New Lines in the Ultraviolet Spectrum of Atomic Iodine

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(Received April 6, 1936)

A total of 250 lines in the arc and first spark spectrum of atomic iodine have been photographed with a vacuum grating spectrograph. A grating of one meter radius and ruled with 30,000 lines per inch was used. The region covered extended from λ1900A to λ800A. The spectrum was produced in a mixture of argon and iodine. In part of the work, iodine was prevented from entering the spectrograph by a continual flow of pure argon from the spectrograph through the slit to the discharge tube. This permitted the extension of wave-length measurements below the fluorite region to λ800A.

The arc spectrum of atomic iodine has been observed by Turner[1] and others to wave-lengths as short as 1235A. The range of the work has been limited on the short wave-length side by the necessity of having a fluorite window between the discharge tube and the vacuum grating spectrograph. The object of the present work was twofold: first, to reexamine the spectrum in the fluorite region with higher resolution, and second, to extend the work to shorter wave-lengths.

Apparatus

The vacuum spectrograph had a grating of one meter radius of curvature and was ruled with 30,000 lines per inch. The dispersion was about 8.4A per mm. Schumann plates made by Messrs. Adam Hilger Co. were used throughout.

The plateholder could be dropped to successive positions by means of a magnetic control. An occulter was placed in front of the plateholder and could be moved from the outside by a tapered joint. This arrangement permitted comparison spectra to be placed adjacent to each other without moving the plateholder.

Fig. 1 shows the general arrangement of the vacuum system used for the first part of the investigation. A fluorite window over the slit prevented the iodine from entering the spectrograph. The discharge was excited in a mixture of iodine and argon. The partial pressure of iodine was its vapor pressure at room temperature, about 0.2 mm of Hg. The argon pressure was kept at about 5 to 6 mm of Hg.

A mercury diffusion pump circulated the argon in such a direction as to prevent as far as possible the iodine from coming in contact with the waxed-on fluorite window over the slit. The two refrigerated traps collected iodine and mercury vapor, respectively.

All the stopcocks shown, except the one connecting to the main vacuum pump were of a special "dry" type. They were the right-angled type and were greased only at the end of the barrel next the atmosphere. A circular groove around the plug of the stopcock prevented grease from working down to the vacuum system. They were vacuum tight to the outside atmosphere but were not of course completely tight between different parts of the system. Their purpose, in most cases, was to control the diffusion of iodine throughout the apparatus when it was not in use. Their "dry" feature reduced the chance of the iodine being contaminated with stopcock grease. Apiezon grease was used.

The whole discharge tube could be quickly cleared of iodine by circulating argon through it.

The electrodes were of coiled tungsten wire. A current of 100 ma from a transformer secondary could be run through the tube without overheating it.

Some plates were exposed when a condenser and spark gap were in the circuit. A few spark lines of iodine were recorded in that way.

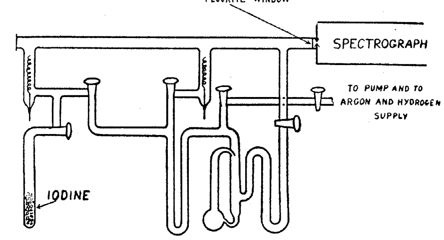

Fig. 1. Apparatus for the photography of the spectrum of iodine to the limit of transmission of fluorite.

* Now at Kodak Research Laboratories.

[1] Turner, Phys. Rev. **27**, 397 (1926); Kalia, Ind. J. Phys. **9**, 179 (1934).

TABLE I. *Iodine ultraviolet lines.*

	λ	Int.	ν
A	2062.2	10	48491
A	1876.4	7	53292
A	1844.4	8	54217
A	1839.6	1	54361
Abs.	1830.4	10	54634
A	1799.1	9	55583
Abs.	1782.8	10	56092
A	1702.1	8	58750
Abs.	1642.2	6	60893
A	1640.8	9	60945
Abs.	1617.66	5	61818
A	1593.64	7	62749
Abs.	1582.69	3	63184
A	1561.48	2	64042
A	1560.75	1	64072
A	1526.52	3	65508
A	1518.10	9	65872
Abs.	1514.76	8	66017
A	1514.38	4	66034
Abs.	1507.14	5	66351
A	1492.96	7	66981
A	1486.01	1	67294
	1468.43	0	68100
	1465.92	5	68217
A	1459.22	5	68530
A	1458.88	6	68546
A	1458.07	9	68584
A	1457.48	9	68612
	1453.28	5	68810
	1446.34	7	69140
	1443.44	0	69279
	1440.97	1	69398
	1437.64	0	69558
	1436.25	1	69626
	1435.12	0	69681
A	1425.61	9	70145
Abs.	1421.47	7	70350
	1400.11	2	71423
	1393.05	2	71785
A	1390.86	6	71898
A	1383.33	6	72289
A	1380.60	1	72432
S	1368.28	3	73084
A	1367.80	4	73110
S	1366.56	1	73176
A	1361.03	8	73473

	λ	Int.	ν
A	1358.06	5	73634
A	1355.18	3	73791
S	1350.31	1	74057
S	1349.01	2	74128
S	1343.67	2	74423
A	1340.79	3	74583
S	1339.96	1	74629
A	1336.58	5	74818
	1336.06	1	74847
	1331.11	0	75125
A	1330.26	3	75173
	1327.63	1	75322
	1325.09	1	75467
A	1317.62	4	75894
A	1314.02	1	76102
A	1313.51	1	76132
S	1306.08	2d	76565
A	.1303.06	2	76742
S	1302.64	1	76767
A	1300.43	4	76898
S	1296.50	4	77131
A	1291.12	2	77452
A	1289.36	2	77558
S	1286.06	6	77757
S	1285.73	5	77777
S	1275.41	10	78406
	1261.23	1d	79288
	1259.50	2	79397
A	1259.14	4	79419
A	1251.30	2	79917
S	1250.51	8	79967
	1243.16	2	80440
	1239.94	1	80649
	1239.26	3	80693
A	1237.90	2	80782
	1236.37	1d	80882
A	1234.06	10	81033
	1233.45	2	81073
	1233.06	5	81099
	1230.19	4	81288
	1228.91	2	81373
	1224.85	2	81643
	1224.52	1	81665
	1224.05	1	81696
	1223.31	1	81745

	λ	Int.	ν
A	1220.88	6	81908
	1216.10	4	82230
	1212.68	2	82462
	1212.17	2d	82497
	1210.67	1d	82599
S	1208.38	2d	82755
	1205.92	6	82924
S	1204.00	1d	83058
	1198.86	10	83413
	1198.25	2d	83455
	1194.18	1	83739
	1190.85	9	83974
	1187.33	9	84222
	1185.75	1	84335
	1185.25	1	84370
	1184.98	1	84390
S	1184.15	4	84449
	1178.66	9	84842
	1175.83	9	85046
A	1174.92	1	85112
	1171.01	2	85396
	1170.59	0	85427
	1168.84	8	85555
	1168.54	1	85577
	1168.21	2	85601
	1167.67	1	85641
S	1167.07	9	85685
	1166.47	9	85729
	1165.55	0	85796
	1164.83	1	85849
	1163.36	0	85958
	1161.76	0	86076
A?	1160.57	9	86164
	1159.86	7	86217
	1159.41	1	86251
S	1154.68	10	86604
	1139.79	10	87735
S	1132.71	1	88286
	1131.50	6	88378
	1125.25	7	88869
	1123.89	1	88977
	1117.21	6	89509
S	1111.16	6	89996
	1110.51	5	90049
	1104.99	9	90498
	1104.34	1	90552

	λ	Int.	ν
S	1103.58	6	90614
	1102.09	1	90737
	1101.08	6	90820
A	1099.35	3	90963
	1097.52	1	91114
	1094.64	3	91354
	1090.32	2	91716
	1089.97	1	91746
	1089.79	2	91761
S	1085.39	6	92133
S	1082.50	4	92379
	1076.37	2	92905
	1075.20	9	93006
	1068.93	2	93552
	1066.34	2	93789
	1065.00	5	93897
S	1054.64	6	94816
	1042.14	0	95956
	1034.67	6	96649
	1033.79	3	96731
A	1030.04	4	97084
	1026.05	3	97461
	1023.53	2	97701
	1019.35	5d	98102
	1018.59	6	98175
	1017.97	4	98235
	1016.39	1d	98387
	1016.07	1d	98418
	1009.91	4	99018
S	1003.44	8	99656
A	1000.61	6	99939
	999.04	1	100096
S	995.76	5	100427
	994.73	1	100530
	992.46	4	100759
	988.42	4	101173
	978.38	4	102209
Measured on one plate only from here on			
	968.65	1	103236
	967.36	2	103374
	861.97	0	103953
	959.60	2	104210
	953.45	3	104882
	948.64	0	105414

	λ	Int.	ν
	947.71	1	105518
	946.99	2	105598
	942.45	1	106106
	941.95	0	106163
	940.88	2	106283
	931.52	1	107351
	931.10	3	107400
	930.47	2	107473
	930.10	2	107515
	929.12	3	107629
	925.47	1	108053
	922.05	1	108454
	921.66	2	108500
	916.99	3	109054
	914.92	2	109299
	910.26	3	109859
	907.98	0	110135
	905.27	1	110464
	902.10	1	110852
	900.98	1	110990
	896.65	2	111526
	896.34	2	111565
	895.89	3	111621
	893.10	2	111969
	890.97	1	112237
	886.49	0	112804
	884.85	0	113013
	877.22	2	113996
	873.47	2	114486
	872.37	1	114630
	870.30	1	114903
	861.10	2	116130
	857.94	1	116558
	855.50	1	116891
	847.85	3	117945
	846.28	4	118164
	845.63	1	118255
	843.07	1	118614
	841.08	2	118895
	838.02	1	119329
	834.09	1	119891
	831.24	0d	120302
	823.84	1	121383
	809.13	1	123590

Each of the plates exposed for measurement purposes had three overlapping spectra. The two outer ones were of iodine and the third, placed in the middle, was of hydrogen for comparison. One of the iodine spectra was made first, then the hydrogen one, and finally the second iodine one. Between each exposure the discharge tube had to be pumped out and the proper gas or gases admitted. Only such plates as showed no shift between the two iodine spectra were used for measurement. Table I includes the lines measured. Those marked "Abs." were previously reported[2] as absorption lines.

Separation of Arc and Spark Lines

A few plates were exposed for the purpose of distinguishing between arc and spark lines of iodine. They were made by alternately exciting the tube for short periods with a spark discharge and with uncondensed a.c. The occulter was moved between each exposure in such a way that all the "spark" exposures came on one part of the plate and all the "arc" exposures came on an adjacent strip. The total time of exposure for each type of discharge was adjusted so as to give about the same average intensity to the two spectra.

Lines that appeared to be definitely stronger in the spectrum made with the arc discharge are marked A in Table I, and those definitely stronger in the spectrum made with the spark discharge are marked S. A great many lines were too weak in intensity, or for other reasons did not give sufficient indication of their character, to be classified.

Lines of Shorter Wave-Length

In order to photograph the spectrum below the transmission limit of fluorite it was necessary to make some changes in the apparatus. The fluorite window over the slit of the spectrograph had to be removed of course, but, since iodine would corrode the grating if allowed to come in

[2] McLeod, Phys. Rev. **45**, 802 (1934).

contact with it, some other means had to be found to prevent iodine from entering the spectrograph. This was successfully accomplished by extending the circulating system of argon to include the whole spectrograph. As shown in Fig. 2 pure argon filled the spectrograph and was maintained in it at a higher pressure than in the discharge tube. Argon therefore continually flowed outward through the slit and thus prevented the entry of iodine. As an extra precaution the old circulating system shown in Fig. 1 was maintained.

When an exposure was being made the light from the discharge tube passed through the large bore of the stopcock *T*. The stopcock was closed whenever the spectrograph was not in use. After a run the argon in the spectrograph was recovered by adsorbing it on charcoal cooled with liquid air.

The plates were exposed in the same general manner as already described. Lines down to λ809A were recorded. They are listed in Table I. As already mentioned lines that were stronger when a condensed spark discharge was passed through the argon and iodine mixture are marked S. Those stronger when an uncondensed discharge was used are marked A. Intensities are as usual estimated from 0 to 10. Diffuse or broad lines are marked d.

Standard Wave-Lengths

The values for the wave-lengths of the hydrogen lines in the comparison spectrum were those given by Hori[3] from λ1100 to λ1350, and those given by Hyman[4] from λ1350 to λ1600. In addition the impurity lines given in Table II were used as standards. Since the wave-lengths

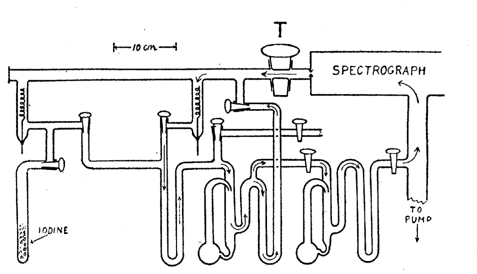

Fig. 2. Apparatus for the photography of the spectrum of iodine to wave-lengths shorter than those transmitted by fluorite.

[3] Hori, Zeits. f. Physik **44**, 834 (1927).
[4] Hyman, Phys. Rev. **36**, 194 (1930).

Table II. *Impurity lines used as standards.*

A II	919.78	N I	1199.547
A II	932.05	N I	1200.220
H I	1025.73	N I	1200.706
N I	1134.171	O I	1302.27
N I	1134.419	O I	1304.96
N I	1134.980		

of these lines are known to greater precision than those of hydrogen, considerable weight was given them in determining the correction curves for the plates.

The probable error in the wave-lengths given in Table I is thought to be of the order of ±0.03A between λ800 and λ1600. Because of the lack of standard wave-lengths above λ1600A the accuracy in that region is not very good. The values given above λ1600A were obtained partly by extrapolation and partly by use of the well-known frequency difference of 7601 cm^{-1}.

Analysis

The analysis of the spectrum has not as yet progressed very far. It might be remarked, however, that the well-known frequency difference 7601 cm^{-1} is prominent. The pairs of lines given in Table III show this frequency difference. The pairs marked with an asterisk are believed to be new.

Evans[5] has given an analysis of a number of lines in the visible and infrared. His arrangement

Table III. *Pairs of lines showing the frequency difference 7601 cm^{-1}.*

	ν	$\Delta\nu$		ν	$\Delta\nu$		ν	$\Delta\nu$
10 A	48491	7601	4 A	73110		1 S	76767	7603*
10 Abs.	56092		9 A	65872	7601	1	84370	
7 A	53292	7601	8 A	73473		2 A	80782	7596*
6 Abs.	60893		4 A	66034	7600*	6	88378	
8 A	54217	7601	5 A	73634		2	81373	7604*
6 Abs.	61818		7 A	66981	7602	1	88977	
8 A	55583	7601	3 A	74583		6 A	81908	7601*
3 Abs.	63184		5 A	68530	7602	6	89509	
7 A	58750	7601	1 A	76132		9	90498	7604*
4 Abs.	66351		7	69140	7602*	5 b	98102	
9 A	60945	7601	2	76742		6	90820	7598*
6 A	68546		1 S	74629	7601*	1 d	98418	
7 A	62749	7601	4	82230		0	105414	7599*
6 Abs.	70350		1	75322	7602*	0	113013	
3 A	65508	7602*	6	82924				

[5] Evans, Proc. Roy. Soc. **A133**, 417 (1931).

has been supported by work by Tolansky.[6] Turner,[7] it may be recalled, located the two low terms $^2P_{1/2}$ and $^2P_{3/2}$. Their frequency difference is 7601 cm^{-1}. A careful search was made for lines connecting these two low levels with the appropriate levels found by Evans in the visible. No set of lines gave the frequency differences to be expected. It is thought that many of the arc lines in the region investigated must arise from electronic transitions from higher levels built upon the ^1S and ^1D states of the iodine spark spectrum.

Murakawa[8] has made an analysis of the first spark lines in the visible. This work would indicate the presence of a number of prominent spark lines in the ultraviolet having predictable frequency differences. These frequency differences have not been found.

It is with pleasure that I take this opportunity to thank Professor O. Oldenberg for the benefit of many helpful discussions.

[6] Tolansky, Proc. Roy. Soc. **A136**, 585 (1932); **A149**, 269 (1935).
[7] Turner, Phys. Rev. **31**, 983 (1928).
[8] Murakawa, Sci. Pap. Inst. Phys. and Chem. **20**, 285 (1933).

JUNE 1, 1936 PHYSICAL REVIEW VOLUME 49

Magneto-Optical Rotation and Natural Dispersion in Gases

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(Received April 6, 1936)

Formulae for the natural dispersion and for the magnetic rotation are tested together by use of recently determined data for gases. Similar checks have been made by Evans and his co-workers for liquids. Dispersion equations of the Kettelar-Helmholtz type, with a single ultraviolet absorption term, together with Becquerel's equation for the Verdet constant are found to fit the experimental data in the case of the gases, acetylene, ethylene and carbon dioxide. The computed wave-lengths of absorption bands lie within the experimentally determined bands for these gases. Other constants of the two equations are also computed. For several other gases, methyl chloride, chloroform, oxygen, nitrogen and hydrogen, apparently more complicated formulae are required.

OTHER than the early work of Becquerel, Siertsema, and later Sirks, very few data have been available on the Verdet constants of gases at different wave-lengths. Recently however Gabiano[1] measured the Verdet constants of a number of gases under low pressure at three different wave-lengths. He has thus made possible the following investigation. This is an attempt to fit the magnetic rotation and the natural dispersion of gases by expressions involving only one absorption band in the ultraviolet. The method is similar to that used by Evans[2] and his associates in their study of liquids.

According to Becquerel[3] and to Larmor's[4] theory of magneto-optical rotation Verdet's constant δ is given by the relation

$$\delta=\frac{e}{2mC^2}\lambda\frac{dn}{d\lambda} \qquad (1)$$

where $dn/d\lambda$ is the dispersion of the refractive index, C is the velocity of light, and e/m is the effective ratio of the charge to the mass of the dispersion electrons.

If it is assumed that there is only one ultraviolet absorption band influencing the dispersion, then an equation of the Kettelar-Helmholtz type giving the variation of the refractive index with wave-length is

$$n^2-1=b_0+b_1/(\lambda^2-\lambda_1{}^2), \qquad (2)$$

where b_0 and b_1 are constants and λ_1 is the wave-length of the absorption band. Differentiation of (2) with respect to λ and combination with (1) gives

$$\delta=\frac{eb_1}{2mC^2n}\cdot\frac{\lambda^2}{(\lambda^2-\lambda_1{}^2)^2}, \qquad (3)$$

[1] P. Gabiano, Ann. de physique **20**, 68 (1933).
[2] E. J. Evans, Phil. Mag. **3**, 546 (1927); **5**, 593 (1928); **8**, 137 (1929); **10**, 749 (1930); **11**, 377 (1931); **11**, 1220 (1931); **13**, 265 (1932); **15**, 905 (1933); **15**, 1065 (1933); **17**, 351 (1934); **18**, 386 (1934).
[3] H. Becquerel, Comptes rendus **125**, 679 (1897).
[4] Sir J. Larmor, *Aether and Matter*, App. F. 352.