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Greene.

Effect of Temperature, Density, and Strength
of Electric Current on the Spectra of Gases.

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E F F E C T O F
T E M P E R A T U R E , D E N S I T Y , A N D S T R E N G T H
O F E L E C T R I C C U R R E N T
O N T H E S P E C T R A O F G A S E S .

—++—

When the infant first opens his eyes upon the world, he receives as a first sense impression the sensation of vision. He does not understand nor does he behold with amazement, the wide expanse before him, but gazes upon the wonderful with as much thought as the dreamer who, in abstraction, looks out from himself when but partly awakened from his deep sleep.

But as time begins to mature his thoughts, he becomes conscious of light and darkness as respecting his own daily conveniences. However, he has not yet asked what light is, but thinks of it only for its utility. Nor does he note but few of the most obvious phenomena which are wrapped in its beautiful folds.

Light may be defined as that vibration of the ether which, acting on the organ of sight, produces in us the sensation of vision. But when, on reflection, we realize that the sense of sight is the most useful of all man's senses, and recall to mind how slowly we have come to understand that kind of energy which makes the organ of sight so useful, then we are prone to exclaim, How strange that man through all the many centuries should be totally ignorant of the various phenomena of light, the study of which has been the revelation to him of so many hidden mysteries!

Man has long ago ceased to be silently content with the

answer that it is the god of day or the god of night that has wrought this or that object of wonder. "In wonder all philosophy began; in wonder it ends; and admiration fills up the interspace. , But the first wonder is the offspring of ignorance; the last is the parent of adoration."

So then "the scientist is born when man begins to wonder." Explanations are sought by him, and neither the ambiguous responses of the priestess of Apollo nor the stentorian tones of a god himself will suffice. He must see and know for himself. He no longer trusts the meaningless words of men or of gods, but breaks away from the sacred traditions handed down through all the past and begins to think for himself. He notices, he compares, he concludes. Then he postulates, formulates and at last discovers some principles which make a basis for further progress. He becomes axiomatic in his statements. He has, up to this time, watched the phenomena as they would appear in nature. Now he prepares to produce the phenomena himself in order that he may study them with greater exactness.

Here begins the use of apparatus, at first of course, of the crudest type. And it is at this point that we must narrow our subject, and draw it from the vast field of the general and place it in the smaller field of the specific.

Of all the optical instruments that have been the means whereby man could peer into the great unknown, none has been so serviceable as the prism. When its discovery and use first became known to man, he realized that he knew only the alphabet to the

great volumes of knowledge that the prism was to open up.

An optical prism is a portion of transparent medium bounded by plane surfaces inclined to each other, and whose edges are parallel. In the general use of the prism it forms a part of the spectroscope which "is an instrument in which the action of a prism or a combination of prisms is best studied."

HISTORICAL. "The field of research which has been opened up by the spectroscope is one with which we have so recently become familiar, that it may almost be said that twenty years ago a course of lectures on the spectroscope would have been an impossibility. The instrument, as we now know it, was then only in embryo; and even at the present time (1873), although immense strides are every day being made, the science of spectroscopy must still be considered in its infancy. And yet, so far as one can see now-- it is always very easy to prophesy after the event --- there seems very little reason why lectures on the spectroscope should not have been given two centuries ago; for nearly two centuries have elapsed since the immortal Newton made his classical researches on the action of a prism upon sunlight. You may, perhaps, be inclined to ask, how it could take 200 years for a knowledge of the prism, and of the wonders that can be worked by it, to become part and parcel of our common stock of information. If you ask me to explain this, I tell you candidly that I cannot, but there is this grain of caution connected with it which none of us should forget: we may almost say for certain that Newton and his successors would have brought a great deal more out of the prism than they did, if they had given a little more attention to it, and had tortured it

as they did other things. Those who follow us may point to us and say the same; they possibly will say that in the 19th century, men of science, in working and experimenting, saw a great many things, and chronicled them, but did not care to go any further with them. This is very true; and the result is, that work is not done which might be done if we were more receptive and original in our methods of investigation; that is to say, if we trusted Nature more and ourselves less." (Lockyer).

The discoveries that were made by Newton in connection with prisms, were based on well-known properties of light. One thing we owe Newton is the fact that we obtain the best spectrum when the angle of deviation is a minimum. We are also indebted to him for the explanation of the dispersive power of the prism.

It is very strange, however, that Newton, although making many experiments with the prism omitted a very important point, i. e. he allowed his source of light to come through a round hole in the shutter when he ~~should~~ have allowed it come through a slit. "But this did not come until Dr. Wollaston, by merely using a slit instead of a round hole, made a tremendous step in advance." Newton had told us that the spectrum of the sun was continuous, but when Dr. Wollaston tried the slit, he found that the spectrum was really broken by a succession of a fine -- beautifully fine--- black lines. These were the same lines that were afterwards mapped by the great German optician, named Fraunhofer; hence these lines are termed "Fraunhofer lines."

"If we say, then, that spectroscopic inquiry dawned with

Newton, certainly the sun began to rise with Fraunhofer."

Other observers, such as Kirchhoff, Thalen and Ångström, have worked at the dark lines of the solar spectrum, mapping 2,000 of them while Fraunhofer mapped 576, in 1814.

We are next indebted to Mr. Simms who in 1830 made another important improvement on the spectroscope. He invented the collimating lens.

But the most important discovery that has been made, to my mind, is that made by Kirchhoff of the connection between the dark lines of the solar spectrum and the bright lines of the terrestrial flames. This gave man a volume of information concerning the members of the solar system, and concerning the far distant stars, - information that the astronomer had been trying to obtain for many centuries. We are now told what elements are in the sun, and in the other heavenly bodies. We learn too the state that any one of these various bodies may be in. By the displacement of lines of the spectrum of any one of these heavenly bodies it is possible to calculate with some degree of accuracy the velocity of the body in motion, as well as determine whether it be coming toward us or receding from us. If the displacement of any of the spectrum lines be toward the violet, the star is approaching us; a displacement towards the red shows that the star is receding from us, and the amount of this displacement indicates the rate of motion. Hence it has been calculated that Sirius is receding from the earth at the rate of 41.1 miles per second.

Others who have made discoveries in the use of the spectro-

scope are fast becoming numerous. I shall note but a few.

In 1752 Thomas Melville took the first particular notice of the yellow soda flame. In 1822 Brewster introduces the monochromatic lamp in which the soda light is used, getting his idea from Melville.

Sir John Herschel, in 1822, investigated the spectra of many colored flames. Fox Talbot, the famous photographer, noticed that the yellow sodium line was common to all spectra, and found even in the spectra of substances he thought were absolutely pure. Hence he says, "The only matter which these substances have in common is water," and he suggests that this yellow line is due to the presence of water.

Prof. William Allen Miller made some very interesting experiments in 1845, and his results agree pretty generally with those of the great Bunsen and Kirchhoff who soon follow him.

In 1856 it was Prof. Swan who determined the very great sensitiveness of the sodium reaction.

But it was the patient and untiring Bunsen who evaporated forty-four tons of water from the Duerkheim spring in order to get the small amount of the mixed salts of caesium and rubidium. These elements were discovered by him.

Many others could be mentioned at length such as Karlsbrum, Nauheim, Crookes, Hartley, Becquerel, Faraday and on down the list. But the two men to whom we are most indebted for the great volumes of information in spectroscopy only forty years ago, are the noted Bunsen and Kirchhoff.

Passing any further historical notices we shall now take up in detail our laboratory research.

As a preliminary statement it is in order to call to mind that in experimenting with the spectroscope, there are conditions to be taken into consideration as in the performing of many other experiments in the physical or chemical laboratory.

For instance, if we desire to know what effect a change of temperature has on the spectrum of a gas, two constants should be maintained throughout the experimenting; viz, the density of the gas must remain the same, and the strength of the electric current must be kept constant. If we wish to compare the spectrum of a gas at 23 degrees C. with that of the same gas at 100 degrees C., difficulty will be found in keeping the former from rising above 23°, or in the case of the latter in maintaining it at the high temperature of 100°.

Exactness in that respect has not been a result in our experimenting, but approximate values afford us sufficient data on which to base our experiments and to form our conclusions.

First in order will be to note the effect of temperature on the spectra of gases.

P A R T I.

EFFECT OF TEMPERATURE ON THE SPECTRA OF GASES.....

In all experimenting to determine the effect of temperature on the spectra of gases, we used the Plücker tubes.

The first experiment was with the carbonic dioxide tube at the approximate temperature of 23° C. The same tube was heated

to about 12° C. and maintained at such as nearly so as possible.

The following is the data obtained:-

Reading.	Color of band.	Location at 230°	Location at 120°	Width 'Width 1st'	'Width 2d.'
1	Red.	47°-58' to 48°-1'	47°-59' to 48°-4'	3'	5'
2	Orange.	48°-20' " 48°-23'	48°-20' " 48°-26'	3'	6'
3	Yellow- ish Green	48°-45' " 48°-48'	48°-46' " 48°-53'	3'	7'
4	Green.	49°-14' " 49°-18'	49°-15' " 49°-20'	4'	5'
5	Blue.	49°-44' " 49°-51'	49°-45' " 49°-53'	7'	8'
6	Violet.	50°-21' " 50°-28'	50°-23' " 50°-34'	7'	11'
7	"	Two lines barely visible.	Lines invisible.		
8	Extremes of Spect!	47°-35' to 51°-53'	47°-25' " 51°-55'	4°-18'	4°-30'

The general effects produced on the spectrum by raising the temperature are, 1:- The spectrum as a whole is much brighter. 2:- The bands widen almost without exception in the direction of the more refrangible region of the spectrum. 3:- The bands ~~xx~~ themselves are less bright and less distinct, having a fuzzy appearance instead of a sharp, well marked outline.

"Taking the whole of these experiments together, (Experiments on effect of temp.) they do, I believe, indicate that the lines of sodium widen more easily at a comparatively low temperature; but, as they may also be seen very wide at high temperatures and narrow at low ones, they leave the original cause of the widening unexplained.

"The fact that the sodium lines widen more easily at a comparatively low temperature is in accordance with the theoretical

speculations we have given on the cause of the widening of lines." (Spectrum Analysis, Roscoe, p. 167.) May not what is true sodium, be true also for other spectra?

The following is the result ~~of~~ obtained with the iodine tube at 23° C and 120° C:-

Read- ing	Color of line	Location at 23°C	Location at 120°C	Width 1st	Width 2d.
1.	Extrem of red	48°-30'.	48°-30'		
2.	Red.	48°-00' to 48°-6'	48°-00' to 48°-4'	6'	4'
3.	Yellow	Not visible.	48°-35' " 48°-38'		3'
4.	Green	" "	5 grn. bands btwn. 48°-54' & 49°-23'.		
5.	Bright Green	" "	49°-17' to 49°-19'		2, 1/2
6.	Bluish Green	49°-37' to 49°-40'	49°-38' to 49°-40'	3'	2'
7.	Bright Blue	49°-43' to 49°-50'	49°-42' to 49°-46'	7'	4'
8.	Violet	50°-4' to 50°-15'	50°-4' " 50°-8'	11'	4'
9.	"	50°-17' " 50°-19'	50°-9' " 50°-14'	2'	5'
10.	Dim "	50°-48' " 50°-54'	50°-49' " 50°-53'	6'	4'
11.	Very Dim Violet.	Not visible.	Two very dim lines.		

On examining the results of the above we note the following;

1. All lines in hot tube are clearer in outline than in the cool tube.
2. Lines are narrower in hot tube than in the cool tube.
3. Many more lines are seen in the hot tube than in the other.
4. In the cool tube the lines broaden mostly in the direction of those rays having the shorter wave length.
5. The lines in the cold tube while broader yet have a fuzzy outline, thus making them somewhat indistinct and less bright than the lines in the hot

tube.

The following is the result obtained with the carbon monoxide tube at the temperatures of 23°C. and 120°C.:-

Reading	Color of line	Location at 23°C	Location at 120°C	Width 1st	Width 2d.
1.	Extreme red.	of 47°-30'	47°-36'		
2.	Red.	48°-00' to 48°-5'	47°-59' to 48°-5'	5'	5, 1/2'
3.	Orange	48°-23' to 48°-28'	48°-21' to 48°-28'	5'	7'
4.	Yellowish Green.	48°-48' " 48°-52'	48°-47' " 48°-52'	4'	5'
5.	Green	49°-16' " 49°-19'	49°-15' " 49°-20'	3'	5'
6.	Blue.	49°-48' " 49°-53'	49°-47' " 49°-54'	5'	7'
7.	Violet Blue	50°-26' " 50°-30'	50°-23' " 50°-31'	4'	8'
8.	Broad Dim Vio.	50°-40' " 50°-57'	50°-40' " 50°-56'	17'	16'
9.	Broad Dim Vio.	51°-00' " 51°-20'	50°-58' " 51°-7'	(20'	(9'
10.			51°-11' " 51°-19'	(	(8'
11.	Broad Dim Vio.	51°-27' " 51°-32'	51°-25' " 51°-32'	5'	7'
12.	Broad Dim Vio.	51°-40' " 51°-44'	51°-39' " 51°-47'	4'	8'
13.	Extreme of Violet	52°-30'	52°-40'	5°-00'	5°-4'

By examining the data before us we note the following; 1.

All the bands widen with one exception, with an increase of temperature. 2. In reading No. 9, or line 8 of the cold tube divides into two bands when the temperature of the tube is raised. 3. The bands widen in both direction, but widen mostly in the direction of that part of the spectrum having the least refrangibility, or the

greatest wave length. 4. The spectrum of the hot tube is brighter than that of the cold tube, but the general outline of the bands is not as distinct.

GENERAL SUMMARY. On comparing the data there seems at first glance to be an inconsistency. For instance in the cases of the carbonous and carbonic oxide the bands widened with an increase of temperature while in the case of iodine ~~x~~ the bands became narrower with an increase of temperature. Let us bear in mind, however, that iodine in its natural state is a solid, and that which is used in the Plucker tube is the vapor of iodine. By close inspection it may be seen that minute iodine crystals are to be found on the sides of the tube ~~when~~ in the cool state. Hence, when the tube is heated the effect of the temperature is more than counterbalanced by an increase of pressure which is due to more iodine crystals being vaporized by the increase of temperature. The peculiar action of the iodine, therefore, is ruled out of the question under consideration. Only the spectra of gases whose density remains constant throughout the experiment should enter into consideration.

We note the data, then, of the two substances, carbonous oxide and carbonic oxide, and come to the following conclusions: By raising the temperature of a gas (not a vapor), we have (1) a brighter spectrum; (2) a widening of the bands; (3) the bands that widen first and most are those in the more refrangible portion of the spectrum; (4) while in the majority of cases the bands widen both ways, yet the widening takes place mostly in the direc-

tion of the more refrangible portion of the spectrum; (5) and lastly the bands of the spectrum obtained from the hot tube present a fuzzy appearance, and are less distinct in outline than the bands of the spectrum of the cold tube.

"We may say that, as a general rule, if a system of lines widens much or easily, the more refrangible lines of the system will be the first to widen, while if a system of lines shows the broadening to a small degree only, no general rule can be given.

"When a line widens, it may do so either symmetrically on both sides, or the widening may be greater on one side. It is a remarkable fact that when a line widens chiefly towards one side, that side is in nearly all, if not in all cases, the less refrangible one." (Spectrum Analysis, Roscoe p. 159.)

"It is the almost unanimous opinion of spectroscopists that the widening is produced by an increase of pressure." (Enc. Brit. Vol. XXII p. 378).

P A R T II.

EFFECT OF DENSITY ON THE SPECTRA OF GASES.

Owing to the somewhat limited time and facilities, only one tube was used to determine the spectrum of; viz., air. An effort was made to keep the density constant, the Sprengel air pump being used. The electric current and temperature were maintained constant. We took the readings of the spectrum at two different densities, (1) at 70/76ths of a vacuum, and (2) at 60/76ths of a vacuum. The result is as follows;-

Reading	Color of line.	Location at 44 <i>of a vacuum</i>	Location at 49 <i>of a vacuum</i>	Width 1st	Width 2d
1.	Extreme of red.	47°-18'	47°-20'		
2.	Red.	47°-57' to 48°-00'	47°-58' to 48°-00'	3'	2'
3.	Yellow	48°-30' " 48°-37'	Invisible	7'	
4.	Green.	48°-53' " 48°-57'	48°-52' " 48°-55 ¹ / ₂ '	4'	3 ¹ / ₂
5.	Bright Bright blue.	49°-39' " 49°-44'	49°-40' " 49°-44'	5'	4
6.	Dim Blue	49°-45' " 49°-49'	49°-46' " 49°-50'	4'	4'
7.	Violet "	49°-55' " 50°-00'	49°-54' " 50°-00'	5'	6'
8.	" "	50°-2' " 50°-8'	50°-2' " 50°-9'	6'	7'
9.	" "	50°-12' " 50°-18'	50°-13' " 50°-18'	6'	5'
10.	Bluish violet.	50°-22' " 50°-30'	50°-22 ¹ / ₂ ' " 50°-29 ¹ / ₂ '	8'	7'
11.	Violet.	50°-35' " 50°-39'	50°-35' " 50°-39'	4'	4'
12.	Bright violet.	50°-42' " 50°-48'	50°-42' " 50°-48'	6'	6'
13.	Violet.	50°-56' " 51°-1'	50°-57' " 51°-1'	5'	4'
14.	"	51°-8' " 51°-14'	51°-9' " 51°-13'	6'	4'
15.	"	51°-17' " 51°-22'	51°-18 ¹ / ₂ ' " 51°-22 ¹ / ₂ '	5' X	X 4'
16.	"	51°-27' " 51°-13'	Too dim to locate	4'	
17.	"	51°-33' " 51°-39'	51°-36' " 51°-39 ¹ / ₂ '	6'	3 ¹ / ₂
18.	"	51°-47' " 51°-54'	51°-49' " 51°-43'	7'	4'
19.	"	51°-59' " 52°-5'	Too dim to locate	6'	
20.	Extreme of Vio.	54°-10' Five other dim violet lines seen.	53°-20'	6°-52'	6°-00'

From the above data we note the following: The spectrum of the tube whose pressure or density of gas was least, was much

the brightest. But most important to note is that, ----

Of the 15 bands to be compared in the two spectra, when the density or pressure is decreased,-

- (TEN become wider, seven of which are in the more refrang-
 (ible region.
 (TWO become narrower, and both in the more refrangible
 I. (portion of spectrum.
 (THREE remain unchanged in width and in the more refrangible
 (portion of spectrum.

- (Of the ten (FOUR widen totally in the direction of the
 (which become (less refrangible portion.
 (wider. (ONE widens totally in the direction of the
 (more refrangible portion.
 (THREE widen partly in both directions, but
 (more in the less refrangible region.
 (TWO widen equally in both directions of re-
 (frangibility.
 II (Of the two (ONE narrows in the direction of the less
 (which become (refrangible portion.
 (narrower. (ONE narrows in the direction of the more re-
 (refrangible portion.
 (Of the three (ONE moves in the direction of the less
 (which remain (refrangible portion.
 (unchanged. (TWO remain entirely unchanged in position.

I (Hence eleven bands of the fifteen, widen totally, mostly

(or partly, or narrow in the direction of, or reaming equal, move
(into the less refrangible portion of the spectrum.

(Only two which either narrow or widen do so in the direction
(of the more refrangible portion of the spectrum. And two remain
(entirely unchanged in width and in position.

It is further noticed that when the pressure is decreased the bands are more ~~distinct~~ in outlines. Also more bands become visible in the spectrum when the density is decreased.

Our conclusions must therefore follow. 1. When the density of a gas is decreased the bands of its spectrum will generally widen. 2. The bands which widen are generally situated in the ~~more~~ refrangible portion of the spectrum. 3. The bands generally widen, narrow or move in the direction of the less refrangible portion of the spectrum. 4. More bands are to be seen, the outline of bands is more distinct, and the spectrum is brighter when the density is decreased.

"When a system of lines widens it is generally found that the most refrangible lines widen most easily. A line may expand towards both sides or chiefly towards one side; in the latter case the expansion towards the less refrangible side preponderates pretty nearly in every case." (Encyclopaedia Brit. Vol. XXII, p. 378.)

"If the pressure of a gas is increased, or if, as in the case

of vapors, its properties are no longer those of a perfect gas
 ----- the lines of the spectrum will then appear with indistinct
 edges and expand the more, the more the gas deviated from the laws
 of Mariotte and Gay-Lussac." (Spec. Anal. Roscoe p. 164.)

"It is, I believe, the almost unanimous opinion of spectroscopists that the widening is, in most cases, produced by an increase of pressure." (Spectrum Analysis Roscoe p. 163.)

P A R T. III.

EFFECT OF STRENGTH OF ELECTRIC CURRENT ON THE SPECTRA OF GASES.....

We now turn our attention to the last topic of our research,
 viz., the effect ~~on~~ the strength of the electric discharge will
 have on the spectra of gases. Using e don nitrogen tube with
 different current strengths we have the following:-

Color of band.	Location 1 cell strength.	Location 2 Cells	Location 3 Cells	Location 4 Cells	Changes: Band,
Red	47°-50' to 48°-13'	47°-46' to 48°-8'	47°-27' to 48°-21'	47°-26' to 48°-21'	Widens
Orange	48°-16' " 48°-21'	48°-15' " 48°-21'	48°-21' " 48°-28'	48°-21' " 48°-28'	"
Yrn'h					
Vel.	48°-21' " 48°-34'	48°-21' " 48°-35'	48°-28' " 48°-41'	48°-28' " 48°-40'	Narrows
dk.					
Yrn.	Invisible.	Invisible.	48°-41' " 49°-6'	48°-40' " 48°-48'	Wid.
Brt. Grn.	" 48°-49' "	49°-00'	All one band	48°-48' " 49°-4'	"
Dim Dk. Yrn.	49°-10'	49°-5' " 49°-16'	49°-6' " 49°-16'	49°-4' " 49°-14'	Unchn'd
tr.					

(Continued.)

Br.					
grn.	Invisible	Invisible	49°-16' to 49°-20'	49°-14' to 49°-20'	Wid.
Dim Dk.	"	49°-20'	49°-20' " 49°-25'	49°-20' " 49°-24'	Nar.
Br.	"	Invisible	Invisible	49°-27'	
grn.	"	"	"	49°-30'	
Limit	"	"	"	49°-35'	Unch.
of grn.	"	"	"	49°-39'	Nar.
Bluish	49°-25'	49°-36'	49°-36'	49°-35'	
grn.	49°-44'	49°-43'	49°-40'	49°-39'	
Brn'h.					
blue.	Invisible	Invisible	49°-51'	49°-48'	"
blue.	"	50°-00'	50°-00'	50°-00'	"
"	"	50°-10'	50°-10'	50°- 8'	"
Vio.	"	50°-22'	50°-19'	50°-18'	"
blue.	"	50°-32'	50°-30'	50°-27'	"
.Bl.	"	Invisible	50°-39'	50°-38'	"
. Bl.	"	50°-42'	50°-48'	50°-50'	Wid.
Bl'sh.	50°-45'	50°-55'	51°-00'	51°-00'	"
Violet	Invisible	51°- 8'	51°-11'	51°-13'	"
Bl'sh.	51°-14'	Invisible	51°-23'	51°-23'	Unch.
Violet	Invisible	51°-32'	51°-31'	51°-33'	Wid.
Vio.	"	51°-45'	51°-40'	51°-39'	Nar.
Vio.	Invisible	Invisible.	51°-53'	51°-50'	"
Vio.	"	"	52°- 3'	52°- 4'	Wid.
Vio.	"	"	52°-16' to 52°-24'	52°-15' to 52°-28'	"
Vio.	"	"	52°-39'	52°-38'	Nar.
Dim Vio.	"	"	52°-50'	52°-51'	Wid.
Very	"	"	53°- 3'	53°- 5'	"
Dim Vio.	"	"	53°-17'	53°-17'	Unch.
Very	"	"			
Dim Vio.	"	"			

(Continued.)

Very dim Vio.	Continued.	Continued	53°-51'	53°-51'	Unch.
Extr- emes.	47°-50' to 53°-10'	47°-46' to 53°-40'	47°-27' to 54°-4'	47°-26' to 54°-6'	Wid.

We note that there are twenty-two bands in 4th spectrum not seen in 1st.

We also note that there are ~~XXXXX~~ fourteen bands in 4th spectrum not seen in 2d.

We also note there are two bands seen in 4th spectrum not seen in 3d.

In spectrum No. 1, the whole spectrum is very dim, and after leaving the green, the bands have no color.

In spectrum No 2, the whole spectrum has the proper color, but only two bands can be seen in the violet.

In spectrum No 3, the spectrum has become sufficiently bright, that some of the dark bands have gained color, and all the violet bands have color except the last three.

We observe then, 1. The spectra grow brighter as the electric current becomes stronger. 2. The bands, as a general thing, widen with the increase of current strength. 3. Some dark bands take on color, and some bright bands subdivide, making two or more bands, when current is strong.

We next introduced a resistance wire in the battery so that the current could be weakened or strengthened at will. This method was used throughout the rest of the experimenting.

We then experimented with the endon tube of hydrogen, and got

the following results:-

Reading	Color of line	Location weak current.	Location strong current.	Width First.	Width Second.
1.	Red	47°-58' to 47°-59'	47°-57' to 47°-59'	1'	2'
2.	Blue	49°-39' " 49°-40'	49°-38' " 49°-40'	1'	2'
3.	Violet	50°-41' " 50°-43'	50°-41' " 50°-43'	1'	1'

We note in the case of the hydrogen that the red and blue bands expand when this strength of the current is increased. The expansion is also in the direction of the less refrangible portion of the spectrum. In the laboratory we also noted that when the current is weak a green line and a yellowish-green line both appear brighter than the violet; but when the current is strengthened they almost fade from view.

The spectrum that we shall next examine is that obtained from the endon tube of water vapor, which is as follows:-

Reading	Color of line	Location weak current.	Location strong current.	Width First.	Width Second.
1.	Red	47°-55' to 47°-57'	47°-55' to 47°-58'	1, 1/2'	3'
2.	Grn'h. Blue	49°-37' " 49°-39'	49°-36' " 49°-39'	2'	3, 1/2'
3.	Violet	Too dim to locate	50°-40' " 50°-44'		4'
4.	Extremes spectrum,	47°-55' " 51°-15'	47°-40' " 52°-00'	3-20'	4-20'

There is one dim line in green and three in violet which entirely disappear when current is made weak. The bands widen when the

current is strengthened, and in both the direction of the more and less refrangible portions.

It is true of the hydrogen and water spectra that each is brighter and the outline of the bands more clearly defined when the current is strong.

We next experimented with the endon tube of nitrogen, using the resistance wire for regulating the current strength, instead of putting one, two, three or four cells in the circuit and then taking our readings. Slightly more accurate results were obtained which are as follows:-

Read- ing.	Color of band.	Location		Location,		Width	
		Wk. Current.		str. Current.		1st.	2d.
2.	Red	47°-57' to	48°-17'	47°-44' to	48°-17'	20'	33'
2.	Orange	48°-17' "	48°-20'	48°-17' "	48°-20'	3'	3'
3.	Yellow	48°-20' "	48°-36'	48°-20' "	48°-36'	16'	16'
4.	Brt. Grn.	48°-36' "	48°-59'	48°-36' "	48°-59'	23'	23'
5.	" "	49°-7' "	49°-11'	49°-7' "	49°-12'	4'	5'
6.	" "	49°-18' "	49°-19'	49°-17½' "	49°-19½'	1'	2'
7.	" Blue	49°-40' "	49°-43'	49°-40' "	49°-43'	3'	3'
8.	Violet	50°-00' "	50°-4'	49°-59' 50°-4'		4'	5'
9.	"	50°-20' "	50°-24'	50°-19' "	50°-24'	4'	5'
0	"	Too dim to locate		Too dim to locate			
1.	"	50°-40' "	50°-45'	50°-40' "	50°-46'	5'	6'
2.	"	50°-53' "	50°-57'	50°-53' "	50°-58'	4'	5'
3.	"	51°-4' "	51°-8'	51°-3' "	51°-8'	4'	5'
4.	"	51°-15' "	51°-18'	51°-15' "	51°-19'	3'	4'

15	Violet	51°-24' "	51°-27'	51°-22' "	51°-27'	3'	5'
16	"	51°-30' "	51°-33'	51°-30' "	51°-34'	3'	4'
17	"	51°-42' "	51°-45'	51°-41' "	51°-45'	3'	4'
18	Extremes of spectrum.	47°-34' "	53°-51'	47°-20' "	54°- 1'	6°-7'	6-41'

We observe that twelve of the sixteen bands widen with an increase of current strength; and most of these bands lie in the more refrangible region of the spectrum.

The majority of the bands widen in the direction of the less refrangible portion of the spectrum.

The spectrum is brighter and the outline of the lines is more distinct when the current is strong.

We next experimented with the endon tube of Carbonic Dioxide and obtained the following result;-

Reading.	Color of band.	Location wk. Current.	Location, str. Current.	Width, 1st.	2d.
1.	Red.	47°-55' to 47°-59'	47°-54' to 47°-59'	4'	5'
2.	Orange	48°-17' " 48°-18'	48°-16' " 48°-19'	1, 1/2'	3'
3.	Yellow	48°-40' " 48°-42'	48°-40' " 48°-42'	1, 1/2'	2'
4.	Green	49°- 7 1/2 " 49°-12'	49°- 8' " 49°-12'	4, 1/2'	4'
5.	Blue	49°-40' " 49°-44'	49°-40' " 49°-44'	3, 1/2'	4'
6.	Violet	50°-19' " 50°-22'	50°-19' " 50°-22'	3'	3 1/2'
7.	"	50°-36' " 50°-39'	50°-36' " 50°-39'	3'	3'
8.	"	Too dim to locate	51°-20' " 51°-23'		3'
9.	Extremes	47°-52' " 52°-10'	47°-36' " 52°-20'	4°-20'	4°-44'

It is now to be noted that of the seven bands for which we have full data, six of them widen as the current is strengthened. ~~The bands widen as the current is strengthened.~~ The bands widen mostly in the direction of the less refrangible portion of the spectrum. The bands that widen most are in the less refrangible portion of the spectrum. Several of the bands widen in both directions, but even in that case, the bands expand more in the direction of the less refrangible portion of the spectrum. The whole spectrum widens through the space of $24'$ and mostly in the direction of the less refrangible region.

We next experimented with the iodine Plücker tube, varying the current as in the case of the endon tubes. The experiment resulted as follows:-

Read- ing.	Color of band.	Location wk. Current.	Location str. Current.	Width, 1st.	2d.
1.	Red.	$47^{\circ}-57^{\frac{1}{2}}'$ to $47^{\circ}-59^{\frac{1}{2}}'$	$47^{\circ}-56'$ to $47^{\circ}-59'$	$2'$	$3, 1/2'$
2.	Yellow	$48^{\circ}-30'$ " $48^{\circ}-33'$	$48^{\circ}-29'$ " $48^{\circ}-34'$	$3'$	$5'$
3.	Dim Grn.	$49^{\circ}-31'$ " $49^{\circ}-33'$	$49^{\circ}-30'$ " $49^{\circ}-34'$	$2'$	$4'$
4.	Bl'h. Grn.	$49^{\circ}-38'$ " $49^{\circ}-40'$	$49^{\circ}-37^{\frac{1}{2}}'$ " $49^{\circ}-40'$	$2'$	$2, 1/2'$
5.	Violet.	$50^{\circ}-00'$ " $50^{\circ}-3^{\frac{1}{2}}'$	$50^{\circ}-00'$ " $50^{\circ}-4'$	$3^{\frac{1}{2}}'$	$4'$
6.	"	$50^{\circ}-9'$ " $50^{\circ}-11'$	$50^{\circ}-10'$ " $50^{\circ}-13'$	$2'$	$3'$
7.	Extremes	$47^{\circ}-50'$ " $52^{\circ}-00'$	$47^{\circ}-38'$ " $51^{\circ}-55'$	$4^{\circ}-10'$	$4^{\circ}-17'$

Analyzing the above data we note 1. All the bands as well as the whole spectrum expands. 2. The number of bands are equally divided as to the fields of refrangibility into which they expand. The violet

bands expand into the more refrangible field, while the red and blue expand into the less refrangible field. Others expand both ways.

The last tube we experimented with was the endon stannous chloride, and obtained the following data:-

1. Red.	47°-57' to 47°-59'	47°-57' to 47°-59'	1, 1/2'	2'
2. Dim yel	Too dim to locate	48°-29' to 48°-31'		2'
3. " grn	48°-53' to 48°-57'	48°-52' to 48°-59'	4, 1/2'	7'
4. Green	49°-6' to 49°-10'	49°-6' to 49°-10'	3, 1/2'	4'
5. Blue	49°-38' to 49°-40'	49°-37' to 49°-40'	2'	2, 1/2'
6. Violet	Almost invis- ible	50°-1' to 50°-5'		4'
7. "	Invisible	50°-11' to 50°-13'		2'
8. "	"	50°-40' to 50°-45'		5'
9. Extreme	47°-57' to 51°-10'	47°-55' to 51°-35'	3°-13'	3°-40'

Examining these results we note that of the four bands whose data are complete, all widen with the increase of the current strength. Three of them widen exclusively in the direction of the less refrangible field. The other band expands partly in both directions, but more in the more refrangible field. The whole spectrum widens, but 25' of the 27' of expansion is in the less refrangible portion of the spectrum.

GENERAL SUMMARY. By increasing the current strength we

note the following general effects on the spectra of gases; 1. The spectrum is sharper and more distinct. 2. More lines become visible than when the current is weak. 3. The line spectrum resulting from the weak current tends to become a continuous spectrum when the current strength is increased, that is, some dark bands assume color. 4. In some cases bright bands break up into ^{two} bands. 5. In the very great majority of cases the lines or bands widen into the field of the less refrangible portion of the spectrum. 7. The position of a band has nothing to do with its expansion, either as to whether it will expand or not, nor does its position regulate the amount of expansion. 8. An error making factor should here be considered; viz., the rise of temperature of a tube resulting from the electric discharge. This may in turn also cause a change in the density of a gas. Hence two errors in these experiments are to be guarded against, and taken into consideration when the experimental results are analyzed.

"In the case of gases, the easiest way to produce the widening is by an increase in the pressure of the gas, -----
But we may also, in the case of hydrogen, for instance, widen the lines by an increase in the intensity of the discharge."
(Spectrum Analysis, Roscoe, p. 163.)

"Without altering the pressure, we may often produce a widening of lines by an increase in the intensity of the discharge but here the pressure is indirectly increased by the rise of temperature." (ENGLISH (En. Brit. Vol. XXII p. 378.)

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