ered as an active process; and hence, the question as to *mere* effects is, to say the least, unnecessary. The real point of interest is the relation of the consequences of any thought to the larger whole of experience, the sort of situations that produced the thoughts and the function of the latter in the onward movement of the process. There is really no ultimate statement to which the particular can be squared, aside from its function in the development of experience. The single act is not interesting as a mere act or as a part of a static system, but only as accomplishing something that is related to other acts.

We will not deny to pragmatism its right to define what is real and vital, and what is false; we simply maintain that it must make a preliminary investigation of what it is that we can rightfully assume as real, or what is subject to any statement that we can legitimately try to make. For one thing, we cannot state *our* experience in terms of any more ultimate reality. If it cannot itself be made consistent, there is no consistency for us anywhere. The problem of philosophy is to explain the particular by locating it in its context. There is no such thing as a merely verbal concept, nor a meaningless or erroneous idea. Whatever exists has meaning and validity, if not in one context in another; and the task for philosophy is not one of selecting and rejecting, but of finding the setting of that which is.

IRVING KING.

OSHKOSH NORMAL SCHOOL.

SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE

VOL. XXIX

EVERY MAN IS A VALUABLE MEMBER OF SOCIETY WHO, BY HIS OBSERVATIONS, RESEARCHES, AND EXPERIMENTS, PROCURES KNOWLEDGE FOR MEN.—SMITHSON.

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1903

SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE
1413

Hodgkins Fund

ON THE ABSORPTION AND EMISSION OF AIR AND ITS INGREDIENTS FOR LIGHT OF WAVE-LENGTHS FROM 250$\mu\mu$ TO 100$\mu\mu$

BY
VICTOR SCHUMANN

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1903

Commission to whom this memoir has been referred:

CARL BARUS

C. G. ABBOT

ADVERTISEMENT.

This work forms part of Volume XXIX of the *Smithsonian Contributions to Knowledge*, and gives an account of researches, aided by grants from the Hodgkins Fund, on the emission and absorption of the gases of atmospheric air in the ultra-violet spectrum.

Within the last fifteen years our knowledge of radiation has been greatly increased, and now embraces wide ranges of the spectrum heretofore unknown. Without assigning any place to the numerous kinds of "rays" whose discovery has been associated in the public mind first with the work of Röntgen, and later with that of the Curies, I am speaking here rather of the extensions of the spectrum in wave-lengths which are actually measurable and known. Thus beyond the red the spectrum has now been studied in practical continuity to a wave-length of nearly 100 microns; and at a great remove beyond this is another known region embracing the so-called Hertzian, or electric, waves now employed in wireless telegraphy.

Beyond the violet, progress has been, relatively speaking, less rapid, unless indeed it shall prove that the Röntgen and other radiations fall in this region. But a great step in advance has been made by the unwearied and able investigations of the author of the present work, Doctor Schumann.

The difficulties hindering research in the ultra-violet are great, and consist chiefly in the opacity of the usual optical media to the short wave-length rays. Quartz, for a long time considered best in this part of the spectrum, is found to be too opaque, and has been largely superseded in Doctor Schumann's investigations by fluorspar for prisms and plates. Air, even in layers of a few millimeters thickness, is almost wholly opaque, and other gases absorb strongly. It has therefore been necessary to employ a spectroscope from which the air is exhausted to the highest practicable degree; and this and other necessary apparatus Doctor Schumann has designed and constructed with his own hands, though aided by grants from the Hodgkins Fund of the Smithsonian Institution. Commercial photographic plates were found to have films too opaque for the recording of these

short wave-lengths, and the author was obliged to devise an improved method of coating the plates used in his investigation.

This memoir contains an account of the special apparatus and method of using it, and continues with a description of the emission and absorption spectra of oxygen, nitrogen, hydrogen, carbon monoxide and dioxide and aqueous vapor for wave-lengths reaching in the case of hydrogen to about 0.10 micron. Illustrations of the apparatus and spectra accompany the text, and it is thought the whole will be a valuable contribution to knowledge, though but preliminary to the researches Doctor Schumann alone is continuing in this spectral region.

In accordance with the rule adopted by the Smithsonian Institution, the work has been submitted for examination to a committee consisting of Doctor Carl Barus of Brown University and Mr. C. G. Abbot of the Smithsonian Astrophysical Observatory.

S. P. Langley,
SECRETARY.

Smithsonian Institution,
Washington, September, 1903

ON THE ABSORPTION AND EMISSION OF AIR AND ITS INGREDIENTS FOR LIGHT OF WAVE-LENGTHS FROM 250 $\mu\mu$ TO 100 $\mu\mu$.

By Victor Schumann, Ph.D.

(Translated from the German Manuscript by Charles S. Peirce.)

The present report describes the most essential results obtained up to the end of the year 1900 in an unfinished investigation which was begun at the end of March of the same year, and was continued without interruption during the interval, this research having had the support of a grant from the Hodgkins Fund of the Smithsonian Institution.

General considerations.—The chief instrument of this investigation was a vacuum-spectrograph with lenses and prism of white fluor-spar.

In a general way, its mechanical arrangement is that of an ordinary spectroscope with collimator and telescope; except that a little photographic camera takes the place of the eye-piece. Its parts, however, have air-tight connections, so that a high vacuum can be produced in it by a mercurial air-pump.

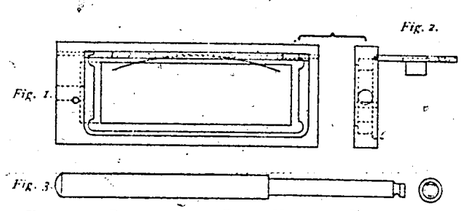
Figs. 1 to 9 are photographic reproductions of the original working drawings in accordance with which the apparatus was constructed by my own hands; so that any instrument-maker who may desire to undertake the execution of such a vacuum-spectrograph may trust implicitly to these figures. The following explanations may be useful.

Figs. 1 and 2 show the photographic plate-holder open. It is adapted to plates 37 x 12.7 mm.

Fig. 3 shows a key by means of which the plate-holder can be shoved into the camera and by which it can also be withdrawn.

Fig. 4 is the slit with its three micrometers, a'', t'', y''. The first of these, a'' (1 division = 0.001 mm.), regulates the width of the slit. The second, t'' (1 division = 0.01 mm.), adjusts the length of the slit. The third, y'' (1 division = 0.1 mm.), serves to shift the adjustable diaphragm which regulates the length to any part of the slit that it may be desired to employ. The screw c'' effects the

fine adjustment of the slit to parallelism with the refracting edge of the prism. The three micrometer screws are rendered air-tight by means of the three steel cones, m'', s'', w''. The slit box d'' is connected with the source of light through a cover shown in Fig. 5, e''.



FIGS. 1–3. PHOTOGRAPHIC PLATE-HOLDER. NATURAL SIZE.

This cover, e'', carries by a flat ground greased joint the Geissler tube, which is centered by the steel pin e''', and after centering is secured against lateral shifting by a slide, h''. It is needless to say that the steel pin is withdrawn when the centering of the tube has been effected. The mode of connection of the tube with the vacuum-spectrograph does not permit the two to be filled independently of one another with such gas as may be under investigation at the time. It will not do to fill both unless the gas is sufficiently transparent. This, however, is not the case with the majority of gases; so that a window has usually to be interposed between the Geissler tube and the cover, e'', so as to diminish the thickness of the stratum of gas to be traversed by the rays. The same arrangement is useful in photographing by sparks and arc-light. In case the observation is not to extend farther to shorter wave-lengths than 155 $\mu\mu$, a sufficiently thin quartz window will answer the purpose. For more refrangible rays it is not transparent enough, and white fluor-spar is the only suitable material.

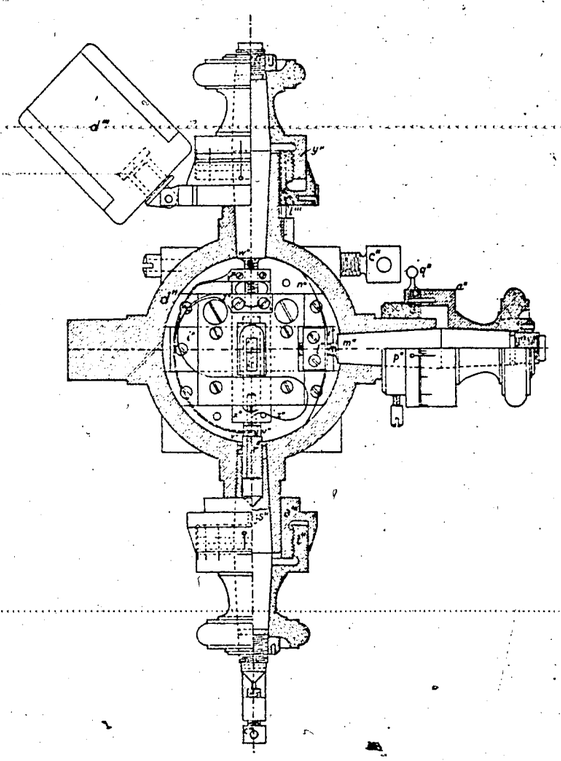


FIG. 4. SLIT WITH THREE MICROMETERS. NATURAL SIZE.

Fig. 6 shows a section of the part in which the prism (which appears in Fig. 8 as k) is set up. A thick-walled cone, b, is rigidly connected with the collimator.

A hollow cone, d, very accurately ground to fit upon b, is capable of turning round it to the extent of its opening, d_1 d_2, and carries the camera.

Fig. 7 shows the camera in cross-section. The plate-holder, drawn in the cross-section, must be shoved into the inner cone, b', through the slot, k', in dark-room light. When the cone is turned, the plate-holder comes before the opening, m', and is exposed to the rays from the prism. A certain amount of air is

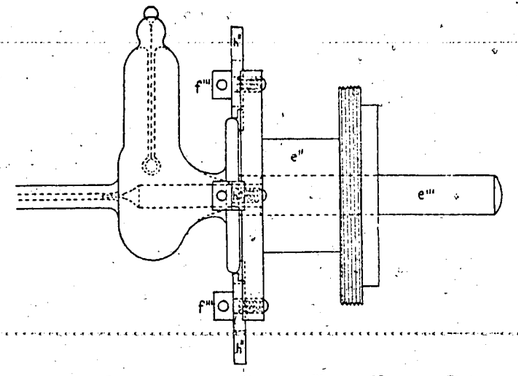


FIG. 5. CONNECTION WITH GEISSLER TUBE. NATURAL SIZE.

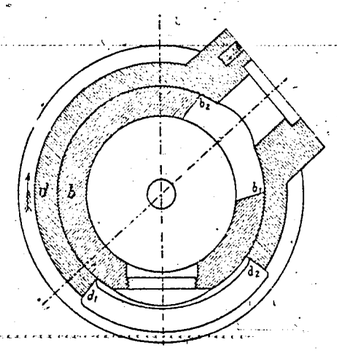


FIG. 6. CROSS-SECTION OF PRISM-HOLDER. HALF NATURAL SIZE.

unavoidably introduced when the plate-holder is shoved in; and in case this interferes, it has to be pumped out before the exposure begins; and it will sometimes even be requisite to wash out the entire interior of the spectrograph with hydrogen.

Working in dark-room light involves many inconveniences; and I have, therefore, lately provided the plate-holder with a brazen sheath which is shoved into a vertical groove made in k'. In this way, the plate-holder can be introduced into the camera, quite light-tight, in full daylight.

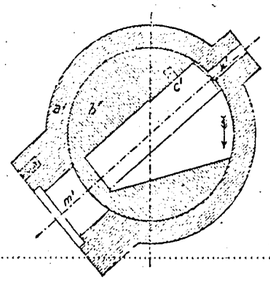


FIG. 7. CROSS-SECTION OF CAMERA. HALF NATURAL SIZE.

Fig. 8 is the elevation of the spectrograph. i is the prism-stand with the prism, k, upon it. It rests, free to turn, upon a conical pivot of the little table, h, which is rigidly connected by a screw-thread with the steel axis, g; and this in turn carries the alidade, l, at the bottom outside the vacuum. The apparatus is connected with the air-pump by means of the ground-glass cock, o. The two thumb-screws, t_1 and t_2, serve to focus the lenses of the collimator and telescope respectively. At the right-hand side of them the camera is seen in section, showing the photographic plate, i', with its plate-holder. The micrometer, s', above it (1 division = 0.1 mm.), serves to move the plate in its own plane parallel to the refracting edge of the prism. This is requisite in case several exposures are to be made successively without changing the plate.

Fig. 9 is the horizontal plan of the spectrograph. The slit is shown at d'', with the collimator-tube, e, in which there is a peep-hole, u_1, indispensable for the adjustment of the lens. The telescope has a similar peep-hole, u_2. The telescope carries the camera, which is provided with handles, l', for the purpose of turning its interior cone, b'. Upon the outer cone of the camera the drawing shows a divided arc whose divisions are whole degrees. This serves for the adjustment of

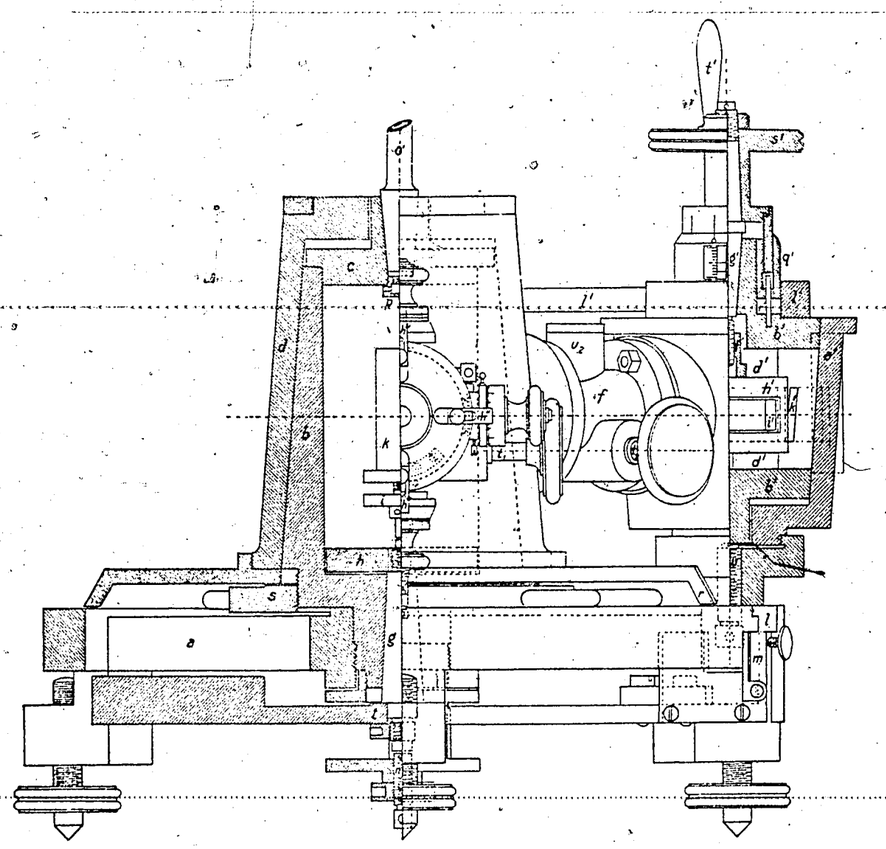


Fig. 8. Elevation of Spectrograph. Half Natural Size.

the inclination of the photographic plate to the optical axis of the lens; which depends upon the refrangibility of the rays to which exposure is to be made. With a sixty-degree prism of fluor-spar, this angle of incidence is 68° when light of wave-length 185 $\mu\mu$ falls on the middle of the plate. From that point on, it diminishes considerably with the wave-length; so that for the most refrangible region photographed by me it only amounts to 55°. The camera has a counterpoise, q. At r is the index for the setting of the angle between the optical axes of the two lenses

in exposures to different portions of the spectrum. At l is the vernier for the alidade of the prism; but for a very fine setting this vernier is insufficient, and a

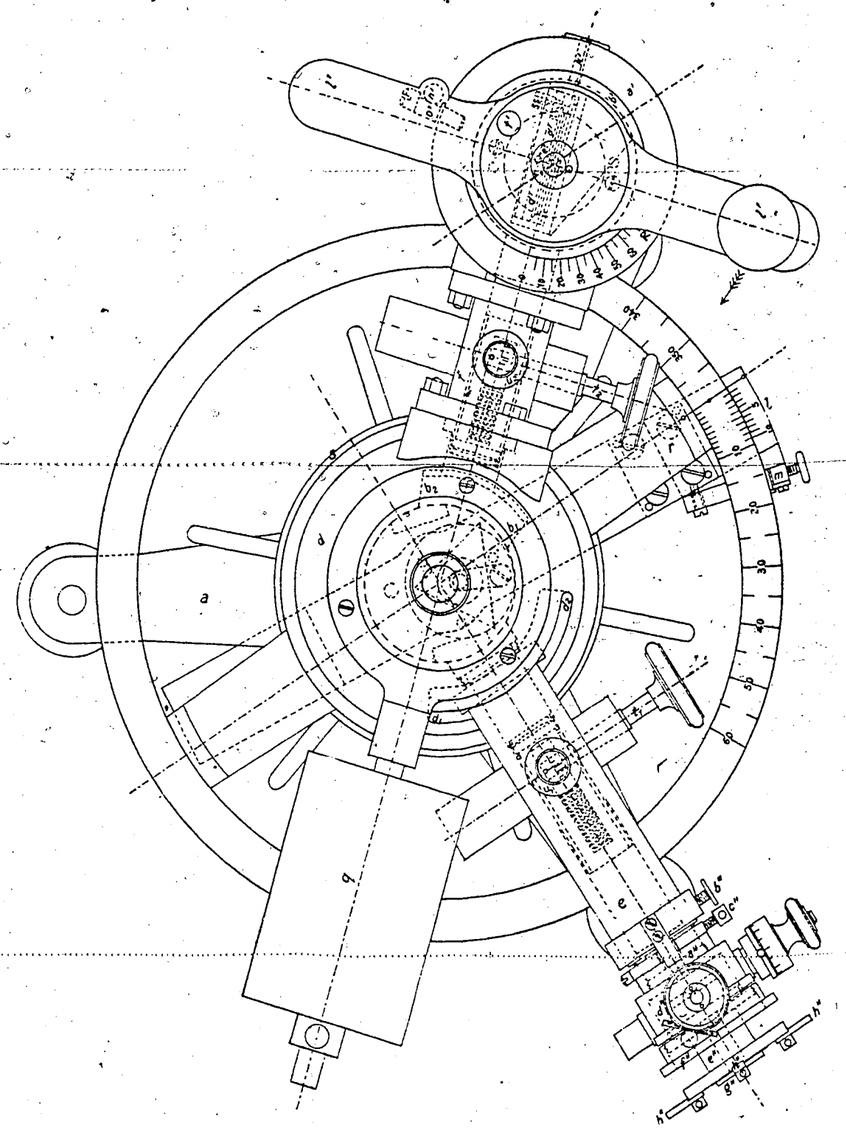


Fig. 9. Horizontal Plan of Spectrograph. Half Natural Size.

micrometer (not shown in the drawing) is connected with it, so that the angle may be read to two seconds of arc. This is used in the measurement of the

wave-lengths with a plane grating and lens *in vacuo*. The six rods arranged starwise about the main cone are handles of a large nut (see *s* in Fig. 9) which serves to loosen the outer cone in case the apparatus is to be taken down to renew the grease or for any other reason. For the greasing causes the two cones to cling together remarkably. The screws, *u'* (Fig. 8), of the camera and the nut, *f''* (Fig. 9), of the slit-carriage serve similar purposes.

The entire spectrograph, with the exception of the main axes, the micrometer-screws, and the slit-jaws is constructed of brass. The air-tightness of the instrument depends no less upon the homogeneity of its material, especially of its castings, than upon the accurate workmanship of its execution.

All the closing surfaces of a chamber from which the air is to be exhausted, no matter how accurately they may be ground together, require, in order to sustain the vacuum, to be lined with a tightening medium. For this purpose, after having tried various kinds of grease, I employ a mixture produced by melting together five parts by weight of white wax with seven parts of the yellow vaseline of Chesebrough & Co. of New York,[1] the mixture being twice filtered through a hot funnel. Care must be taken to have it free from dust, since even small particles of dust, especially filaments, if they get into the grease between the smeared surfaces, may endanger the tightness. In the heats of summer it is advisable to diminish the proportion of vaseline. This grease is sensitive to light, and on exposure shortly turns dark yellow; but this coloration does no harm in the present case. I must warn experimenters against the employment of white vaseline; for (at least, when mixed with white wax) it oxydizes the brass-work quite considerably. The application of the coat of grease to the bearing surfaces is a matter of great importance for the tightness of the apparatus, as well as for its efficiency. Above all, before laying on the grease, the surfaces upon which it is to be laid have to be cleaned with the most scrupulous care. Then, having carefully examined them to see that no little filaments have settled upon them, one should lose no time in proceeding to the application of the grease. In doing this, I make use of a spatula of a thin lancet shape made of instrument-makers' dogwood (*Euonymus europæus*). The grease is to be laid on more or less thickly, according to the size of the surface; but in any case it should be applied as uniformly as possible. In the case of the great cones, I go all over the film so produced with my finger, which I have previously scrupulously cleaned, rubbing the grease in, in two directions. Of course, only one of two surfaces which are to be put together is greased.

When the surfaces are small and are optically plane polished, such as those of the fluorite window, the grease will better be laid on with the finest grade of photographers' retouching pencil, so that the film may be as thin and narrow as possible. If, in doing this, one keeps the line of grease as far as possible from the border of the inner opening, one will easily prevent any grease from getting into the interior of the apparatus when one puts the window into place, a dry strip

[1] In another part of this Report I have recommended watch-oil,—a discrepancy due to my only recently having resorted to vaseline, and to the circumstance that this description of the instrument has only been inserted in the report long after the main part of it was submitted.

remaining between the line of grease and the border of the opening. This is a matter of consequence; because any grease exuding into the inside gradually spreads over the entire surface of the window and powerfully absorbs the most refrangible rays. The state of the film of grease has, however, no greater influence upon the duration of the air-tight closure than has the form of the bearing surfaces. We know by the behavior of the glass cocks of the mercurial air-pump that cones without openings close tightly for years, even though they be in frequent motion, like the above-mentioned cones of the micrometers and main axes. Less trustworthy are plane annular and discoid surfaces, particularly if they be subject to frequent movement. Still less secure are rectangular surfaces that are subject to motion of translation. But the air-tightness is diminished in quite a surprising degree by openings through the bearing surfaces such as the passage of light or of the gas to be exhausted may demand. Such openings, as I have found in the case of optically plane surfaces, have a tendency to shove the grease together at the openings, and thus gradually to denude the bearing surfaces, and in this way to form a canal into the exhausted chamber; and this canal, though fine at first, soon increases in cross-section, so that the air, which at first enters only in excessively small amount, soon begins to pour in in larger volume, especially if the closing parts continue to be moved from time to time. When this sort of leakage once sets in, there is no other remedy than that of replacing the spoiled greasing by a fresh one. The circumstances most adverse to tightness are where there are plane slides moving rectilinearly over rectangular openings. Here the denudation of the surfaces from grease at times takes place after but little sliding back and forth; so much so, that, with some kinds of grease, I never could succeed in getting an air-tight closure. For such surfaces Chesebrough's vaseline, without wax, answers best. Slides of this kind ought to be provided with the largest possible bearing surfaces, such surfaces presenting a longer resistance to the tendency of the air to pour in. Here may be mentioned another inconvenience which regularly occurs as soon as the greased parts come to be frequently moved, as for example is the case with all the cones. The initial facile mobility of these parts is of short duration. After some use they begin to run considerably harder, and where the bearing surfaces are subjected to stronger air pressure they begin to oppose no little resistance to motion. This inconvenience is most felt in the cold part of the year when the grease is harder. This can only be remedied by frequent greasing of the surfaces in question. The considerable resistance which the great cones of the camera and of the prism-block offer to turning calls for an installation which shall prevent lateral displacement. Otherwise, the glass tubes leading to the air-pump will be exposed to constant danger of breakage. I have met this need in my spectrograph by bridging over [each of ?] its three levelling-screws with ⎍⎍ shackles of the form here shown, so that the screws perfectly permit a vertical, but no lateral, motion of the apparatus. A still more detailed description of this spectrograph is contained in my report to the Imperial Academy of Vienna: *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien; mathem.-naturw. Classe*, vol. cii, Part IIa, June, 1893, pp. 625–694.

The exhaustion of the spectrograph was effected by a Geissler mercurial air-pump. The source of light was usually a Geissler tube of the "end-on" form, the rays entering and leaving the tube through plates of quartz or fluor-spar. Occasionally, electric sparks from metals were employed. The discharge was furnished by a Ruhmkorff coil giving sparks of 25 cm., the primary current being derived from a number of Grove cells. The electro-motive force and the intensity of the primary current were accurately measured. To furnish layers of the different gases for observations of absorption, air-tight brass tubes were interposed lengthwise, coaxially with the collimator, between the source of light and the spectrograph. They could be exhausted and filled with the gas whose absorption was to be studied. The lengths of the tubes therefore correspond to the thickness of the strata of gas which measured 65, 30, 25, 20, 15, 10, 5, 2½ cm. Most gases appear, even in very thin strata, strongly to absorb the rays of the most refrangible parts

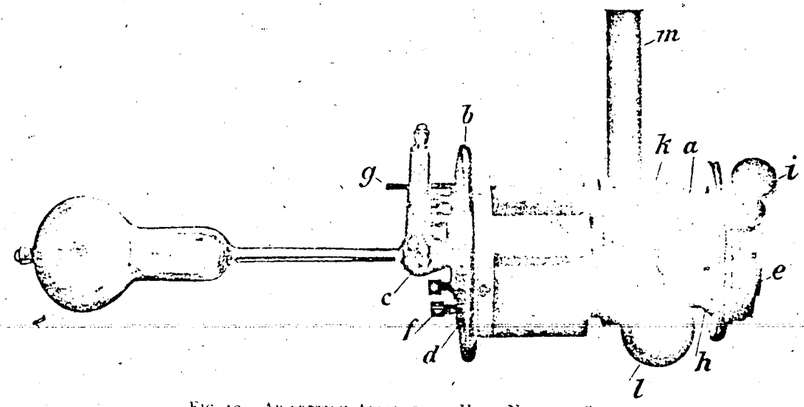


FIG. 10. ABSORPTION APPARATUS. HALF NATURAL SIZE.

of the ultraviolet spectrum. Some gases exercise a general absorption, while others give characteristic rising and falling selective absorption-curves. Since these curves interest physicists for various reasons, I have constructed a special apparatus for the exhibition of them in the photographic way. This is shown in Fig. 10 in half its natural size. The principle of it is as follows:

A Geissler tube filled with hydrogen, or other gas, sends its rays to the prism through a chamber of variable depth provided with two opposite and parallel walls of fluor-spar, and filled with the gas to be investigated at atmospheric pressure. One of the windows remains fixed, while the other can be so shifted in the direction of the rays that the distance apart of the two can be continuously varied from 0 to 15 mm. This distance is evidently the thickness of the plane-parallel gas-stratum to be investigated. This whole apparatus is put in the place of the cover of the slit-carriage marked e'', in the foregoing description of the vacuum-spectrograph, so that the capillary is in line with the produced geometrical axis of the collimator. The apparatus is constructed in detail as follows: The cover, e (Fig. 10),

that fits to the slit-carriage of the spectrograph is connected air-tight with the body of the absorption apparatus; that is, with a thick-walled hollow cylinder of brass. In the interior of the hollow cylinder there is a tube of cast-steel which can be displaced along the axis by the aid of a milled-edged disk provided with a female screw-thread within. The measure of the displacement can be read upon the two scales visible in the picture; namely, the whole millimeters upon the longitudinal one, and the tenths of millimeters upon the circumferential one. Upon the face of the steel tube turned toward the cover, e, is fixed the fluor-spar window that is moved with the tube, while upon the inner plane surface of the cover, e, the other, which is fix abuts upon the central light-opening, which leads to the slit. The two windows main in parallel planes, whatever their distance apart may be. The air-tight connection between the steel tube and the brass cylinder, a (Fig. 10), is effected by means of a ring of sole-leather turned upon the lathe and having a cross-section 3 millimeters square, this ring being pressed against tube and cylinder by means of an annular female screw. For the same purpose, the greatest care was taken in preparing the steel tube and its brass guide, to render the cylindrical surfaces precisely circular. To the milled disk, b, the Geissler tube, c, is fastened by its rim. As the medium of attachment the above-mentioned mixture of wax and vaseline is employed, a small amount being laid upon the rim of the tube. In this case the tube cannot be adjusted by a steel pin as it is adjusted to the cover e''; and the following process has to be resorted to: The apparatus by the annular shoulder of e is stuck into a well-fitting ring, not too light, in which it can be steadily turned about its axis. A suitable pin-hole is now arranged, or better, a short-focussed reading-telescope is directed so as to place the middle of the mouth of the capillary upon the cross-wires. Then, by turning the apparatus round through 180°, and shifting the tube by a suitable amount, it will easily be accurately centered. Lest the centering so attained should be lost, which at first, before the exhaustion, might easily happen, while the tube is only attached by the grease on its rim, four guides, d, sliding in the radial grooves of the disk, b, are delicately pushed up against the wall of the tube, and are secured there by their screws, f. Further, to render the centering quite secure, the support g is required. The lateral part of the Geissler tube that carries electrodes should rest against this support throughout the operation of centering, and should continue to do so thereafter. These precautions would, indeed, be needless if the rim of the Geissler tube were precisely on the circumference of the base of a right cone having its vertex at the center of the mouth of the [illegible]. But this condition is not fulfilled, and could be only at great cost; [illegible] cheaper arrangement with the support, g, is preferable. What is indispensable is that the bearing surface of the rim of the tube should be optically plane and should lie in a plane to which the axis of the capillary is perpendicular; the former condition being required for air-tightness, and the latter for the uniform illumination of the slit.

The filling of the Geissler tube is performed through the spectrograph, which is for this purpose connected with an apparatus for the evolution of the gas wanted. The gas then flows in through the cock, i, and through a narrow channel

continuous with this, and having its orifice near the Geissler tube. When the cock is closed, the tube continues to hold its gas while the spectrograph is exhausted. Although the gases of the tube and of the absorption-chamber are only separated by the steel tube, I have never found that even hydrogen entered the latter, diffusible as that gas is. The gas whose absorption is to be investigated flows into the absorption-chamber through the tube, *h*, and leaves it through a second tube placed diametrically and having its further end a little below the surface of some mercury. The mercury forms an escape-valve effectually preventing the entrance of atmospheric air, while a very slight over-pressure will cause an outflow.

The circumstance that the steel tube and its bearing are of different materials has the disadvantage that, owing to the different expansibilities of the two metals, the steel tube in the cooler part of the year does not move as readily as it should; and besides, the bearing may be injured. The bearing was originally fitted with great accuracy at the mean temperature of the room. Experiments that were instituted upon the appearance of this inconvenience showed that the reduction of the temperature by only a few degrees Celsius would suffice to damage the bearing and sometimes even the tube itself, if this were moved. Since the whole utility of an apparatus upon the design and construction of which no little pains had been bestowed was thus placed in jeopardy, I provided it with a little heater consisting of a water-jacket, *k*, to enclose the brass cylinder, *a*, at the point of the bearing of the steel tube, which water-jacket, by the aid of a funnel-shaped projection that stands vertical when in use, could be filled with water, and then, by means of the warming-tube, *m*, could be warmed to 27° C. by a little alcohol flame. At this temperature, or even a couple of degrees higher, the apparatus works faultlessly.

It may be thought that it would have been better to construct the whole apparatus of one metal. But there were certain technical objections to this into which it would lead me too far to enter here. It may be added that the apparatus has no pretension to universal applicability, being restricted to the study of such gases or vapors as are chemically indifferent to steel and to fluor-spar. The preparation of the atmospheric gases proceeded throughout in vessels connected by ground-glass fittings. The same thing is true of experiments with the gases which, as will be shown, enter as impurities into the Geissler tubes, such as CO and $C_m H_n$, whose influence, as appeared in the course of my investigation, required searching attention.

For photographic experiments ultra-violet plates prepared according to my process could alone be thought of, since the gelatine plates have not sufficient sensibility for rays beyond 185 $\mu\mu$. For although the gelatine plates are not completely insensitive for those rays, yet they are so inefficient that nothing more than a barely visible and worthless continuation of the spectrum appears in any case. The cause of this want of sensitiveness is, as I formerly proved, the want of transparency of the gelatine. By keeping this fact in view, I have succeeded, by persistent experimentation, in reducing the proportion of gelatine on my plates until it ceases to do any harm. The thickness of the sensitive layer is, at the same time, thus reduced to but one fifth of what it is upon the ordinary gelatine plates. To

this diminution of thickness is due not only their sensitiveness for the most refrangible ultra-violet rays, but also their power of promoting the optical efficiency of the photographic apparatus. What adds to the importance of this fact is that if the spectrum is to be sharply defined over the longest possible portion of it, then the rays will not traverse the sensitive layer perpendicularly, but will, on the contrary, have an angle of incidence of 60° to 69°. The short focal distance (the focus at 589 $\mu\mu$ is 12 cm.) and weak dispersion (with a fluorite prism of 60°) of my spectrograph make the last named property of the ultra-violet plates incomparably more important in the present case than with instruments of stronger dispersion. And it is not the least of the advantages I owe to that property that the very small negatives of the part of the spectrum in question, in consequence of their uncommon capacity for enlargement, nevertheless answer the demands of exact spectroscopy. A numerical example will best show what my spectrograph was in this way able to do. In a part of the hydrogen spectrum about 160 $\mu\mu$ it resolved a length of 13 millimeters into more than 300 clearly marked lines. I need not say that very exact edges and very narrow opening of the collimator-slit were needed for this. My negatives measure 37 by 12.7 mm. The image of the spectrum appears upon them upon a ground as clear as glass. It bears a far greater enlargement than is possible with ordinary gelatine plates.

Filling the absorption and emission tubes.—The absorption-tubes were filled at the atmospheric pressure, at first merely by drawing the gas through them for a long time before the final filling. But it was found that the air was not in this way as completely expelled from the tubes as my experiments required, since even a small residue notably altered the transmissivity of the gas concerned. Consequently in the later work, the tubes were pumped out before the gas was allowed to enter, and were then repeatedly washed out with the gas. The connections of the apparatus for the evolution of the different gases with the absorption-tube would have been much easier manipulated if india-rubber could have been used for them. But my experiments showed that such tubing, because of its exhalations, if for no other reason, may introduce such impurities into the tube as to render it not fit for use, giving the spectrum a totally different appearance. I also ascertained that leakage of air was to be feared even with the thickest india-rubber tubes. For example, through an exhausted Para-rubber tube of 40 centimeters length, 1.15 cm. external diameter, and 0.35 cm. internal diameter, 2.4 $(cm.)^3$ of air passed in fifteen hours. But I attribute only a subordinate prejudicial effect to the air that was carried in through this tube along with the gas, because the washing out and filling of the absorption-tube was at that time done at the ordinary pressure, so that but a very small amount of air would enter, and because there was nothing in the appearance of the spectrum as altered by the influence of the rubber to suggest the influence of air. This opinion was confirmed by the circumstance that when this tube of Para-rubber was replaced by a tube of black rubber, such as is often used to make connections of chemical apparatus, the distribution of energy in the spectrum underwent a new change: namely, while with the former tube the spectrum was weakened generally, the use of the black tube completely

annulled the effect of the rays at a wave-length of about 162 $\mu\mu$ through an extended stretch. This behavior of india-rubber led me, in the sequel, to connect the apparatus only with glass tubes and a metallic-screw closing device, which depends upon having optically plane surfaces which are pressed together with great force. I have used this clamp for different purposes and with constant success.

In the preparation of the emission tubes (Geissler tubes), several difficulties arose. The first of these lay in attaching a suitable window; for glass is entirely opaque to such short waves. Quartz is eminently proper for the purpose, and fluor-spar is still more so, since it allows the most refrangible rays to pass freely, which quartz, as is well known, does not. Quartz has the advantage of greater hardness, which is no small consideration owing to the frequency with which the windows have to be taken off and cemented on again. Fluor-spar is relatively soft and in constant use, especially when its surfaces are often cleansed, is hard to preserve from damage. Moreover, there is a circumstance which has narrowly limited its applicability for the windows of Geissler tubes in my experiments. The state of things is this. With Geissler tubes we are led to employ the end-on form for the most refrangible ultra-violet, because it gives a greater emission of light than the cross-wise tubes, and, besides, it is better adapted to the insertion of a plane window. I follow the usual practice of giving such a tube a plane rim at one end upon which the window is readily fastened. But this closure, to be absolutely staunch, is a more difficult matter with the rays here concerned than one would think. The closure must fulfil three conditions, to wit: 1st, it must cut off the photographic energy as little as possible; 2d, it must not soil the purity of the gas in the tube; 3d, it must easily be removed without damage to tube or window. But none of the plans for closing tubes hitherto known satisfy these conditions, not even the grinding out of quartz in the manner published by me in 1886, since, because of its great thickness, it absorbs too much refrangible rays. For my experiments, therefore, a more suitable method of closing had to be invented. Of several processes to which my thorough trials led me, the following has satisfied me best: The rim of the tube and the closing plate, which latter should only be 1 mm. to 2 mm. thick, after being carefully cleaned, are put together and held with a clamp which must not be too large, so that there can be no lateral displacement. Then the joint between the tube and plate around the latter on the outside is to be painted with a thick coat of soluble soda-glass. After two or three hours, when it is dry, a second coat is to be applied. A third would make the tube stauncher, but it is not absolutely necessary. Such a tube will bear the highest exhaustion that a Geissler tube can take, while by scraping away the crust of water-glass with a knife, which is easy, the tube is opened without trouble and readily closed again. The convenient opening and closing is an important point in observations of the ultra-violet, because the inner surface of the quartz window often after a brief use gets a deposit upon it, which partly absorbs the most refrangible rays, and, indeed, sometimes entirely cuts them off, an inconvenience which is the more troublesome because the deposit is generally invisible to the eye. Water-glass proved most

useful with quartz, but did not work well with fluor-spar. In this case, the layer of luting loosens itself, usually in a short time, from the fluor-spar and crumbles away. Of course, this throws doubts upon the security of the closure. It is possible that a much thicker coat than that I used would answer better. I have not, however, tried it, but have employed as luting for the fluor-spar a mixture of white wax and clock-maker's oil, which is spread in a very thin layer forming a band half a millimeter broad, in a ring round the end of the tube. Now pressing down the fluor-spar disk a neat and perfect closure is obtained; and it is loosened even easier than the water-glass. It has, however, the inconvenience of soiling the gas in the tube after long illumination, by producing fatty vapors.

The source of light for the absorption experiments.—The best thing for this purpose would be a Geissler tube which should give a continuous spectrum of equal intensity of energy in all parts. Unfortunately, no single tube meets this requirement completely. The hydrogen tube, however, does so in part, giving a continuous spectrum down to 170 $\mu\mu$, where begins a rich line spectrum of tolerably uniform distribution of energy. Such a tube closed with fluor-spar has given me good service in my absorption experiments, particularly by its continuous spectrum. A merit of it not to be undervalued when long exposures are required, as they sometimes are, is that it has an uncommon photographic brightness. For comparison spectra I have employed the spark-spectra of hydrogen, aluminum, and cadmium, which were photographed beside the absorption-spectra.

The source of light for the emission-spectra.—These spectra were given by Geissler tubes of different shapes and arrangements, closed with quartz. Some of these tubes, after being filled, remain in connection with the air-pump, so that they can readily be emptied and refilled. Others are melted off like ordinary Geissler tubes, before they are attached to the spectrograph. For some investigations, however, none of these tubes will answer. In such cases, Paalzow-Vogel tubes of the Paschen-Runge pattern were preferred. In these, the place for the discharge communicates at both ends through liquid valves, of which one consists of sulphuric acid and the other of a solution of bichromate mixed with sulphuric acid, with which the air-pump is so connected that the pumping out of the tubes can go on unhindered, while the vapors from the mercury and from the grease of the pump-cocks are kept away from it. At the same time, the sulphuric-acid valve of such a tube, of which the receptacle is arranged as an apparatus for evolving hydrogen and oxygen electrolytically, serves to produce the oxygen and hydrogen to fill the tube.

The filling of the tubes has hitherto been limited to

Nitrogen
Oxygen
Water
Carbon monoxide
Carbon dioxide
Hydrogen.

These gases have been in part obtained from the atmosphere, and in part have

been chemically or electrolytically produced. After being carefully purified, they were dried with phosphorus-pentoxide and in some cases with sulphuric acid.

The pressure in the absorption-tubes was equal to the atmospheric pressure at the time. In the emission-tubes, it varied from 0.05 to one centimeter of mercury-pressure.

The electric discharge was effected either by the Ruhmkorff coil alone, or with a Leyden jar, or Leyden jar and spark gap interposed into the circuit, or a Leyden jar and a Hemsalech self-induction coil. The primary current never exceeded 2.5 amperes and 10.5 volts.

Difficulties.—Before I touch upon the results thus far obtained, I must allude to a phenomenon which I encountered as soon as I took my first emission-spectrograms. The fact substantially was this. I photographed the spectrum of a Geissler tube filled with air, and obtained a spectrum of considerable photographic effect compounded of numerous thickly successive bands shading off on the red side. Numerous repetitions of the experiment confirmed the result. I concluded from this that I was dealing with the spectrum of air or, at any rate, of one or more of its ingredients. But when I came to examine the latter separately, as I had done the air, I found that the same supposed air-bands dominated every one of them. With carbon monoxide and carbon dioxide, however, they were much stronger; while with water and hydrogen they were weaker. After comparing these photographs with one another, no room for doubt seemed to remain that these bands belonged to a carbon compound which presumably had been derived from the fat of the air-pump cocks and from the occluded and absorbed gases of the inner wall of the tube. However, increased care in cleaning the tubes and in the production of the gases to fill them, from which I promised myself better success, made no difference; the bands remained as strong as before. Now, in order to keep the air-pump vapors of the cock-fat and mercury completely away from the place of discharge, I exchanged the Geissler tubes, which had up to that time been employed, for Paalzow-Vogel tubes. By way of greater precaution, these tubes, before being used, were cleaned for twelve hours with a solution of bichromate of potassium in concentrated sulphuric acid, to destroy any impurities of organic origin which might be present, and were then repeatedly rinsed out with distilled water, and were forthwith closed with a quartz window and water-glass, and dried by the air-pump, though the two sulphuric-acid valves of the tube itself had in the main effected this. In this way, the penetration into the tubes of particles of dust, which might have occasioned the formation of carbon compounds, was as far as possible prevented. By thereupon washing out the place of discharge with oxygen which was evolved from the sulphuric acid of the electrolytic apparatus belonging to the tube, I promised myself, judging by the visible bands of carbon compounds, the sure attainment of my object. Still, these means too proved without effect. Thereupon the suggestion presented itself that occluded gases from the aluminum electrodes might have caused the bands, and the electrodes were laid aside and replaced by glass cylinders covered with tin-foil. But in spite of all, the bands after this alteration remained intact. The tubes were now furnished with new aluminum

electrodes obtained from another source, but there was no change in the spectra. The bands afterwards, as before, were the regular accompaniments of the photographs of the spectra of hydrogen and of oxygen. As a last attempt in that direction, I shall use a form of Geissler tube which is under construction and which is so arranged that, in the cleaning during exhaustion, a far more energetic heating can be attained than was possible for the tubes previously employed.

It ought not to go unmentioned that all the tubes were observed with a spectroscope both during the cleaning and during the photographing of the spectrum without any impurities making themselves noticeable. This shows how little the visible spectrum can serve as criterion of purity, in filling a tube. The most refrangible ultra-violet is far better adapted to the purpose, and according to my observations, the most sensitive spectral reactions belong to the region of the shortest waves.

Production of the ingredients of air and the spectrographic results.—I pass now to the results directly relating to my investigation. Since these results are not complete, notwithstanding my numerous experiments, I can in this preliminary communication only give the most important of them, and not even those without reserve. For it is clear that, as long as the question of the origin of the supposed bands of oxide of carbon is open, a not inconsiderable measure of uncertainty attaches to them all. Besides this, substantially nothing is known of the part of the spectra of gases to which my observations relate, so that at no point did any information come to me from the scientific literature. Finally it ought not to be forgotten how difficult the analysis of the facts relating to spectra in Geissler tubes has, at all times, been found, and how little we really know about the subject to-day, notwithstanding the fact that scarcely any other part of spectroscopy has occupied so much acumen and gift for observation as the exploration of the spectra of electrical discharge-tubes.

I begin with the spectrum of

Nitrogen.—It was prepared in two ways: first, by passing air over potassium pyrogallate; and, secondly, from potassium nitrate and ammonium chloride. It was dried with phosphorus pentoxide, over which the gas remained standing for some time before it was passed into the tube. Nitrogen proved itself very transparent, even beyond 162 $\mu\mu$; yet it absorbed particular wave-lengths very energetically. Its emission-spectrum consists of a number of groups of bands of moderate photographic power shading off toward the shorter wave-lengths and ending below (that is on the less refrangible side of) 185 $\mu\mu$. The observation of this spectrum is uncommonly interfered with by the bands of carbon monoxide overlying it. Beyond 185 $\mu\mu$, I have been unable to prove any nitrogen bands.

Oxygen.—Electrolytically formed oxygen was exclusively employed. The carbon dioxide which was invariably present in small amount at the beginning of the evolution was eliminated by caustic potash; the aqueous vapor, by phosphorus pentoxide or sulphuric acid. In passing to the absorption-tube, the gas was strongly heated in order to destroy the ozone. Oxygen absorbs the rays in the neighborhood of 185 $\mu\mu$ in a series of clearly resolved groups of lines, fourteen in number. These groups, which are of band-like form, constantly approach nearer one

another with their deviation, and are shaded off toward the red. Complete absorption is found with the most refrangible of them. It is this which makes the air opaque for all rays beyond 185 $\mu\mu$. The presence of a moderate amount of ozone did not alter the absorption at all.

The emission-spectrum of oxygen is compounded of three continuous maxima, of which the most refrangible is the strongest. It lies at about 185 $\mu\mu$. The observation of these maxima is attended with considerable difficulty, on account of their slight photographic efficiency and because of the bands of oxide of carbon which appear with them. It succeeds best with a Paalzow-Vogel tube and 10 to 16 mm. of mercury pressure. With much smaller pressure even these tubes, though completely guarded against fat and mercury, gave dominating bands of carbonic oxide which hardly allowed the oxygen maxima to appear. It is surprising that I have in this region never obtained lines of oxygen. True, traces of them sometimes emerged upon the maximum near 185 $\mu\mu$, but as soon as I tried to bring them out by longer exposure, the bands of carbonic oxide appeared and covered the supposed lines, so as to make them invisible. Nor was it possible, notwithstanding numerous attempts, to bring out more refrangible rays than those of the maximum at about 185 $\mu\mu$. It may well be assumed that the stratum of oxygen between the capillary opening and the window of the Geissler tube contributed to the ill success of this search by its defective transparency. This stratum might be considerably reduced in thickness, were it not that the deposit on the window would then become worse. Now this inconvenience seems to come on earlier with oxygen than with other gases. For that reason, I have not reduced the thickness of the stratum of this gas below 2 cm., though with others I have not hesitated to go down to 1 cm. The deposit on the window takes place very easily with the Paalzow-Vogel tubes, especially if they have an outer covering, and is a very inconvenient adjunct of them. In this case, in a few hours' use, it often goes so far as to produce complete opacity. The opening and reluting of the window thus necessitated is not only a waste of time, but, on account of the filling with sulphuric acid, a very dubious piece of work.

Carbon dioxide.—This gas was prepared by the action of hydrochloric acid upon calcium carbonate. The gas was twice washed with a solution of sodium bicarbonate in water in order to eliminate the hydrochloric-acid vapor. It was dried with phosphorus pentoxide.

The absorption-spectrum of carbon dioxide is similar to that of oxygen. Here, too, there are indications of a rhythmical series in the shape of inverted groups of lines. But the end of this series is considerably more refrangible than that of oxygen. Accordingly, total absorption begins at a shorter wave-length.

The emission-spectrum is overlaid with the bands of carbon monoxide, the unwelcome attendants of all my spectra. Its photographic action is uncommonly strong, and it extends far beyond 162 $\mu\mu$ into the region of the shortest wave-lengths. I doubt not that, were the tubes sufficiently transparent, it could be photographed as far as the hydrogen spectrum extends. For its wealth of lines it stands unrivalled. I have not been able to make sure whether these bands really belong to carbon monoxide or not. The carbon dioxide itself seems not to participate in the photographic effect. For even the freshly filled tubes gave during the first discharges no other spectrum than the later photographs. Since the dissociation of the carbon dioxide, which according to the general assumption precedes these occurrences, is dependent upon the height of the temperature, I have made preparations to institute experiments in which the heat of discharge shall be far below that of the tubes I have hitherto used. I hope, in this way, to obtain better information than I have hitherto concerning the spectral behavior of carbon dioxide.

Carbon monoxide.—This concerns us here less as an ingredient of the atmosphere, which contains it in very small amount, than as one of those impurities of Geissler tubes which have at all times created the greatest obstacle to the spectroscopic investigation of gases. Carbon monoxide was prepared: 1st, from oxalic and sulphuric acids; 2d, from yellow prussiate of potash and sulphuric acid; 3d, from formic and sulphuric acids; and it was then washed with caustic potash solution to retain the sulphur dioxide or the formic acid, as the case might be, as well as traces of carbon dioxide.

Carbon monoxide absorbs the most refrangible rays somewhat less than carbon dioxide, and gives, like oxygen, a series of rhythmical, inverted groups of lines. The clearness and sharpness of these lines are less than with oxygen, but far more perfect than with carbon dioxide.

The emission-spectrum has already been sufficiently considered in treating of that of carbonic dioxide, so that I have nothing to add here upon the subject.

Aqueous vapor.—The filling of the Geissler tube was effected from a small glass vessel with a faucet containing a few drops of distilled water. This vessel was melted on laterally to the tube connecting the Geissler tube with the air-pump. Aqueous vapor was evolved in the absorption-tube by introducing into it before exhaustion a little cup containing a few drops of water. Then, by pumping out the tube repeatedly, it was at last filled with aqueous vapor free from air. Unfortunately this process has not, thus far, led to certain results, in consequence of the deposit of dew. I must, therefore, reserve a report upon this matter until these experiments have been repeated. What takes place in the tube of aqueous vapor is not clear. The spectrum differs according to the mode of discharge. It consists mainly of hydrogen lines, of the oxygen maximum of 185 $\mu\mu$, and of a great number of other lines, concerning which I have not yet been able to make quite sure whether they belong to aqueous vapor or not. Upon these spectra is laid, in addition, the more or less intense spectrum of carbon monoxide. Finally, by a suitable choice of pressure, form of tube, strength of current, and mode of discharge, all these spectra can be greatly weakened and the spectrum of the electrodes of the tube brought out. My numerous observations indicate a regular dissociation of the aqueous vapor into its elements accompanied by a simultaneous recombination to form water. I have been led to this conclusion more particularly by the study of the spectra of certain Geissler tubes which carried an absorption vessel or drying vessel, as the case might be, which was cut off from the proper place of discharge by a mercury valve, the arrangement being such that the vessel could be opened

and closed without trouble by simply turning the tube about its capillary axis. The absorbents used were phosphorus pentoxide, sulphuric acid, and platinum black.

There is a phenomenon which readily comes into play in the Paalzow-Vogel tubes which I regard as affording a more certain proof that oxygen and hydrogen combine under the electric spark even at a pressure of but a few millimeters: namely, if such a tube be filled with a mixture of the two gases, its initial brightness rapidly falls off, and after a short time the tube fluoresces in the highest degree. But the capillary shines forth more or less brightly. The only possible explanation of this phenomenon is that, after oxygen and hydrogen have combined to form water, this is promptly absorbed by the sulphuric acid, which affords a relatively large surface, and that there is consequently a great diminution of pressure, giving rise to the fluorescence. The gases were not mixed by me in equivalent proportions, so that, after the formation of the water, one or other must have remained in excess, and this excess, enjoined with the ineradicable carbon monoxide from the impurities of the tube, would occasion the light in the capillaries. But although I followed these phenomena spectrographically, I have never obtained the lines which, in the other spectra of aqueous vapor, can be regarded as water-lines. Still, a reason for the Paalzow-Vogel tubes not giving these lines may be found in the circumstance that the vapor was too quickly absorbed by the sulphuric acid to give a spectrum for a sufficient time to make an image capable of being photographically developed.

Hydrogen.—Armand Gautier found that this gas in the free state occurs in the air in no negligible proportion. I should, therefore, in any case, have had reason to include it in the list of ingredients of the air here investigated. Besides that, it affords me an admirable comparison spectrum. For none of the spectra with which I have become acquainted beyond 185 $\mu\mu$ has its energy so uniformly distributed and such a wealth of lines as this. Nor is there any that extends so far as that of hydrogen.

The gas was produced from the purest chemicals, sometimes chemically, sometimes electrolytically; and moreover, where it seemed necessary, it was most carefully purified by sodium hydrate, silver sulphate, and potassium hydrate. Particular pains were taken in drying it; for the gas for the final experiments flowed through three successive vessels, filled with phosphorus pentoxide, with stop-cocks in their connections, in such a way as to remain for some time enclosed in each before it was allowed to escape into the next.

The transparency of hydrogen had appeared by my former experiments to be uncommonly great. But my new experience has shown that it is a matter of great difficulty to attain perfect definiteness on this point, since the production of thick strata of pure hydrogen is well-nigh impossible. The walls of the place of absorption will, even with the most scrupulous cleansing, always at last secrete small amounts of gaseous impurities; and these will affect the transparency of hydrogen more proportionately than they would that of other gases, precisely because its transparency is so extraordinarily great. At any rate, it is in that way that I explain the repeated contradictions in the results which I have obtained for the absorption

of this gas at different times. I accordingly abstain from making further statements upon this subject.

The spectrum of hydrogen ends, according to my latest results, far beyond the limit which I obtained in 1893 with the apparatus I then used, and which by a merely estimated wave-length I placed at 100 $\mu\mu$. This estimate, as will be later known, was by no means correct. The number of lines in the photograph, which, magnified 20 times, has a length of 1.4 meters, and of which a portion is shown in Plates I–III, I estimate as at least 1500. Hydrogen develops its highest photographic efficiency at 162 $\mu\mu$. At the supposed wave-length of 100 $\mu\mu$ its effect suddenly diminishes, and this is still more marked if in the path of the light from the tube to the photographic plate, one or more fluor-spar plates are interposed, a thing which the arrangements of the apparatus not infrequently call for. A single such plate 1 mm. thick may weaken the photographic effect at 100 $\mu\mu$ by one half. The thickness of the plate is a secondary matter, for the loss of light depends chiefly upon the number of reflecting surfaces. We may conjecture that the cause of the enfeeblement lies in metallic reflection, possibly aided by absorption of light exercised by gases which these surfaces condense. The weakening is by no means limited to the region mentioned, but with longer waves it is greatly diminished. It may be conjectured that, on the other hand, it increases with shorter waves.

I proceed to give photographic reproductions twenty times enlarged from my photographed spectra. They are the only photographs of the hydrogen spectrum which have been obtained up to this time *in vacuo* or in an atmosphere of hydrogen. In consideration of the not inconsiderable difficulties which had to be overcome in their production, and which still oppose the repetition of the experiments, it may not be deemed superfluous to enter into the details of the taking of this photograph further than, for ordinary photographs of spectra, is either necessary or usual. Vacuum-spectrography can be accomplished even now only under conditions of great difficulty.

The spectrum that is mapped is that of the light of an end-on Geissler tube with a narrow capillary, such as is shown in Spectrum 5, Plate II. This tube was connected with the collimator of the spectrograph. The four originals of the first eight enlarged photographs of this spectral series were obtained with a fluor-spar window interposed between the tube and the collimator. The other four were made without the window, since the spectra that they show would be unduly weakened by the window, and the time of exposure thus rendered extraordinarily long. In the former case, with the window in, the tube and spectrograph could be filled and exhausted independently of one another. But in the latter case, where tube and spectrograph were in communication through the open hole in the slit-cover, both contained hydrogen at such a pressure as the electrical discharge demanded. Since this pressure is only that of some centimeters of mercury, at highest, and since hydrogen is very transparent, since the depth of hydrogen through which the rays had to travel was only 30 cm., since the deviation of the rays by the hydrogen must have been extremely small owing to its small refractivity, and the taking up of any impurities by the hydrogen in the interior of

the spectrograph could not seriously be feared, considering the many years during which it has been in use, I do not think that any of these sources of error can be supposed to have affected the correctness and purity of the photographs obtained.

The rays in their passage to the photographic plate traversed a hydrogen atmosphere of moderate density, and not the exhausted interior of the spectrograph only. For the first five photographs, the gas, most scrupulously purified and dried, was led directly into the discharge-tube, and thence into the air-pump. In this way the tube was continuously traversed and eventually filled with gas which must have been either altogether or very nearly free from mercurial vapor. For the other seven photographs the hydrogen, obtained by the action of the purest zinc upon the purest sulphuric acid, and afterward dried, was led through two meters of the air-pump tubing before entering the spectrograph and thence into the Geissler tube. Consequently, it could not, in this case, be so free from mercury as in the other. I have not, however, been able to perceive any particular disadvantage from the presence of the greater amount of mercury.

The induction-current was given by a Ruhmkorff coil, fed by 5 Grove cells and giving sparks 25 cm. long. The effective rays from the tube[1] traversed successively the fluor-spar window, the collimator-slit, the first lens, a 60° prism, and the second lens, over against which was the plate sensitive to ultra-violet light. The lenses and prism are composed of white fluorite. The lenses were plano-convex and had the same focal length, namely, 120 mm. for sodium yellow. The equality of the focal lengths made proper positions of the lenses to be at equal distances, the one from the slit and the other from the mid-plate. Since the refrangibility of the short-wave rays increases very fast in fluor-spar with decreasing wave-length, the focus rapidly shortens with the wave-length. The consequence is that the scale of the image of the line diminishes from the less refrangible to the more refrangible end of a photograph. In photographs patched together to show a long stretch of the spectrum this difference of scale makes itself unpleasantly noticeable, owing to the varying breadth. But on such short photographs as these of the hydrogen spectrum it may be neglected.

When there was no particular reason for placing the prism symmetrically to the course of certain rays, the rule was to give their minimum deviation to the most refrangible lines of the part of the spectrum to be photographed at one exposure; for this is the only way to get a uniformly sharp definition throughout the stretch photographed. If rays are to traverse the prism symmetrically, it will only be necessary, while preserving the equality of the foci of the two lenses and the minimum of deviation, to turn the camera-tube until those rays fall on the middle of the plate. For, as Fig. 9 shows, the camera is so constructed that, whatever may be the angle between the plane of the photographic plate and the axis of the lens, this axis must always cut the mid-vertical of the sensitive side of the plate, which coincides with the geometrical axis of the camera-cone. The considerable obliquity of the plate to the axis of the lens has, along with the advantage of about

[1] To protect the window from possible heating, the electrode farther away from the slit was made the cathode.

doubling the image of the spectrum, the disadvantage of rendering the operation of focussing difficult, inasmuch as the image of the slit partakes of the same enlargement; so that, for example, the breadth of lines of about 185 $\mu\mu$ will be somewhat more than double the width of the slit, while lines of about the shortest wave-length hitherto photographed will be somewhat less than double the width of the slit. The edges of such a broadened spectral line correspond accordingly to two different focal distances. This difference becomes proportionately more noticeable the wider the slit and the shorter the focus. Since in my hydrogen photographs foci down to 70 mm. occur and a width of slit of 0.010 mm. corresponds nearly to a difference of focus of 0.02 mm., it might be concluded that under circumstances so unfavorable no spectra good for anything could be produced. Nevertheless photographs of this sort are clearer than might be expected. The reason is that with this relatively wide slit the scattering of the rays by diffraction is of less importance than with narrower slits, although with the latter the disadvantage of the difference of foci of the two edges is not noticeable. I shall return to the subject below. But a more serious difficulty arises from this cause; and an acquaintance with it is desirable in adjusting a vacuum-spectrograph for the different photographic fields within its reach. The state of things is this: Before a vacuum-spectrograph is set to its regular work, it should be calibrated. That is to say, for each photographic field the following constants should be definitively determined: the focal distances, the minimum deviation, the angle between the two optical axes, the angle between the sensitive plate and the optical axis of the telescope. I distinguish, for my apparatus, nine such photographic fields beyond 185 $\mu\mu$. Suppose, now, that the observer has gone through with this arduous task of calibrating his spectrograph for its entire range, and has performed it with a somewhat wide slit; for to save time in the exposures he will naturally prefer to do it so. He will take, let us say, a width of 0.01 mm., and although his slit opens unsymmetrically, he will assume that this same adjustment is applicable for narrower slits. But with these he will find that the greatest sharpness of image has not the focus found for the wider slit, but a somewhat different one; that, moreover, for the attainment of the highest sharpness of images the lenses can now be adjusted incomparably more finely; and finally, that the useful part of the spectrum has materially suffered in length. The principal cause of this phenomenon is the oblique position of the photographic plate with reference to the optical axis; but the unsymmetrical variation of the slit-width, that is, the assumed fact that the slit-carriage has only one movable jaw, aggravates it. It might seem that the difficulty could be obviated by a symmetrical slit. But little could be gained in that way; since the symmetrical motion of the slit-jaws with a slit of a micron's width will present to the instrument-maker insuperable difficulties, as I have sufficiently convinced myself by extensive experiments with slits of the highest precision I could construct.

The reason why, with a plate standing obliquely to the optical axis, the focus depends upon the width of the slit, appears from the following considerations: Suppose the focus for any spectral line has been ascertained with a very narrow

slit, say for a slit of width 0.001 mm.; and it is proposed to photograph the same line with unaltered setting, but with a slit of width 0.005 mm.; then undoubtedly that border of the line which corresponds to the stationary edge of the slit would remain in focus, and retain its original sharpness, while the other, since the altered position of the slit-edge corresponds to a different focus, and its image consequently no longer falls within the sensitive film, would become less sharp, and the less so, the more the slit is widened. A good photograph, in short, can now only be obtained after a new focussing has rendered the two edges of the line equally hazy.

Of course, as far as resolution is concerned, photographs taken with a wide slit are greatly inferior to those with fine slits. When the fineness of single lines is desired, as in the measurement of wave-lengths, or the resolution of dense groups of lines, the slit must be narrowed to its utmost. In such cases, I have gone down from several microns to a single micron. Good results of this sort can only be expected with faultlessly linear and sharp-edged slit-jaws. Rounded slit-edges and those formed by little planes, such as are found in the majority of spectrometers, are not adapted to the purpose, since the image of the slit is broadened by the light reflected from the sides, and consequently their resolving power is greatly injured. The duration of exposure and that of development must, if the desired fineness and sharpness of the image is to be attained, be scrupulously adapted to this purpose. Otherwise, the line will be too thin or broadened by diffraction to utter worthlessness. But with some painstaking one soon succeeds in photographing lines so fine that they are only formed of one or two rows of grains of silver somewhat coarser than the average and, it must be admitted, not quite regularly distributed. The hydrogen spectrum shown affords some examples of this kind. But let it be expressly noted that the spectrum, with all its lines, can never be successfully photographed with slits of 1 μ or 2 μ, supposing that it contains many thickly crowded lines of very different intensity. The stronger lines, with a time of exposure suited to the weaker ones, acquire great broadening, giving them a washed-out look unadapted to measurement. This is my reason for photographing every one of the fields in the spectrum of hydrogen four times over with increasing time of exposure and sometimes with widened slit. This proceeding is the best adapted for carrying the resolving effect of a vacuum-spectroscope of such slight dispersive power to its highest. If we compare the dispersion of this prism-spectrograph in the most refrangible ultra-violet with that of a grating-spectrograph, the latter will turn out, notwithstanding its considerably longer focus, but moderately superior. A numerical example will best show this. In the vacuum-spectrograph, when the aluminum lines at 1989.90 and 1854.09 Angström units (focal length *in vacuo* 106.75 mm.), with a 60° prism appear at the middle of the plate, they are separated by a distance of 5.8 mm. from one another, while in the spectrum of the first order of a grating spectroscope belonging to me (having a concave grating of 106 cm. radius and 14,439 lines to the inch), they are separated by 8.2 mm. as measured on Rowland's circle. With increasing refrangibility this ratio varies more and more to the advantage of the prismatic spectrum, so that for the shortest wave-lengths it is superior in dispersion to the grating spectrum of the first order.

In the spectra shown in Plates I–III (spectra 1 to 12) the refrangibility increases from left to right and with the numbering of the strips. It begins, at the least refrangible end, with a continuous spectrum of weak intensity, after which come, first, some faint lines, but then numerous and remarkably strong lines. The continuous spectrum, which is a peculiarity of hydrogen, reaches down without interruption from here to the line 369.9 $\mu\mu$ (Ames). The few lines that are found in it probably belong, not to hydrogen, but to slight impurities of it, among which mercurial vapor from the air-pump may well be the chief. Some spectroscopists incline to regard the continuous spectrum itself as a consequence of these impurities, but I am unable to bring myself to this view because of many experiments with very pure gases and with different tubes. It must not, however, be concealed that the intensity of the continuous spectrum is connected with the purity of the filling of the tube. The more scrupulously the gas within the Geissler tube is purified, the weaker becomes the continuous spectrum. But I have never been able to bring about its complete disappearance provided the exposure was long enough.

The numbers in the table on p. 24 will serve as an approximate measure of the photographic activity of these rays on the one hand and of the sensitiveness of the ultra-violet plate on the other.

The first column refers to numbers in my spectroscopic journal.

The "camera-angle" is the angle between the plane of the photographic plate and the optical axis of the camera-lens.

The lines of exposure refer to the taking of the original negatives of the four parts of the plate.

The width of the slit was altered by movement of one jaw only, and the effect of this asymmetry is plainly visible in the photographs.

The values given for the current are merely the values without the coil, when it was short-circuited. These, as well as the times of exposure, are merely given so that differences in the different photographs should not be attributed to variation either of the energy of the rays or of the width of the slit.

The first eight enlargements correspond to only four originals, as each of these originals is twice as long as those of the last four. This is due to the fact that the image for the first two thirds of the spectrum is much flatter than for the last third and so permits photographs twice as long.

The enlargements were performed with a projection-combination with an aperture of 75 mm. by Carl Zeis of Jena. It is the most perfect objective for this purpose in the world.

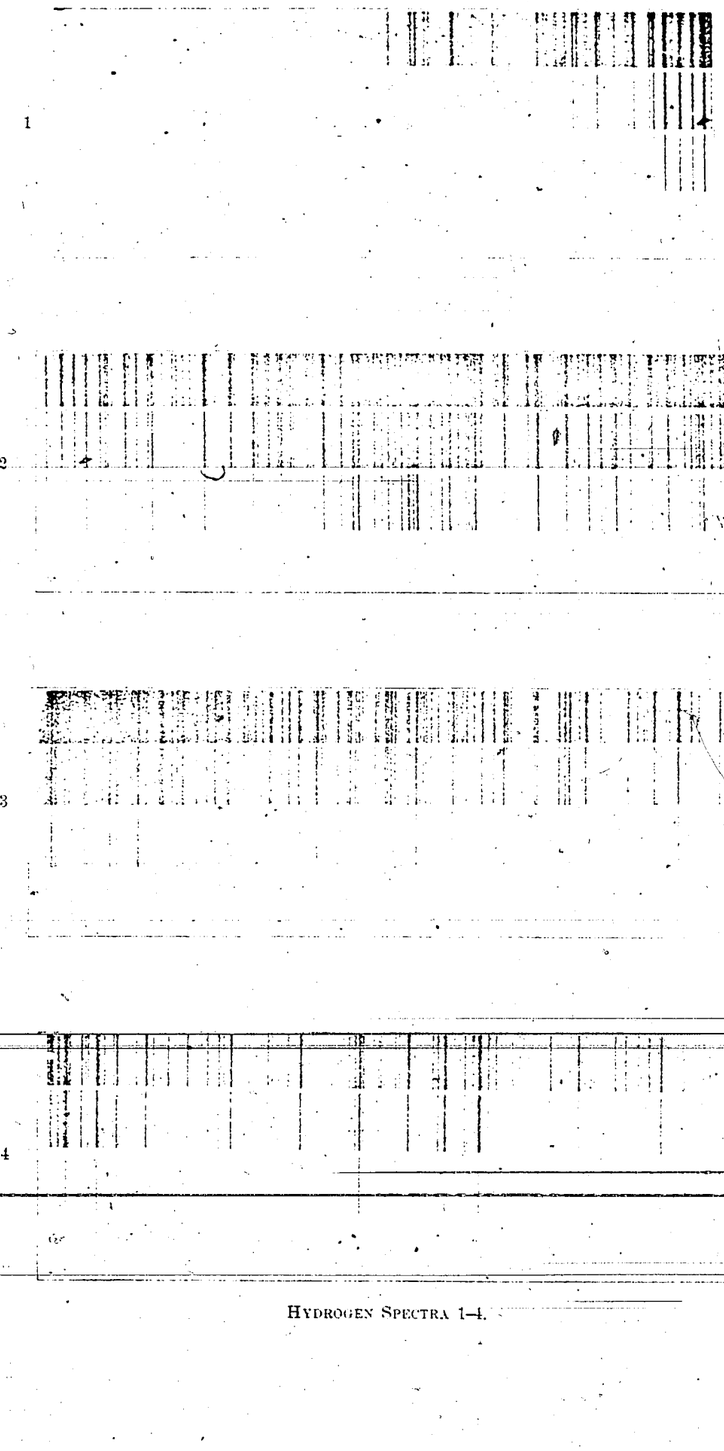
The dots and little spots are on the originals, being due to slight defects of the coating of the plates which belonged to the method of making them that I still employed in 1895, when these spectra were photographed.[1]

[1] V. Schumann: On an improved process for making sensitive plates for the ultra-violet. *Annalen der Physik*, vol. v., pp. 349–374, 1901.

Fourfold original.	Camera-angle.	Exposure.	Width of slit.	Ampères.	Volts.	No. of the Enlargement.
4116	22°.5	1 5 min. 2 2 " 3 50 sec. 4 50 "	0.0038 mm. " " " " 0.0013 "	13.5	7.7	1 and 2
4125	25°.75	1 20 min. 2 8 " 3 2 " 4 45 sec.	1.0025 mm. " " " " " "	8.0	7.7	3 and 4
4130	27°.25	1 20 min. 2 6 " 3 2 " 4 1 "	0.0038 mm. " " " " " "	21.5	8.1	5 and 6
4138	29°.0	1 50 min. 2 20 " 3 8 " 4 3 "	0.0050 mm. " " " " " "	13.9	7.8	7 and 8
4179	32°.5	1 20 min. 2 10 " 3 5 " 4 2 "	" " " " " " " "	25.5	7.6	9
4186	34°.0	1 45 min. 2 16 " 3 8 " 4 4 "	0.0063 mm. " " " " " "	16.0	7.5	10
4194	36°.0	1 35 min. 2 16 " 3 8 " 4 4 "	0.0075 mm. " " " " " "	24.5	7.5	11
4199	38°.0	1 60 min. 2 25 " 3 10 " 4 4 "	" " " " " " " "	16.0	7.5	12

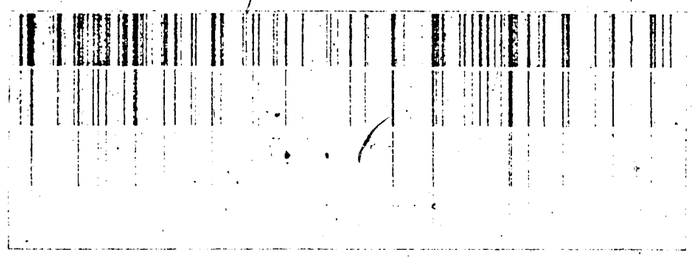
OF THE LIMIT OF THE KNOWN HYDROGEN SPECTRUM.

I have been able to follow the hydrogen spectrum for about 6° beyond the last of the spectral series of Plates I–III; but hitherto not with sufficient clearness for reproduction. The most perfect of my photographs of this region (No. 4222) is not clearly enough defined to bear a twenty-fold enlargement. Accordingly, they may here receive a merely verbal treatment. At first, with all my pains, I was able only to secure traces of some blurred lines. It was not until I interchanged the

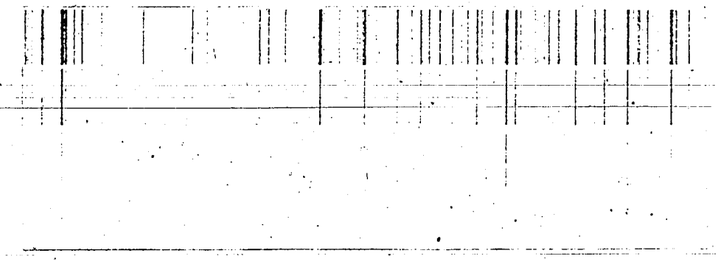


HYDROGEN SPECTRA 1–4.

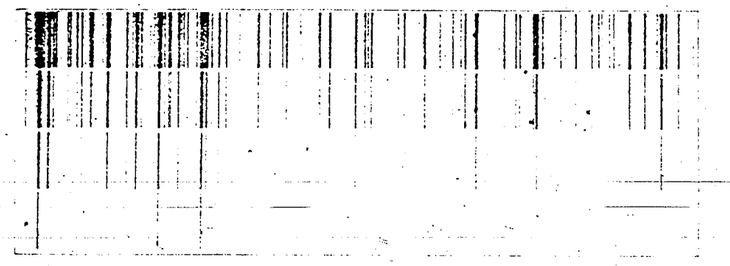
5



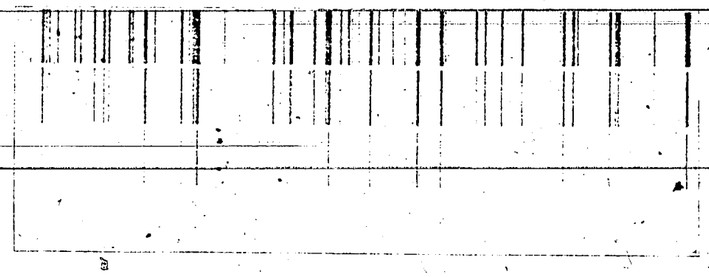
6



7

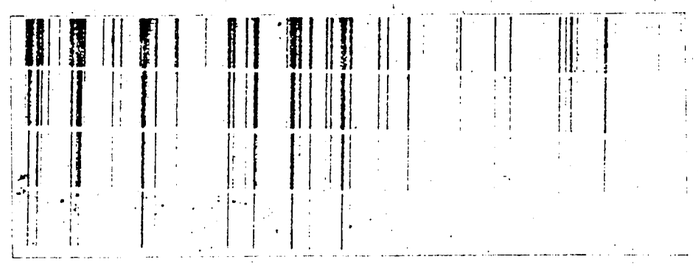


8

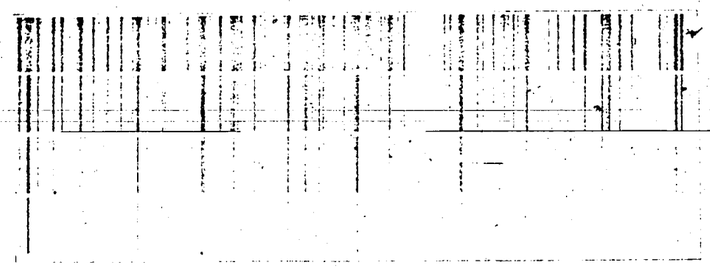


HYDROGEN SPECTRA 5-8.

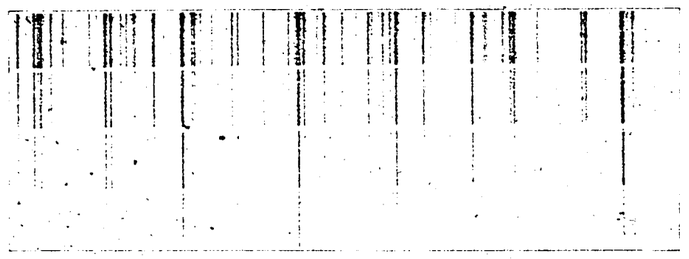
9



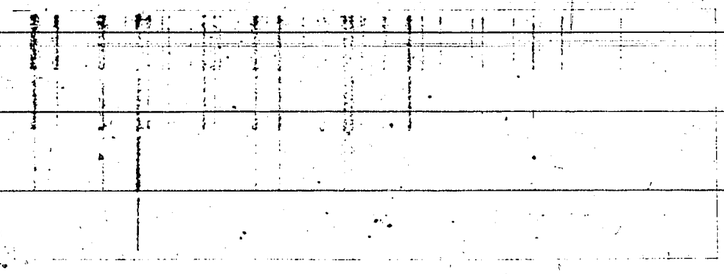
10



11



12



HYDROGEN SPECTRA 9-12.

electrodes, taking for the cathode (which with all the other photographs had been at the distant end of the tube) the electrode nearest the slit, that I got any better results. It appears, therefore (and this is confirmed by all repetitions) that the cathode-light of hydrogen, under existing circumstances, contains more refrangible and active rays than the anode-light.

Why do my hydrogen photographs end at this place? For all essays to photograph more refrangible rays with a 60° prism came to naught. I can find the reason for it neither in the want of energy of the rays nor in the insufficient sensitiveness of the ultra-violet plate. Nor can I attribute it to metallic reflection, since this concerns decidedly shorter waves than these with which we have here to do. I suspect rather that this limitation of the effect of my spectroscope is due to the approach to grazing incidence of the rays upon the prism. For I met with a similar reduction of energy with my former 70° prism; yet afterwards when I came to repeat the photographs with a 60° prism I found the spectrum considerably strengthened. It is therefore to be expected that a still further diminution of the refracting angle will lead to the photographing of still shorter rays of hydrogen.

OF THE WAVE-LENGTHS BEYOND 185 $\mu\mu$.

Information as to the wave-lengths of the new region would be of particular interest. The difficulties of measuring them are, however, so great that neither I nor others have succeeded in overcoming them. The wave-length 162 $\mu\mu$ to which I arrived in 1892[1] was but the result of a first essay; and the apparatus I then had was so far from perfect that this determination is hardly sufficient. Last year, Mr. F. F. Martens[2] took up the question, and resting upon the Ketteler-Helmholtz dispersion-formula deduced from the angle of 21°, which is the difference in deviation between the middle of my most refrangible field and the last aluminum-line at 185.4 $\mu\mu$, calculated the wave-length of that place in my last photograph to be 125 $\mu\mu$, but this should probably be 2 $\mu\mu$ higher. It is inaccurate to say, as Mr. Martens does, that this is the wave-length of the most refrangible ray photographed by me; since the deviation of 21° refers to the middle of spectral field in question, and the most refrangible line is deviated about 6° more; which should have been taken into account in the computation. My most refracted line has therefore a wave-length decidedly less than 127 $\mu\mu$. It must, however, be confessed that my estimate of 1893[3] of 100 $\mu\mu$ was too hasty; since it appears that even now I have not got down quite to that point.

OF THE VACUUM APPARATUS FOR THE MEASUREMENT OF WAVE-LENGTHS.

If, in Nos. 1 and 9, Plates I–III, of the spectrograph, the prism be replaced by a plane reflecting grating and the collimator and camera by two air-tight tubes arranged

[1] *Sitzungsberichte d. kaiserl. Akademie d. Wissensch. in Wien; math.-naturw. Classe*, vol. cii, Part IIa, pp. 625–694, 1893.

[2] *Annalen der Physik*, 1901, Heft II, p. 619.

[3] *Sitzungsber. d. kaiserl. Akad. d. Wissensch. in Wien; math.-naturw. Classe*, vol. cii, Part IIa, p. 677, 1893.

for the measurement of wave-lengths, the wave-lengths can be determined by grating and lens, according to the method devised by Cornu and applied by Liveing and Dewar. It is a method of coincidences resting upon the fact that the wave-lengths of two lines which coincide in the axis of the lens are inversely proportional to the numerical orders of the spectra. This method has the advantage of not requiring any ray-filter, such as is required with a concave grating for the separation of mixed spectra. For in my case, the lens not being achromatic, the spectra do not at all coincide, being separated by the considerable difference of their foci. This is an important advantage; for we are acquainted with no suitable filter for these short-wave rays, and a search for such a filter could hardly fail to be a very laborious task indeed. Unfortunately, there is a serious drawback to the advantages of this grating-and-lens method in the circumstance that the one of the two spectra which is sharply focussed is so frequently overlaid with the out-of-focus spectra as to be doubtful. This, of course, will prevent the lines which so suffer from being employed for measurement. The operation, moreover, takes up a great deal of time. Every determination of a wave-length requires a series of photographs which because of numerous particular observations occupies from 5 to 8 hours.

The following remarks relate to the suitable arrangement of the two tubes for measuring wave-lengths *in vacuo*. The slit-jaws are micrometrically movable independently of one another, so that the slit may be symmetrically widened and narrowed. It thus becomes possible, in case the lines to be compared demand very different exposures, to shorten the exposure of the weaker line by symmetrically widening the slit. A rotating shutter is provided for half closing the slit at times. The camera-tube carries the camera with a plate-holder for plates of 12 mm. square. The plate-holder during the photographing is carried by a slide which is vertically movable both micrometrically and by the free hand, and which is also capable of being turned over in the plane of the plate very accurately through 180°, about the optical axis of the camera lens as its axis of rotation. This is requisite in order to ascertain the point at which that optical axis cuts the plane of the plate. Special care has been taken to secure accurate centering of the lenses and their draw-tubes, on which the accuracy of the measures essentially depends.

Whenever the intensity of light is sufficient, the concave grating should be preferred in the determination of wave-lengths. It is important that with it there is but a single surface at which the intensity of the rays is reduced. For the fewer times the light is weakened, the stronger it will be when it reaches the photographic plate, other things being equal. Now the more energetically the extreme ultra-violet light acts upon the photographic plate, the easier it will be to obtain photographs of this light. Nor ought it to be forgotten that these short-wave rays suffer much more by reflection than do long-wave rays. My recommendation of the concave grating stipulates two provisos, viz.: 1st, that the material of the grating should sufficiently reflect these short-wave rays; and 2d, that the grating-spectrum should be sufficiently bright in this part. My photographs with plane grating and lens prove that speculum-metal does in fact sufficiently reflect the short waves. But the second condition relates to an individual character of the grating selected for

use. It must be tested by special photographs made for this purpose. For such test a vacuum-spectrograph of suitable dimensions is required. There is no shorter way to the ascertainment of the serviceableness of a diffraction grating for use in the ultra-violet.

The body of the spectrograph should be so constructed as to afford the broadest guarantee for its air-tightness. Moreover, there should be no flexure upon exhaustion. Should there be flexure, however, it is still possible to obtain useful photographs under unaltered pressure, since to this would correspond a constant bending. But should leakage or any other cause alter the pressure fallacious results would be obtained, in consequence of the shifting of lines due to the bending of the apparatus. The exterior best adapted to such a spectrograph would be that of a tube having its walls not too thin and composed of drawn or rolled material. For a tube presents equal resistance to outward pressure, and therefore, supposing its walls to be equally strong, and to be subjected to equal pressure in all directions, will show the smallest bending. A tube drawn of brass or a Mannesmann tube of steel is preferable to a cast tube on account of its greater homogeneity. The open ends must be closed with permanent covers. At one end the concave grating should be set up so as to be capable of rotation about its mid-ruling as an axis, while at the other end should be the slit-carriage, movable in the direction of the rays. To one side of the slit there should be a horizontal slot in the cover of the tube, giving exit to the rays coming back from the grating. Before this slot there should move vertically an air-tight slide containing the plate-holder, so that a series of photographs could be taken one under the other without altering the pressure within. The focussing of the different photographic fields would have to be effected by displacement of the slit-carriage, which to this end must be provided with a sufficiently long air-tight draw-tube.

The most important part of the whole apparatus is the slide carrying the plate-holder. Upon the sufficiency and permanence of its air-tightness depends the minimum pressure obtainable by exhaustion of the apparatus and thus the success and the cost in time of the photographs. But the displacement of the plate and the prevention of the entrance of air when it is taken out are not the only purposes subserved by the plate-holder slide. It has also to make it possible to exhaust the air that comes in with the plate before the latter is exposed to the light. For it is clear that this small quantum of air can be removed much more quickly from the narrow space of the interior of the slide than from an apparatus of many liters' volume. The plate should not be brought before the air-slot until in this way the slide and the plate-holder have been exhausted. Thus when the apparatus has once been exhausted, supposing its other parts to hold, it will only have to be thoroughly pumped out now and then. I must not, however, be understood to assert that in this way the vacuum will hold in the spectrograph for weeks or even for days, as a good mercurial pump, for example, will. Such a degree of tightness is not often met with among vacuum-spectrographs. At best, it will be necessary to pump a little after every change of plate in order to remove gas that has been set free; as, for example, absorbed air. Even when the closing surfaces have been

treated with the most scrupulous care and the material is faultlessly tight, small amounts of absorbed gas little by little get set free. In the same way, some air diffuses in through the grease film as soon as it has been for some time in use; and the inflow becomes continually greater the longer the apparatus is left to itself without being pumped out.

All this shows how little any apparatus without such a slide or other equivalent contrivance can be recommended for the investigation of the ultra-violet.

The arrangement of the slide is founded on the supposition that only uncurved plates of moderate length are to be used. It would be desirable, however, for a better general view of the whole region to be photographed as well as for the sake of saving some of the time lost during exposures, to be able to photograph at a single exposure a greater extent of the spectrum, if possible, the entire sensitive region of the plate. In this way, we might perhaps photograph at once the whole spectrum from the cyan blue to wave-length 100 $\mu\mu$ or indeed still farther. The great curvature of the photographic plate which would be requisite could be obtained with ordinary plates, as is well enough known, by means of a film or of mica. Not so with ultra-violet plates, since the preparation of their coating is greatly affected by any unevenness of the surface to be coated, from which films are far from free and even sheets of mica are not sufficiently so; for the coating is deposited thicker in depressions and thinner on elevations of the surface, giving rise to differences of sensitiveness as well as to other defects.[1] Even if one is willing to overlook these inconveniences and to content himself with graphically less perfect spectrograms, or if the process of preparation of ultra-violet plates could be improved in this respect, the inconvenience of the varying activity of the spectrum in different spectral regions will still subsist. Judging by my prismatic photographs this variation is greatest in the ultra-violet, that is, precisely in the part which requires to be photographed *in vacuo*. The consequence would be that the most active regions would be greatly over-exposed before the weaker parts became developable at all, and as a result partial photographs would again have to be reverted to. I cannot therefore advise the employment of long plates, particularly since, for constructive reasons, the advantages of the slide would thus disappear, and at every change of plates the spectrograph would fill with air and would have to be pumped out. In like manner the employment of gratings of long radius is not unhesitatingly to be adopted where the ultra-violet is to be observed to its most refrangible rays. For there is here the unavoidable difficulty of absorption, however far the exhaustion be carried, owing to the small residue of air as well as the vapors from the air-pump; the absorption, of course, being much greater with the long distance which the rays have to traverse owing to the long radius of the grating. This obstacle of absorption is the reason why the shortest wave-lengths are incomparably more easily investigated with short foci than with larger apparatus.

Air.—I must pass over my observations of the emission-spectrum of air, on

[1] V. Schumann: On an improved method for the preparation of ultra-violet plates. *Annalen der Physik*, vol. v, pp. 349–374, 1901.

account of the bands of carbon monoxide which thus far have made up the whole. Nor is there ground for confident hope that better success will be met with in the sequel. For with low pressure, where success was most confidently to be anticipated, these bands appear irrepressibly in their full force; and with higher pressure the absorption, as I shall presently show, is so marked that the attempt to get an extended air-spectrum in this way promises little. The increased absorption which follows higher pressure might, indeed, be avoided by reducing the thickness of the stratum; but in that case the window of the tube would be so near the capillary orifice that in a very short time the deposit upon it would produce complete opacity.

Information regarding the transparency of air is easier to obtain. All the old investigations upon this subject were limited to strata of considerable thickness, but I have extended my observations to very thin layers. This was suggested by the fact, long ago repeatedly ascertained by me, that the rays beyond 185 $\mu\mu$ were remarkably weakened even by strata less than 1 cm. thick. Since then, notable data concerning the behavior of thin layers of air have come to light, and since I have occupied myself more with this matter than with others, it is proper that I should here confine myself to this.

The above described absorption-apparatus, Fig. 10, was used for the production of the thin strata of air. From the negatives which I obtained with it, I take two and give photographic reproductions of them magnified fourfold.

In one plate (No. 5941), *A*, Plate IV, the thickness of the stratum of air was 15 mm., 14 mm., . . . 3 mm., 2 mm., 1 mm., 0.5 mm., 0.25 mm., 0.10 mm.; while the time of exposure was in every case 1 minute, and the width of the slit 0.020 mm. The Geissler tube was filled with dry air at a pressure of $\frac{1}{4}$ mm., and before photographing, electric discharges were passed through it for some time. Without this precaution the source of light would be wanting in the requisite constancy. The first eight spectra, with thicknesses of 15 mm. to 8 mm., end, without any material gain in length, at the wave-length 178 $\mu\mu$. The exposures following extend beyond that wave-length; yet the stratum of thickness 4 mm. first allows the band at 170 $\mu\mu$ to appear. From that point the gain in length of spectrum with diminution of thickness of the stratum is more rapid; and with a stratum of 0.5 mm. the spectrum runs to the end of the plate, corresponding to wave-length 163 $\mu\mu$. The last two strata of the series of thicknesses 0.25 mm. and 0.10 mm. give spectra of considerably increasing intensity, and the inference that the photographed spectra would be longer is confirmed by *C*, Plate IV. These two spectra show more than any of the foregoing how energetically the air absorbs these rays. For better orientation, I add to *A*, Plate IV, a small series of spectra (No. 6066), *B*, of which the uppermost band-spectrum is similar to the uppermost of *A*, while beneath the banded spectra appear the most refrangible lines of the spectrum of aluminum, at 1989.90, 1935.29, 1862.20, and 1854.09 Angström units.

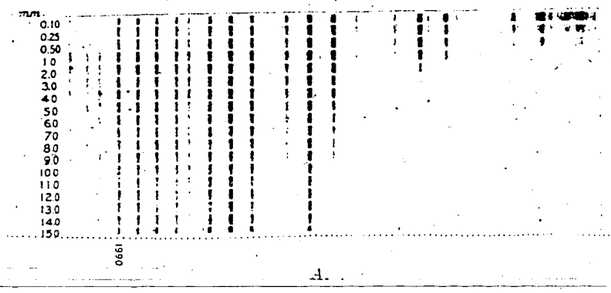
Plainly, a longer exposure would extend the photographic spectra to shorter wave-lengths; and this is confirmed by another plate (No. 5935), *C*, where the exposure was for two minutes, the width of slit 0.020 mm. as before, and the

thicknesses of strata of air, 0.05 mm., 0.1 mm., 0.2 mm., 0.4 mm., 0.6 mm., 0.8 mm., 1.0 mm. Unfortunately, the wave-lengths beyond 160 $\mu\mu$ being unknown, I am not in condition to state exactly the limits of these spectra. But it will suffice to compare their lengths to show how enormously thin strata of air absorb rays more refrangible than those of wave-length 160 $\mu\mu$. This fact is most evident in the comparison of the effects of strata of thicknesses of 0.1 mm. and 0.2 mm.; for this difference corresponds to a considerable difference in the extension of the spectra. Even the reduction of the thickness from 0.1 mm. to 0.05 mm. results in a very perceptible increase of the energy. It is true that this is not very well shown by *C*, because the most refrangible lines, for which the increase of energy is most marked, have not sufficient intensity to bear the fourfold magnification, so that they disappear entirely from *C*. I believe, however, that I shall not exaggerate if I say that the increase of the thickness of the stratum from 0.05 mm. to 0.1 mm. involves a loss of 50 % of the energy.

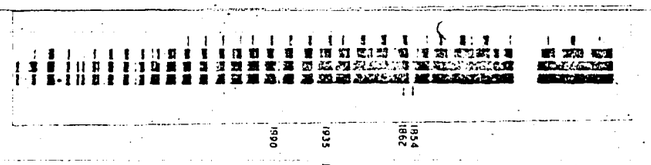
The spectrum of the Geissler tube filled with air, owing to the discontinuity of its spectrum, never shows the absorption-bands near 185 $\mu\mu$ due to the oxygen, which appear so clearly when the tube is filled with hydrogen.

Considering the value which an acquaintance with continuous spectra has for absorption-spectroscopy, and in view of the difficulty of searching out suitable sources of light, let me refer to a discharge-tube with which I made many emission-experiments in 1886. It was an end-on tube with an uncommonly narrow capillary — about $\frac{1}{2}$ or $\frac{1}{3}$ mm. wide. If such a tube is exhausted until no discharge will pass through it, or even until it fluoresces strongly, then as soon as a Leyden jar and a spark-gap are inserted in the secondary circuit of a powerful Ruhmkorff coil, it gives an uncommonly bright light of a white color. If the spectrum of this longitudinally emergent light is photographed with correct arrangements, one obtains, instead of a line-spectrum, a continuous spectrum in which, at most, a few traces of washed-out lines are remarked. Sometimes the continuous spectrum enters only as a stripe, several millimeters broad, running the length of the line-spectrum. In both cases this continuous spectrum is well adapted to absorption-experiments in which occur lines and especially groups of lines like those of oxygen. The photographic action of this capillary light is very powerful. Unhappily these tubes are of shorter life than those of the usual caliber. The spark widens the narrow opening by degrees, and with the widening the photographic energy diminishes, and worst of all, it then ceases to be so easy to convert the line-spectrum into a continuous spectrum.

LEIPZIG, January 19, 1901.



A.



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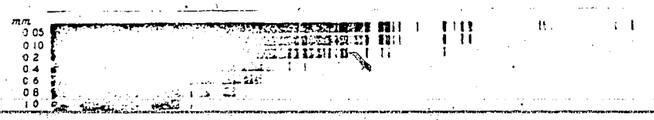

C.

AIR ABSORPTION SPECTRA.

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