THE STARK EFFECT IN HELIUM AND NEON.

BY HARRY NYQUIST.

THE effect of an electric field on spectral lines has been studied by Stark[1] in a number of substances but particularly in hydrogen, helium and lithium. Lo Surdo[2] studied the effect by a different method from that employed by Stark. Sonaglia[3] using Lo Surdo's method extended the investigations of hydrogen to the line H_ϵ. Koch,[4] using the method of Stark, investigated helium and discovered two new lines produced by the electric field. He also extended some of the results previously obtained by Stark. Brunetti[5] applied Lo Surdo's method to helium, but unfortunately it has not been possible to obtain a copy of his paper. Evans and Croxson,[6] also using Lo Surdo's method, investigated a mixture of helium and hydrogen particularly with reference to the bearing of Epstein's theory on the line 4686.

In the present investigations discharge tubes both of Stark's and Lo Surdo's type were employed and compared in preliminary experiments. Stark's tube has the disadvantages that the intensity of the light from it is low and that it is difficult to replace when broken, while the disadvantages of Lo Surdo's tube are that it breaks readily at the cathode due to heating and that the glass about the Crookes dark space soon becomes opaque owing to sputtering from the cathode.

An ideal discharge tube for observing the effect would be one that would produce a great light intensity in a strong electric field without covering the walls with opaque matter or otherwise changing with time. Unfortunately an improvement in any one of these directions seems to be disadvantageous in others, so a tube must be something in the nature of a compromise.

After much experimenting the form of tube illustrated in Fig. 1 was adopted as being more satisfactory than any other type tried.

[1] Elektrische Spektralanalyse chemischer Atome, Hirzel, Leipzig, 1914; Ann. d. Physik, 48, p. 193, 1915.

[2] Accad. Lincei, Atti 22, p. 664, 1913; 23, p. 82, 1914.

[3] Accad Lincei, Atti 24, p. 621, 1915; N. Cimento, 11, p. 207, 1916.

[4] Ann. d. Physik, 48, p. 98, 1915. Cf. Stark, Elektrische Spektralanalyse chemischer Atome, p. 73.

[5] N. Cimento, 10, p. 34, 1915.

[6] Phil. Mag., 32, p. 327, 1916.

The tube consists of a main portion M, of about 12 mm. internal diameter, into which a bottle-shaped portion B is fitted rather loosely and made tight with sealing wax, so it can be removed and inserted without difficulty. Within the portion B is a solid aluminium rod of about 4.8 mm. diameter which serves as cathode. It is inserted so that one end, which is filed flat, comes nearly flush with the narrow upper end of B. A small vacant space is left between the sides of the cathode and the glass to prevent conduction over the glass. Resting on the upper end of portion B and partly surrounding it is the aluminium cylinder D. One half of this cylinder is bored to a diameter sufficient to fit loosely over B. The remainder is bored to a diameter 3.25 mm. The upper end of the larger hole does not form a square shoulder but is slightly curved. Thus the metal cylinder is not in contact with the cathode but is insulated from it by means of the glass. From a point opposite the upper end of the cathode and extending about 7 mm. toward the anode there is a slit S, .75 mm. in width, through the wall of the aluminium cylinder. Opposite this slit there is a side tube G whose outer end is covered by a window W. The anode A is situated about 12 cm. from the top of the aluminium cylinder and at this place there is a side tube T for exhausting the tube and introducing the gas under investigation. The whole discharge tube is made of Pyrex glass. This glass has a small coefficient of expansion and softens only at a high temperature, both of which qualities make it a desirable material for the tube. The electrical connections are made by means of platinum wires. These are sealed through the glass without any special precaution and without the use of any other kind of glass. The seal thus formed is not quite gas-tight but can be made so by a small drop of sealing wax. Wax joints are used to connect the window to the side tube G, the side tube T to the remainder of the apparatus, and part B to part M. As this last place is heated by the discharge, two fine jets of air are employed to keep its temperature down.

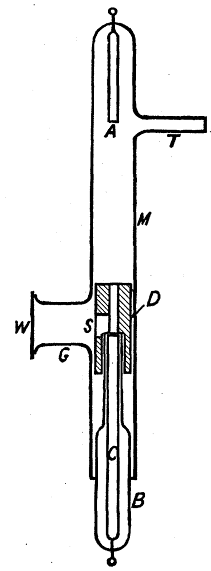

Fig. 1.

The spectrum was investigated by means of a spectrograph consisting of six prisms made by Krüss and reground by Brashear. The faces of the prisms are 6 cm. by 6 cm. The collimator lens is an achromatic triplet whose focal length is 90.5 cm. and whose diameter is 6.5 cm. The camera lens is a doublet whose focal length is 116 cm. and whose diameter is 8.5 cm. These lenses, both of very good quality, are the property of Professor Hastings, to whom I am indebted for kindly allowing me to use them.

About 12 cm. in front of the discharge tube is a double image prism. An achromatic photographic lens focuses the light that has passed through the double image prism on the slit. The two images thus formed are plane polarized, one parallel and one perpendicular to the discharge tube and the slit. As was to be expected with so many prisms, it was found that light having the electric vector parallel to the slit is reflected from the faces to such an extent that it is almost impossible to photograph the lines. To obviate this a mica half-wave plate having its axes at 45° with the slit is placed in the path of that beam near the slit. This changes the polarization so that the light from both images has its electric vector perpendicular to the slit.

For some of the work in the red portion of the spectrum a plane grating was used in place of the prisms and the mica plate was eliminated. The grating is 8.0 by 5.3 cm., has about 15,000 lines to the inch and has a total of 44,100 lines. The second order was used. The plane of the grating is nearly perpendicular to the axis of the camera. The grating being thus inclined to the collimater axis the full aperture is utilized.

The dispersion of the prism spectrograph varied from 2.1 A per mm. in the violet to 8.2 A per mm. in the red. Both these figures are for minimum deviation. On any one plate the light of shorter wave-length suffers a greater dispersion and that of a longer wave-length suffers less dispersion. The dispersion of the grating is 7.3 A per mm. in the second order.

The electrical arrangement is indicated schematically in Fig. 2. This is essentially the same kind of apparatus that is employed by Dr. A. W. Hull,[1] of the General Electric Company, for energizing X-ray bulbs. His apparatus, however, supplies about ten times the voltage of the present one. The present apparatus was obtained from the General Electric Research Laboratory through the kindness of Drs. Whitney and Hull.

The source of energy is a 110-volt alternating current circuit. T_2 and T_2' are transformers which step down the voltage to about 25 volts. The primary current is regulated by means of the variable resistances r_2 and r_2'. K and K' are hot-wire rectifiers or kenotrons, the filaments of which are kept incandescent by the current from the transformers T_2 and T_2'. The anodes of the rectifiers are connected together. T_1 is a transformer which steps up the voltage from 110 to 13,200 volts. The

[1] Gen. El. Rev., 19, p. 173, 1916.

middle point of the secondary is grounded to the transformer case and is connected to one side of the capacity C, the other side of which is connected to the anodes of the rectifier. The two ends of the secondary of transformer T_1 are connected to the middle points of the secondaries of transformers T_2 and T_2' respectively. The secondaries of the transformers T_2 and T_2' are in turn connected to the filament of the rectifiers. The capacity (.17 microfarad) consists of 100 small commercial condensers connected in parallel. The condensers are kept continuously charged by the rectifiers and are continuously discharging through the inductance L, the ballast resistance R and the discharge tube D.

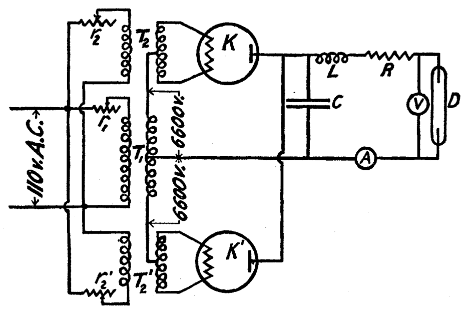

Fig. 2.

The inductance L consists first of a coil of carrying capacity of 50 milliamperes and with an inductance of 400 henrys. To this was added the secondary of an induction coil of unknown inductance. The ballast R consists of a rectangular sheet of asbestos painted on one side with lampblack and wood alcohol and has a resistance of about .8 megohm. The discharge tube D is shown in detail in Fig. 1.

The tube was exhausted by means of a Geissler pump. A reservoir containing the gases was connected to the tube by means of stopcocks in such a manner that a small portion could be admitted at each turn of the stopcocks. Another Geissler pump served to transfer the gas from the tube back into the reservoir, when not in use. A charcoal bulb and a U-tube were connected to the tube as near to it as convenient. They were immersed in liquid air and served to withdraw all gases and vapors from the tube with the exception of hydrogen, helium, and neon. The pressure was measured by a McLeod gauge. A palladium tube was attached to the apparatus and served to introduce hydrogen by being heated in a hydrogen flame.

The helium was prepared by Professor Boltwood from thorianite. The neon was produced from crude argon by freezing out the other constituents with charcoal and liquid air. The crude argon had been prepared by Professor Boltwood from atmospheric air by passing it through a mixture of CaC_2 (90 per cent.) and $CaCl_2$ (10 per cent.) heated to bright redness. The neon contained appreciable quantities of helium and hydrogen. My thanks are due to Professor Boltwood for kindly putting the gases at my disposal and for assisting in their manipulation.

For wave-lengths less than 5,000 Å., Seed 30 plates were used, while Cramer's Spectrum plates were employed in the red and yellow. For a short region in the green neither of these plates was very satisfactory and in this region the Seed 30 plates were used after being stained with erythrosin. The recipe used is that given in Baly's Spectroscopy, p. 351, 1st ed. The plates were cut into strips 25 cm. by 2.5 cm.

The range of pressure which is suitable is rather small. If the pressure is increased above ordinary working conditions, the conductance of the tube is very much increased, the drop of potential and hence the field becomes too small for satisfactory work. On the other hand, if the pressure is decreased much the luminosity of the discharge diminishes rapidly and soon ceases altogether. The best working pressures with the present apparatus were found to be for helium about 2.6 mm. of mercury and for neon about 1.5 mm.

The fall of potential across the tube as measured with an electrostatic voltmeter varied rapidly with small changes in the pressure. Under working conditions the fall of potential was 4,000–6,000 volts. The current varied from 2 to 8 milliamperes.

The times of exposure varied from 2 min. to 13 hrs. depending upon the region of the spectrum investigated and the intensity of the lines.

When the current is turned on, the positive rays in the region above the cathode collect at the axis of the aluminium cylinder where they form a narrow but very luminous beam. This beam is the source of light and being situated in the cathode fall of potential is affected by a strong field. The beam or stream of positive rays rapidly attacks the aluminium cathode when freshly prepared and digs a pit in its center. While this pit is forming the electrical field is not stable nor is the discharge even and continuous. After having run for about an hour, however, a stable condition appears. The field stays constant and the discharge appears to be continuous. The pit is then conical, has a diameter of about .5 mm. and a depth of about 1.5 mm. and changes only very slowly.

After being run for about 40 hrs. a point is reached when a black film accumulates about the cathode on the glass surrounding it and in the aluminium cylinder. Then a condition of instability again sets in and it becomes necessary to take the tube apart at the wax joint and clean the parts. At no time is there any trouble from sputtering on the window. This is a great advantage over the original Lo Surdo tube where the glass is close to the cathode.

While no attempt was made to study the Balmer series of hydrogen, photographs of these lines were obtained incidentally. They serve as a comparison of the resolution of the present apparatus with apparatus used formerly. All the strong components given by Stark for H_β, H_γ, and H_δ appear. The weak components given by Stark do not appear, probably because with the amount of hydrogen present the exposure was not long enough. It is possible, however, that their relative intensity is greater in the strong fields employed by Stark. The moderately strong components do appear with the exception of the outer ones vibrating parallel to the field in H_β and H_γ. For H_α the resolution is essentially that attained in Stark's "Grobzerlegung" or rough analysis. The number of components is in each case except H_α greater than hitherto obtained with the ordinary Lo Surdo tube.

If the frequency of a spectral line is affected by the field, it follows that its image on the photographic plate is no longer a straight line in its usual position but its various points are displaced, the displacement being a function of the field strength. Moreover, since the field is a continuous function of the distance from the cathode, the line on the plate will in general be changed into one or more curved lines. With the particular construction employed the field strength has a maximum at the lower end of the narrow hole in the aluminium cylinder, which point is situated about .5 mm. above the cathode. The field falls off in both directions from this point and has three-fourths its maximum value at the cathode and reaches a value very nearly zero at a point about 4 mm. above the cathode, this distance being a function of the pressure. It should be pointed out in this connection that the field depends on the diameter of the hole in the aluminium cylinder; the smaller the diameter the greater the field. It is possible to increase the field by making the hole narrower, but the intensity is decreased as a result.

Stark's measurement of the effect in the lines of the Balmer series of hydrogen was carried out with considerable precision, and, as the hydrogen lines were present along with those of helium and neon, his measurements have been used in the present investigation for determining the field. An absolute method would be to integrate the displacement along the line, *i. e.*, to find the area inclosed between the original line and the displaced line. Then this area would be to the total drop as the displacement at any point is to the field at that point, assuming that the displacement is proportional to the field. However, this method would involve a separate series of exposures to establish such linearity of relation, and the accuracy would probably be much less than that obtained by reference to Stark's results in hydrogen. It should be stated here that the potential of the aluminium cylinder is nearly that of the anode, a preliminary experiment showing a difference of less than 200 volts between them.

The relation between the displacement and the field is in general expressed by the relation

$$\delta\lambda = a + bE + cE^2 + \text{etc.},$$

where $\delta\lambda$ is the displacement of a given component, E the electric field intensity, and a, b, c, etc., are coefficients independent of E. The measurements of Stark show that all these coefficients with the exception of b are zero for all the components of the lines of the Balmer series of hydrogen. The idea that a may be different from zero appears strange at first consideration, since it signifies a definite displacement for zero field. It might be argued that if there is a displacement for zero field, we should see in the spectrum from an ordinary discharge tube, not single lines but groups of lines, doublets, triplets, etc. The explanation of this apparent contradiction to observed facts is that the intensity of a given component as well as its displacement is a function of the field strength. In components where a differs from zero, the light intensity approaches zero as the field strength approaches zero. The method of finding a will be understood from Fig. 3 (*c*), which illustrates four such components. It will be seen from that figure that these components approach asymptotically a line which is parallel to the undisplaced line. The distance between these parallel lines is a measure of a. The presence of terms in E^2, etc., is investigated by comparing the components of the lines with the components of the Balmer series of hydrogen. If c has an appreciable value for any component of a helium or neon line, its form will differ from that of the components of the hydrogen lines. No such difference has been found. Hence it will be assumed that with the field strength employed cE^2 is negligible and that

$$\delta\lambda = a + bE.$$

Components in which a differs from zero are found mainly in the helium lines, but a few are also found in some neon lines. Such components may be looked upon as new lines, especially as a number of new lines appear which are not components of any known lines, but since it is obvious that they are closely related to certain undisplaced lines, it is perhaps best to treat them as components.

In some of the earlier plates a comparison spectrum was used produced by letting light from an ordinary capillary discharge tube fall on the slit. The comparison spectrum consisted of three sections; one between the two spectra under investigation, one above, and one below them. By thus having three sections it was possible to eliminate the uncertainty arising from the curvature of the lines, which curvature is inevitable in prism spectrographs. It was found that there was no displacement between the lines in the comparison spectrum and the upper part of the lines investigated, hence, it was assumed that the field is zero at the source of such upper portion. This assumption is further borne out by the fact that lines which are symmetrically divided by a field and which therefore would be broadened if a field was present show no such broadening.

In Fig. 3 are shown some illustrations of the lines as they occur on the photographic plate. In these drawings the wave-length increases from left to right. The upper part of the illustrations show the line as it appears when the field is zero; the lower part shows the effect of the field. The pair of components illustrated at (*a*) is typical of the Balmer series All the components in that series, except the central unaffected ones, seem to arrange themselves in such pairs. In helium there is only one line (4,686) which has such a symmetric pair of components and in neon there are none. The form shown in (*b*) is typical of lines which show no appreciable Stark effect. While it is distinctly broadened in its lower portion there is no doubt that at least the greater part of that broadening is due to increased intensity in the stronger field. The illustration (*c*) represents those components of He 4,388 whose electric vector is perpendicular to the field. It shows in order from left to right two components having $a < 0$ and $b < 0$, one component having $a < 0$ and $b = 0$, one having $a < 0$ and $b > 0$, and finally two having $a = 0$ and $b > 0$. The line He 4,922, sketched at (*d*), illustrates a line having one of its components so far removed that it might well be looked on as a new line. However, the intensity and general appearance of this component indicates that it is closely related to the other components of the line. The type (*e*) is very common in neon as is also type (*f*). It is possible that some of the lines found to be of the type illustrated at (*e*) are in fact of the type illustrated at (*f*), the resolving power of the spectrograph being too small to separate them. A few lines in neon are of the general type illustrated at (*g*). Unfortunately the components farthest away are in this case so faint that they are difficult to measure. A number of lines of the type shown at (*h*) occur, particularly in neon. They will be called for convenience new lines. They seem to appear only in the electric field where they are very broad and intense, several times as intense, in fact, as any other neon line in the same region. Where the field is zero these lines disappear altogether, or at least become so faint that they leave no impression on the photographic plate.

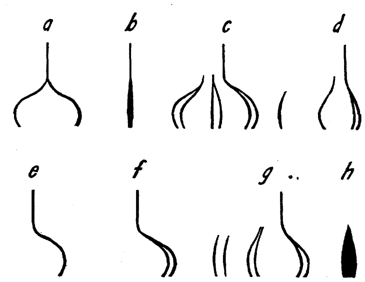

Fig. 3.

Helium.

The results obtained in helium are tabulated in Table I. Each line in the table refers to a component. The first column indicates the wave-length of the line unaffected by the electric field. The second column gives the field strength, and the third indicates the means whereby E has been calculated. α indicates that E has been computed from the distance between the parallel components of H_α and the data given for that line by Stark.[1] Similarly β indicates that the field has been obtained from the data given for the parallel components $5-5$ of H_β[2]. Also γ refers in the same manner to components $6-6$ of H_γ[3] and δ to components $7-7$ of H_δ[4]. In the next column, headed polarization, is indicated whether the component has its electric vector parallel to the field (p) or perpendicular to the field (s) or whether there is a component in both images (ps). The next column gives the change in wave-length due to the field. A positive value indicates that the wave-length is increased, a negative one that it is decreased. The last two columns give the coefficients in the relation $\delta\lambda = a + bE$. The units are A and volts per centimeter throughout.

The displacement was found in most cases by measuring the distance on the plate between hydrogen lines of known wave-lengths, one on each side of the line under investigation and assuming that the distances are proportional to differences in wave-length within this region. When no such lines of reference exist close enough together, the table given by Merwin[5] has been employed after being tested on known lines.

The following new lines were reported by Koch: 4,519, 4,046. In addition the following new lines appear on my plates: 3,962, 3,946.

In referring to the components, the following convention will be employed to identify them. First, the wave-length of the undisplaced line will be given, then, in order, the numerical values of a and of b, and finally, if necessary, the letter p, s, or both.

The component 4,686, 0, 0, is probably made up of several components but the present apparatus does not separate them. Most of the other components in helium are very sharp and are probably not further separable. The components 4,472, 0, 0, ps, are weaker in the stronger portions of the field, the contrary being the general rule. The component 4,388, $-.80$, -1.16, p also is weakened as the field increases and is nearly invisible at the point of maximum field, whereas the component 4,388,

[1] Elektrische Spektralanalyse chemischer Atome, p. 51.

[2] Loc. cit., p. 54.

[3] Loc. cit., p. 55.

[4] Loc. cit., p. 56.

[5] Am. Jour. Sci., 43, p. 49, 1917.

Table I.

Helium.

λ.	E.	Computed From	Polarization.	δλ.	a.	b.
6678	30,900	α		Doubtful		
5876	"	"		"		
5047	20,000	β		"		
5015	"	"		"		
4922	"	"	p s	2.31	0	1.16×10^{-4}
"	"	"	s	1.49	0	.75
"	"	"	p s	−2.31	−1.24	−.54
"	"	"	p s	−11.90	−11.35	−.28
4713	38,600	"		Doubtful		
4686	"	"	p	1.24	0	.32
"	"	"	s	0	0	0
"	"	"	p	−1.24	0	−.32
4472	36,400	γ	p s	1.17	0	.32
"	"	"	p s	.78	0	.20
"	"	"	p s	0	0	0
"	"	"	p s	−3.12	−1.52	−.43
"	"	"	p s	−3.80	−1.52	−.63
4438	"	"	p s	.58	0	.16
4388	"	"	p	6.33	0	1.74
"	"	"	p	5.75	0	1.58
"	"	"	s	5.50	0	1.51
"	"	"	s	3.67	0	1.01
"	"	"	p	.86	−.40	.13
"	"	"	s	.61	−.40	.06
"	"	"	s	−.40	−.40	.0
"	"	"	p s	−5.02	−.80	−1.16
"	"	"	p s	−8.58	−3.61	−1.36
"	"	"	p	−9.64	−3.61	−1.66
4169	26,200	γ	p s	1.12	0	.43
4144	"	"	p s	6.90	0	2.64
"	"	"	s	5.17	0	1.97
"	"	"	p s	2.97	0	1.13
"	"	"	s	1.57	0	.60
"	"	"	p s	−.93	−.41	−.20
"	"	"	s	−2.17	−.41	−.67
"	"	"	s	−6.00	−.41	−2.13
"	"	"	p s	−8.13	−.41	−2.95
"	"	"	p	−9.06	−.41	−3.30
4121	"	"	p s	.09	0	−.03
4026	26,800	δ	p s	2.91	0	1.09
"	"	"	s	2.30	0	.86
"	"	"	s	−.54	−.54	0
"	"	"	p s	−.70	−.54	−.06
"	"	"	s	−3.16	−1.08	−.78
"	"	"	p s	−3.78	−1.08	−1.01
3965	"	"	s	−.44	0	−.16
"	"	"	p	−.73	0	−.27
3889	"	"		Doubtful		

$-.80$, -1.16, s is strengthened with an increase of the field. The true explanation probably is that the component in question 4,388, $-.80$, -1.16, ps is elliptically polarized and that the eccentricity of the ellipse increases with the field. For any line having several values of a those values are simple multiples of the least one.

An examination of the table discloses the fact that the lines may be divided more or less sharply into types and that the lines of any given series are in general of the same type.

The line of the principal series of helium (3,889) does not show any Stark effect or, if it does, it is too small to measure. In the first subordinate helium series three members are represented: 5,876, 4,472, 4,026. They show a progressive change as follows. The first line has one group of components (probably only one component); the second has two groups with different values of a and the third has three such groups. The second subordinate helium series shows a small effect in the two lines representing it in the table (4,713, 4,121). In both cases the effect seems to be nearly the same, merely a single component displaced slightly toward the red. The lines of the first subordinate series of parhelium (6,678, 4,922, 4,388, 4,144) are separated into more components and the components are farther separated than in any other series. The lines of this series resemble each other very much on the photographic plate. The second subordinate series of parhelium (5,048, 4,438, 4,169) resembles the corresponding series in helium in that its members are composed of a single component having a positive $\delta\lambda$. The values of $\delta\lambda$ are greater than in the helium principal series. The line 3,965, which is the only member of the parhelium principal series showing a measurable deflection, is exceptional in that its component has $a = 0$, $b < 0$. No other line in helium or neon shows this effect. The line 4,686 is very much like the line H_α. It is in fact different from any other helium line. This line is interesting from the point of view of Epstein's theory[1] of the Stark effect. It has unfortunately not been possible to obtain a copy of Epstein's paper, but according to Evans and Croxson[2] it demands the value 24/7 = 3.43 for the ratio of the separation of H_β to that of 4,686. The actual ratio found is 4.75 (nearly 24/5) a discrepancy of about 38 per cent. In other words the ratio instead of being $24/(4^2-3^2)$ is $24/(3^2-2^2)$.

Neon.

As has already been pointed out a very general phenomenon is the increase of the intensity in the portion of the lines which corresponds to the field. It seems likely that this is not due to the field directly but may

[1] Epstein, Phys. Zeitschr., 17, 148, 1916; Ann. d. Physik, 50 (5), 489, 1916.

[2] Loc. cit.

TABLE II.

Neon.

λ.	E.	δλ.	b.
6206	30,900α	.17u	.05×10⁻⁴
6189	"	.13u	.04
6175	"	.80	.26
6151	"	.50u	.16
5992	"	.43	.14
5988	"	.53	.17
5976	"	.70	.23
5966	"	.57	.18
5962	"	.30u	.10
5919	"	.33	.11
5914	"	.50	.16
5907	"	1.20	.39
5903	"	.60	.19
5873	"	.35	.11
5820	"	.57	.18
5812	22,500n	+?	(blurred by an H line)
5805	30,900α	.99	.32
5765	"	.62	.20
5761	22,500n	.15	.07
5748	30,900α	.74	.24
5719	22,500n	.27	.12
5690	"	.18	.08
5657	"	.27	.12
5653	"	.32u	.14
5589	"	.34u	.15
5563	"	.45	.20
5419	20,000β	1.07	.54
5413	"	1.43	.72
5383	"	1.43u	.72
5375	"	3.03	1.52
5356	"	3.21	1.61
5333	"	2.97	1.49
5327	"	.40	.20
5214	"	1.19	.60
5211	"	1.38	.69
5209	"	1.80	.90
5204	"	2.76	1.38
5193	"	1.60	.80
5189	29,600n	.13	.04
5159	20,000β	1.78	.89
5155	"	2.15	1.08
5152	29,600n	4.18	1.41
5117	"	.51	.17
5114	20,000β	.26	.13
4945	29,600n	.71	.24
4939	"	.32	.11
4892	38,600β	1.00	.26
4866	"	9.00	2.30

TABLE II.—*Continued.*

λ.	*E.*	δλ.	*b.*
4822	38,600β	.44	$.11 \times 10^{-4}$
4819	"	3.54*u*	.92
4790	"	4.65*u*	1.20
4789	"	.33	.09
4750	"	6.96*u*	1.80
4713	"	2.12*u*	.55
4712	"	7.96	2.06
4709	"	1.68	.44
4703	"	2.48	.64
4646	"	.14	.04
4615	36,300γ	1.25	.34
4583	"	1.13	.31
4575	"	5.45	1.50
4425	"	6.12	1.69
4423	"	3.30	.91

be due to other causes such as more complete ionization. At any rate the effect of this increase in intensity is to broaden the line on the photographic plate. Now if the displacement of such a line is small it may well happen that the broadening masks the displacement either completely or to such an extent that the displacement can not be measured.

The following neon lines showed no displacement but were broadened. The ones marked with an asterisk were investigated by means of the grating as well as with the prisms. The field strength as computed from Stark's data for H_α was 30,900 volts/cm.

7,059, 7,033, 6,930, 6,717*, 6,678*, 6,599*, 6,533*, 6,507*, 6,445, 6,410, 6,402*, 6,383*, 6,352, 6,335*, 6,331, 6,328*, 6,314, 6,305*, 6,294, 6,267*, 6,247, 6,217*, 6,214, 6,182, 6,164*, 6,143,* 6,129, 6,118, 6,096*, 6,074*, 6,046, 6,030*, 5,975, 5,945*, 5,939, 5,882*, 5,852*, 5,829, 5,663, 5,434, 5,401, 5,372, 5,234, 5,189.

The following neon lines show a positive displacement, but it is so small compared with the broadening of the line that it can not be measured. The field is from 20,000 to 30,900 volts/cm.

6,001, 5,349, 5,343, 5,341, 5,331, 5,320, 5,305, 5,298, 5,280, 5,274, 5,222, 5,150, 4,837, 4,828.

The lines in Table II. have one component parallel and one perpendicular to the field. Further the two components appear to be displaced equally, which makes it probable that the light is unpolarized. The letter (α, β, γ, n) after the field strength refers to the known line from which the field has been computed. In this connection the letter n refers to the neon line 5,204, which was used in some cases, and for which the constant has in turn been computed from H_β. The value of a is zero for all lines in this table. The letter *u* after a number indicates that, by reason of obscurity of lines or other causes, the measurement is uncertain.

The component of 5,117 is probably double. The line 4,713 is blurred by the helium line.

In Table III. are listed the neon lines which have more than one component. The notation is the same as in Table I.

The component 5,360, 0, 1.25, *ps*, is very faint in comparison with the components 5,360, 0, 0, *ps*. The component 5,074, − 4.30, − 1.31, *s*, is faint and blurred. It may consist of two components. The component 5,074, − 4.30, − 1.31, *s*, is so weak on the plate that its presence can not be established with certainty. The component 5,038, 0.96, *ps*, may be made up of two. The components 5,031, − 4.75, − 1.69, *p*, and 5,031, − 4.09, − 1.14, *p*, are uncertain. The component 4,810, − 4.65, −.52, *s*, probably consists of two components.

A considerable number of new lines appear. These are very much more intense in the field than any other neon line in the same region, but the plates show no trace of them where the field is zero. The field strengths given in connection with these lines is the maximum field in the tube at the time of exposure. They do not indicate that those field strengths are the minimum required to produce the lines.

A field of 20,000 (β) produced the new lines 5,200, 5,188, 5,149, 5,139, 5,073, and 5,071. A field of 36,400(γ) produced the new lines, 4,616, 4,589, 4,569, 4,556, 4,555, 4,534, 4,533, 4,524, 4,513, 4,500, 4,458, 4,430, 4,427, 4,420, 4,413, 4,412, 4,409, 4,402, and 4,392. A field of 34,800 produced the lines 4,380, 4,371, 4,307, 4,291, 4,253, 4,242, 4,235, 4,230, 4,228, and 4,216.

The new line 5,139 has a displacement $\delta\lambda = .20$ or $b = .10 \times 10^{-4}$. The line 5,071 may be the hydrogen line.

These tables and lists probably are not complete even in the region of the spectrum which they cover (the visible). Some relatively strong lines are split up into components some of which are so faint as to be barely detectable. It is thus quite possible that other fainter lines have components that are too faint to be detected with the present means. This will be appreciated when the vast number of faint neon lines is taken into consideration. Further a number of known faint lines do not appear.

On examining the data given above, certain general facts are evident. They may be briefly summarized into the following rules which are applicable to helium and neon only.

1. The Stark effect increases with the frequency and more rapidly than the first power of the frequency.

TABLE III.

Neon.

λ.	E.	Polarization.	δλ.	a.	b.
5360	20,000β	p s	2.50	0	1.25×10^{-4}
"	"	p s	0	0	0
5145	29,600n	p s	3.46	0	1.17
"	"	s	2.24	0	.76
5122	"	p s	3.52	0	1.18
"	"	s	2.38	0	.80
5081	"	p s	2.76	0	.93
"	"	s	1.65	0	.56
5074	"	p s	4.23	0	1.43
"	"	p s	− .31	−1.48	.40
"	"	p s	−2.70	−3.27	.19
"	"	p s	−8.18	−4.30u	−1.31
5038	"	p s	2.85	0	.96
"	"	s	1.50	0	.51
5031	"	p s	3.89	0	1.31
"	"	p s	− .16	−1.38	.41
"	"	p s	−2.59	−3.06	.16
"	"	p s	−7.47	−4.09	−1.14
"	"	p s	−9.75	−4.75	−1.69
5005	"	p s	3.17	0	1.06
"	"	s	1.90	0	.64
4957	"	p s	3.28	0	1.11
"	"	s	2.03	0	.69
4885	38,600β	p	4.15	0	1.08
"	"	s	1.55	0	.40
"	"	p s	.28	0	.07
4863	"	p	9.12	0	2.37
"	"	s	6.95	0	1.80
4818	"	p s	4.65	0	1.20
"	"	p s	2.15	0	.56
"	"	p s	−4.87	−3.92	− .25
4810	"	p s	6.75	0	1.75
"	"	p s	.33	−1.54	.47
"	"	p s	−6.64	−4.65	− .52
4753	"	p s	6.77	0	1.75
"	"	s	5.42	0	1.40
"	"	p s	0	−2.33	.60
"	"	p s	−6.96	−5.21	− .45
4715	"	p s	7.85	0	2.04
"	"	s	5.70	0	1.48
4710	"	p s	1.77	0	.46
"	"	p s	−1.77	−0.60	− .30
4705	"	p s	2.48	0	.64
"	"	p s	−3.54	−4.65	.29
"	"	p s	−4.86	−5.77	.24
"	"	p s	−11.05u	−7.43	− .94
4541	36,400γ	p	12.65	0	3.48
"	"	s	9.78	0	2.69

Table III.—*Continued.*

λ.	E.	Polarization.	δλ.	a.	b.
4538	36,400γ	p	9.05	0	2.48×10^{-4}
"	"	s	6.78	0	1.86
"	"	p s	3.06	0	.84
"	"	p s	1.69	0	.46
4488	"	p	4.70	0	1.29
"	"	s	4.48	0	1.23
"	"	p s	.61	0	.17
"	"	p s	.24	0	.07
4467	"	p	1.12	0	.31
"	"	s	.56	0	.15

2. Of two lines in the same region of the spectrum the weaker is usually affected more than the stronger.

These two rules have frequent exceptions. Indeed, they are sometimes contradictory, namely, when the line of greater intensity also has the greater frequency. If we combine the two rules into one giving proper weight to the two factors, the number of exceptions is small.

3. When $a = 0$, b is positive. Only two exceptions have been found to this rule, viz., He 4,686, and He 3,965.

4. a is never positive.

5. If a given helium line has several values of a these values are simple multiples of the least one.

6. Where $a = 0$ the ratios of b for different components approximate to simple numerical ratios. Sometimes this approximation is poor and the discrepency is greater than the error in measuring.

7. When $a = 0$ for a group of components the s components are never farther displaced than the p components; the p components are displaced as far or farther than the s components. When $a = 0$ no corresponding rule can be stated because as has been said the p components are then too faint to be observed with certainty.

It was pointed out in discussing the helium spectrum that the lines which belong to the same series are similarly affected. We should therefore expect a similarity in neon between lines of the same series. Some neon series have been given by Rossi.[1] Unfortunately most of the lines in these series are so faint that it has not been possible to get them on the negatives. However, as far as the present data go some correspondence with Rossi's series is suggested. The first series of Rossi is represented by the following lines on my plates: 5,820, 5,765, 5,081, 5,038, 4,753, 4,715. The first two are given in the table as having one component each. The lines 5,081, 5,038, and 4,715 show two components

[1] Phil. Mag., 26, 981, 1913.

each. 4,753 has more than two components and differs in this respect from the other lines of the series but these components are faint and there may be components corresponding to them in the other lines which are too faint to make an impression on the plate. It is possible also that 5,820 and 5,765 may have two components and that the spectrograph does not resolve them. The second series of Rossi is represented by the lines 5,805, 5,748, 5,074, 5,031, 4,750, and 4,712. The lines 5,074 and, 5,031 differ from nearly all other lines in the number of detached components. We should then expect such components in the other four lines as well, and the plates have been carefully examined with this in mind. As for the first two there are a number of hydrogen lines where the faint components might be expected and nothing definite can be said about the absence or presence of detached components. As for the pair 4,750 and 4,712 the plate does indeed show detached components in this region but they have been attributed to other lines in the table. When several neon lines are close together there is of course no certain way of telling whether a detached component belongs to one line or another. If we attribute to 4,750 the detached components which have been attributed to 4,753 and to 4,712 the ones which have been attributed to 4,710 and 4,705, we not only increase the agreement between lines of the second series but secure nearly perfect agreement in the first series. Moreover, the lines in the second series of Rossi and the lines 4,818 and 4,810 will then be the only lines in the neon spectrum which have detached components.

Summary.

1. The Stark effect in helium and neon has been investigated by means of a high dispersion prism spectrograph and a new type of tube which is essentially a modification of the Lo Surdo tube.

2. It has been found that the various lines investigated may be classified in several types, and that lines which belong to the same series are of the same type.

3. The components obtained have been tabulated.

4. It has been found that the displacement is approximately a linear function of the field and that the absolute term in the equation relating the displacement and the field is not always zero.

5. In the helium spectrum the two new lines produced by the field and discovered by Koch were observed and, in addition, two other new lines. In the neon spectrum thirty-four such lines are observed and recorded.

6. A set of empirical rules has been given, which summarize qualitatively the results given in the tables.

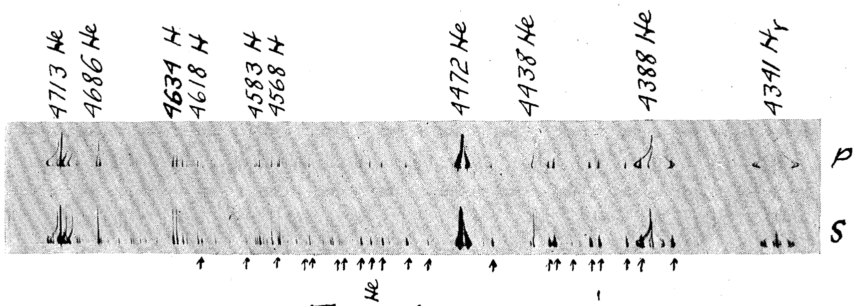

Fig. 4

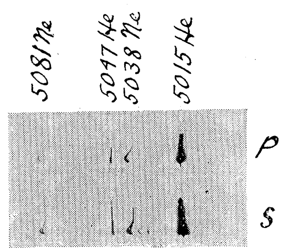

Fig. 5

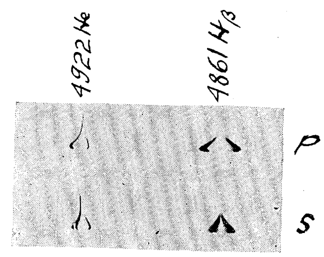

Fig. 6

HARRY NYQUIST.

The present investigation has been conducted under the supervision of Professor Bumstead, to whom I wish to express my thanks for constant direction and encouragement. My thanks are also due to Professor Taylor for assisting me in the more difficult glassblowing, particularly in making a tube of the Stark type. My thanks are further due to Professor Uhler for frequent advice about the use of the spectroscopic apparatus.

Sloane Physical Laboratory,
Yale University,
April 30, 1917.

Description of Plate I.

On Plate I. are illustrated portions of the spectrum that are of special interest. These photographs were obtained with a mixture of neon, helium and hydrogen. As has been stated previously separate photographs were taken with helium and hydrogen only.

While some of the lines are so faint as to be barely detectable, others are greatly overexposed. For this reason it was necessary to take several photographs of different times of exposure. Those shown in the plate are of rather long exposure.

The upper spectrum in each figure is produced by light having its electric vector parallel to the electric field, the lower by light vibrating perpendicularly to the field. These figures all have the long wave-length end toward the left.

Fig. 4, exposure 3 hrs., voltage on tube 5,000, pressure 1.5 mm., is from the blue portion of the spectrum. On the left is shown the helium line 4,713 together with a number of neon lines. To the right of this group are some detached components which have been mentioned in the discussion of Rossi's series. An examination of the figure will make clear the difficulty of assigning the detached components to the proper line. To the right of this group appears the line 4,686, which, as has been pointed out, is the only helium line which shows a symmetric effect. The helium line 4,472 is overexposed in this figure. The helium line 4,388 shows a great number of components and has been illustrated in Fig. 3. In the present figure the lower spectrum shows two images of this line. This is due to a fault in the optical system probably in the double image prism. In most of the photographs this does not appear and in some it occurs in the upper image. The line H_γ shows the same defect, but in neither case does it interfere with the measurements. On the negative, there appear a number of weak components between the strong components in the upper image of H_γ. These are nearly lost in the process of printing. The small arrows below the figure indicate the new lines which are situated in this region, one (4,519) belonging to helium, the rest to neon.

Fig. 5, exposure 5 hrs., voltage on tube 5,000, pressure 1.4 mm. This figure shows some helium and some neon lines. Between the lines 5,038 and 5,015 several components appear. They belong to the line Ne5031 which is of the type shown at (*g*) in Fig. 3. The upper part of this line appears on the negative but is practically lost in printing. Fig. 6, exposure 3 hrs., voltage on tube 6,000, pressure 1.6 mm. This figure shows the line 4,922 in greater detail than the drawing Fig. 3.

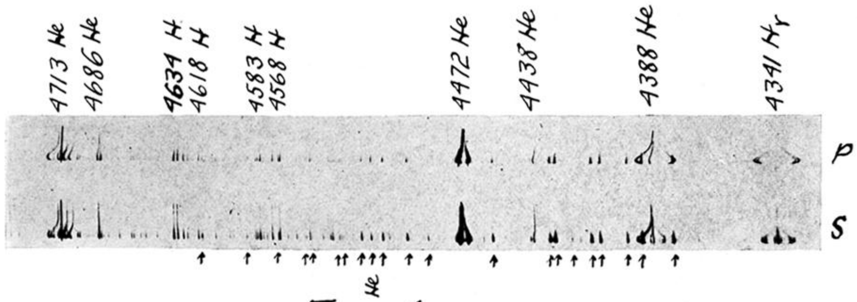

Fig. 4

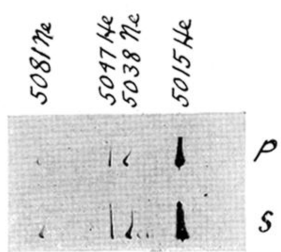

Fig. 5

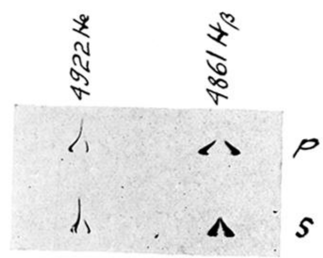

Fig. 6