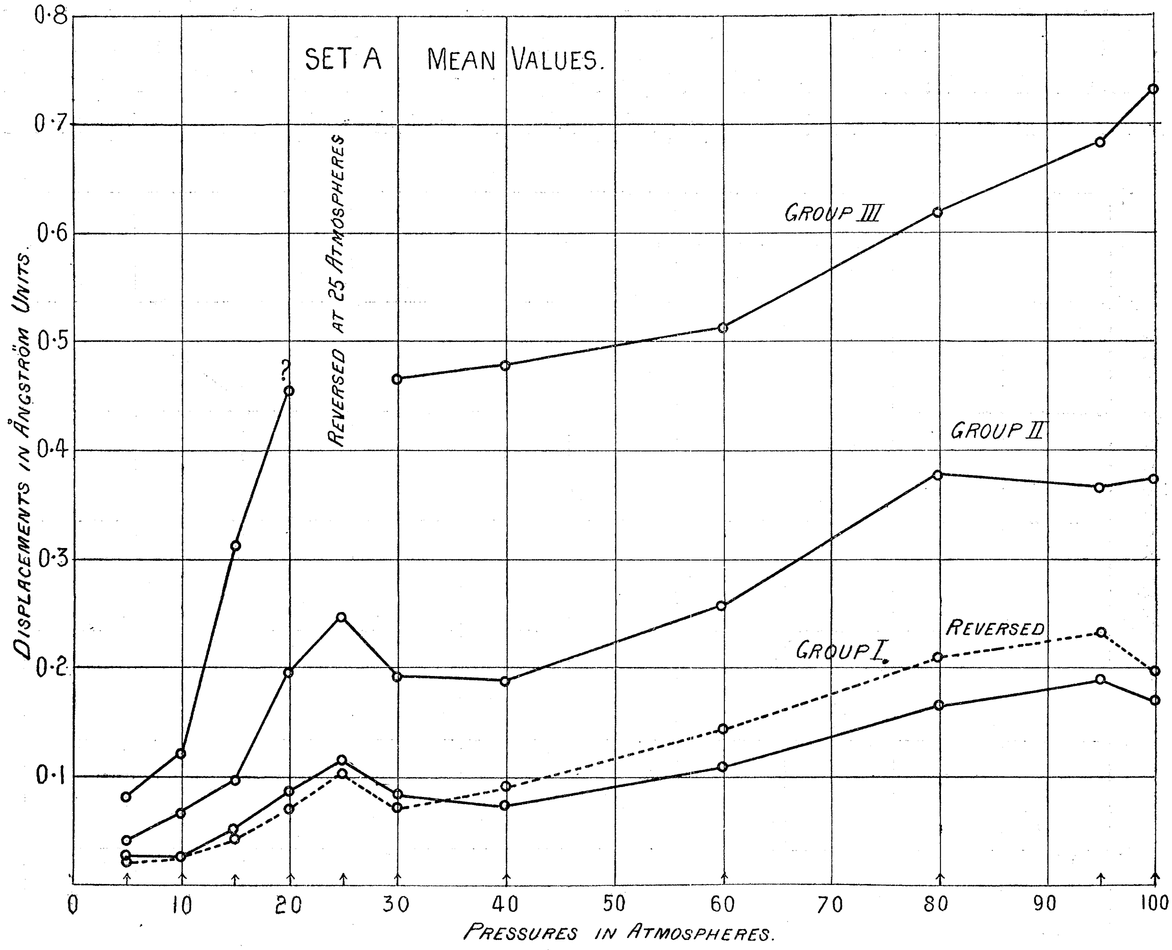


Diagram V.

Diagrams V. and VI. have been plotted from the Tables III. and IV. respectively, and refer both to reversed and unreversed lines. They emphasize the difference in magnitude of the displacements of the three groups, and exhibit graphically their rates of increase with pressure.

The increase of wave-length corresponding to a difference in pressure of 1 atmosphere, calculated on the assumption of a linear relation, is given below ;—

	Thousandths of an Ångström unit.		Ratios.	
	Set A.	Set B.	Set A.	Set B.
Group I., unreversed . . .	1·9	1·5	1·0	1·0
Group II.	4·0	3·3	2·1	2·2
Group III., unreversed . . .	7·8	6·8	4·1	4·5

In the last two columns are given the ratios of the displacements of Groups II. and III. (unreversed lines) to that of Group I. (unreversed lines). The ratios are not very different from 1 : 2 : 4 for both sets, which, however, are not in this respect in accurate agreement, but this may perhaps be accounted for by some fogging of the plates of Set A, which renders the intensity curves rather too flat-topped and explains a tendency for the settings on the lines to be in them rather nearer the red end of the spectrum than in the photographs of Set B, in which the background is clear. On the side of the intensity curves on which the slope is gradual, the additional general exposure makes the percentage change in intensity less than it is

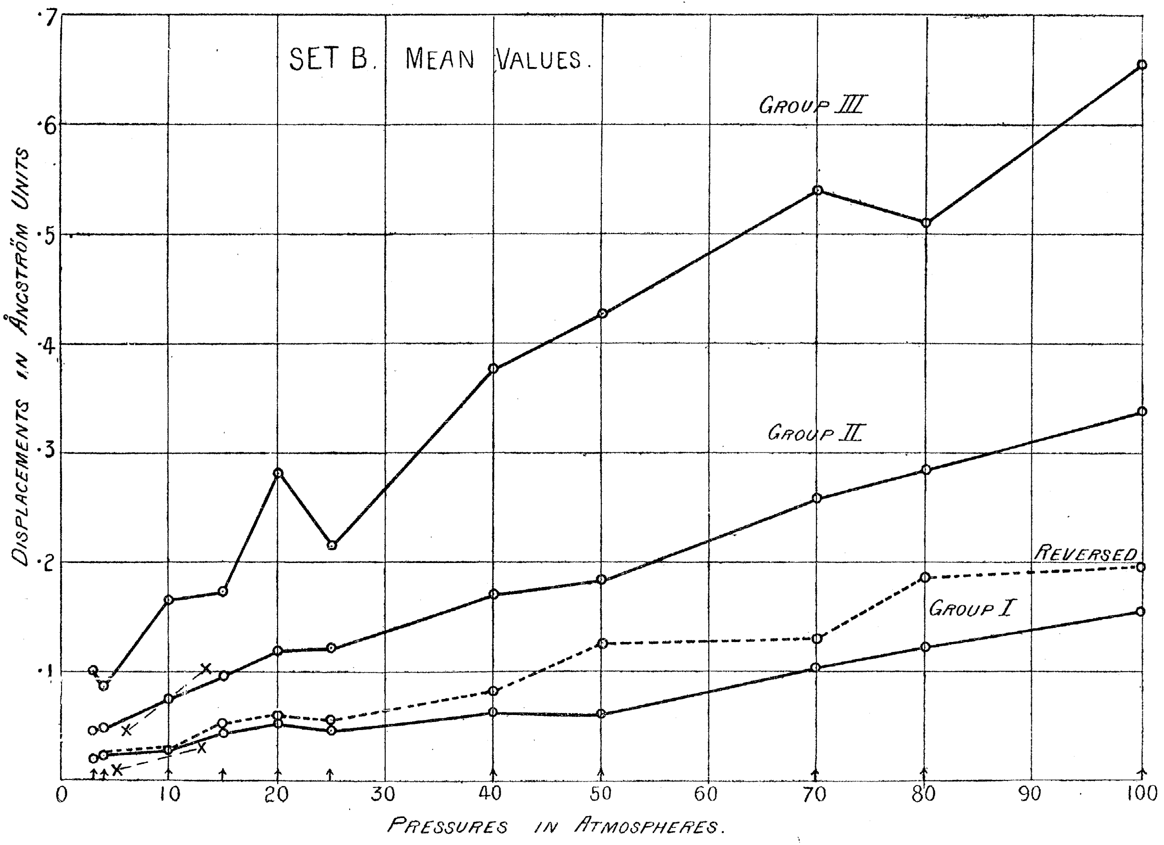
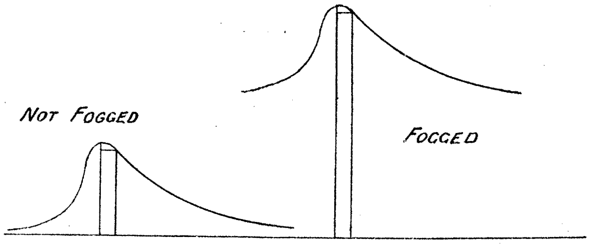


Diagram VI.

on the steeper side and less easily distinguishable by the eye. (See accompanying small diagram.)



The magnitude of this phenomenon is of an order which only interferes materially with the measurements of the lines of Group I.

Though roughly divisible into three groups, it is by no means certain that the shifts of all members are the same; indeed, the converse is indicated by the displacement curves (Diagram II.), in which there is a tendency for the lines to maintain the same relative displacements throughout the range. The mean values of the shifts agree, however, to an extent which cannot be disregarded, in assigning to the ratios of the three groups the values 1 : 2 : 4, which HUMPHREYS states holds good for the spectra of other elements.

13. *The Relation between the Pressure and the Displacement.*

In August, 1906, the measurement of Set A was completed, but as the displacement curves then showed a departure from a linear relation between the displacement and the pressure at 15, 20, and 25 atmospheres (where the values were roughly double those required by the readings at other pressures for a linear connection to hold good, Diagrams I., III., V.), it was deemed advisable to re-measure the plates taken at those pressures. The second measurements agreed well with those originally obtained, but it was then found possible to measure a few of the strongest lines on another plate, D18, taken at 25 atmospheres, which had previously been rejected as being too under-exposed. The fourteen readings obtained from it indicated that the linear relation would be satisfied at that pressure if they were substituted for the readings given by photograph D19.

On both the photographs at 25 atmospheres the comparison spectrum was in the central strip, and as the precautions that had been taken (p. 129) seemed to preclude the possibility of an undiscovered fictitious shift, it was decided to investigate the phenomenon carefully, and to repeat the whole series of photographs.

The photographs of the second set, B, give results more consistent with a linear connection between the pressure and the displacement (Diagrams II., IV., VI.), except in the case of Group III., where the displacements at 20 atmospheres are again too high, though the readings given by Groups I. and II. agree well with those obtained at higher pressures in making the function a linear one.

At 5 atmospheres most of the lines of Groups I., Set A, as well as most of the lines of Set B, at 3 and 4 atmospheres, show too great a value for the linear relation to hold, and in this region the curves are not accurately directed to the origin; but too much stress must not be placed upon the measurements at these pressures, because the percentage error in the measurement of a shift is greater at low than at high pressures, since in the former the shift of the line is but a fraction of its own width. At higher pressures the percentage error is less, because the broadening of the lines does not increase as rapidly as their displacement.

The existence of the linear relation described by HUMPHREYS between the displacement and the wave-length is not confirmed by the present investigation. The discrepancies in the displacement of the lines of Groups I. and III. are not to be accounted for on this hypothesis, since the sequence of the lines on the diagram is not the same as their sequence on the photographs.

The conclusion arrived at from the displacement curves is that the relation between the pressure and the displacement is in general a linear one, but that it may be affected by a disturbing cause in the region 15 to 25 atmospheres.

14. *Phenomena relating to the Departure from a Linear Relation between the Pressure and Displacement.*

The photograph showing the most marked departure from the linear relation is D 19, taken at 25 atmospheres pressure, and its measurement by different observers is given in Table V., which also contains the readings obtained from three other plates, D18, D24, D25, taken at the same pressure. The last three agree well, and their mean values have been placed in the last columns of the table, where they may be compared with the mean values for Plate D19, given in the preceding column.

The table shows that the difference between the two plates is not to be explained by errors of measurement, and the fact that the discrepancy is different for different lines would in itself indicate that there had been no accidental disturbance of the camera, but we have additional evidence of this, because the two exposures of the comparison spectrum, which were taken before and after the pressure spectrum, are exactly superposed. An irregularity in the magnitude of the displacements might be introduced by the unlikely, but still possible, contingency of an alteration in the temperature, and therefore of the dispersive power, of the grating, during the exposure of the pressure spectrum, and a return to its original value for the second half of the divided exposure, but this irregularity would be progressive and should not displace the lines of one group more than those of another group when the members of the two are interspersed. There is strong evidence in favour of this phenomenon being a genuine one.

In the table the lines are arranged according to their groups, and the ratios of the shifts on Plate D19 to those on Plates D18, D24, and D25 for the different groups are as follows :—

TABLE V.

Plate . .	D19.		D18.	D25.		D24.		Mean values.		
								D19.	D18. D24. D25.	
Line.	Displacements in thousandths of an Ångström unit.									
		M.			M.		M.			
*e*3	164	203	—	90	93	87	—	183	90	Group III., reversed.
							Ratio	2·0	1	
*f*1	**211**	—	—	215	231	—	—	**211**	223	Group III., reversed and unreversed.
*f*2	**190**	—	—	185	220	—	—	**190**	202	
*f*3	**194**	—	—	237	—	—	—	**194**	237	
							Totals . .	**595**	662	
							Ratio	**0·9**	1	
3	267	280	159	121	142	157	155	274	146	Group II.
*a*1	271	237	142	103	129	—	—	254	125	
*a*2	263	226	—	86	129	103	142	246	116	
*a*4	—	204	—	95	112	101	116	204	103	
*b*0	233	181	—	91	99	97	—	207	95	
							Totals . .	1185	585	
							Ratio	2·0	1	
*b*3	**103**	**103**	**69**	**43**	**47**	—	—	**103**	**53**	Group I., reversed.
*b*4	**99**	**121**	**60**	**60**	**60**	—	—	**110**	**60**	
*d*0	**99**	**108**	**60**	**56**	—	—	—	**103**	**58**	
*e*1	**99**	**99**	—	**56**	—	—	—	**99**	**56**	
*e*4	**86**	**108**	—	**43**	—	—	—	**97**	**43**	
*g*3	**90**	**112**	—	**60**	**47**	—	—	**101**	**53**	
*i*2	**103**	—	—	**60**	**65**	—	—	**103**	**62**	
*j*0	**90**	**95**	—	**52**	**65**	—	—	**92**	**58**	
							Totals . .	**808**	**443**	
							Ratio	1·8	1	

The readings given in the columns marked M were made by assistants.
Numbers in black figures signify reversal.

Group I.	Reversed lines	1·8
Group II.	Unreversed lines	2·0
Group III.	Unreversed lines	1·8 ?
Group III.	Reversed lines	2·0

The ratio for the unreversed lines of Group I. is difficult to determine, since the readings of the plates made by different observers are not very concordant; it does not fall below 2.

The value for Group III. unreversed is derived from the readings for $f1$, $f2$, $f3$, in which the value for D19 (reversed) is seen to be 0·9 times the mean value for the other three plates (unreversed). Section 16, p. 151, indicates that for this group the reversals are displaced roughly half as much as the emission lines, consequently, if unreversed lines in one case could be compared with unreversed lines in the other, the ratio of the displacements would be 1·8 to 1.

From Table VI. it may be seen that the photographs at 20 atmospheres exhibit the same phenomenon for Groups II. and III.; the values for the different lines are given in the Tables I. and II., and a comparison of them shows that the same kind of difference exists at this pressure as was found at 25 atmospheres.

At 15 atmospheres, also, discrepancies appear to exist between the values given by different plates for some of the lines, but at this pressure only the measurements for Group III. are discordant. There is a similar, but less marked, difference between the values for Group III. at 10 atmospheres; here it is the plate belonging to Set B that shows the higher values.

It has been suggested that the phenomenon may be due to different parts of the arc having been focussed upon the slit during the two exposures. Each photograph is, however, the integration of a number of short exposures due to the intermittent nature of the arc, and what is obtained on the photographic plate appears to be the average effect of the whole arc; nevertheless, the fact that reversals are found on all the plates shows that during each exposure we have been dealing with a hot central core surrounded by an absorbing envelope.

15. *The Displacement and the Tendency to Reverse.*

There is some evidence that the abnormal displacements measured in the region between 15 and 30 atmospheres are connected with the great tendency of the lines to reverse at these pressures. The Displacement Tables, I. and II., in which the lines which are reversed are distinguished from the rest, show that at 25 and 20 atmospheres, in Sets A and B respectively, the maximum number of reversals occurs, and the photographs also indicate that at these pressures the reversals are specially broad and strong. These are precisely the pressures at which the displacements in the two sets show their most marked departures from a linear relationship.

HALE and KENT* have remarked, for the spark discharge in compressed gases, that "when a bright line is beginning to show signs of reversal, or when bright and dark lines occur in pairs, the observed pressure shifts are irregular, probably because the overlapping lines prevent settings from being made on their true centres." The phenomenon is, however, in the present research presented by lines of Set A which are symmetrically reversed, and these should not be affected by overlapping. For unreversed lines belonging to Group III. (which reverses unsymmetrically) the existence of a faint absorption line on the edge of an emission line would imitate a very large displacement of the bright line, as HALE and KENT suggest, but these have been searched for carefully, and no displacements are included in this paper in which there is any suspicion of error due to such a disturbing cause. Plate 6, fig. 2, shows two lines, *f* 1 and *f* 2, belonging to Group III.; the former is reversed, but the latter presents no trace whatever of any absorption which might affect the accuracy of the readings. The evidence points to the phenomenon being due to pressure and not to errors of observation.

TABLE VI.

(The Displacements are in Thousandths of an Ångström Unit.)

Atmospheres.	Plates.	Number of reversals.	Mean values of displacements of Groups			Ratios of displacement, Group		
			I.	II.	III.	I.	II.	III.
25	$D19_a$	43	102	245	**203**	2·3	2	**1** = 2†
	$D18_a$, 21_b, 22_b	15	45	120	212	1	1	1
20	$D8_a$, 9_a, 16_a	43	54	194	490	1	1·7	1·8
	$D27_b$	24	52	116	280	1	1	1
15	$D19_a$	26	52	94	310	1·2	1	1·8
	$D24_b$, 25_b	18	43	95	171	1	1	1
10	$D31_b$	26	27	74	166	1·2	1·2	1·4
	$D4_a$, 7_a	19	23	63	118	1	1	1

† See next section, p. 151.

The evidence that favours a connection between the tendency to reverse and the abnormal displacements is comprised in Table VI., in which the displacements of the lines shown by a photograph are compared with the number of reversals on that photograph. In those cases in which two or more photographs show the same number of reversals at the same pressure, the mean values of the displacements have been taken. The table shows that, in all cases in which there is a discrepancy

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* HALE and KENT, 'Publications of the Yerkes Observatory,' Vol. III., Pt. II., 1907.

between the values for the displacement, the photograph giving the higher value contains more reversed lines.

The ratios of the displacements are also given, and the higher value will be seen to be in each case (except at 10 atmospheres, where the accuracy is probably not as great as in the other cases) roughly twice the lower value.

Another peculiarity is that at 10 and 15 atmospheres pressure only Group III. is affected, that both Group II. and Group III. are affected at 20 atmospheres, and that at 25 atmospheres all the groups may show abnormal displacements. Whatever may be the nature of the disturbing cause, Group III. appears to be most susceptible to it.

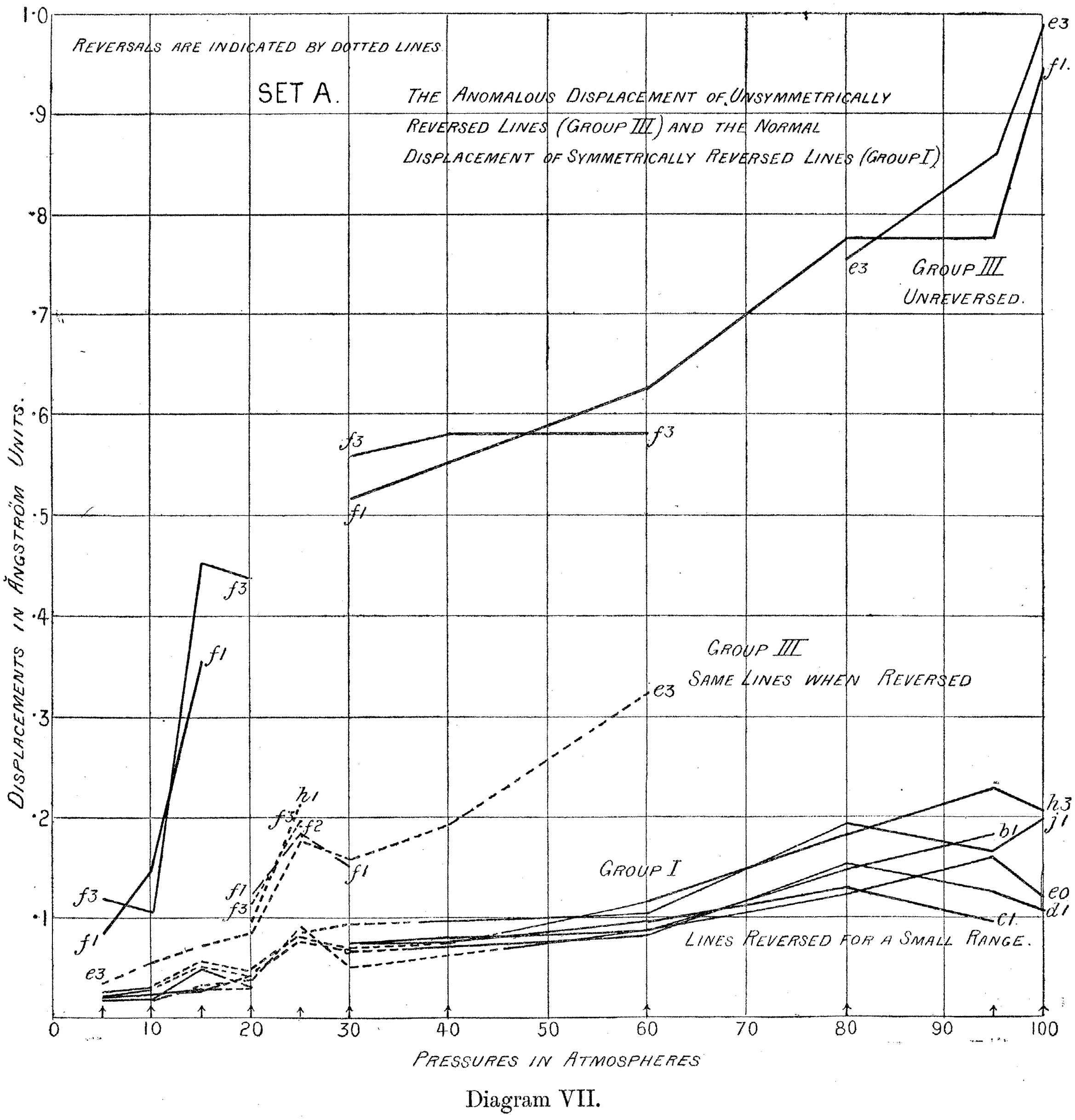

Diagram VII.

NOTE.—In this diagram the doubtful value for *f*1 at 40 atmospheres has been omitted,

16. *The Anomalous Displacement of Unsymmetrically Reversed Lines.*

Tables I. and II., pp. 136 and 137, show that several lines reverse for a small range of pressure only.

Diagram VII. illustrates the behaviour of lines of this type belonging to Set A, Groups I. and II., the dotted parts of the curve relating to the reversed line. It is apparent that for Group I. the atom absorbing the vibration follows the same course under pressure as the one producing the radiation. But this is not the case for the reversed lines of Group III., whose displacement curves may be compared with the displacement curves for unreversed lines belonging to this group, and also with their own displacement curves for that range of pressures during which reversal does not take place.

The remarkable fact is brought to light that the *lines of Group III. present two rates of increase of the displacement with pressure—one for the lines when unreversed, and the other, very much lower, for the line in its reversed state.*

Corroborative evidence of this phenomenon has been obtained from the second series of photographs, Set B, for which similar curves are shown in Diagram VIII.

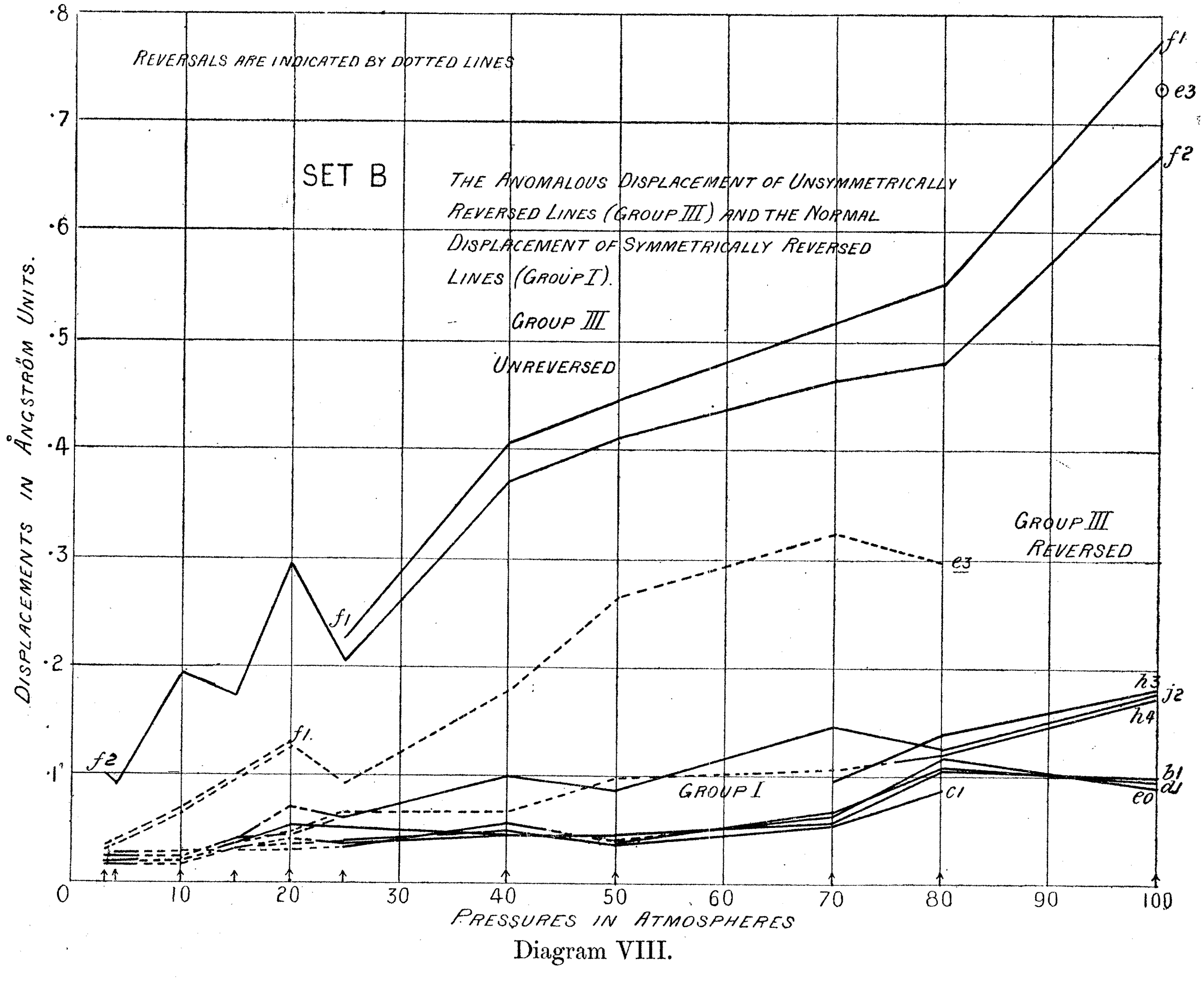

Diagram VIII.

These agree well with those obtained from Set A, and testify to the fact that the lines of Group III., when reversed, fall approximately in Group II.

The ratio of the displacements of the unreversed to those of the reversed lines of Group III. is for Set A 1·6, and for Set B 1·7, if the general directions of the curves be considered. From individual values at the pressures at which actual readings have been made, the ratio is very much higher, but the uncertain region, 15 to 30 atmospheres, has then an undue influence.

Diagram VIII. emphasizes the possibility of subdividing Group I.

17. *The Reversal of Lines under Pressure.*

It has already been pointed out (p. 133) that the immediate effect of pressure is to increase the number and intensity of the reversals, and that there is a pressure at which the reversals reach a maximum in these respects. The varying tendencies of the different lines towards reversal may be studied in the two tables of displacements, in which the number indicated by different type signifies that at the corresponding pressure the spectral line is reversed.

It will be seen that

Lines Originally Not Reversed either

(1) remain without reversal throughout the whole range of pressures investigated, *e.g.*, 3, 4, 5, *a*1, *a*3, *c*2, *c*3, &c. ; or

(2) suffer reversal for a certain range of pressure, and then, as the pressure is increased, return to their initial condition. For Set A the range is 15 to 25 atmospheres. For Set B the greatest tendency to reverse occurs at 20 atmospheres. Lines belonging to this class are : *b*1, *c*1, *d*1, &c. (Diagram VIII.).

Two lines appear to suffer reversal in the neighbourhood of 3 to 5 atmospheres in Set B, and then to return to their unreversed condition. These lines are remarkable also for their large displacements under pressure. They are *g*6, *g*7, and are discussed under the heading of "Lines Enhanced under Pressure," p. 156.

Lines Originally Reversed

Continue as reversed lines up to the highest pressure. These are almost invariably strong lines, and their reversals are broad, *c*0, *d*0, *d*2, &c. The width, however, decreases in the neighbourhood of 100 atmospheres, and two of these lines in Set A do not show reversal above 80 atmospheres.

For Set A the reversals become more numerous and stronger up to 25 atmospheres, but at higher pressures they decrease in number and intensity. For Set B the maximum occurs at 20 atmospheres, though at 10 atmospheres they are also numerous, but not so broad. It may be that the paucity of reversals at the highest pressures is due entirely to the short duration of the arc in those regions, but though this undoubtedly causes a decrease in the amount of metallic vapour surrounding the arc, there must be a large number of atoms capable of absorbing certain vibrations even at 100 atmospheres, since at that pressure broad reversals are still apparent for the lines *c*0, *d*0, *d*2, &c.

It is interesting to note that it is at the pressure at which the maximum number of reversals occurs (20 to 25 atmospheres) that the change occurs in the amount of condensation upon the window of the pressure cylinder, mentioned on p. 131. This suggests that the size of the chamber possibly has some influence in determining the pressure at which the maximum number of reversals is found.

The reversals are of two types, (α) symmetrical, and (β) unsymmetrical. Examples of (α) are *b*3, *b*4, *c*0, *d*0, *d*2, Plate 4, and *e*1, *e*4, Plate 8. Example of (β) is *e*3, Plate 8.

In the measurement of all reversed lines the centre of the reversed portion has always been taken as its true position. For symmetrical lines this is probably strictly correct, and for the accuracy of the measurements it is fortunate that only lines of this type are found with broad reversals. It may not be accurate for type β, but any error introduced is not large, because the total width of a reversal is only a small percentage of the displacement associated with lines of this type.

It not infrequently happens that the same line occurs on two different plates taken at the same pressure with different amounts of reversal (see page 149). ANDERSON* has discussed the possible effect of the duration of the exposure on the widths of reversed lines, but the plates taken during the progress of this research were all sufficiently exposed for this cause to be negligible, and the determining factors are the amount and the temperature of the vapour in front of the arc, which are liable to variations on account of the fluctuations in the current which accrue from the continual striking of the arc, and from its comparatively short duration.

On this account the photographs show an integration of the effects of the temporary distributions of the vapour round the arc, and in view of this fact the labour of measuring the widths of the reversals has not been undertaken, especially as the widths are different on different plates at the same pressure, but inspection of the plates brings forward the fact that in general *those lines which reverse similarly are also displaced by equal amounts under pressure.* For example, the lines *b*4, *d*0, *d*2, *e*1 are reversed symmetrically and have approximately the same widths of reversal, and their wings are of the same nature; it will be seen, too, that their displacement curves also agree. Lines *b*1, *c*1, *d*1, *e*0 also reverse similarly and equally, and they are displaced to the same extent (Diagram VIII., p. 151). The converse is not necessarily true.

The reversals show no tendency to undergo change of type as the pressure is increased; those lines that at low pressures are unsymmetrically reversed are, if reversed at all at higher pressures, still of type β. Those of type α preserve their

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* ANDERSON, 'Astrophysical Journal,' XXIV., 238, 1906.

approximate symmetry. The photographs also show that *in all cases of unsymmetrical reversal occurring between* 4000 *and* 4500 *Å.U., the absorbed part of the line is on the violet side of the emission line.*

(This phenomenon occurring in the arc has been observed in spark discharges in liquids and gases under pressure by HALE and KENT,* and by ANDERSON.† WILSING,‡ LOCKYER,§ and HALE and KENT* have discussed its bearing upon the spectra of New Type Stars.)

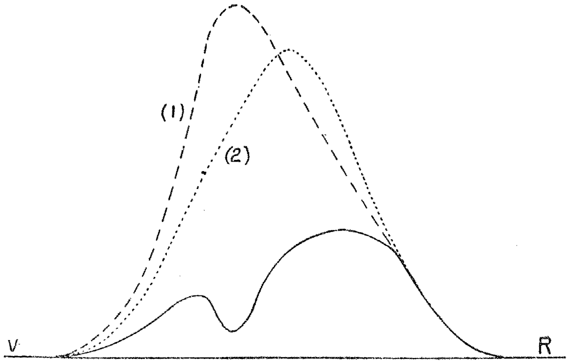

Fig. 11.

For unsymmetrically reversed lines under pressure the intensity curve is of the nature shown by the full line, fig. 11, which may be due either to the emission line represented by the dotted curve (1) (in which the maximum ordinate coincides with the centre of the absorption line) or that represented by the dotted curve (2) (in which it is on the red side of it), together with corresponding amounts of absorption.

The present experiments afford a means for deciding upon the correct emission line, because it is not unusual to find that some lines are reversed on one photograph at a definite pressure, but not on another taken at the same pressure :—

e.g., at	15	atmospheres	line	*f*1	is reversed on	plate	D25,	but not on	D19,
,,	20	,,	,,	*f*2	,,	,,	D9, D16,	,, ,,	D27,
,,	30	,,	,,	*f*1	,,	,,	D9,	,, ,,	D26,
,,	80	,,	,,	*e*3	,,	,,	D32,	,, ,,	D15.

The position of the most intense portion of the bright line has been determined from one plate, and in all cases its displacement towards the red has been found to be greater than that of the absorption line on the other plate, Table VII. Hence the maximum of the intensity curve for the emitting atom falls in such cases of unsymmetrical reversal on the red side of the absorption line on the photographic plate, *i.e.*, the curve (2) more nearly represents the true emission line, and hence *in an iron arc, for the*

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* HALE and KENT, 'Astrophysical Journal,' XVII., 154, 1903.

† ANDERSON, 'Astrophysical Journal,' XXIV., 238, 1906.

‡ WILSING, 'Astrophysical Journal,' X., 113, 1899.

§ LOCKYER, 'Astrophysical Journal,' XV., 190, 1902.

unsymmetrically reversed lines of Group III., it is not in general the most intense portion of the emitted light that is absorbed.

This result might have been deduced from the displacement curves given in Diagrams VII. and VIII., which show that when the members of Group III. reverse, their reversals are at that pressure less displaced towards the red than are the emission lines.

Since the values of the displacements of *e*3 at 80 and 100 atmospheres correspond to those for the other lines of Group III., it is legitimate to assume that if its emission could be examined without the superposed absorption, its displacement curve would be identical with those of *f*1, *f*2, &c. This being the case, it is clear that its absorption line is on the violet side of the most intense part of the emission line, and it again follows that for the lines of Group III. the most intense vibration emitted is not necessarily that which is most strongly absorbed by the vapour surrounding the arc.

Only one line of Group II. shows reversal, and that is line 2, which reverses unsymmetrically at 10, 20, and at 25 atmospheres; its displacements at these pressures seem consistent with the absorption of its most intense emission, differing in this respect from the lines of Group III.

TABLE VII.

Pressure in atmospheres.	Line.	Wave-length.	Displacements in thousandths of an Ångström unit.	
			Reversed.	Not reversed.
15	*f*1	4236·09	**95**	355
20	*f*2	4233·76	**108**	296
30	*f*1	4236·09	**155**	344
80	*e*3	4250·64	**293**	754

From Table VII. the change in the frequency under pressure of the absorbing particles is less than one-half the change in the frequency of the primary radiation from the core of the arc, but as the measurements are taken from the region of anomalous displacements, and are from plates bearing different amounts of absorption, the readings are not strictly comparable; the better method is to derive the values from Diagrams VII. and VIII., when the displacements of the reversal approximate closely to one-half that of the emission line.

The suggestion that a possible cause of the anomalous displacements of the absorption lines is some interaction in the outer envelopes of the arc between the iron and the surrounding atmosphere of air is capable of experimental investigation by a study of the effect of different gases upon the spectrum, and this is on the programme for future work; but the effect of any such interaction would be the loading of the absorbing metallic systems, and the consequent increase in the wave-length of the light they absorb, whereas the opposite effect has been observed by ANDERSON,[*] who measured the displacements of some spark lines under pressure in atmospheres of carbon dioxide and hydrogen, and obtained larger values when the denser gas was used, but it is possible that the effect may be less obvious in the arc than in the spark, since in the former the surrounding gas will not presumably influence so strongly the nature of the discharge.

Differences in physical properties (density, temperature, specific inductive capacity, &c.) between the absorbing layer and the core of the arc, as well as the possible influence of abnormal dispersive properties of the surrounding vapours, have also been suggested as causes of this phenomenon. There is also considerable evidence in favour of the existence in the gaseous envelopes of a modified system derived from the iron atom.

18. *The Order of Reversal.*

In their study of the spectrum obtained from a spark discharge in liquids and gases under pressure, HALE and KENT[†] noticed that the reversals appeared first at the violet end of the region observed, 3550 to 4500 Å.U., becoming more intense and gradually extending towards the red end as the pressure about the spark was increased.

In the case of the arc spectrum of iron within the range of wave-lengths 4000 to 4500 Å.U., this phenomenon does not make its appearance between pressures of 1 and 101 atmospheres (absolute), the intensities of the reversals at the more refrangible end of the plate bearing very nearly the same ratio to the intensities of the reversals at the red end for all pressures.

A recent research[‡] affords a possible explanation of the difference between the results obtained by HALE and the present writer on the hypothesis that different temperature and radiation gradients exist in the arc and spark. These are shown to be determining factors in the reversals of lines when the same amounts of vapour are present—the steep gradient of the electric spark being more favourable than that of the arc for the production of this phenomenon.

19. *Lines Enhanced and Weakened under Pressure.*

The majority of lines continue throughout the range of pressure with nearly the same relative intensities that they possess at 1 atmosphere, but a few undergo a change and are enhanced as the pressure is increased, while others appear as weakened lines under high pressures.

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[*] ANDERSON, 'Astrophysical Journal,' XXIV., 221, 1906.

[†] HALE and KENT, 'Astrophysical Journal,' XVII., 154, 1903; also HALE, 'Astrophysical Journal,' XV., 227.

[‡] A. SCHUSTER, "Radiation through a Foggy Atmosphere," 'Astrophysical Journal,' XXI., 1, 1905

Attention was drawn to this phenomenon by what was at first thought to be the displacement of a line (*a*2) towards the violet. Under pressure this line appeared to have a reversal on the violet side of the comparison line, but the phenomenon has now been traced to the enhancing of a very faint line occurring close to *a*2 on its more refrangible side, which gave to the space between them the appearance of a reversal. It was also found that the only other apparent displacement of a line (*b*0) to the violet was due to a similar cause.

(The measurements given for two other lines are possibly vitiated by the appearance in close proximity to them, in this case on their red side, of two enhanced lines. The displacements tabulated for *g*6 and *g*7 are larger than those for any other lines at the same pressures [Table II.], and the range of pressures at which they are reversed, 3–5 atmospheres, does not coincide with the region of reversal for other lines. Their behaviour may possibly be explained by the enhancing of two faint lines on their red side. This consideration has prevented them from being definitely assigned to a Group IV. possessing a displacement about four times as large as that of Group II.)

An examination of Photograph 1, Plate 5, led to the discovery of several lines that are enhanced under pressure. The spectra were photographed under 1, +25, +50, +75, +100 atmospheres, and although the spectrum at 1 atmosphere is not exposed as much as the others, the relative intensities of the lines in it can be readily compared with their relative intensities in the other spectra. Pairs of lines to be compared are marked on the plate, and the member with the × will be seen to have increased in intensity under pressure. A list of such lines occurring in the region 4000–4500 Å.U. is given in Table VIII.

TABLE VIII.

Letter.	Wave-length.	
	LINES ENHANCED UNDER PRESSURE.	
a1α*	4454·50*	
a3	4443·30	* Marked × on Plate 5, fig. 1.
b0	4430·74	
b2*	4422·67*	All enhanced lines are marked E on the same Plate.
c2*	4369·89*	
g0	4219·47	
	LINES WEAKENED UNDER PRESSURE.	
	4484·36†	† The weakening effect may be to some extent due to widening of the lines.
	4469·53†	
e2	4282·58	Weakened lines are marked W on Plate 5, fig. 1, and on Plate 8.
f0	4250·28	
	4247·60	
	4238·95‡	‡ Marked ○ on Plate 5, fig. 1.

NOTE.—The relative intensities also seem to vary in the different photographs at normal atmospheric pressure, but different amounts of exposure possibly account for this.

Above 25 atmospheres there is little change in the relative intensities, though the increasing width of some lines and their diffuseness make them appear weaker.

The line 4238·95 that has diminished in intensity under pressure is marked by an ○ on Plate 5, fig. 1, and it will be seen only in the spectrum under 1 atmosphere—at 25 atmospheres it seems to have been obliterated. The spectrum taken at a pressure of 1 atmosphere is under-exposed, so the difference in relative intensity is greater than is apparent on the plate. The other lines that are weakened are marked W on Plate 5, fig. 1, and on Plate 8. The two lines *f*0 and *e*2 do not appear to contribute anything to the wings of the symmetrically reversed lines *e*1 and *e*4.

A third class of phenomena relating to changes in intensity is exhibited by the line which occurs in the spectrum under 20 atmospheres, Set A, as a strongly reversed line, whose corresponding emission line in the comparison spectrum cannot with any certainty be ascertained* (see Plate 6, fig. 3).

The wave-lengths assigned to the enhanced lines are taken from Kayser and Runge's tables. If any of them are due to impurities, the same impurity must have existed in the poles used by both Kayser and Runge and the writer.†

20. *Series of Lines in the Iron Spectrum.*

From the displacement curves we have overwhelming evidence of the existence in the iron spectrum of lines of different types, see Section 12, p. 139. The photograph reproduced in Plate 5, fig. 2, in which the lines belonging to Groups I., II., and III. are linked together, shows that the lines possessing the same shift have in general the same appearance, and that their broadening and manner of reversal are similar.

The lines of Group I., which are characterised by their strong reversals, are linked by a dotted line and are marked Group I.R. The unreversed lines of Group I. are marked Group I.U.

The photograph only includes a portion of the region of the spectrum examined.

Table IX.

	Group I.	Group II.	Group III.
Displacement per atmosphere in Ångström units . . Set A.	0·0019	0·0040	0·0078
„ B.	0·0015	0·0033	0·0068
Ratio of shift . . . . . „ A.	1	2·1	4·1
„ B.	1	2·2	4·5
Broadening under pressure	Rather broadened	Much broadened	Very broad and diffuse.
Type of broadening.	Nearly symmetrical	Unsymmetrical	Very unsymmetrical, almost a band.
Nature of reversals	Symmetrical	Unsymmetrical?	Very unsymmetrical.

[* *Note added December* 1907.—Mr. H. F. Newall suggests that this may be due to the calcium line 4227 produced by an impurity which has found its way into the outer layers of the arc. This explanation must, I think, be accepted.]

† See note p. 138.

Table IX. shows the characteristics of the different groups, and indicates that they may be the Principal, First and Second Subordinate Series into which the spectra ot other elements are generally divisible.

HUMPHREYS found that the ratios of the shifts for these series are for other elements 1 : 2 : 4, and that in the iron spectrum two groups exist with shifts in the ratio of 1 : 3.

As already suggested, the groups seem capable of further subdivision; for instance, *c*1 and *d*1 present differences in shift and in reversal from the majority of lines in Group I., Diagram VIII., p. 151. There are also very obvious triplets in the spectrum, as well as what are at present thought to be doublets. A detailed account of these is reserved for future publication, when a larger range of the spectrum has been investigated.*

The photograph, Plate 5, fig. 2, shows the remarkable "gregarious" tendency of the lines of Groups II. and III. The members of the former all occur at the less refrangible end of the region investigated, and those of the latter within a small range of wave-lengths near the centre.

HUMPHREYS states that the lines belonging to any group behave similarly when the source is placed in a magnetic field, but the Zeeman effect upon the lines investigated in the present research is not to hand.

The two groups into which HUMPHREYS originally divided the lines of the iron spectrum are shown by the broken lines XX in Diagram VI. As already stated, HUMPHREYS† has recently obtained a photograph at 37 atmospheres pressure; though the displacements given by it are of the same order as those obtained in the present research, the agreement between the readings is not as good as one would wish to find.

The evidence for the existence of a Group IV. has already been given (see Table II., p. 138, lines *g*6 and *g*7, also p. 157). The displacements are roughly eight times those of lines belonging to Group I.

In the present research the two sets of photographs agree in assigning the same lines to the same groups. A list of the lines belonging to each group is given in Table X., p. 160.

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* Attention may be drawn to the three lines *d*0, *d*2, *e*1 (λ for *d*2 = 4308), which appear to form a triplet in which the frequency relation between its members is approximately the same as that for the triplets *b*3, *b*4, *c*0 at 4404, and for *j*3, *j*4, *k*1 at 4063, though the frequency differences are not the same.

[† *Note added December*, 1907.—Subsequent to the presentation of this paper, a paper by HUMPHREYS has appeared in the 'Astrophysical Journal,' XXVI., 18, 1907, describing experiments in which photographs of arc spectra were obtained under pressures of 42, 69, and 101 atmospheres.]

TABLE X.

Line.	Wave-length.	Line.	Wave-length.
GROUP I.—UNREVERSED.			
5	4476·20	g0	4219·47*
6	4466·70*	g2	4204·07
a0	4461·75*	g4	4199·19*†
a1α	4454·50	h2α	4184·99
a3	4443·30	h3	4181·85*†
b1	4427·44*†	h4	4175·71*
b2	4422·67	i0	4156·88*
c1	4376·04*†	i1	4154·57*
c2	4369·89	i3	4143·50*†
c3	4352·86	i4	4134·77*
c4	4337·14*	j1	4127·68*
d1	4315·21*†	j2	4118·62*†
d4	4294·26*†	k0	4062·51*
e0	4282·58*†	k2	4033·16*
GROUP I.—REVERSED.			
b3	4415·27	g3	4202·15
b4	4404·88	i2	4143·96
c0	4383·70	j0	4132·15
d0	4325·92	j3	4071·79
d2	4307·96	j4	4063·63
e1	4271·93	k1	4045·90
e4	4250·93	—	—
GROUP II.			
2	4528·78*†	a2	4447·85
3	4494·67	a4	4442·46
4	4482·35	b0	4430·74
a1	4459·24	—	—
GROUP III.—UNREVERSED.			
d3	4299·42*†	f4	4222·32
f0	4250·28*	g5	4198·42*
f1	4236·09*†	h0	4191·57
f2	4233·76*	h1	4187·92*
f3	4227·60*	h2	4187·17*
GROUP III.—REVERSED.			
e3	4260·64	—	—
GROUP IV.‡ ?			
g6	4196·31†	g7	4195·46†

* Signifies that under pressure the line is reversed in Set A.

† ” ” ” ” ” Set B.

‡ *Cf.* p. 159.

21. *Summary of Results.*

The spectrum of the iron arc in air has been examined in the region $\lambda = 4000$ to $\lambda = 4500$, under pressures varying from 1 to 101 atmospheres (absolute).

I. *Broadening*:—

1. With increase of pressure all lines become broader.

2. The amount of broadening is different for different lines, some almost becoming bands at high pressures and others remaining comparatively sharp.

3. The broadening may be symmetrical or unsymmetrical; in the latter case the broadening is greater on the red side.

II. *Displacement*:—

1. Under pressure the most intense portion of every line is displaced from the position it occupies at a pressure of 1 atmosphere.

2. Reversed as well as bright lines are displaced.

3. With increase of pressure the displacement is towards the red side of the spectrum.

4. The displacement is real and is not due to unsymmetrical broadening.

5. The displacements are different for different lines.

6. The lines of the iron arc can be grouped into series according to the amounts of their displacements.

7. Three groups can in this way be distinguished from one another; the displacements of Groups I., II., III. bear to one another the approximate ratio 1 : 2 : 4. (The existence of a fourth group is suggested by the behaviour of two lines, but further evidence is needed upon this point. 1 : 2 : 4 : 8 would be the relations existing between the four groups.)

8. Though all the lines, with two exceptions, fall definitely into one or other of these groups, the lines belonging to any one group differ to an appreciable extent amongst themselves in the amounts of their displacements.

9. The relation between the pressure and the displacement is, in general, a linear one, but some photographs taken at 15, 20, and 25 atmospheres pressure give readings incompatible with this relation. Other photographs at 15 and 25 atmospheres present values which are compatible with it.

10. The abnormal readings are approximately twice those required by the displacements at other pressures for the displacement to be a continuous and linear function of the pressure.

11. On the photographs showing abnormal displacements, the reversals are more numerous and broader than they are on plates giving normal values, and there is some evidence in favour of a connection between the occurrence of abnormal displacements and the tendency of the lines to reverse.

III. *Reversal:—*

1. As the pressure is increased, reversals at first become more numerous and broader.

2. The tendency to reverse reaches a maximum in the neighbourhood of 20 to 25 atmospheres, and a further increase in pressure reduces their number and width.

3. Two types of reversal appear on the photographs, symmetrical and unsymmetrical.

4. Within the range of pressures investigated, the reversals show no tendency to change their type.

5. In the case of unsymmetrically reversed lines in the electric arc, the reversed portion does not in general correspond to the most intense part of the emission line, being usually on its more refrangible side.

6. The displacements of the reversed parts of the unsymmetrically reversed lines of Group III. are about one-half the displacements of the corresponding emission lines. Indeed, the reversed parts of the lines of Group III. fall approximately in Group II.

7. No relation between the order of reversal and the frequency of vibration, such as exists in the spark, has been observed in the iron arc for the ranges of wave-length and pressure examined.

IV. *Intensity:—*

1. The intensity of the light emitted by the iron arc is, under high pressures, much greater than at normal atmospheric pressure.

2. Changes in the relative intensity of the lines are produced by pressure. Lists of enhanced and weakened lines are given.

I express with pleasure my appreciation of their services to Mr. T. ROYDS, B.Sc., who assisted me in the preliminary operations, and in taking and measuring the first set of photographs, and to Messrs. BLEAKLEY, RILEY, ROSSI, and WEST, who assisted in the measurement of the plates and in the taking of the second set of photographs.

My indebtedness to Mr. PETAVEL, F.R.S., who designed the essential part of the pressure apparatus, has already been recorded.

The research was suggested to me by Professor SCHUSTER, F.R.S., and for placing the necessary apparatus at my disposal and for his advice and inspiring interest I am very grateful.

In conclusion, I cannot resist the opportunity of expressing my admiration of the work of HUMPHREYS and MOHLER, the pioneers in this subject, whose results are here, in the main, confirmed.

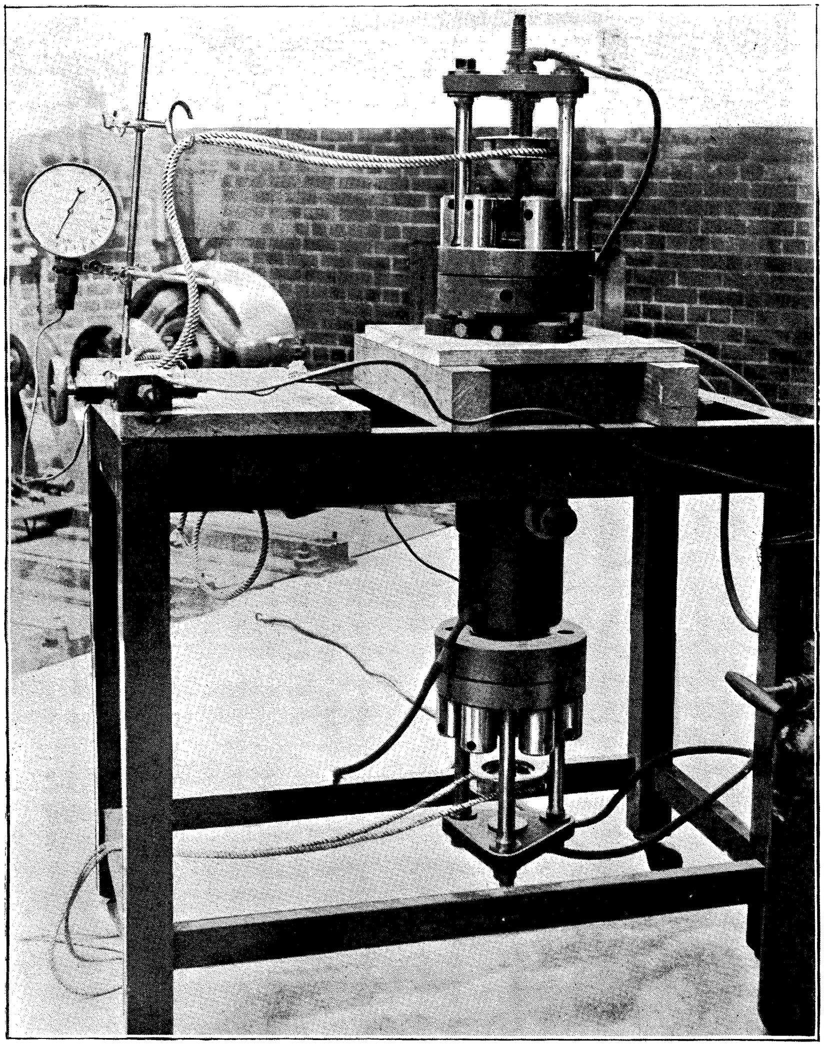


Fig. 1. Pressure cylinder and connections.

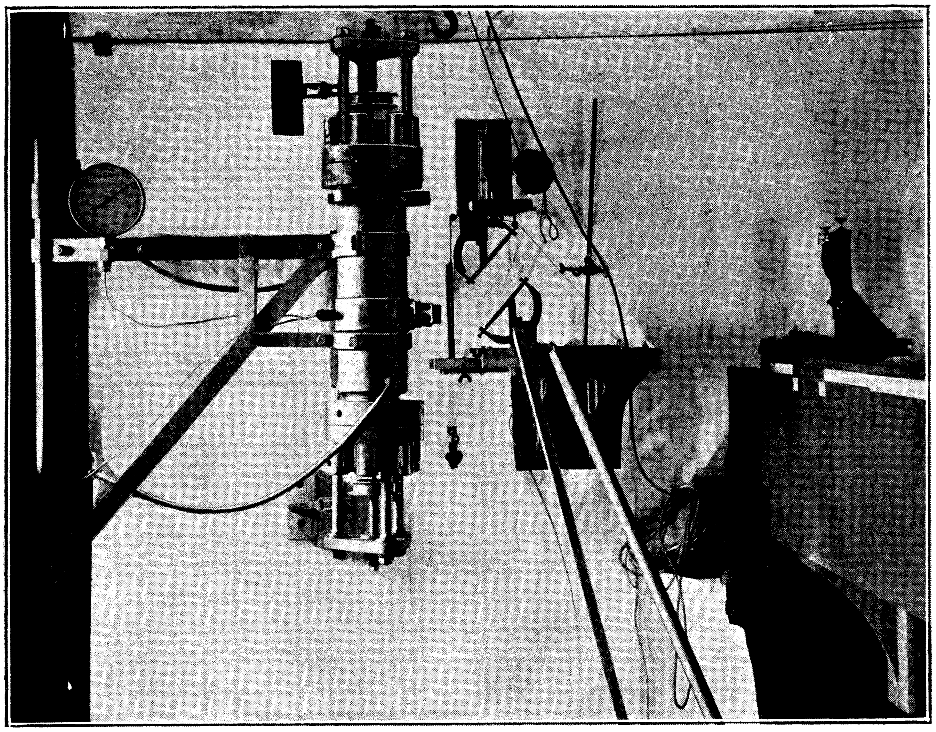
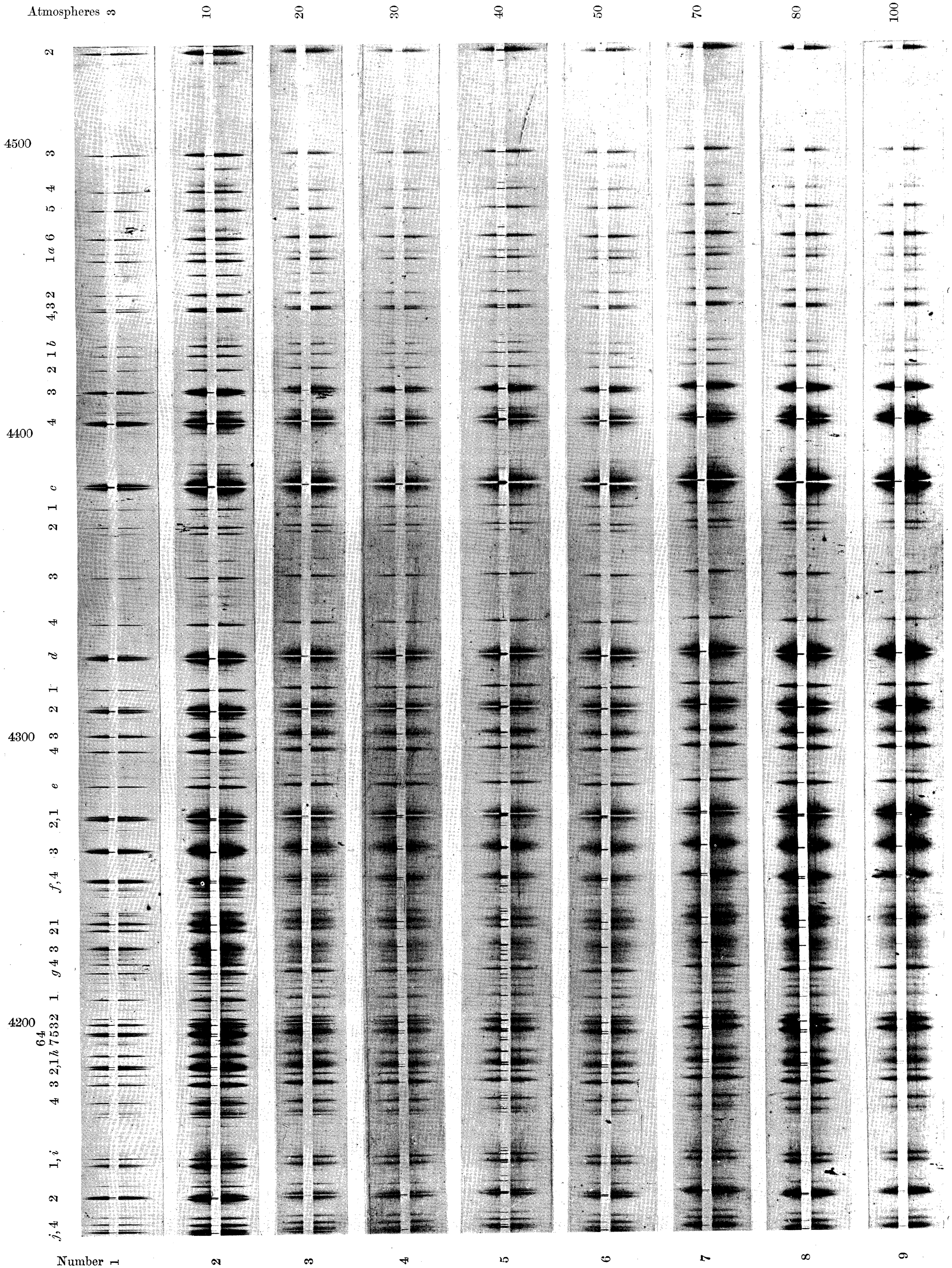
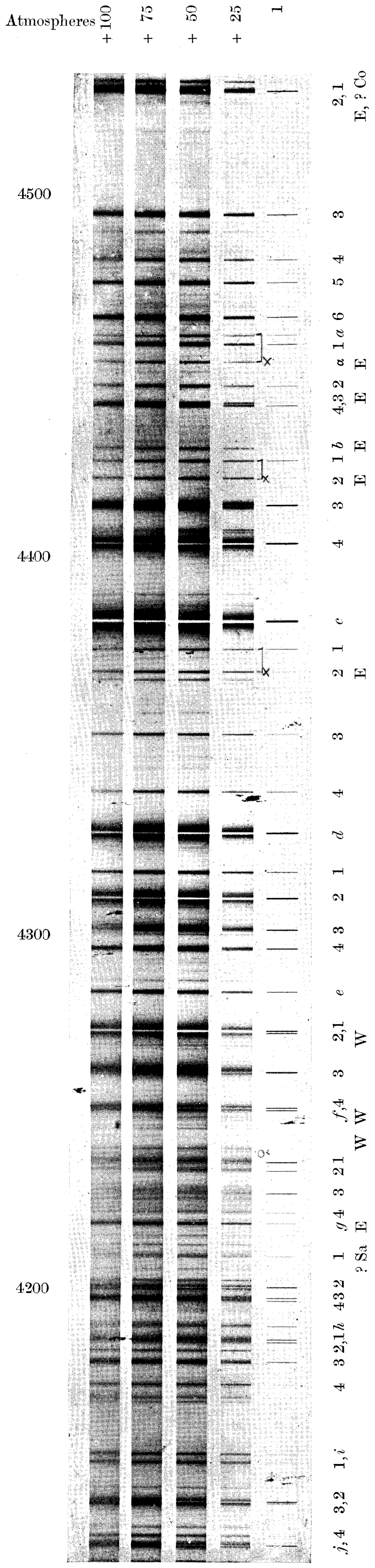


Fig. 2. Pressure cylinder and mirrors in position.

W. G. Duffield. Phil. Trans., A, vol. 208, Plate 4.

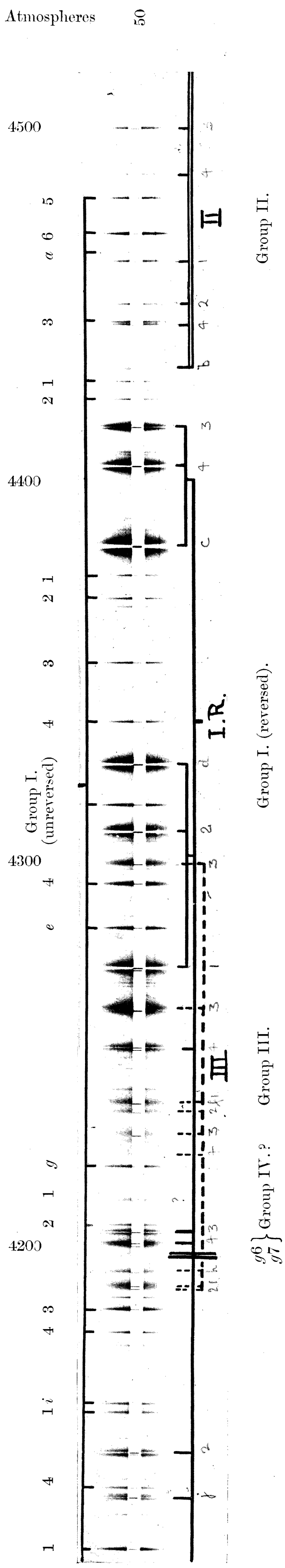


Negative (reduced). For wave-lengths corresponding to lettering, see pp. 136–138.



W = Weakened lines. E = Enhanced lines.

Fig. 1. Negative (reduced). For wave-lengths corresponding to lettering, see pp. 136–138.



Group I. {Unreversed lines linked together above photograph.
Reversed lines linked together below photograph.

Triplets occur in Group I. reversed.

Group II. linked together with a double line.
Group III. linked together with a dotted line.

The lines of Groups II. and III. show a "gregarious tendency."

Fig. 2. Negative (reduced). For wave-lengths of the lines belonging to different groups, see Table X., p. 160.

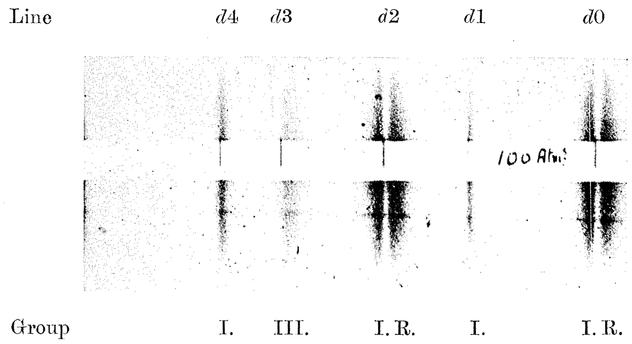


Fig. 1. Negative (enlarged).

Line.	Wave-length.
*d*0	4325 ·19
*d*1	4315 ·21
*d*2	4307 ·96
*d*3	4299 ·42
*d*4	4294 ·26

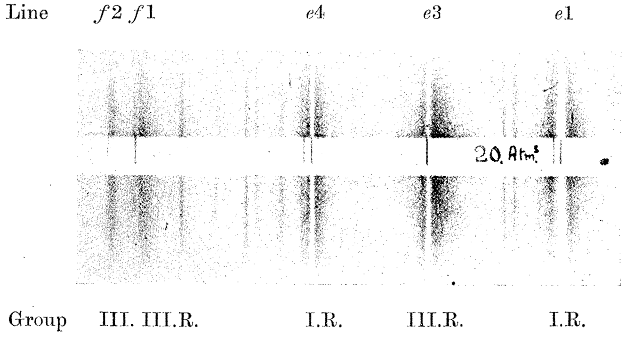


Fig. 2. Negative (enlarged).

Line.	Wave-length.
*e*1	4271 ·30
*e*3	4260 ·64
*e*4	4250 ·93
*f*1	4236 ·09
*f*2	4233 ·76

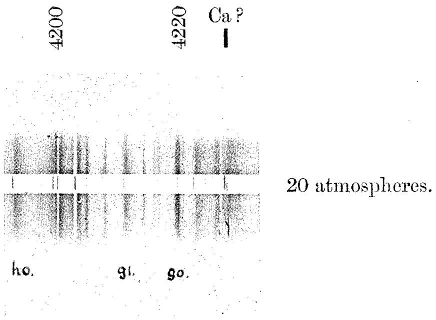
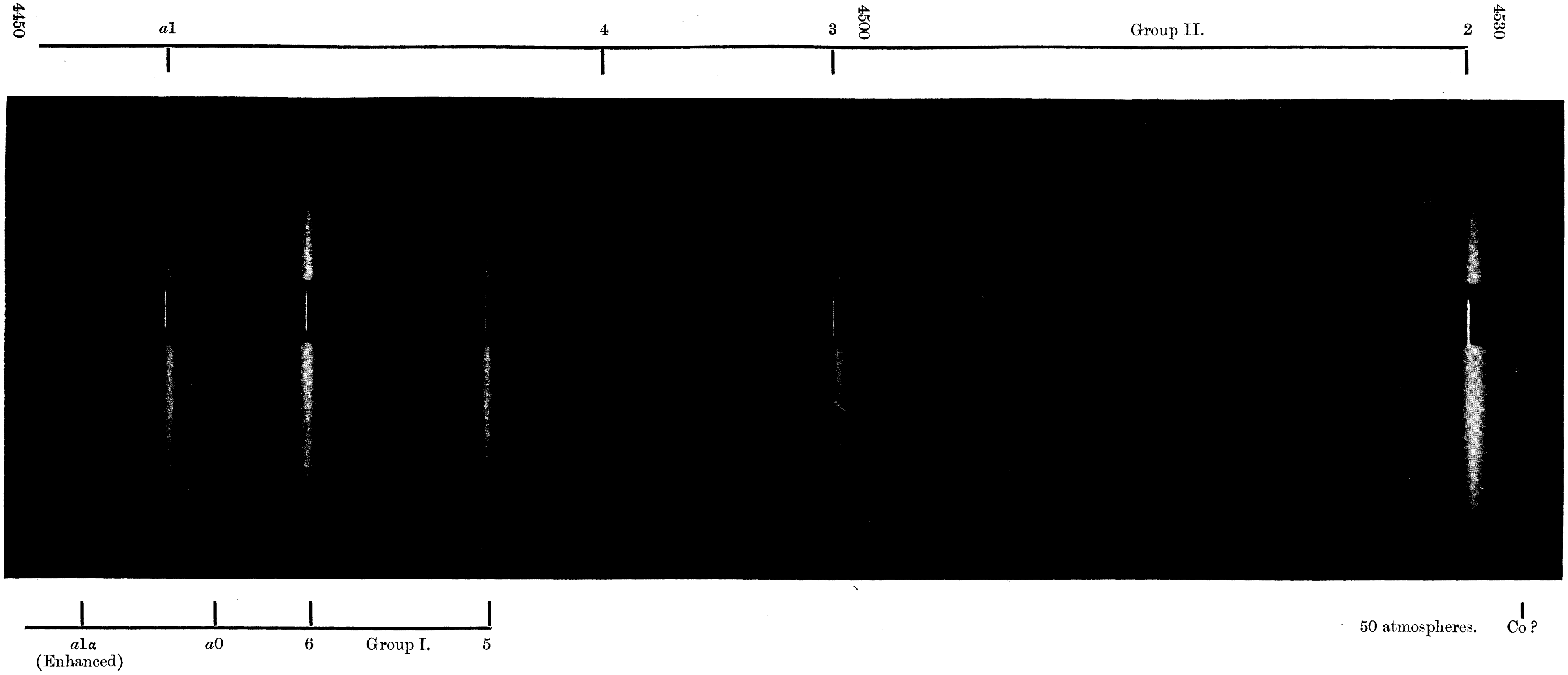


Fig. 3. Original negative.

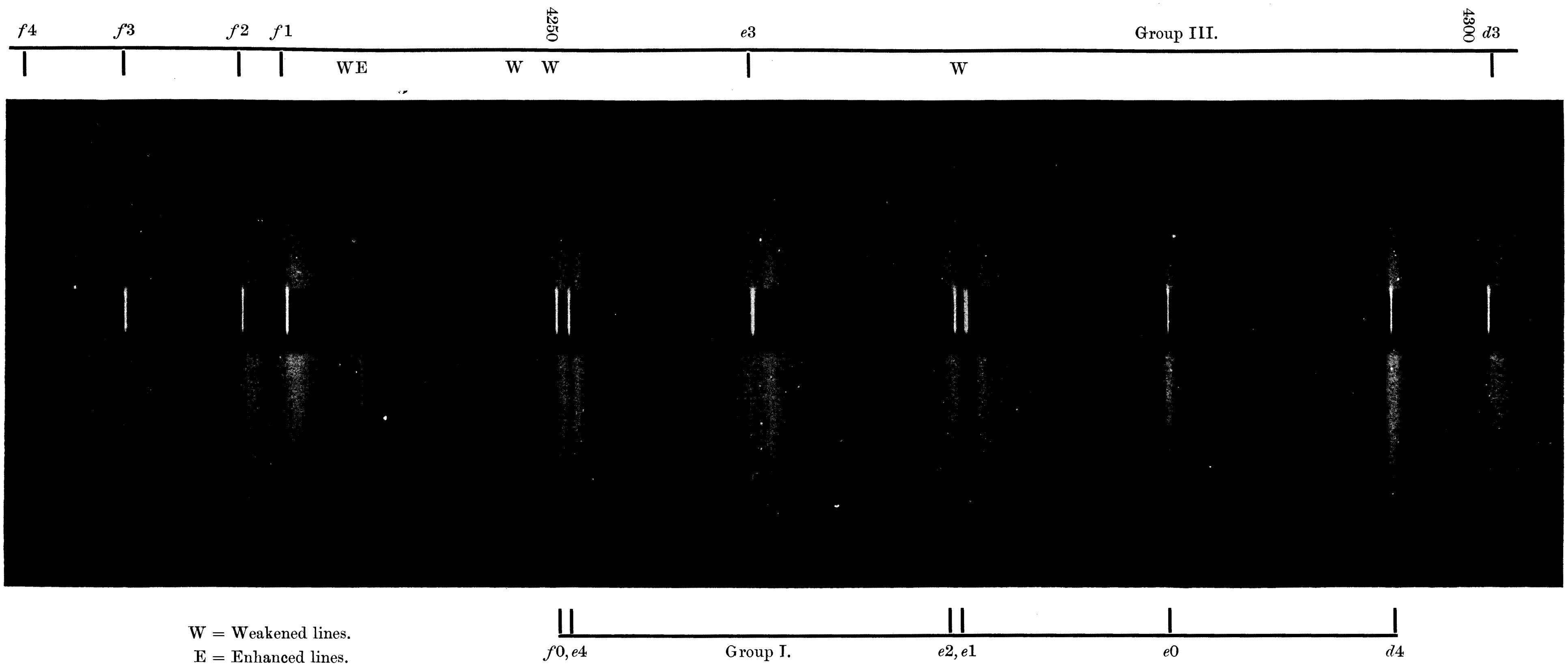
Line.	Wave-length.
Ca ?	4226 ·91
*g*0	4219 ·47
*g*1 ? Sa	4210 ·48
*h*0	4191 ·57



Line.	Wave-length.
Co ?	4531·25
2	4528·78
3	4494·67
4	4482·35
5	4476·20

Line.	Wave-length.
6	4466·70
*a*0	4461·75
*a*1	4459·24
*a*1*a*	4454·50

Positive (enlarged).



W = Weakened lines.
E = Enhanced lines.

50 atmospheres.

Line.	Wave-length.
*d*3	4299 ·42
*d*4	4294 ·26
*e*0	4282 ·58
*e*1	4271 ·93

Line.	Wave-length.
*e*2	4271 ·30
*e*3	4260 ·64
*e*4	4250 ·93
*f*0	4250 ·28

Line.	Wave-length.
*f*1	4236 ·09
*f*2	4233 ·76
*f*3	4227 ·60
*f*4	4222 ·32

Positive (enlarged).

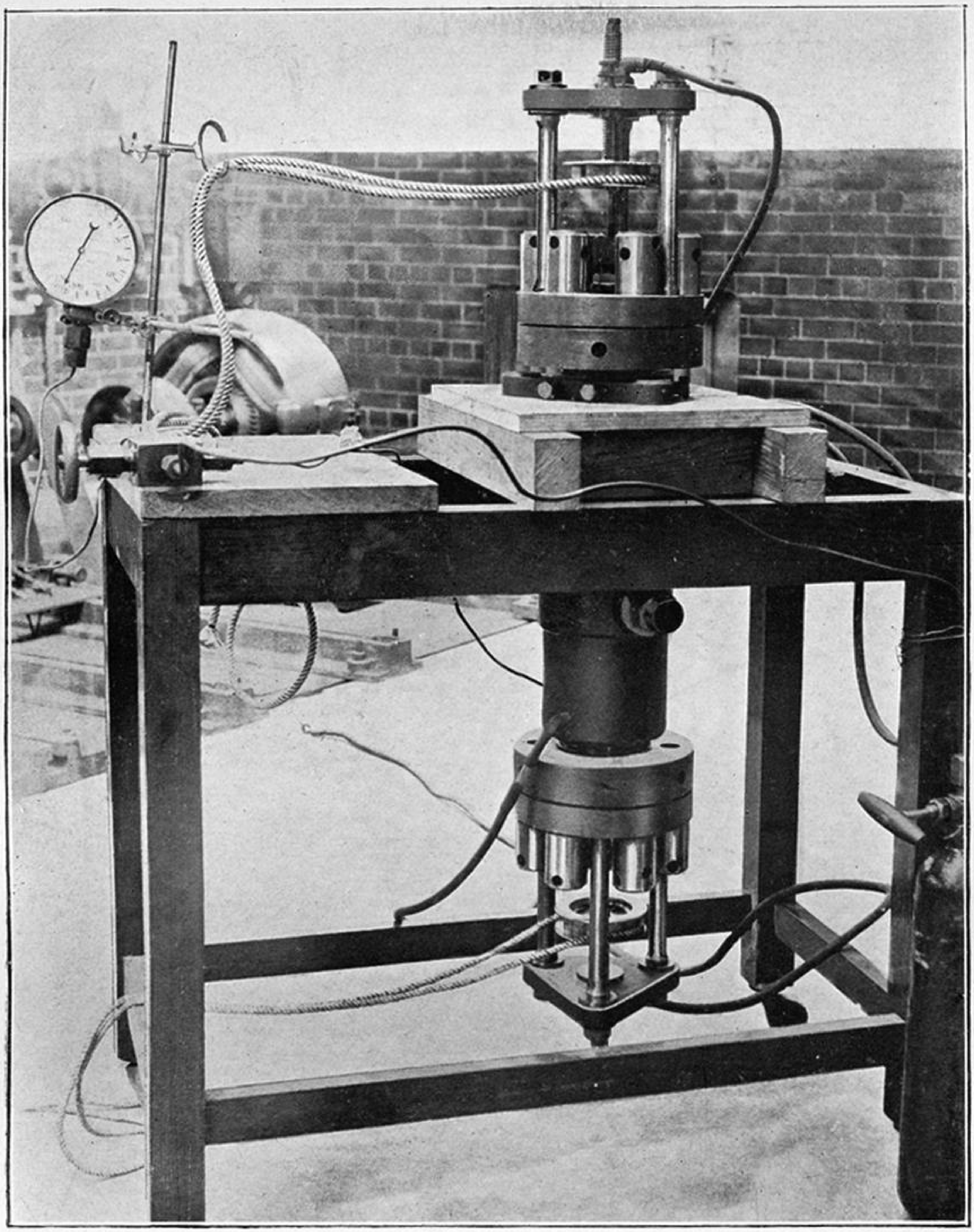
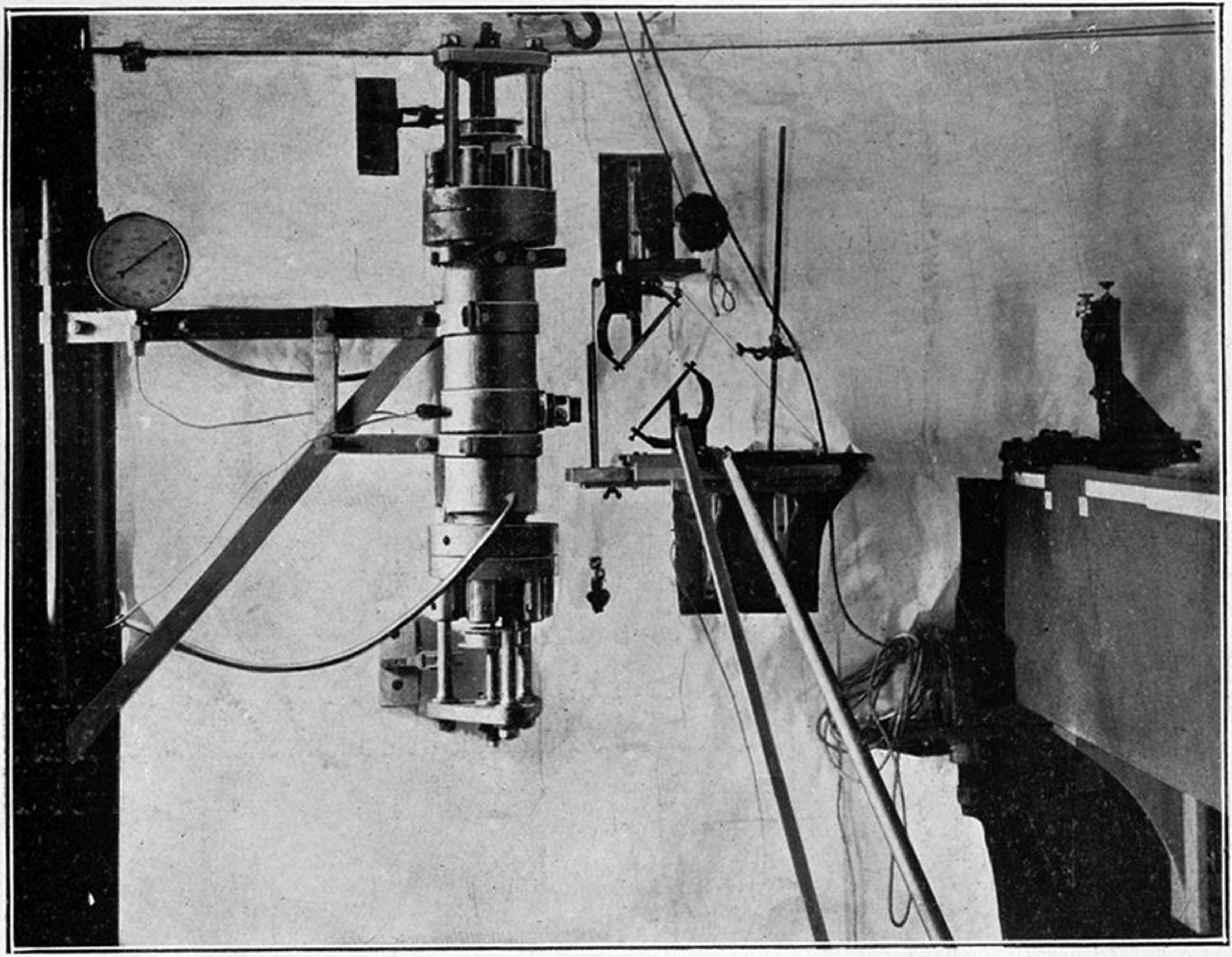


Fig. 1. Pressure cylinder and connections.



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Negative (reduced). For wave-lengths corresponding to lettering, see pp. 136–138.

Fig. 1. Negative (reduced). For wave-lengths corresponding to lettering, see pp. 136–138.

$\left.\begin{matrix} g6 \\ g7 \end{matrix}\right\}$ Group IV.? Group III. Group I. (reversed). Group II.

Group I. $\left\{\begin{matrix}\text{Unreversed lines linked together above photograph.} \\ \text{Reversed lines linked together below photograph.}\end{matrix}\right.$

Group II. linked together with a double line.
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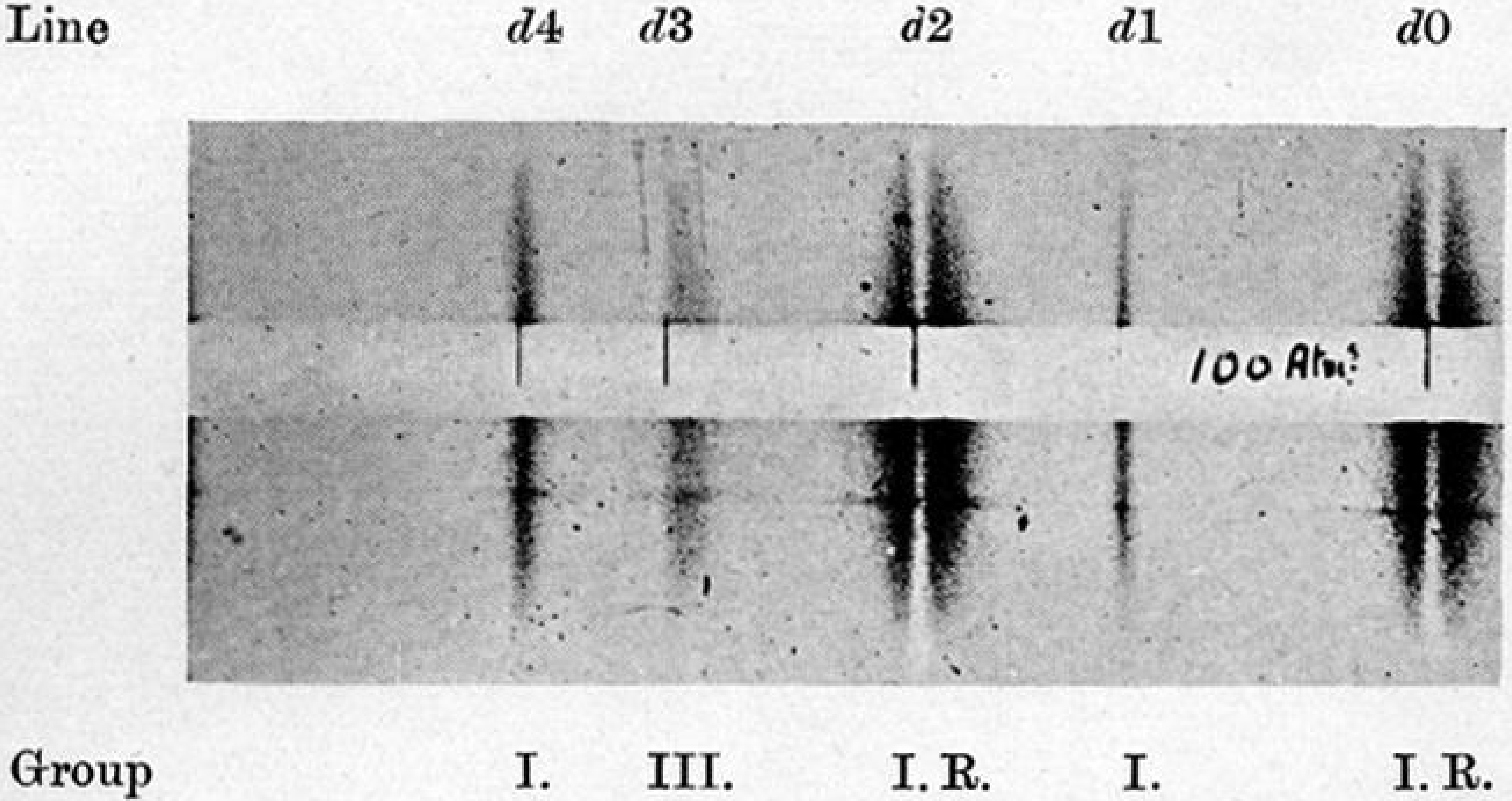
Triplets occur in Group I. reversed.

The lines of Groups II. and III. show a "gregarious tendency."

Fig. 2. Negative (reduced). For wave-lengths of the lines belonging to different groups, see Table X., p. 160.



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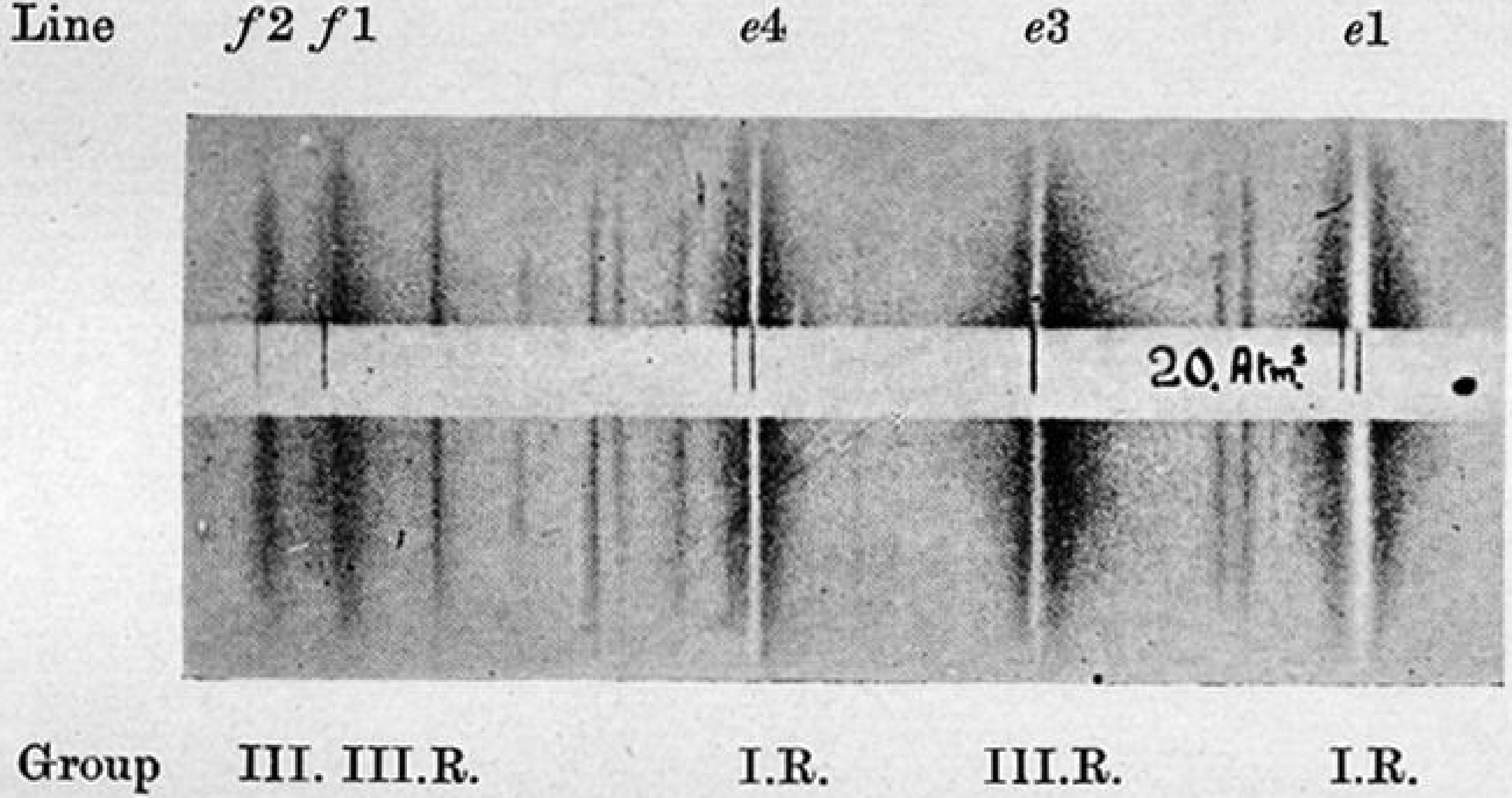

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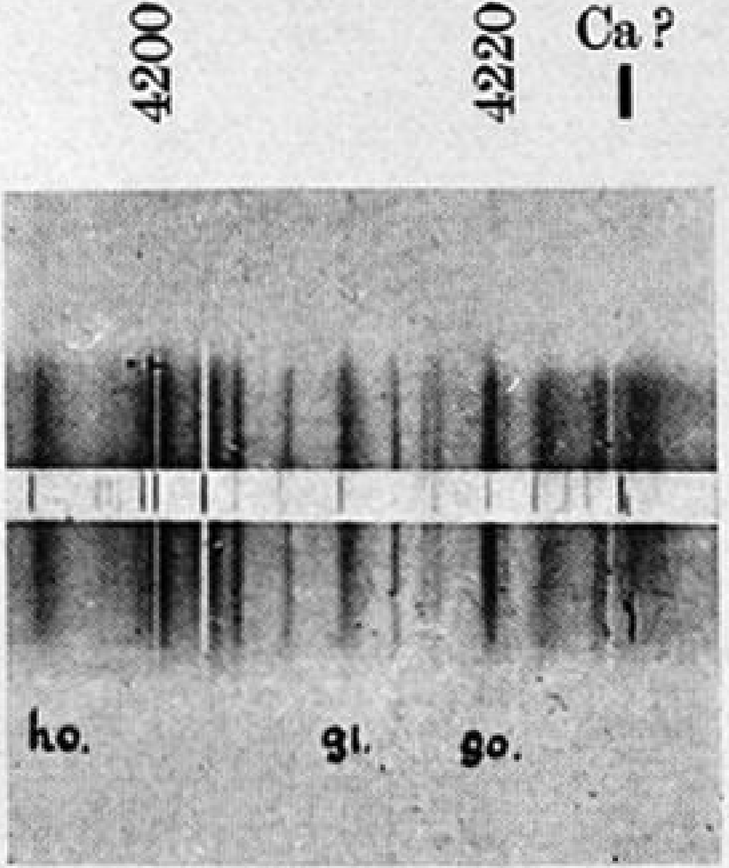

20 atmospheres.

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