

ON THE INFRA-RED SPECTRA OF THE ALKALIES.¹

II.

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V. THE ENERGY SPECTRA OF THE ALKALIES.

THE problem which had to be solved when the various alkalis were burned in the electric arc consisted in finding a means whereby the metals or their salts could be continuously and uniformly introduced. The following methods, among others, appeared the most feasible:— 1. To surround the lower (positive) carbon with a crucible in which could be placed the salt to be investigated. 2. To throw, with the aid of a suitable apparatus, a jet of the salt solution in the form of a fine spray directly into the arc. 3. To bore out the carbon and to fill with the salt to be burned the cavity thus formed, as the wick is imbedded in a candle. 4. To mix with the powdered carbon, during the process of manufacture, a sufficient quantity of the metallic salt, and to make from this mixture the special carbons to be used. The first three of these methods were tried, the third giving the best results, so that this was the means which was uniformly used in the actual experiments.

In the axis of the positive (lower) carbon, 8 mm. in diameter, was bored a hole 3 mm. in diameter, in which the dry and finely powdered salt was pounded with a hammer to a solid core. The negative carbon was also prepared in a similar manner, with the exception that the diameter of the cavity was only 1.5 mm.

As soon as the electric lamp was set in operation, the glowing of the carbon points, in which the salt was imbedded, caused the

¹ Continued from page 50.

salt to boil, and to send a perfectly uniform stream of metallic vapor directly into the arc.

The appearance of the arc was completely changed by this introduction of the salt. Instead of the peculiar bluish violet color, was seen at once the characteristic color of the metallic vapor. Even the form changed immediately, from the little spherical ball playing uniformly about the two carbon ends, into a slender ellipsoidal figure whose vertices were never at rest. These extremities in general rotated slowly around the two rings formed by the ends of the cored carbons (see Fig. 8). Since it was found impossible to obviate this wandering of the arc, an assistant was secured



Fig. 8.

who, throughout all the following investigations, changed the position of the projecting lens, as the arc moved, so that the slit of the spectrometer, upon which a real image of the arc was cast, was always symmetrically and uniformly illuminated. The length of the arc was, moreover, examined before each observation and regulated when necessary.

The consumption of electrical energy in the lamp was also quite different when carbons were used which were prepared in the manner already described. It was found by trial that to maintain the current constant at 7.7 ampères, a resistance of six ohms had to be included in the lamp circuit when the solid carbons were used, but that this resistance must be increased to ten ohms when carbons were used containing the core of salt. In both cases the length of the arc remained the same. Whether this change was due to a decreased resistance of the arc when filled with metallic vapor, or to a smaller counter-electromotive force of the arc, could not be decided without further experiments. Since this phenomenon had no vital connection with the more immediate objects of the investigation, no further experiments were made bearing upon this point.

Inasmuch as the employment of the different salts of a metal gave similar results, as, for instance, metallic sodium, sodium carbonate, and sodium chloride, only the chlorides of the metals were used in the investigation of the other alkalies.

With one exception, the salts employed were obtained in the

purest possible condition from the Trommsdorff Chemical Works in Erfurt. Only in the investigation of the chloride of sodium was the ordinary commercial article used. Below is found the number of definitive experiments carried through with each salt :—

With NaCl, 6;
“ KCl, 4;
“ LiCl, 3;
“ CsCl, 3;
“ RbCl, 2.

So complete was the uniformity of the results obtained with each metal that no hesitation is felt in selecting at random, from the material at hand, a series of observations illustrative of each group.

The contents of the following tables may be found in graphical form in Figs. 5–9, Plates II. and III. Wave-lengths are again chosen as abscissæ, and galvanometer deflections as ordinates. Even these curves can in no way lay claim to representing the true distribution of energy in the normal spectrum, since here also the lines partially, at least, overlap, as may be clearly observed in the curve for sodium from the fact that the yellow D-line does not appear double.

TABLE V.

SODIUM. $k = \frac{1}{135000}^{\circ}\text{C}.$

ϕ	λ	I	ϕ	λ	I
52° 37½'	0.3836 μ	0	48° 21½'	0.610 μ	29
28½'	0.3852 "	1	19'	0.616 "	91
23'	0.3870 "	0	16'	0.622 "	11
20½'	0.3880 "	0	10½'	0.637 "	13
13'	0.3908 "	0	7½'	0.644 "	22
7'	0.3932 "	31	6'	0.648 "	13
3½'	0.3950 "	2	3½'	0.654 "	8
			½'	0.663 "	6
51° 59½'	0.3967 "	31			
55½'	0.3983 "	0	47° 57½'	0.671 "	26
11½'	0.4218 "	1	56'	0.676 "	10
8½'	0.4236 "	42	54½'	0.680 "	10
5½'	0.4255 "	4	53'	0.685 "	4
			51½'	0.690 "	7
50° 10½'	0.4650 "	0	50'	0.695 "	5
7'	0.4677 "	11	48½'	0.699 "	7
4'	0.4703 "	1	47'	0.704 "	6
			45½'	0.710 "	14
49° 37'	0.4963 "	6	44'	0.714 "	13
34'	0.4996 "	62	42½'	0.720 "	12
31'	0.5028 "	4	41'	0.726 "	9
22'	0.5130 "	7	39½'	0.731 "	9
19'	0.5164 "	12	38'	0.737 "	10
16'	0.5200 "	3	36½'	0.743 "	5
13'	0.5240 "	4	35'	0.749 "	6
10½'	0.5271 "	16	33½'	0.755 "	9
7½'	0.5310 "	1	32'	0.761 "	12
			30½'	0.768 "	24
48° 50½'	0.5560 "	10	29'	0.775 "	12
48'	0.5600 "	19	27½'	0.781 "	6
46½'	0.5625 "	15	25½'	0.789 "	8
43'	0.5685 "	186	24'	0.796 "	8
39½'	0.5742 "	21	22½'	0.803 "	22
38'	0.5772 "	20	21'	0.811 "	166
36½'	0.5800 "	27	20¼'	0.814 "	603
31½'	0.5892 "	877	19½'	0.818 "	659
28½'	0.5950 "	96	18'	0.825 "	170
24½'	0.6040 "	28	16½'	0.833 "	27

TABLE V. — *Continued.*

SODIUM. $k = \frac{1}{133000}^{\circ} \text{C.}$

ϕ	λ	I	ϕ	λ	I
47° 15'	0.841 μ	22	46° 21½'	1.317 μ	5
13½'	0.849 "	18	20'	1.337 "	4
12'	0.857 "	18	18½'	1.358 "	3
10½'	0.865 "	11	17'	1.380 "	5
9'	0.874 "	8	15½'	1.399 "	4
7½'	0.884 "	6	14'	1.421 "	3
6'	0.895 "	6	12½'	1.442 "	3
4½'	0.905 "	6	11'	1.461 "	4
3'	0.916 "	4	9½'	1.482 "	3
1½'	0.926 "	7	8'	1.503 "	2
0'	0.938 "	7	6½'	1.523 "	3
			5'	1.543 "	2
46° 58½'	0.949 "	5	3½'	1.563 "	0
57'	0.962 "	6	2'	1.583 "	6
55'	0.977 "	5	½'	1.603 "	2
53½'	0.988 "	8			
52'	1.003 "	8	45° 59'	1.624 "	3
50½'	1.014 "	4	57½'	1.645 "	2
49'	1.028 "	6	56'	1.667 "	0
47½'	1.041 "	5	54'	1.694 "	4
46'	1.055 "	7	52½'	1.713 "	6
44½'	1.067 "	12	51'	1.733 "	5
43'	1.082 "	12	49½'	1.755 "	17
41½'	1.096 "	11	48'	1.776 "	12
40'	1.111 "	45	46½'	1.795 "	17
38½'	1.127 "	415	45'	1.816 "	11
37'	1.143 "	112	43½'	1.836 "	33
35½'	1.158 "	24	42'	1.857 "	25
34'	1.176 "	11	40½'	1.878 "	11
32½'	1.191 "	7	39'	1.898 "	5
31'	1.208 "	8	37½'	1.918 "	4
29½'	1.223 "	10	36'	1.938 "	2
28'	1.242 "	30	34½'	1.958 "	0
26½'	1.257 "	16	33'	1.978 "	0
25'	1.276 "	8	31½'	2.000 "	0
23'	1.300 "	6			

TABLE VI.

POTASSIUM. $k = \frac{1}{127000}^{\circ}\text{C}.$

ϕ	λ	I	ϕ	λ	I
52° 35½'	0.3830 μ	0	47° 54½'	0.680 μ	8
29½'	0.3850 "	2	51'	0.691 "	74
23½'	0.3870 "	0	49'	0.698 "	13
21'	0.3877 "	0	44½'	0.713 "	7
14'	0.3903 "	0	39'	0.733 "	12
			36'	0.745 "	27
51° 46'	0.4030 "	0	31'	0.767 "	1443
43'	0.4045 "	30	30'	0.770 "	622
40'	0.4060 "	0	28½'	0.777 "	82
12'	0.4214 "	2	27'	0.783 "	31
9'	0.4233 "	16	25½'	0.790 "	31
6'	0.4251 "	0	24'	0.796 "	27
			22½'	0.803 "	36
50° 17½'	0.4590 "	2	21'	0.811 "	34
			19½'	0.818 "	22
49° 46'	0.4870 "	2	18'	0.825 "	16
41½'	0.4915 "	0	16½'	0.832 "	16
39½'	0.4942 "	3	15'	0.841 "	17
32'	0.5023 "	0	13½'	0.850 "	14
25'	0.5095 "	4	12'	0.857 "	12
23½'	0.5113 "	5	10½'	0.866 "	12
20½'	0.5148 "	0	9'	0.876 "	13
8'	0.5307 "	0	7½'	0.886 "	12
5½'	0.5340 "	9	6'	0.896 "	9
4'	0.5362 "	6	4½'	0.906 "	8
2'	0.5388 "	0	3'	0.917 "	10
			1'	0.931 "	7
48° 40'	0.5737 "	1			
36½'	0.5800 "	14	46° 59½'	0.943 "	20
34'	0.5848 "	7	58'	0.954 "	20
31½'	0.5892 "	55	56½'	0.966 "	9
28½'	0.5950 "	3	55'	0.977 "	8
21½'	0.6093 "	2	53½'	0.990 "	7
19'	0.616 "	6	52'	1.002 "	9
10'	0.638 "	8	50½'	1.015 "	8
8'	0.643 "	11	49'	1.029 "	14
5½'	0.649 "	8	47½'	1.042 "	16

TABLE VI. — *Continued.*

POTASSIUM. $k = \frac{1}{127000}^{\circ}\text{C.}$

ϕ	λ	I	ϕ	λ	I
46° 46'	1.055 μ	21	46° 3½'	1.563 μ	6
44½'	1.068 "	17	2'	1.583 "	3
43'	1.082 "	102	½'	1.603 "	2
42½'	1.090 "	57			
41½'	1.096 "	25	45° 59'	1.625 "	4
40'	1.110 "	13	57'	1.652 "	2
38½'	1.127 "	35	55½'	1.672 "	2
37'	1.144 "	207	54'	1.693 "	4
35½'	1.158 "	389	52½'	1.713 "	3
34'	1.175 "	34	51'	1.733 "	3
32½'	1.193 "	14	49½'	1.755 "	2
31'	1.209 "	126	48'	1.776 "	5
29½'	1.225 "	190	46½'	1.795 "	0
28'	1.243 "	43	45'	1.816 "	0
26'	1.264 "	10	43½'	1.836 "	2
24½'	1.283 "	11	42'	1.857 "	5
23'	1.301 "	10	40½'	1.876 "	3
21½'	1.317 "	8	39'	1.898 "	2
20'	1.336 "	10	37½'	1.918 "	4
18½'	1.359 "	10	36'	1.938 "	0
17'	1.379 "	5	34½'	1.958 "	0
15½'	1.400 "	5	33'	1.978 "	0
14'	1.420 "	8	31½'	2.000 "	0
12½'	1.440 "	19	30'	2.021 "	0
11'	1.461 "	60	28½'	2.042 "	0
9½'	1.482 "	56	27'	2.062 "	0
8'	1.503 "	49	25'	2.087 "	0
6½'	1.523 "	12	23½'	2.108 "	0
5'	1.543 "	5	22'	2.128 "	0

TABLE VII.

LITHIUM. $k = 134000^{\circ} \text{C.}$

ϕ	λ	I	ϕ	λ	I
52° 33½'	0.3838 μ	2	47° 58'	0.670 μ	1191
26'	0.3860 "	2	56'	0.676 "	57
22'	0.3875 "	2	54½'	0.680 "	29
16'	0.3900 "	0	53'	0.684 "	24
11½'	0.3913 "	8	51½'	0.689 "	18
4'	0.3947 "	0	50'	0.694 "	15
			48½'	0.699 "	11
51° 29½'	0.4116 "	1	47'	0.704 "	10
25½'	0.4140 "	58	45½'	0.709 "	10
22½'	0.4155 "	5	44'	0.715 "	11
11'	0.4220 "	0	42½'	0.720 "	8
8½'	0.4238 "	11	41'	0.725 "	7
4½'	0.4260 "	0	39½'	0.732 "	6
½'	0.4288 "	10	38'	0.737 "	5
			36½'	0.743 "	10
50° 57½'	0.4305 "	2	35'	0.749 "	6
18'	0.4590 "	8	33½'	0.754 "	6
14½'	0.4615 "	331	32'	0.760 "	11
10½'	0.4650 "	7	30½'	0.768 "	12
			29'	0.775 "	8
49° 37½'	0.4958 "	2	27½'	0.781 "	9
34½'	0.4990 "	34	26'	0.787 "	17
31½'	0.5023 "	2	24½'	0.794 "	18
			22½'	0.803 "	151
48° 59½'	0.5420 "	8	21¾'	0.807 "	292
34½'	0.5840 "	8	21'	0.811 "	238
31½'	0.5892 "	51	19½'	0.819 "	22
28½'	0.5950 "	8	18'	0.825 "	15
26½'	0.5993 "	5	16½'	0.833 "	12
25'	0.6025 "	20	15'	0.841 "	11
21½'	0.6102 "	570	13½'	0.849 "	15
18'	0.6180 "	17	12'	0.857 "	12
12½'	0.6308 "	7	10½'	0.865 "	10
5½'	0.6490 "	18	9'	0.876 "	9
½'	0.663 "	46	7½'	0.885 "	8

TABLE VII. — *Continued.*

LITHIUM. $\lambda = \frac{1}{134000}^{\circ}$ C.

ϕ	λ	I	ϕ	λ	I
47° 6'	0.895 μ	5	46° 15½'	1.397 μ	2
4½'	0.904 "	7	14'	1.420 "	3
3'	0.916 "	9	12½'	1.440 "	3
1½'	0.926 "	11	11'	1.462 "	2
0'	0.937 "	11	9½'	1.482 "	4
			8'	1.502 "	3
46° 58½'	0.950 "	9	6½'	1.522 "	2
57'	0.962 "	9	5'	1.543 "	3
55½'	0.973 "	4	3½'	1.563 "	2
54'	0.987 "	8	2'	1.583 "	1
52'	1.002 "	5	½'	1.603 "	4
50½'	1.014 "	5			
49'	1.028 "	6	45° 59'	1.625 "	2
47½'	1.041 "	6	57½'	1.645 "	2
46'	1.054 "	5	56'	1.665 "	0
44½'	1.067 "	7	54½'	1.685 "	0
43'	1.082 "	14	53'	1.706 "	9
41½'	1.096 "	8	51'	1.732 "	10
40'	1.111 "	9	49½'	1.755 "	12
38½'	1.127 "	9	48'	1.776 "	16
37'	1.144 "	6	46½'	1.796 "	13
35½'	1.157 "	7	45'	1.816 "	14
34'	1.176 "	7	43½'	1.835 "	11
32½'	1.192 "	9	42'	1.857 "	10
31'	1.208 "	7	40½'	1.876 "	8
29½'	1.225 "	8	39'	1.898 "	12
28'	1.242 "	5	37½'	1.918 "	8
26½'	1.257 "	7	36'	1.937 "	3
25'	1.276 "	8	34½'	1.958 "	0
23½'	1.294 "	4	33'	1.978 "	0
21½'	1.317 "	4	31½'	2.000 "	0
20'	1.336 "	3	30'	2.020 "	0
18½'	1.357 "	2	28½'	2.042 "	0
17'	1.378 "	3			

TABLE VIII.

RUBIDIUM. $\lambda = \frac{1}{132000}^{\circ} \text{C.}$

ϕ	λ	I	ϕ	λ	I
52° 30'	0.3832 μ	0	48° 14'	0.627 μ	23
24'	0.3868 "	0	11'	0.633 "	12
20½'	0.3880 "	0	6'	0.648 "	10
16½'	0.4190 "	0	1'	0.662 "	8
51° 14'	0.4200 "	6	47° 58½'	0.669 "	11
12'	0.4215 "	4	55½'	0.677 "	8
9½'	0.4230 "	8	49½'	0.696 "	5
6½'	0.4250 "	0	45'	0.711 "	8
50° 18'	0.4588 "	0	41'	0.726 "	21
49° 19'	0.5163 "	3	39½'	0.731 "	17
15'	0.5215 "	5	38'	0.737 "	19
12¾'	0.5242 "	2	35½'	0.747 "	15
10½'	0.5270 "	6	33½'	0.755 "	31
6'	0.5332 "	2	31½'	0.763 "	128
3½'	0.5367 "	4	30½'	0.768 "	188
½'	0.5406 "	2	29'	0.775 "	414
48° 58½'	0.5435 "	4	27½'	0.781 "	262
56'	0.5473 "	2	25¼'	0.791 "	443
48½'	0.5592 "	9	24½'	0.794 "	279
45½'	0.5642 "	3	23'	0.801 "	56
43½'	0.5676 "	1	21½'	0.808 "	38
41½'	0.5710 "	7	20'	0.815 "	32
38½'	0.5762 "	2	18½'	0.823 "	42
35½'	0.5820 "	3	17'	0.831 "	24
31½'	0.5892 "	26	15½'	0.839 "	25
28¾'	0.5942 "	5	14'	0.846 "	50
25'	0.6020 "	4	12½'	0.854 "	14
23'	0.607 "	8	11'	0.863 "	11
21'	0.611 "	6	9½'	0.872 "	45
19'	0.616 "	12	8'	0.882 "	59
17'	0.620 "	11	6½'	0.892 "	17
15½'	0.624 "	10	5'	0.902 "	10
			3½'	0.912 "	11
			2'	0.923 "	9
			½'	0.934 "	9

TABLE VIII. — *Continued.*

RUBIDIUM. $k = 132000^\circ \text{C.}$

ϕ	λ	I	ϕ	λ	I
46° 59'	0.946 μ	10	46° 8½'	1.498 μ	64
57½'	0.957 "	7	7'	1.517 "	71
55½'	0.972 "	7	5½'	1.535 "	16
54'	0.986 "	21	4'	1.556 "	6
52½'	0.998 "	160	2½'	1.576 "	5
51'	1.011 "	32	1'	1.597 "	5
49½'	1.023 "	9			
48'	1.038 "	7	45° 59½'	1.618 "	5
46½'	1.050 "	8	57½'	1.645 "	4
45'	1.064 "	11	56'	1.666 "	4
43½'	1.077 "	10	54½'	1.685 "	2
42'	1.092 "	13	53'	1.705 "	3
40½'	1.105 "	11	51½'	1.725 "	3
39'	1.124 "	7	50'	1.747 "	3
37½'	1.138 "	13	48½'	1.770 "	0
36'	1.154 "	26	47'	1.790 "	0
34½'	1.170 "	10	45½'	1.812 "	0
33'	1.187 "	5	44'	1.831 "	3
31½'	1.203 "	6	42½'	1.850 "	1
30'	1.218 "	13	41'	1.870 "	0
28'	1.242 "	10	39½'	1.890 "	0
26½'	1.258 "	9	38'	1.913 "	0
25'	1.277 "	35	36½'	1.932 "	0
23½'	1.293 "	100	35'	1.952 "	0
22'	1.312 "	197	33½'	1.972 "	0
20½'	1.330 "	151	32'	1.993 "	0
19'	1.352 "	83	30½'	2.014 "	0
17½'	1.372 "	16	29'	2.036 "	0
16'	1.393 "	15	27'	2.062 "	0
14½'	1.413 "	40	25½'	2.082 "	0
13'	1.434 "	82	24'	2.102 "	0
11½'	1.454 "	94	22½'	2.120 "	0
10'	1.476 "	102			

TABLE IX.
 CÆSIUM. $k = \frac{1}{132000}^{\circ}\text{C}.$

ϕ	λ	I	ϕ	λ	I
52° 41½'	0.3812 μ	0	48° 7½'	0.644 μ	10
32'	0.3842 "	0	5'	0.650 "	9
25'	0.3868 "	0	2½'	0.658 "	15
22½'	0.3875 "	0	½'	0.663 "	19
51° 17'	0.4186 "	0	47° 58'	0.670 "	46
14½'	0.4200 "	4	56'	0.676 "	11
12½'	0.4212 "	2	54'	0.681 "	17
10½'	0.4225 "	7	52½'	0.687 "	26
7½'	0.4243 "	0	50'	0.694 "	63
50° 23½'	0.4545 "	0	47½'	0.702 "	20
21'	0.4565 "	15	45'	0.711 "	11
18½'	0.4584 "	2	42'	0.721 "	47
16½'	0.4600 "	6	39'	0.733 "	13
13½'	0.4625 "	0	34½'	0.751 "	12
49° 41'	0.4920 "	4	32½'	0.759 "	43
38½'	0.4950 "	4	31'	0.766 "	65
0'	0.5412 "	4	29'	0.775 "	175
48° 52½'	0.5528 "	7	27½'	0.781 "	95
50'	0.5570 "	4	26'	0.788 "	104
46'	0.5635 "	7	24½'	0.794 "	105
43'	0.5686 "	2	23'	0.801 "	77
38'	0.5772 "	4	21½'	0.808 "	45
35'	0.5828 "	28	20'	0.815 "	29
33½'	0.5856 "	23	18½'	0.823 "	26
31½'	0.5892 "	54	17'	0.831 "	54
28½'	0.5950 "	9	15½'	0.838 "	297
25¾'	0.6010 "	14	14'	0.847 "	226
23'	0.607 "	9	12½'	0.854 "	59
20'	0.614 "	8	11'	0.863 "	151
17½'	0.619 "	23	9½'	0.872 "	140
15½'	0.624 "	8	8'	0.882 "	345
13½'	0.629 "	12	6½'	0.892 "	113
10½'	0.636 "	7	5'	0.902 "	154
			3½'	0.913 "	83
			2'	0.923 "	16
			½'	0.934 "	9

TABLE IX. — *Continued.*

CÆLIUM. $k = 132000^\circ \text{C.}$

ϕ	λ	I	ϕ	λ	I
46° 59'	0.945 μ	10	46° 8½'	1.495 μ	19
57½'	0.956 "	9	7'	1.516 "	20
55½'	0.973 "	7	5½'	1.535 "	5
54'	0.986 "	129	4'	1.555 "	6
52½'	0.998 "	181	2½'	1.575 "	7
51'	1.011 "	17	1'	1.596 "	4
49½'	1.023 "	5			
48'	1.038 "	6	45° 59½'	1.617 "	3
46½'	1.050 "	4	58'	1.638 "	4
45'	1.064 "	6	56½'	1.658 "	3
43½'	1.077 "	6	55'	1.679 "	3
42'	1.092 "	4	53½'	1.700 "	2
40½'	1.105 "	6	51½'	1.725 "	2
39'	1.124 "	8	50'	1.748 "	2
37½'	1.138 "	8	48½'	1.768 "	1
36'	1.154 "	8	47'	1.789 "	2
34½'	1.170 "	4	45½'	1.807 "	1
33'	1.187 "	4	44'	1.830 "	0
31½'	1.202 "	7	42½'	1.850 "	0
30'	1.219 "	6	41'	1.871 "	0
28½'	1.236 "	4	39½'	1.890 "	0
27'	1.253 "	12	38'	1.912 "	0
25½'	1.269 "	13	36½'	1.930 "	0
23½'	1.293 "	27	35'	1.952 "	0
22'	1.312 "	64	33½'	1.972 "	0
20½'	1.327 "	80	32'	1.992 "	0
19'	1.352 "	31	30½'	2.012 "	0
17½'	1.372 "	7	29'	2.036 "	0
16'	1.392 "	11	27½'	2.055 "	0
14½'	1.412 "	35	26'	2.075 "	0
13'	1.433 "	38	24½'	2.095 "	0
11½'	1.453 "	51	22½'	2.120 "	0
10'	1.475 "	25	21'	2.142 "	0

VI. DISCUSSION OF THE OBSERVATIONS.

A hasty consideration of the curves of Plates II. and III. shows that the energy spectra of the alkalis have but little in common with that of the electric arc. While the latter produces, as has been shown above, the impression of a banded spectrum, the former is at once recognized as a spectrum composed of bright lines.

Kayser and Runge mention,¹ in their investigation, the fact that measurements upon the spectral lines of metals vaporized in the electric arc are often rendered difficult by the superposition of the metallic lines upon the banded carbon spectrum.

The present writer, however, has found, by following the method here described of filling the carbons with a core of the salt to be examined, that *the carbon spectrum is completely destroyed, and in its stead appears the pure metallic spectrum.* To attain this result, however, it is necessary to set the lamp in operation about five minutes before beginning the series of observations, since by the ignition of fresh carbons, the bands of the arc spectrum are often to be seen between the lines in the spectrum of the metal in question. After the lapse of this short interval of time, the bolometer, even when placed at the position of maximum heat in the arc spectrum (from $\lambda = .385 \mu$ to $\lambda = .388 \mu$), gives at most a deflection of but 2 or 3 mm., while large deflections at this same place are obtained when pure carbons are used.

It must be mentioned in this connection that to attain this result it is necessary that *both* carbons be filled with a core of salt, since when a solid cathode, for instance, is used, there always clings to the ends of the negative carbon a point of the characteristic violet light of the ordinary arc.

By increasing the dimensions of the cavity containing the salt in the carbons, the energy of the metallic lines may be many times increased. It was observed that a core 5 mm. in diameter increased the intensity of the lines nearly tenfold. On the other

¹ *Kayser und Runge*, Abh. d. K. Acad. d. Wiss. zu Berlin, 2. Abs. p. 3, 1889. Wied. Ann., 38, p. 80, 1889.

hand, the use of such large quantities of salt was attended with other disadvantages which made it desirable to return to the original dimensions of the holes bored; viz. 3 mm. and $1\frac{1}{2}$ mm. respectively.

It is to be noticed in all these drawings that the lines become broader as the more distant portions of the infra-red are reached. This effect does not, however, correspond to a physical cause, but is due in part to the method of representation here chosen, in part also to the chromatic aberration of the lenses of the spectrometer. As the bolometer filament wanders through the entire spectrum, there is concentrated upon its surface a far greater number of rays of different wave-lengths in the infra-red than in the region visible to the eye. If the thread of the bolometer were to be drawn at different places in Figs. 4-9, Plates II. and III., its breadth at $\lambda=2\mu$ would appear nearly forty times greater than at $\lambda=.4\mu$. The same is true of the image of the slit itself. Metallic lines which in the energy curve of the dispersion spectrum appear equally broad, must, accordingly, appear much broader at $\lambda=2\mu$ than at $\lambda=.4\mu$, when wave-lengths are chosen as abscissæ instead of the angular deviation of the bolometer arm.

To this effect is added, as mentioned above, that due to the lack of achromatism of the lenses used. This failure is far more noticeable in the infra-red than in the visible portions of the spectrum, and as a result the lines become more indistinct the farther they lie in the direction of the long wave-lengths. Abney¹ has also remarked that the focus of a lens for infra-red rays is quite different from its focus for radiations of greater refrangibility.

The cause of this failing achromatism in a system of lenses is to be found in the different characters which the curves of dispersion for flint and crown glass show in the infra-red. Rubens, in his investigation "Ueber Dispersion Ultrarother Strahlen," has shown² that the curves of dispersion for specimens of flint glass become nearly straight in the infra-red, but yet are always curved in the same direction, while in the curves of dis-

¹ *Abney*, Phil. Trans., Pt. II., p. 658, 1880.

² *Rubens*, Wied. Ann., 45, p. 255, 1892.

persion of crown glass a point of inflection occurs in the neighborhood of $\lambda=1.4\mu$, which causes the direction of the curvature at this point to change.

The extent to which this effect was noticeable in the measurements of the energy spectra may be illustrated by an example. When the telescope was focused on a green potassium line, the bolometer detected between the limits $\lambda=1.440\mu$ and $\lambda=1.540\mu$ a broad, poorly defined band, which passed into an easily recognized, although not perfectly sharp line, as soon as the focus was adjusted upon the line potassium α .

In conducting the definitive measurements, the observing telescope was so adjusted that the line potassium α appeared perfectly sharp. It is believed by thus focusing upon this most distant visible line toward the infra-red end of the spectrum, that a portion at least of the defective achromatism was avoided.¹

Before a short description of the several metallic spectra is given in detail, a word may be said regarding the influence upon the intensities of the lines of the absorption within the measuring apparatus. In the less refrangible regions of the visible spectrum and in those portions of the infra-red here investigated, the absorption is inconsiderable, as is proven in the paper by Rubens so frequently cited. As is there shown, strong absorption is not perceptible in the specimens of crown glass examined until a wave-length $\lambda=2.3\mu$ is reached, while flint glass exhibits a far greater transparency for infra-red radiations. The absorption produced in the violet end of the spectrum by the lenses of the spectrometer and by the prism is, without doubt, of much greater magnitude, though the amount could hardly be estimated. In a recent paper, Professor Nichols and the present writer have shown² that even a single crown glass lens can produce heavy absorption in this portion of the spectrum. It may then be supposed that the violet bands in the spectrum of the electric arc are far more intense than they appear from the curves shown in Figs. 3 and 4, Plate I.

¹ It need hardly be mentioned here that these errors would not affect the position or wave-lengths of the lines, but would simply tend to diminish the intensity.

² *Nichols and Snow, Phil. Mag. (5), 33, p. 380, 1892.*

VII. ON THE METALLIC LINES.

The visible region of the sodium spectrum contains a series of lines which may be readily observed with the eye, but which are so lacking in energy that they exert no appreciable effect upon the bolometer. On the other hand, the two violet lines at $\lambda = .3932 \mu$ and $\lambda = .3967 \mu$, coinciding, as they do, very closely with the Fraunhofer lines H and K of the solar spectrum, appear sharply defined in the drawing.¹ The green line at $\lambda = .5685 \mu$, the yellow at $\lambda = .5892 \mu$, D, and the red at $\lambda = .616 \mu$ are the strongest in the visible region. In the infra-red are found, besides a series of weaker lines at $\lambda = .770 \mu$, $\lambda = .855 \mu$, $\lambda = .930 \mu$, $\lambda = .995 \mu$, $\lambda = 1.075 \mu$, $\lambda = 1.245 \mu$, two lines of unusual intensity at $\lambda = .818 \mu$ and $\lambda = 1.132 \mu$. The energy of the first of these two is approximately equal to that of the D-line, and, indeed, exceeds the latter in several series of observations. The bolometer shows, further, in the region between $\lambda = 1.70 \mu$ and $\lambda = 1.90 \mu$, the presence of a small amount of energy, which, if the proper focus could be adjusted, might be resolved into a line or a group of lines. It has, however, not been possible thus to analyse this diffuse radiation, which also appears in a similar position in the lithium spectrum.

Much simpler than the spectrum of sodium is that of lithium, which, besides this feeble amount of energy between $\lambda = 1.70 \mu$ and $\lambda = 1.90 \mu$, shows only a single line at $\lambda = .811 \mu$ in the infra-red. There is here noticeable, in addition to the eight visible lines measurable with the bolometer, also the yellow sodium line. This metal occurred in small quantities as an impurity in all the salts investigated, and in all cases made its presence known by a more or less prominent D-line.

In the potassium spectrum, the largest portion of the energy is concentrated in the one line potassium α . While this line exerts only a feeble effect upon the eye, it is, as regards its radiant energy, by far the strongest line found in the spectra of the five alkalies investigated. This is then an illustration of the

¹ Professor Kayser has kindly pointed out that these two lines are undoubtedly due to the presence of a trace of calcium in the salt used.

fact that the human eye is far from sensitive to radiations of this wave-length.

A noticeable difference between the spectrum of this metal and that of sodium and lithium is the relatively luminous background upon which the lines are superposed. Infra-red lines were found at $\lambda = .840 \mu$, $\lambda = .885 \mu$, $\lambda = .950 \mu$, $\lambda = 1.086 \mu$, $\lambda = 1.155 \mu$, and $\lambda = 1.220 \mu$, besides the diffuse line mentioned above at $\lambda = 1.470 \mu$. The other lines occurring at $\lambda = .589 \mu$ and $\lambda = .815 \mu$ in Fig. 6, Plate II., belong to sodium.

The spectra of rubidium and caesium are richer in infra-red lines than those thus far considered. In the visible region the background upon which the lines of these metals seem to be projected appears more luminous than that of potassium — a fact which is undoubtedly closely connected with the whitish appearance which the arc assumes as soon as these metals are introduced. The two blue lines at $\lambda = .4565 \mu$ and $\lambda = .4600 \mu$, to which the metal caesium owes its name, are easily discernible in Fig. 9, Plate III., although of feeble intensity. On the other hand, the two red rubidium lines, the deep red color of which has given the name rubidium to this metal, have, as regards energy, a maximum intensity.

Inasmuch as in the caesium spectrum indications are found of the presence of lines which obviously belong to the metal rubidium, for instance the group at $\lambda = .4200 \mu$ and $\lambda = .4230 \mu$, it is probable that in the caesium chloride used a quantity of the corresponding rubidium salt was present as an impurity. The infra-red caesium spectrum, as given here, may therefore be considerably affected by lines due to rubidium.

In their investigations,¹ Kayser and Runge have undertaken an approximate estimation of the intensity of many of the lines, and have introduced for this purpose a scale of luminosity consisting of six numbers. Since it may be assumed in the present case that with the possible exception of the violet end of the spectrum, the selective absorption of the apparatus plays no important part, it has seemed allowable in this investigation to regard the intensities of the lines as proportional to the galva-

¹ *Kayser und Runge*, *Wied. Ann.*, 41, p. 306, 1890.

nometer deflections. It is to be observed, however, that the more distant infra-red lines appear by this method too weak in intensity, due to the defective achromatism mentioned above.

For all this, the writer does not consider himself justified in introducing a correction in these figures which would thus apply to the intensity of but a few lines at most, and even here the correction is probably not large. In the following tables, in addition to the wave-lengths of the several lines, are added their respective intensities, as read directly from the ordinates of the curves, Figs. 5-9, Plates II. and III. While, indeed, the unit of the energy is an arbitrary one, yet the lines of all the metals examined were measured in terms of the same standard, since the current in the lamp and the sensitiveness of the measuring apparatus were subjected to but feeble fluctuations.

TABLES OF WAVE-LENGTHS AND INTENSITIES.

TABLE X.

LITHIUM.

λ	I	λ	I	λ	I
0.3913 μ	10	0.4615 μ	331	0.670 μ	1191
0.4140 "	58	0.4990 "	34	0.811 "	296
0.4238 "	11	0.6102 "	570	1.800(?) "	(?)
0.4288 "	10				

TABLE XI.

POTASSIUM.

λ	I	λ	I	λ	I
0.4045 μ	30	0.643 μ	11	1.086 μ	108
0.4233 "	16	0.691 "	74	1.155 "	395
0.5113 "	5	0.768 "	1443	1.220 "	205
0.5340 "	9	0.840 "	18	1.470 "	70
0.5362 "	6	0.885 "	13	1.500(?) "	50
0.5800 "	14	0.950 "	23		

TABLE XII.

SODIUM.

λ	I	λ	I	λ	I
0.3932 μ	31	0.5892 μ	877	0.770 μ	22
0.3967 "	31	0.616 "	91	0.818 "	660
0.4236 "	42	0.644 "	22	0.855 "	18
0.4677 "	11	0.671 "	26	0.930 "	8
0.4996 "	62	0.699 "	7	0.995 "	10
0.5164 "	12	0.710 "	14	1.075 "	13
0.5271 "	16	0.714 "	13	1.132 "	419
0.5600 "	19	0.720 "	12	1.245 "	30
0.5685 "	186	0.736 "	10	1.800(?) "	(?)

TABLE XIII.

RUBIDIUM.

λ	I	λ	I	λ	I
0.4200 μ	6	0.627 μ	23	0.945 μ	10
0.4230 "	8	0.669 "	11	0.997 "	151
0.5215 "	5	0.726 "	21	1.063 "	11
0.5270 "	6	0.737 "	19	1.090 "	13
0.5367 "	4	0.775 "	414	1.153 "	26
0.5435 "	4	0.791 "	443	1.224 "	13
0.5592 "	9	0.821 "	42	1.318 "	198
0.5710 "	7	0.845 "	50	1.475 "	102
0.607 "	8	0.878 "	60	1.520 "	71
0.616 "	12	0.913 "	11		

TABLE XIV.
CESIUM.

λ	I	λ	I	λ	I
0.4200(?) μ	4	0.646 μ	10	0.900 μ	155
0.4230(?) μ	7	0.674 "	46	0.995 "	182
0.4565 "	15	0.694 "	63	1.150 "	9
0.4600 "	6	0.721 "	47	1.205 "	7
0.5528 "	7	0.775 "	175	1.323 "	81
0.5635 "	7	0.790 "	107	1.420(?) μ	38
0.5828 "	28	0.833 "	297	1.450 "	52
0.6010 "	14	0.865 "	151	1.520 "	20
0.619 "	23	0.882 "	345	1.575 "	8
0.629 "	12				

The previously mentioned investigations of Becquerel on the wave-lengths of the infra-red sodium and potassium lines gave values which are compared in the following table with the results of the present observations.

TABLE XV.

BECQUEREL.		SNOW.
With the Prism.	With the Grating.	With the Prism.
Na $\lambda = 0.819 \mu$	$\lambda = 0.819 \mu$	$\lambda = 0.818 \mu$
$\lambda = 1.098 "$	$\lambda = 1.142 "$	$\lambda = 1.132 "$
K $\lambda = 0.770 "$	$\lambda = 0.770 "$	$\lambda = 0.768 "$
$\lambda = 1.003 "$		
$\lambda = 1.073 "$	$\lambda = 1.098 "$	$\lambda = 1.086 "$
$\lambda = 1.125 "$	$\lambda = 1.162 "$	$\lambda = 1.155 "$
$\lambda = 1.182 "$	$\lambda = 1.233 "$	$\lambda = 1.220 "$

Becquerel's measurements with the aid of the prism are observed to be in general smaller than the results here presented, while the latter coincide more nearly with his determinations with the grating. More confidence was placed by Becquerel himself in

the grating measurements, so that the better agreement between his values and those here given may be regarded as a partial confirmation of the determinations as given in this paper.

VIII. CONCLUSION.

This investigation was originally begun to test experimentally in the infra-red the empirical formulæ established by Kayser and Runge for the wave-length of lines in the visible and ultra-violet spectrum.

At the writer's request, Professor Runge very kindly furnished a table of the wave-lengths as calculated by himself and Professor Kayser. These values as given in the following table may be in error by an amount from 10 to 20 $\mu\mu$ on account of the extensive extrapolation demanded.

TABLE XVI.

	λ			
Li	0.819 μ			
Na	1.150	1.148 μ		
K	1.266	1.257	1.253	1.244 μ
Rb	1.718	1.653 μ		
Cs	0.922	0.877	0.867	0.828 μ

In a number of cases, for instance with lithium and sodium, the coincidence with the values here obtained is as close as could have been expected. With the other metals, however, noticeably greater discrepancies occur, so that these observations in their present form cannot be regarded as a full confirmation of the formulæ of Kayser and Runge.

I desire in conclusion to express to Professor August Kundt my warmest thanks, not only for the cordial support he so freely gave, but also for his many suggestions and for the kindly interest which he took in the entire investigation.

Fig. 5.

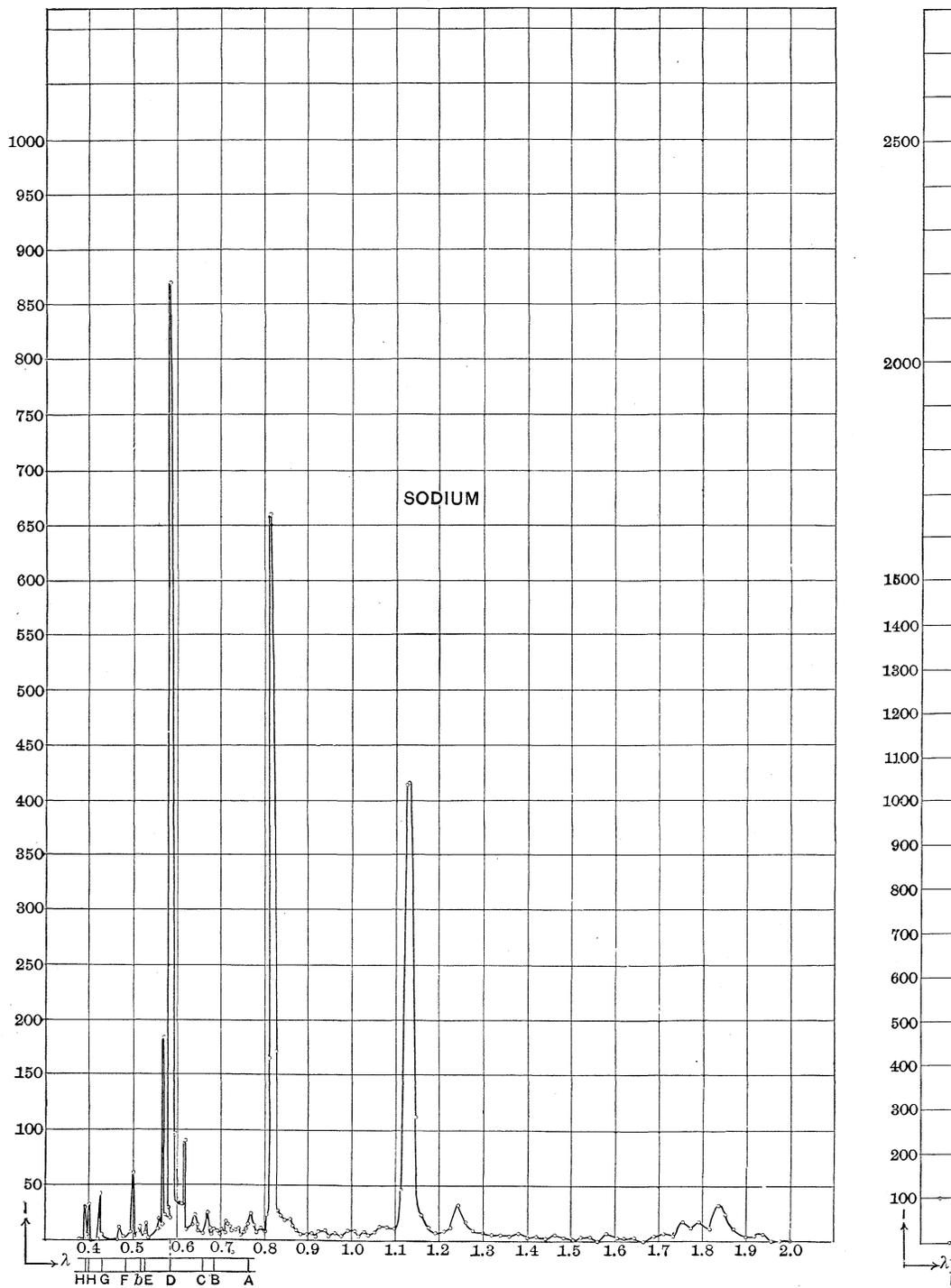
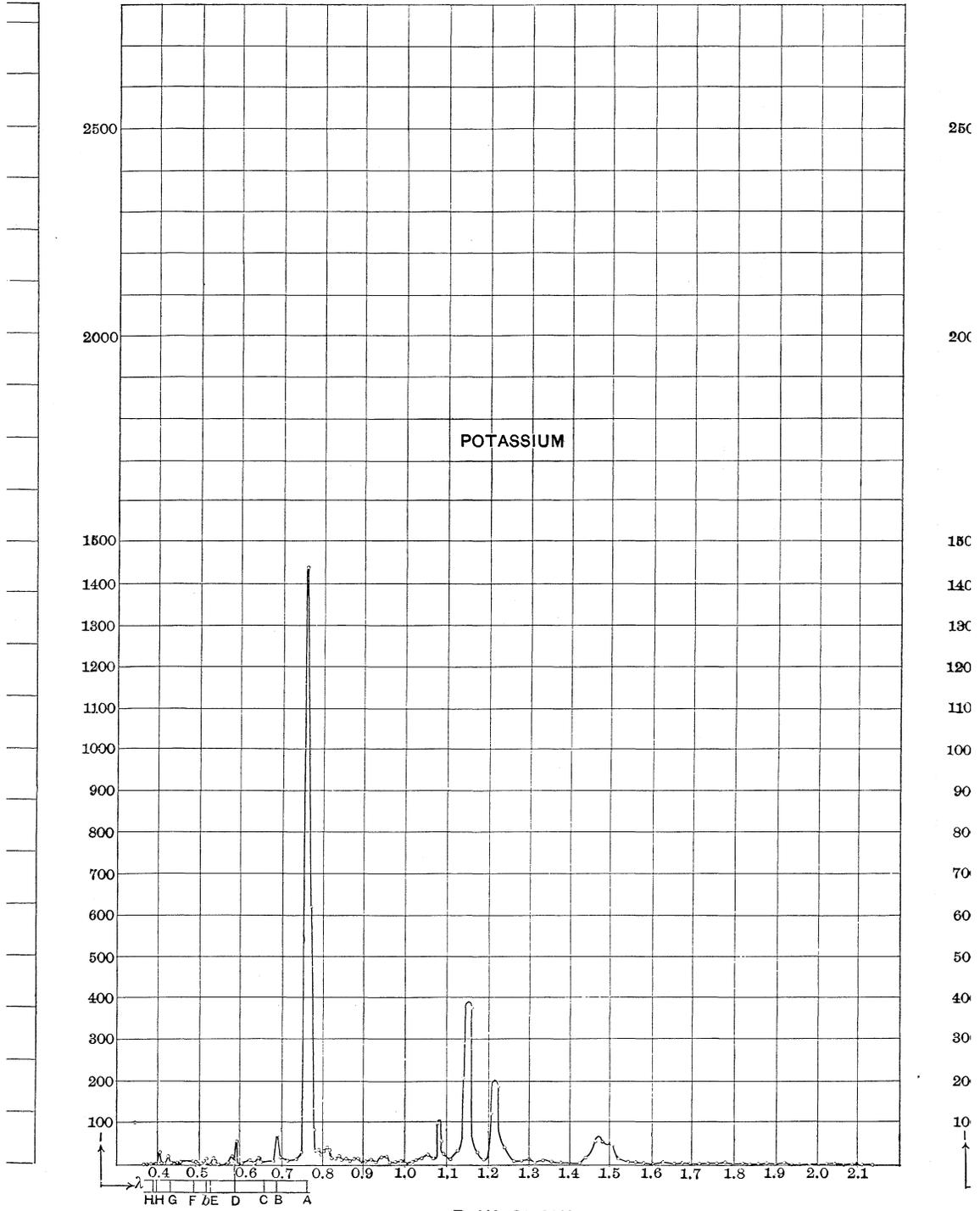


Fig. 6.



B. W. SNOW.

Fig. 7.

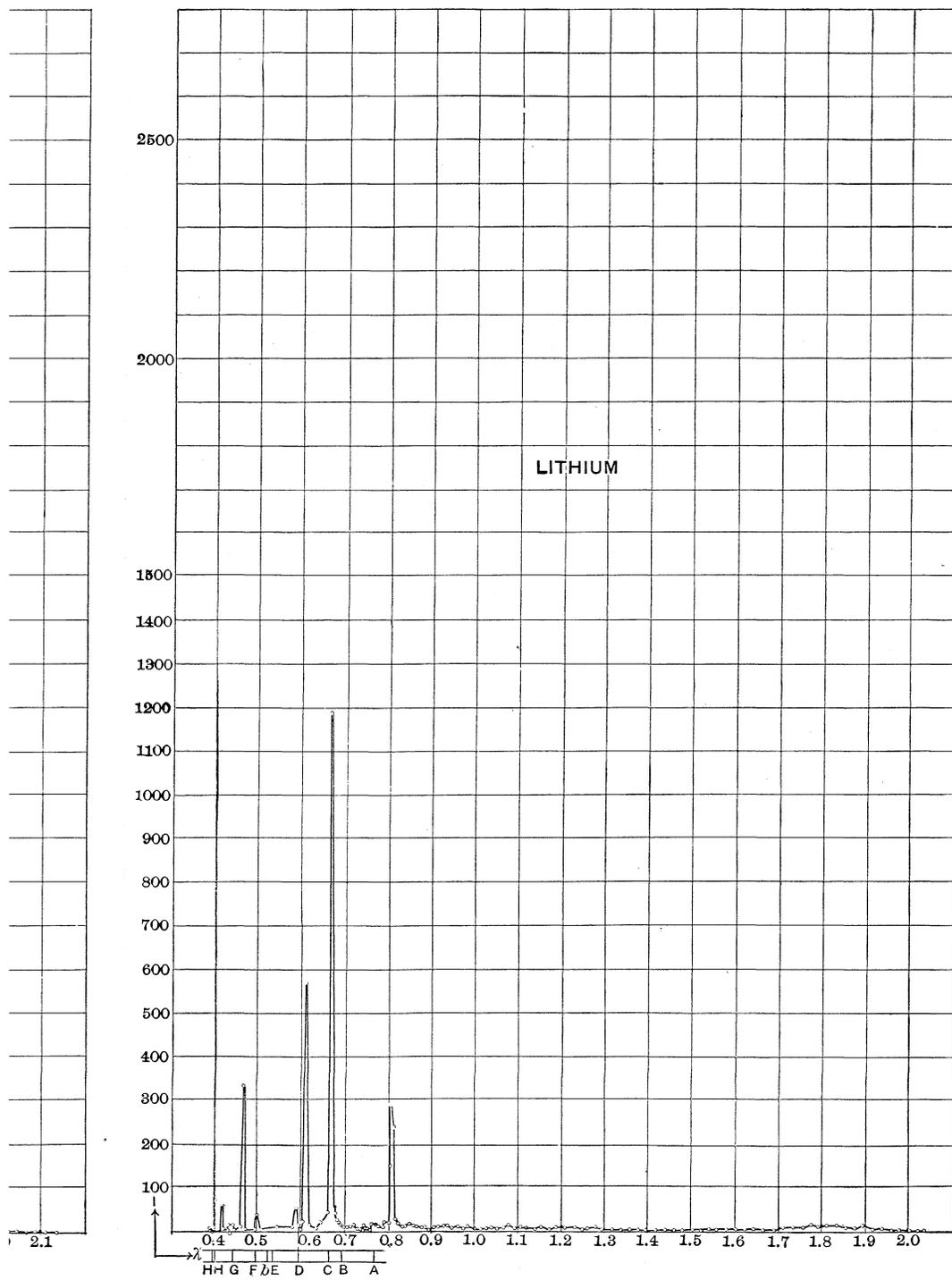
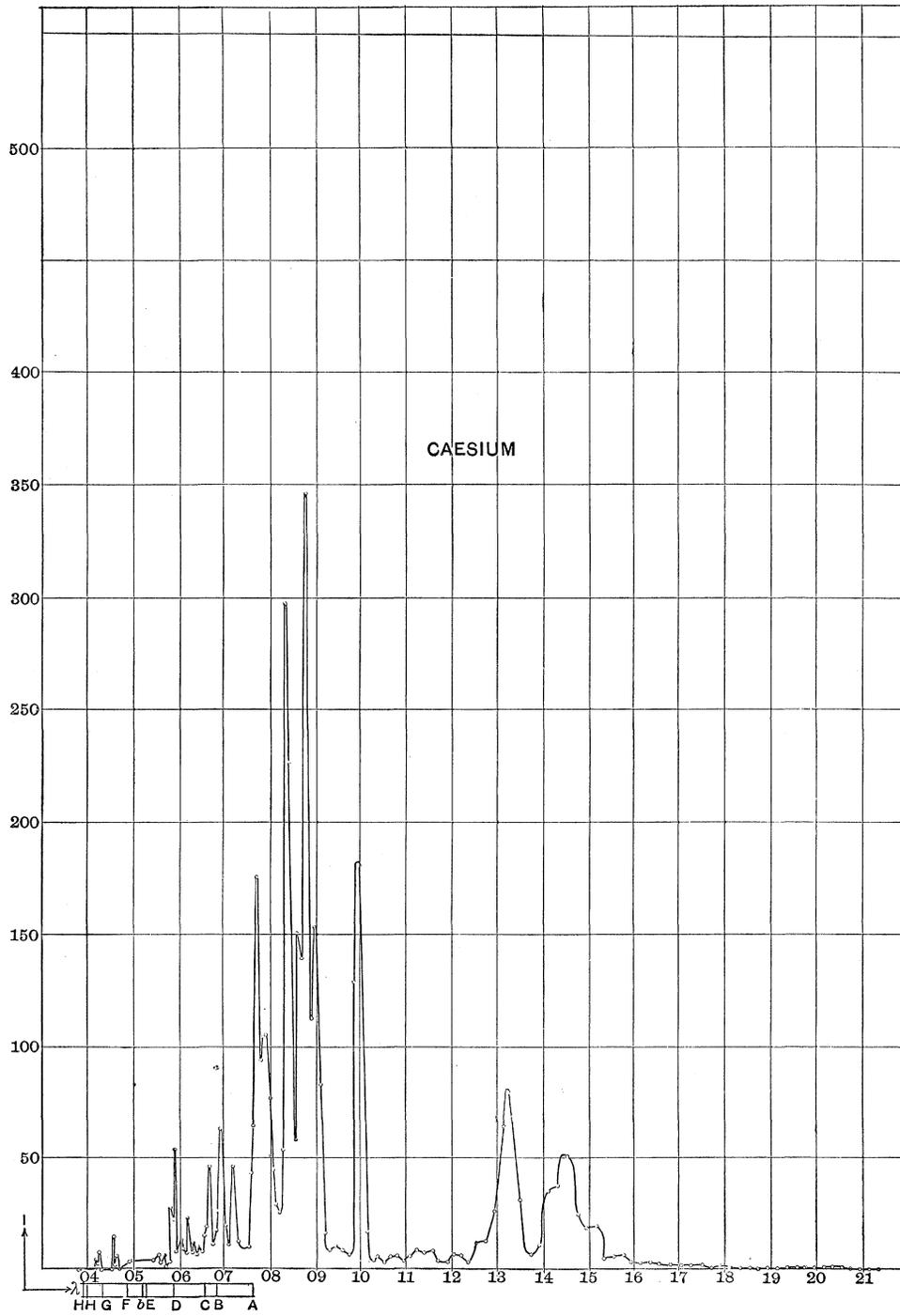
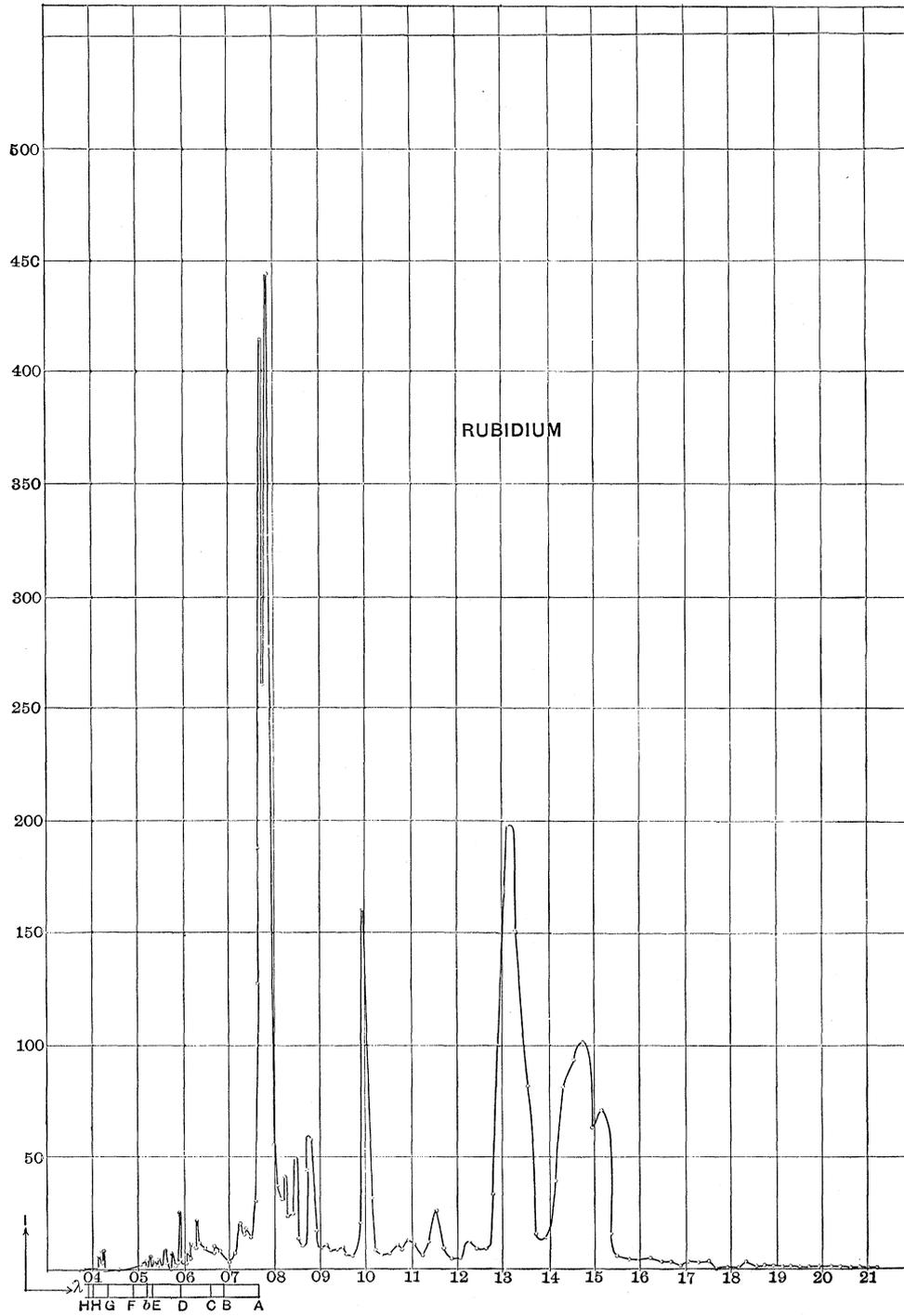


Fig. 8.



B. W. SNOW.

Fig. 9.



B. W. SNOW.