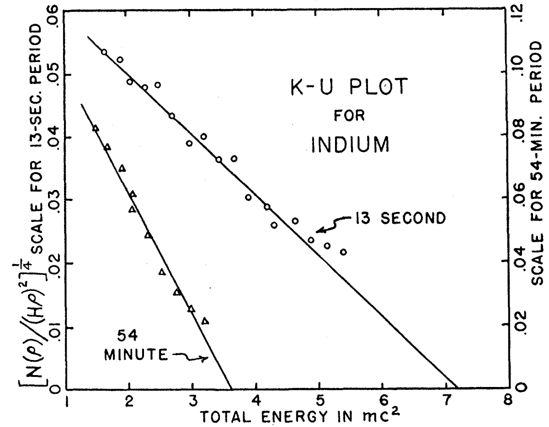

FIG. 10.

tion of this we applied the atomic number correction to the plot of dysprosium (66) and, rhodium (45), and found that it made no significant change either in their form or their end points, insofar as the accuracy of the present data is concerned.

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*Note:* Since completing these experiments a paper has appeared by R. Naidu and R. E. Siday (Proc. Phys. Soc. **48**, 332 (1936)) in which they describe measurements of the energy spectra of Ag, Rh, and Dy. Their upper energy limits, obtained by inspection of the energy distribution plots, are 3.8, 3.6, and 1.9 MEV, respectively. These are about 30 percent higher than the values we obtain by inspection. Also, the limits they give for Si and F are very much higher than previous measurements on the same substances by Kurie, Richardson and Paxton (Phys. Rev. **48**, 167 (1935)) and by Crane, Delsasso, Fowler and Lauritsen (Phys. Rev. **47**, 971 (1935)). Alichanow, Alichanian and Dzelepow (Nature **136**, 257 (1935)) have reported energy limits for Rh, Ag and Mn, which are in fair agreement with our values.

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# The Emission Spectrum of $D_2$ in the Extreme Ultraviolet

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The emission spectrum of the $D_2$ molecule has been photographed in the extreme ultraviolet region by use of a grazing incidence vacuum spectrograph with 2-meter grating In the $2p\,^1\Sigma-1s\,^1\Sigma$ system 37 bands have been analyzed. In the $2p^1\,\Pi-1s\,^1\Sigma$ system 29 bands were obtained. Constants of the three observed electronic states of the $D_2$ molecule are given and the data are compared with that of the $H_2$ molecule. Electronic shifts of 4 $cm^{-1}$ and 23 $cm^{-1}$ are observed for the $2p\,^1\Sigma-1s\,^1\Sigma$ and $2p\,^1\Pi-1s\,^1\Sigma$ systems, respectively.

## INTRODUCTION

THE following paper is concerned with a description of the $2p\,^1\Sigma-1s\,^1\Sigma$ $(B-A)$ and $2p\,^1\Pi_{cd}-1s\,^1\Sigma$ $(C-A)$ band systems in the extreme ultraviolet spectrum of the $D_2$ molecule. Considerable study has been applied to these systems in the spectra of the $H_2$[1] and $HD$[2, 3, 4] molecules and in the present work a comparison is made between the $H_2$ and $D_2$ spectra.

## EXPERIMENTAL PROCEDURE

For excitation of the $D_2$ bands in the extreme ultraviolet the methods used previously[1] for the study of $H_2$ are in general applicable. The chief difficulty in the production of the $D_2$ spectrum is the problem of outgassing the discharge tube so completely that the remaining amount of $H_2$ in the electrodes and the glass is negligible. In our case this is somewhat complicated by the fact that no window can be used between the discharge tube and the slit of the spectrograph. It is therefore necessary either to use a stopcock between the source and slit or to admit air into the discharge tube before attaching it to the spectrograph and after each exposure. It is found that by taking suitable precautions the latter method

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[1] See C. R. Jeppesen, Phys. Rev. **44**, 165 (1933) and references given there.

[2] C. R. Jeppesen, Phys. Rev. **45**, 480 (1934).

[3] Kurt Mie, Zeits. f. Physik **91**, 475 (1934).

[4] Y. Fujioka and T. Wada, Scientific Papers of the Institute of Physical and Chemical Research, Komagome, Hongo, Tokyo, **27**, 210 (1935).

Table IA. $2p\,^1\Sigma - 1s\,^1\Sigma$ *bands of* $D_2$.

| $K$ | $I$ | $R$ branch | $I$ | $P$ branch |
|---|---|---|---|---|
| 0−3 band $\nu_0=82016.4$ | | | | |
| 0 | 0d | 82036.8 | | |
| 1 | 00 | 021.0 | 0 | 81964.5 |
| 2 | | | 00 | 874.6 |
| 3 | | | | |
| 4 | 0 | 81776.1* | | |
| 5 | | | 00d | 416.7 |
| 6 | | | 0d | 197.5 |
| 7 | | | 3 | 80952.0 |
| 0−5 band $\nu_0=76836.0$ | | | | |
| 0 | 3 | 76855.1 | | |
| 1 | 1 | 845.0 | 1 | 76786.3 |
| 2 | 3 | 804.9 | 3 | 707.1 |
| 3 | 1 | 735.3 | 2 | 599.6* |
| 4 | 1 | 632.2 | 2 | 461.9 |
| 5 | 0 | 504.0 | 2 | 295.7* |
| 6 | 00d | 353.8 | 1 | 105.2* |
| 7 | | | 00 | 75887.5 |
| 8 | | | 00 | 643.3 |
| 0−6 band $\nu_0=74421.1$ | | | | |
| 0 | 2 | 74440.2 | | |
| 1 | 1 | 431.3 | 1 | 74372.7 |
| 2 | 2 | 395.9 | 3 | 297.5 |
| 3 | 1 | 332.3 | 2 | 195.5 |
| 4 | 1 | 240.7 | 3 | 067.5 |
| 5 | 00 | 124.6 | 1 | 93912.6 |
| 6 | 0 | 73980.3 | 2 | 733.2 |
| 7 | | | 0 | 527.8 |
| 0−7 band $\nu_0=72121.8$ | | | | |
| 0 | 0 | 72141.3 | | |
| 1 | 0 | 135.0 | 1 | 72076.2* |
| 2 | 2 | 102.7 | 2 | 005.1 |
| 3 | 1 | 045.1 | 2 | 71908.3 |
| 4 | 1 | 71961.6 | 2 | 787.5 |
| 5 | 00d | 854.1 | 0 | 642.5 |
| 6 | 0 | 721.1 | 1 | 474.0 |
| 7 | | | 00 | 282.9 |
| 8 | | | 00 | 070.7 |
| 0−8 band $\nu_0=69936.2$ | | | | |
| 0 | 0 | 69955.5 | | |
| 1 | 0 | 950.6 | 0 | 69892.9 |
| 2 | 1 | 920.3 | 2 | 824.6 |
| 3 | 0 | 871.4 | 1 | 734.5 |
| 4 | 0 | 796.3 | 2 | 621.9 |
| 5 | | | 1 | 487.9 |
| 6 | 0d | 579.2 | 0 | 330.8 |
| 7 | | | 00 | 153.4 |
| 8 | | | 00 | 68957.4 |
| 1−2 band $\nu_0=85704.9$ | | | | |
| 0 | 0 | 85723.5 | | |
| 1 | 0d | 706.3 | 0d | 85652.0 |
| 2 | 0d | 652.0* | 3 | 554.2* |
| 3 | | | 0 | 429.8 |
| 4 | | | 0d | 266.0* |
| 5 | | | 1 | 069.4 |
| 6 | 1 | 075.0 | 0d | 84832.7 |
| 1−3 band $\nu_0=82949.4$ | | | | |
| 0 | 1 | 82968.3 | | |
| 1 | 0 | 951.8 | | |
| 2 | 3 | 902.6* | 1 | 82806.5 |
| 3 | 4 | 819.6* | 1 | 685.6 |
| 4 | 2 | 699.3* | 2 | 529.8 |
| 5 | 0d | 542.9 | 2 | 342.7 |
| 6 | 0 | 361.9 | 0 | 124.7 |
| 7 | | | 0 | 81874.6 |
| 1−4 band $\nu_0=80304.2$ | | | | |
| 0 | 1 | 80323.2 | | |
| 1 | 0 | 312.3 | 2d | 80252.3 |
| 2 | 1d | 264.6 | 2 | 171.0 |
| 3 | 00 | 185.7 | 3 | 052.5 |
| 4 | 1 | 073.7 | 1 | 79907.3 |
| 5 | | | 00d | 728.3 |
| 6 | | | 0 | 521.9 |
| 1−5 band $\nu_0=77778.5$ | | | | |
| 0 | 0 | 77797.1 | | |
| 1 | 0 | 786.8 | 00 | 77729.1 |
| 2 | 1 | 743.9 | 1 | 649.1 |
| 3 | 00 | 670.8 | 0 | 540.4 |
| 4 | 0 | 568.1 | 1 | 400.5 |
| 5 | 1 | 434.1 | 00 | 232.5 |
| 6 | 1 | 277.0* | 0 | 036.8 |
| 7 | | | 00 | 76815.5 |
| 8 | | | 0 | 566.7 |
| 1−7 band $\nu_0=73063.8$ | | | | |
| 0 | 00 | 73083.4 | | |
| 1 | 0 | 073.2 | 00 | 73018.8 |
| 2 | 1 | 042.3 | 1 | 72948.5 |
| 3 | 00 | 72978.3 | 00 | 848.6 |
| 4 | | | 0 | 725.7 |
| 1−8 band $\nu_0=70877.8$ | | | | |
| 0 | 0 | 70895.3 | | |
| 1 | 00 | 891.6 | 00 | 70833.1 |
| 2 | 1 | 859.7 | 2 | 764.9 |
| 3 | | | 1 | 674.4 |
| 4 | 0 | 727.4 | 2 | 559.7 |
| 5 | | | 0 | 421.0 |
| 6 | | | 0 | 262.2 |
| 1−9 band $\nu_0=68806.2$ | | | | |
| 0 | 0 | 68825.0 | | |
| 1 | 0 | 821.7 | 0 | 68764.4 |
| 2 | 1 | 795.7 | 1 | 701.1 |
| 3 | 0 | 747.4 | 1 | 615.3 |
| 4 | 0 | 677.1 | 2 | 508.1 |
| 5 | 0 | 582.4 | 1 | 379.8 |
| 6 | | | 1 | 233.3 |
| 7 | | | | |
| 8 | | | 0b | 67881.3 |
| 2−2 band $\nu_0=86629.9$ | | | | |
| 0 | 1 | 86647.6 | | |
| 1 | 0 | 627.5 | 2 | 86572.4* |
| 2 | 2 | 572.4* | 0d | 480.5* |
| 3 | 0d | 480.5* | 1d | 354.3* |
| 4 | 1d | 354.3* | 2 | 185.8 |
| 5 | 2 | 185.8* | 2 | 85984.5* |
| 6 | 1 | 85984.5* | 0 | 750.9 |
| 7 | | | 2d | 483.3* |
| 2−4 band $\nu_0=81229.0$ | | | | |
| 0 | 00 | 81248.0 | | |
| 1 | 0 | 232.1 | | |
| 2 | 00 | 184.8 | 00 | 81094.0 |
| 3 | 00 | 105.0 | 00 | 80975.9 |
| 4 | 0 | 80990.0 | 3 | 830.5 |
| 5 | 0 | 845.3 | 0dd | 644.5 |
| 6 | | | 2 | 431.1 |
| 7 | | | 00 | 195.0 |
| 2−6 band $\nu_0=76286.9$ | | | | |
| 0 | 2 | 76303.8 | | |
| 1 | 2 | 295.7* | 00 | 76239.0 |
| 2 | 0 | 254.4* | 3b | 165.0* |
| 3 | | | 00 | 058.1 |
| 4 | 00 | 087.3 | 2 | 75924.9 |
| 5 | | | 00 | 764.5 |
| 6 | | | 00 | 577.8 |
| 2−7 band $\nu_0=73985.8$ | | | | |
| 0 | 1 | 74003.4 | | |
| 1 | 0 | 73995.1 | 0 | 73939.9 |
| 2 | 1 | 959.6 | 2 | 867.8 |
| 3 | 00 | 896.2 | 1 | 769.7 |
| 4 | 0d | 807.3 | 2 | 644.2 |
| 5 | 00 | 691.4 | 0 | 494.3 |
| 6 | 0 | 547.2 | 0 | 319.2 |
| 7 | | | 0 | 117.6* |
| 3−2 band $\nu_0=87533.1$ | | | | |
| 0 | 1 | 87551.1 | | |
| 1 | 1 | 528.1 | 0 | 87476.8 |
| 2 | 2d | 473.0 | 3 | 383.6 |
| 3 | 00 | 376.6 | 1d | 257.6 |
| 4 | | | 1 | 087.1 |
| 5 | | | 0d | 86884.7 |
| 6 | 0 | 873.3 | 1 | 647.6 |
| 3−3 band $\nu_0=84775.0$ | | | | |
| 0 | | | | |
| 1 | 0 | 84775.0 | 0 | 84721.3* |
| 2 | 0 | 721.3* | 1 | 631.4* |
| 3 | 1 | 631.4* | 0 | 507.6* |
| 4 | 0 | 507.6* | 1 | 349.2* |
| 5 | 1 | 349.2* | | |
| 6 | | | 00 | 83931.3 |
| 3−6 band $\nu_0=77191.4$ | | | | |
| 0 | 0 | 77209.3 | | |
| 1 | 0 | 197.1 | 1 | 77145.6 |
| 2 | 1d | 154.9 | 2 | 066.5 |
| 3 | 0 | 084.3 | 1 | 960.9 |
| 4 | 1 | 985.2* | 1 | 825.6 |
| 5 | 2 | 855.2 | 2 | 663.0 |
| 6 | 0 | 699.2 | 00 | 474.2 |
| 7 | | | 0 | 254.4 |
| 3−9 band $\nu_0=70632.3$ | | | | |
| 0 | 0 | 70649.9 | | |
| 1 | 0 | 644.4 | 0 | 70591.1 |
| 2 | 1 | 614.5 | 2 | 525.8 |
| 3 | 2 | 559.7 | | 437.9 |
| 4 | 0 | 485.1 | 1 | 327.4 |
| 5 | | | 00 | 196.6 |
| 6 | | | 0 | 041.7 |
| 4−1 band $\nu_0=91293.1$ | | | | |
| 0 | 3 | 91309.2* | | |
| 1 | 0 | 290.9 | | |
| 2 | 0 | 220.1 | 0d | 91137.8 |
| 3 | 00 | 119.5 | 0 | 90999.7 |
| 4 | 0 | 90976.0 | 0 | 823.6 |
| 5 | | | 0 | 610.9 |
| 6 | 0 | 578.1 | 3 | 354.6 |
| 4−2 band $\nu_0=88419.0$ | | | | |
| 0 | 0 | 88435.3 | | |
| 1 | 0 | 415.1 | 0 | 88362.6 |
| 2 | 0 | 355.3 | 2 | 269.8 |
| 3 | | | 0 | 139.0 |
| 4 | | | 1 | 87969.7 |
| 5 | | | 0 | 765.3 |
| 6 | | | 1 | 528.1 |
| 4−5 band $\nu_0=80492.7$ | | | | |
| 0 | 3 | 80510.2 | | |
| 1 | 2 | 493.3 | | |
| 2 | 0d | 447.4 | 1 | 80361.8 |
| 3 | 00 | 368.5 | 1d | 248.5 |
| 4 | | | 0 | 103.4 |
| 5 | | | 0D | 79927.1 |
| 6 | | | 00d | 728.3 |
| 4−7 band $\nu_0=75777.4$ | | | | |
| 0 | 0 | 75794.6 | | |
| 1 | 00 | 783.4 | | |
| 2 | 00 | 744.4 | 2 | 75659.6 |
| 3 | | | | |
| 4 | 00 | 777.8* | 1 | 428.5 |
| 5 | 0 | 459.8 | 1 | 274.0 |
| 6 | 00 | 309.4 | 00 | 094.8 |
| 4−8 band $\nu_0=73590.8$ | | | | |
| 0 | 1 | 73607.9 | | |
| 1 | 0 | 599.2 | 0 | 73547.2 |
| 2 | 1 | 563.5 | 2 | 477.6 |
| 3 | 0 | 502.9 | 1 | 382.6* |
| 4 | 0 | 415.5 | 1 | 262.2 |
| 5 | | | 0 | 117.6* |
| 6 | | | 1 | 72948.5 |
| 5−1 band $\nu_0=92163.5$ | | | | |
| 0 | | | | |
| 1 | 00 | 92155.3 | | |
| 2 | 00 | 091.2 | 1 | 92008.2 |
| 3 | 00 | 91984.9 | 0d | 91868.7 |
| 4 | 00 | 840.0 | 0 | 691.0 |
| 5 | | | 1 | 474.4 |
| 6 | 00 | 430.7 | 0 | 220.1 |
| 7 | | | 0d | 90931.4 |
| 8 | | | 0 | 610.9 |
| 5−4 band $\nu_0=83889.0$ | | | | |
| 0 | 0 | 83906.7 | | |
| 1 | 1 | 886.9 | 1 | 83836.0* |
| 2 | 1 | 836.0* | 1 | 751.4* |
| 3 | 0 | 747.9* | 1 | 632.1* |
| 4 | 2 | 632.1 | 0d | 478.7 |
| 5 | 0 | 473.3 | 00 | 290.0 |
| 6 | | | 0d | 074.4 |
| 5−7 band $\nu_0=76646.9$ | | | | |
| 0 | 2 | 76663.0 | | |
| 1 | 0 | 651.5 | 2 | 76599.6* |
| 2 | 1 | 610.4 | 2 | 527.8 |
| 3 | 0 | 542.4 | 1 | 425.4 |
| 4 | 0 | 446.1 | 2 | 295.7* |
| 5 | | | 0 | 139.1 |
| 6 | 2b | 165.0* | 2 | 75957.2 |
| 7 | | | 0 | 744.4 |
| 8 | | | 00 | 532.1 |
| 5−9 band $\nu_0=72387.7$ | | | | |
| 0 | 0 | 72405.0 | | |
| 1 | 00d | 398.2 | 0 | 72345.3 |
| 2 | 0b | 361.5 | 0 | 280.5 |
| 3 | 0 | 308.1 | 0 | 190.2 |
| 4 | | | 1 | 076.2* |
| 5 | | | 00 | 940.4 |
| 6−1 band $\nu_0=93017.6$ | | | | |
| 0 | 0 | 93034.1 | | |
| 1 | 1d | 009.0* | 00 | 92960.6 |
| 2 | | | 00 | 861.7 |
| 3 | 2 | 92834.7 | 0 | 722.2 |
| 4 | 00 | 687.0 | 1 | 543.3 |
| 5 | 00 | 501.8 | 0 | 323.3 |
| 6 | | | 0 | 067.0 |
| 6−4 band $\nu_0=84742.8$ | | | | |
| 0 | 0 | 84759.4 | | |
| 1 | 2d | 736.4 | 1 | 84691.2 |
| 2 | 2b | 868.9 | 1 | 604.9 |
| 3 | 0d | 597.2 | 0 | 483.9 |
| 4 | 0 | 474.8 | 2 | 329.2 |
| 5 | 00 | 152.0 | 00 | 140.1 |
| 6 | | | 00 | 83921.1 |
| 6−7 band $\nu_0=77500.5$ | | | | |
| 0 | 0 | 77517.6 | | |
| 1 | 0 | 503.5 | 00 | 77454.5 |
| 2 | 1 | 462.3 | 1 | 380.2 |
| 3 | | | 1 | 277.0* |
| 4 | 0 | 292.0 | 1 | 145.6* |
| 5 | | | 1 | 76985.2* |
| 6 | | | 2 | 804.9* |
| 6−9 band $\nu_0=73241.2$ | | | | |
| 0 | 0 | 73257.4 | | |
| 1 | 0 | 244.0? | 0 | 73199.5 |
| 2 | 2 | 214.5 | 2 | 133.1 |
| 3 | 0 | 155.6 | 1 | 042.3* |
| 4 | 0 | 073.2* | 2 | 72927.8 |
| 5 | | | 0 | 789.2 |
| 6 | | | 0 | 629.0 |
| 7−3 band $\nu_0=88220.8$ | | | | |
| 0 | 1 | 88236.4 | | |
| 1 | 0 | 214.9 | 1 | 88165.6* |
| 2 | 3 | 153.5* | 1 | 076.2* |
| 3 | 3 | 060.4* | 1 | 948.4 |
| 4 | 0 | 87926.6 | 1 | 785.1 |
| 5 | | | 1 | 585.5 |
| 6 | | | 1 | 352.2 |
| 7 | | | 1 | 087.1* |
| 7−4 band $\nu_0=85579.3$ | | | | |
| 0 | 00 | 85594.8 | | |
| 1 | 1 | 575.6 | | |
| 2 | 0 | 520.4 | 0 | 85440.9 |
| 3 | 0 | 429.8 | 00d | 319.1 |
| 4 | 00 | 305.7 | | |
| 7−6 band $\nu_0=80637.3$ | | | | |
| 0 | 0 | 80653.6 | | |
| 1 | 00d | 639.3 | 2 | 80591.9* |
| 2 | 2 | 591.9* | 2 | 510.2* |
| 3 | 2 | 510.2* | 1 | 403.0* |
| 4 | 1 | 403.0* | 1d | 260.7* |
| 5 | 1d | 260.7* | 00 | 090.3 |
| 6 | | | 00 | 79891.9 |
| 7−8 band $\nu_0=76149.3$ | | | | |
| 0 | 2b | 76165.0 | | |
| 1 | 0 | 154.0 | 1 | 76105.2* |
| 2 | 2 | 113.6 | 2 | 035.5 |
| 3 | 00 | 047.9 | 1 | 75937.3 |
| 4 | 2 | 75957.2* | 2 | 813.6 |
| 5 | 00d | 833.4 | 0 | 666.7 |
| 6 | | | 0 | 488.8 |
| 7 | | | 1 | 291.8 |
| 8 | | | 0 | 071.1 |
| 7−9 band $\nu_0=74076.8$ | | | | |
| 0 | 00 | 74092.2 | | |
| 1 | | | 00 | 74035.1 |
| 2 | 0 | 047.7 | 0 | 73968.9 |
| 3 | 0 | 73988.0 | 00 | 877.1 |
| 4 | 00 | 902.2 | 0 | 761.0 |
| 5 | | | | |
| 6 | 00 | 661.0 | 00 | 459.7 |

TABLE IB. $2p\ {}^1\Pi_{cd}-1s\ {}^1\Sigma$ *bands of* $D_2$.

| $K$ | $I$ | $R$ BRANCH | $I$ | $P$ BRANCH | $I$ | $Q$ BRANCH |
|---|---|---|---|---|---|---|
| 0 − 1 BAND $\nu_0=96413.4$ | | | | | | |
| 0 | 00 | 96431.1* | | | | |
| 1 | 00 | 431.1* | | | 0 | 96371.8 |
| 2 | 00 | 411.1 | 0 | 96255.7 | 0 | 318.7* |
| 3 | 00 | 363.3 | 1 | 146.5 | 2 | 235.5 |
| 4 | | | 1 | 011.5 | 0 | 131.7 |
| 5 | | | 1d | 95851.2 | 0 | 95995.7 |
| 6 | | | 0 | 667.7 | | |
| 0 − 2 BAND $\nu_0=93539.7$ | | | | | | |
| 0 | 2 | 93555.9 | | | | |
| 1 | 1 | 561.1 | | | 2 | 93499.0 |
| 2 | 2 | 543.0 | 2 | 93388.4 | 3 | 499.9 |
| 3 | | | 1 | 284.9 | 2 | 376.2 |
| 4 | 0 | 433.2 | 3 | 157.3 | 1 | 278.4 |
| 5 | 0d | 344.5 | 1d | 009.0 | 3 | 157.3 |
| 0 − 3 BAND $\nu_0=90779.4$ | | | | | | |
| 0 | 2 | 90795.2 | | | | |
| 1 | 2 | 803.6 | | | 3 | 90741.2 |
| 2 | 2 | 789.8 | 2 | 90634.7 | 4 | 695.5* |
| 3 | 3 | 753.2 | 4 | 538.5* | 0 | 627.3 |
| 4 | 4 | 695.5 | 3 | 417.7 | 4 | 538.5* |
| 5 | | | 1 | 276.3 | 0d | 425.5 |
| 6 | 0 | 511.4 | 3 | 118.5 | 00 | 299.2 |
| 0 − 4 BAND $\nu_0=88138.0$ | | | | | | |
| 0 | 3 | 88153.5* | | | | |
| 1 | 2 | 165.6* | | | 2 | 88102.3 |
| 2 | 3 | 153.5* | 3 | 87999.0* | 3 | 060.4* |
| 3 | 1 | 122.8 | 0 | 908.2 | 3 | 87999.0* |
| 4 | 1 | 076.2* | 2 | 797.0 | 1 | 916.7 |
| 5 | | | 0 | 667.0 | 00 | 813.2 |
| 6 | | | 0 | 518.0 | 0 | 696.8 |
| 1 − 1 BAND $\nu_0=98075.5$ | | | | | | |
| 0 | 2 | 98091.3* | | | | |
| 1 | 2 | 091.3* | | | 2 | 98028.6 |
| 2 | 0 | 067.6 | 2 | 97920.2 | 2 | 977.5 |
| 3 | 0 | 013.8 | 1 | 805.5 | 1 | 893.3 |
| 4 | 1 | 97932.6 | 2 | 667.4 | 1 | 783.2 |
| 5 | 00 | 825.8 | 1 | 502.0 | 2 | 642.2 |
| 6 | | | 1 | 313.5 | 00 | 432.7 |
| 7 | | | | | 0 | 298.0 |
| 1 − 2 BAND $\nu_0=95200.4$ | | | | | | |
| 0 | 1 | 95216.3 | | | | |
| 1 | 00 | 220.9 | | | 1 | 95159.4 |
| 2 | 0 | 197.7 | 0 | 95049.1 | 2 | 107.7 |
| 3 | 00 | 150.2 | 0 | 94942.4 | 0d | 029.9 |
| 4 | 0 | 090.5 | 1 | 812.8 | 0 | 94928.0 |
| 5 | | | 00 | 661.1* | | |
| 6 | | | | | 00d | 661.1* |
| 1 − 3 BAND $\nu_0=92442.1$ | | | | | | |
| 0 | 0d | 92453.9 | | | | |
| 1 | 0d | 464.2 | | | 0 | 92403.5 |
| 2 | 00 | 446.2 | 0 | 92296.5 | 1 | 355.5 |
| 3 | | | 00 | 198.2 | 0 | 284.1 |
| 4 | | | 1 | 073.8* | 00D | 187.1 |
| 5 | | | 0 | 91929.0 | 1 | 073.8* |
| 1 − 4 BAND $\nu_0=89798.1$ | | | | | | |
| 0 | 2 | 89813.4 | | | | |
| 1 | 0 | 821.4 | | | 2 | 89761.8 |
| 2 | 0 | 808.6 | 1 | 89657.8 | 3 | 717.5 |
| 3 | 1 | 773.8 | 4 | 566.4 | 1 | 652.3 |
| 5 | 00 | 638.7 | 1 | 316.3 | 1 | 459.0 |
| 6 | 0 | 544.0 | 2 | 163.1 | 0 | 332.8 |
| 1 − 5 BAND $\nu_0=87271.7$ | | | | | | |
| 0 | 4 | 87287.5* | | | | |
| 1 | 3 | 297.4 | | | 3 | 87237.3 |
| 2 | 4 | 287.5* | 3 | 87138.4 | 4 | 197.7 |
| 3 | 1d | 257.6 | 2 | 050.9 | 3 | 138.4 |
| 4 | 1 | 210.1 | 3 | 86944.8 | 3 | 060.4 |
| 5 | | | 1 | 820.8 | 1 | 86963.7 |
| 6 | 2 | 060.4 | 3 | 679.9 | 0 | 849.1 |
| 7 | | | 1 | 521.3 | 1b | 713.7 |
| 1 − 6 BAND $\nu_0=84857.1$ | | | | | | |
| 0 | 3 | 84871.7 | | | | |
| 1 | 3 | 886.0 | | | 2 | 84824.8 |
| 2 | 2 | 879.9 | 1 | 84730.7 | 4 | 789.1 |
| 3 | 1 | 855.2 | 1 | 648.4 | 2d | 736.4* |
| 4 | 0 | 815.4 | 2 | 550.2 | 2 | 666.1* |
| 5 | 0 | 759.4 | 1 | 434.7 | 0db | 576.2 |
| 6 | 2b | 686.9 | 1 | 305.8 | 0 | 474.8 |
| 2 − 1 BAND $\nu_0=99666.9$ | | | | | | |
| 0 | 3 | 99680.7* | | | | |
| 1 | 3 | 680.7* | | | 2 | 99624.6 |
| 2 | 1 | 649.4 | 1 | 99509.6 | 1 | 566.4 |
| 3 | 2 | 593.6 | 1 | 395.6 | 3 | 478.0 |
| 4 | 1 | 509.6 | 2 | 253.4 | 0 | 364.2 |
| 5 | | | 1 | 084.2 | 00 | 222.1 |
| 6 | 00 | 253.4 | 2 | 98888.8 | 0d | 053.7 |
| 2 − 2 BAND $\nu_0=96793.4$ | | | | | | |
| 0 | 2 | 96807.9* | | | | |
| 1 | 2 | 807.9* | | | 1 | 96749.2 |
| 2 | 0 | 786.7 | 0 | 96641.7 | 1 | 698.7 |
| 3 | 0dd | 735.2 | 0 | 534.4 | 00d | 615.1 |
| 4 | 00 | 665.1? | 1 | 400.6 | 0 | 510.7 |
| 5 | 00 | 554.2 | 2 | 235.5? | | |
| 6 | | | 00 | 057.8 | | |
| 7 | | | | | 00 | 040.2 |
| 2 − 3 BAND $\nu_0=94035.8$ | | | | | | |
| 0 | 2 | 94050.4 | | | | |
| 1 | 2 | 053.9 | | | 1 | 93996.4 |
| 2 | 2 | 033.6 | 2 | 93889.7 | 4 | 946.1 |
| 3 | 0d | 93988.1 | 1 | 787.7 | 3 | 871.8 |
| 4 | 1 | 917.6 | 3 | 662.1 | 3 | 773.4 |
| 5 | 0 | 826.7 | 1d | 513.9 | 0 | 651.5 |
| 6 | 0 | 712.8 | 0d | 344.5 | 00 | 506.0 |
| 7 | | | | | 0d | 338.4 |
| 2 − 4 BAND $\nu_0=91392.2$ | | | | | | |
| 0 | 1 | 91406.8 | | | | |
| 1 | 00 | 414.3 | | | 1 | 91355.1 |
| 2 | 1 | 396.0 | 0d | 91251.7 | 2 | 309.2 |
| 3 | | | 0 | 157.3 | 0 | 240.9 |
| 4 | | | 1 | 037.4* | 0d | 151.0 |
| 5 | | | 0d | 90901.2 | 1 | 037.4* |
| 2 − 5 BAND $\nu_0=88863.0$ | | | | | | |
| 0 | 1 | 88877.8 | | | | |
| 1 | 00 | 885.7 | | | 1 | 88826.7 |
| 2 | 0 | 874.7 | 0 | 88729.5 | 2 | 786.3 |
| 3 | 1 | 838.3 | 1 | 640.6 | 0 | 724.8 |
| 4 | 2 | 786.3 | 1 | 530.8 | 1 | 640.6 |
| 5 | 00 | 711.4 | 1 | 400.5 | | |
| 6 | 0 | 623.0 | 1b | 255.6 | | |
| 2 − 6 BAND $\nu_0=86450.6$ | | | | | | |
| 0 | 4 | 86466.1* | | | | |
| 1 | 1d | 476.7 | | | 3 | 86417.8 |
| 2 | 4 | 466.1* | 4 | 86323.8* | 4 | 380.3 |
| 3 | 1 | 438.6 | 2 | 239.8 | 4 | 323.8 |
| 4 | 1 | 392.2 | 4 | 137.8 | 3 | 249.6 |
| 5 | | | 2 | 018.5 | 1b | 154.7 |
| 6 | 3 | 249.6* | 3 | 85882.6 | 0d | 047.4 |
| 7 | | | | | 1 | 85918.0 |
| 2 − 7 BAND $\nu_0=84148.9$ | | | | | | |
| 0 | 2 | 84163.2 | | | | |
| 1 | 2 | 175.7 | | | 3 | 84118.1 |
| 2 | 2 | 171.0 | 2d | 84027.6 | 4 | 083.9 |
| 3 | 1 | 149.7 | 2 | 83944.7 | 3 | 033.6 |
| 4 | 1 | 110.8 | 3 | 855.7 | 4 | 83967.1 |
| 5 | | | 1 | 751.4 | 1 | 886.9 |
| 6 | 00 | 83989.1 | 2 | 622.1 | 1 | 786.2 |
| 2 − 8 BAND $\nu_0=81963.4$ | | | | | | |
| 0 | 2 | 81978.0* | | | | |
| 1 | 2 | 991.8* | | | 1 | 81934.5 |
| 2 | 2 | 991.8* | 1 | 81848.0* | 1 | 904.1 |
| 3 | 2 | 978.0* | 0 | 776.1 | 0 | 860.7 |
| 4 | 0 | 945.4 | 2 | 690.2 | 1 | 801.6 |
| 5 | 3 | 904.1* | 2 | 587.3? | 00 | 928.7 |
| 6 | 1 | 848.0* | 0d | 479.5 | 00 | 642.0 |
| 3 − 2 BAND $\nu_0=98320.9$ | | | | | | |
| 0 | 3 | 98335.2* | | | | |
| 1 | 3 | 335.2* | | | 2 | 98278.4 |
| 2 | 2 | 305.4 | 2 | 98168.4 | 3 | 222.8 |
| 3 | 00 | 249.2 | 0 | 058.5 | 1 | 138.6 |
| 4 | 2 | 168.4* | 2 | 97920.2 | 2 | 028.6 |
| 5 | | | | | 1 | 97893.3* |
| 6 | | | 1 | 571.8 | 0 | 726.9 |
| 3 − 3 BAND $\nu_0=95562.4$ | | | | | | |
| 0 | 3 | 95576.7* | | | | |
| 1 | 3 | 576.7* | | | 0 | 95522.8 |
| 2 | 1 | 554.3 | 1 | 95416.2 | 2 | 470.6 |
| 3 | 1 | 509.3 | 1 | 312.7 | 1 | 393.6 |
| 4 | 0 | 434.4 | 1 | 181.2 | 2 | 289.8 |
| 5 | 00 | 329.8 | 0d | 029.9 | 1 | 159.4* |
| 6 | 0 | 192.8 | 00 | 94857.7 | 00 | 014.6 |
| 3 − 4 BAND $\nu_0=92919.7$ | | | | | | |
| 0 | 0d | 92937.3* | | | | |
| 1 | 0d | 937.3* | | | | |
| 2 | 0 | 916.9 | 0 | 92778.8 | 3 | 92834.7 |
| 3 | | | 0 | 681.5 | 0 | 761.8 |
| 4 | | | 0 | 559.3 | 0 | 667.7 |
| 5 | | | | | 00 | 549.8 |
| 6 | | | 0d | 255.2 | 00 | 409.5 |
| 3 − 5 BAND $\nu_0=90389.7$ | | | | | | |
| 0 | 0 | 90404.0 | | | | |
| 1 | 0 | 409.0 | | | 3 | 90354.6* |
| 2 | 0 | 392.9 | 2 | 90255.1 | 3 | 310.3 |
| 3 | 3 | 354.6* | 2 | 162.6 | 2 | 243.7 |
| 4 | | | 3 | 049.5 | 1 | 156.7 |
| 5 | | | 0 | 89911.9 | 3 | 049.5* |
| 6 | | | 2 | 761.8 | 0d | 89920.7 |
| 7 | | | | | 1 | 773.8* |
| 8 | | | | | 00 | 606.5 |
| 3 − 7 BAND $\nu_0=85675.9$ | | | | | | |
| 0 | 4 | 85689.8* | | | | |
| 1 | 0d | 699.0 | | | 1 | 85644.0 |
| 2 | 4 | 689.8* | 3 | 85554.2* | 3 | 608.0 |
| 3 | | | 0 | 473.7 | 3 | 554.2* |
| 4 | 0 | 626.0 | 3 | 375.9 | 1d | 483.3 |
| 5 | | | 0d | 266.0 | 00 | 394.2 |
| 6 | | | 0 | 139.1 | 1 | 290.7 |
| 7 | | | | | 00 | 170.8 |
| 8 | | | | | 00 | 035.1 |
| 3 − 8 BAND $\nu_0=83488.3$ | | | | | | |
| 0 | 3 | 83501.1 | | | | |
| 1 | 2 | 513.9 | | | 5 | 83458.8 |
| 2 | 2 | 509.7 | 1d | 83372.2 | 5 | 426.5 |
| 3 | 1 | 484.8 | 2 | 297.2 | 3 | 379.2 |
| 4 | 1 | 448.6 | 3 | 208.5 | 4 | 316.7 |
| 5 | 00 | 407.3 | 1d | 100.0 | 1 | 237.6 |
| 6 | | | 00 | 82980.0 | 1 | 146.3 |
| 7 | | | | | | |
| 8 | | | | | 0d | 921.7 |
| 3 − 9 BAND $\nu_0=81416.6$ | | | | | | |
| 0 | 2 | 81430.9* | | | | |
| 1 | 3b | 444.6* | | | 2 | 81389.0 |
| 2 | 3b | 444.6* | 1 | 81306.8 | 4 | 361.5 |
| 3 | 2 | 430.9* | 1 | 237.1 | 2b | 319.7 |
| 4 | 1 | 408.2 | 3 | 157.1 | 2 | 264.7 |
| 5 | | | 0 | 068.1 | 0d | 197.5 |
| 6 | | | 0 | 80964.8 | 1 | 117.6 |
| 4 − 4 BAND $\nu_0=94382.5$ | | | | | | |
| 0 | 0 | 94392.2 | | | | |
| 1 | 0 | 398.8 | | | 2 | 94343.4 |
| 2 | 2 | 375.0 | 1 | 94238.3 | 3 | 291.6 |
| 3 | 0d | 327.2 | 0 | 142.5 | 1 | 217.4 |
| 4 | 0 | 255.9 | 0 | 016.8* | 2 | 118.5 |
| 5 | | | 2 | 93871.8 | 2 | 93996.4* |
| 6 | | | 1 | 698.8 | 0 | 846.0 |
| 4 − 7 BAND $\nu_0=87137.5$ | | | | | | |
| 0 | 1 | 87148.8* | | | | |
| 1 | 0 | 160.7 | | | 0 | 87105.0 |
| 2 | 1 | 148.8* | 1 | 87011.2* | 2 | 066.3 |
| 3 | 00 | 114.1 | 0 | 86933.5* | 1 | 011.2* |
| 4 | | | 00 | 834.2 | 0 | 86933.5* |
| 5 | | | 1b | 713.7* | 00 | 839.8 |
| 6 | | | | | 00 | 730.7 |
| 4 − 8 BAND $\nu_0=84950.8$ | | | | | | |
| 0 | 0d | 84966.1* | | | | |
| 1 | 1 | 974.7 | | | 0d | 84918.5 |
| 2 | 0d | 966.1* | 0d | 84832.7* | 2 | 886.0* |
| 3 | | | 0 | 759.4* | 0d | 832.7* |
| 4 | 00 | 901.0 | 0d | 666.1* | 00 | 767.3 |
| 5 | 00 | 845.0 | | | 2d | 686.9* |
| 4 − 9 BAND $\nu_0=82879.7$ | | | | | | |
| 0 | 2 | 82888.7 | | | | |
| 1 | 1 | 905.3 | | | 4 | 82850.0 |
| 2 | 3 | 902.6 | 2 | 82765.2 | 4 | 819.6 |
| 3 | 1 | 883.7 | 1 | 699.3 | 3 | 744.8 |
| 4 | 3 | 850.0* | 3 | 614.8 | 3 | 715.7 |
| 5 | 2 | 806.5 | 1 | 517.1 | 1 | 642.6 |
| 6 | | | 1 | 408.2 | 0 | 556.3 |

may be used, making the objectionable presence of a stopcock unnecessary.

The amount of remaining $H_2$ which outgasses continuously to dilute the concentration of $D_2$ may be reduced by continuous operation of the discharge tube and frequent refilling with a high concentration of deuterium. In the present study this process was so successfully carried out that no $H_2$ lines and less than a score of the strongest HD lines appeared on the spectrograms.

The spectrum was photographed by use of a grazing incidence spectrograph with a two-meter glass grating having 30,000 lines per inch. The dispersion of this instrument in the region of the present study is about 2.4A per mm. The lines of carbon, nitrogen, and oxygen as measured by Boyce and Rieke[5] were used as standards for the reduction of the plates. All the wave numbers given in the tables accompanying this paper are (with the exception of a limited region near 1400A) the results of measurements of two, and in more than half of the range, three spectrograms. Wave-lengths should in general be accurate to within 0.02A and relative values over the range of a single band are somewhat better than this.

## ANALYSIS

The previous data on $H_2$ and HD are of course useful in making the analysis of the $D_2$ bands. In general the theoretical relations derived for the isotope effect in diatomic molecules furnish preliminary values of the vibrational and rotational constants that can be used to locate the approximate position of any band in the systems under consideration. As usual in this type of spectrum the very great number of closely spaced lines and consequent overlapping of bands forms the chief obstacle to a ready analysis. It may be mentioned that while considerably more than 2000 lines have been measured in the extreme ultraviolet spectrum, less than half of this number has been identified. The same situation exists in the case of the $H_2$ and HD spectra. It is thought that the data now made available will materially assist in the more difficult analysis of the remaining parts of these spectra.

The wave numbers of all identified lines together with the origins of the bands to which they belong and eye estimates of their intensities are given in Table I. Lines indicated by an asterisk are known blends. The letter "d or b" following the intensity estimate of a line indicates that the line is either diffuse or broad, as the case may be.

## DERIVATION OF THE CONSTANTS

The calculation of the rotational constants for the $D_2$ molecule has been carried out in detail by the analytical method described by Birge.[6] The method of least squares has been used throughout.

The rotational energy for the $1s\,{}^1\Sigma$ and $2p\,{}^1\Sigma$ states may be expressed as usual:

$$F=BK(K+1)+DK^2(K+1)^2+FK^3(K+1)^3\cdots \quad (1)$$

and for the $2p\,{}^1\Pi_{cd}$ states:

$$F=B_i^x[K(K+1)-\Lambda^2]+D_i^xK^2(K+1)^2+F_i^xK^3(K+1)^3\cdots. \quad (2)$$

In the latter case the subscript $i$ indicates the double valued nature of the function, one set of rotational constants being necessary for the $c$ component levels and another for the $d$ components of the $\Lambda$-type doubling. The superscript $x$ indicates that these are the so-called "effective" values of the constants, the $B^x$ for example being different from the "true" $B$. As is indicated previously,[1] however, the true rotational constants for our $2p\,{}^1\Pi_{cd}$ level are equal to those given by the $c$ component levels (our $B_c^x$, $D_c^x$, etc.). Unfortunately these cannot be directly determined since only $Q$ branches originate on the $c$ component levels. This difficulty is not serious, however, as the rotational term differences ($\Delta_2F$ values) can first be determined for the final $1s\,{}^1\Sigma$ state and these in combination with the wave numbers of the $Q$-branch lines yield values of $\Delta F$ for the $c$ component levels of the $2p\,{}^1\Pi_{cd}$ state.

Unfortunately, no bands were found with $v=0$ in the normal ($1s\,{}^1\Sigma$) state as their final level. But the accurate Raman effect measurements of Teal and MacWood[7] happily supply both the

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[5] J. C. Boyce and C. A. Rieke, Phys. Rev. **47**, 653 (1935).

[6] R. T. Birge, Bull. Nat. Res.Council No. 57, "Molecular Spectra in Gases."

[7] G. K. Teal and G. E. MacWood, J. Chem. Phys. **3**, 760 (1935).

TABLE IIA. $\Delta_2F$ values for the 1s $^1\Sigma$ state.

| $v=$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $K$ | | | | | | | | | |
| 1 | 171.5(4) | 167.1(8) | 160.5(7) | 154.8(10) | 148.5(6) | 142.4(5) | 135.9(9) | 130.0(6) | 124.0(7) |
| 2 | 286.1(4) | 275.9(7) | 265.9(7) | 256.1(10) | 245.8(6) | 236.7(6) | 226.0(7) | 216.3(7) | 206.6(4) |
| 3 | 398.5(5) | 385.8(8) | 372.2(6) | 357.6(9) | 343.4(6) | 329.0(5) | 315.4(9) | 300.3(7) | 287.0(7) |
| 4 | 510.6(6) | 492.3(2) | 476.5(6) | 457.5(7) | 438.8(4) | 420.3(5) | 401.3(4) | 385.5(4) | 367.1(4) |
| .5 | 620.2(5) | 596.6(1) | 575.8(7) | 555.7(5) | 529.8(4) | 507.7(6) | 488.1(5) | 467.0(5) | 443.2(6) |
| | | 702.5(1) | 668.9(2) | | 62.7(2) | 598.8(2) | 572.5(2) | | |

TABLE IIB. $\Delta_2F$ values for 2p $^1\Sigma$ state.

| $v=$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| $K$ | | | | | | | | |
| 1 | 58.5(4) | 56.4(4) | 55.6(3) | 52.5(4) | 52.3(2) | 51.9(3) | 47.0(2) | 48.5(2) |
| 2 | 97.4(9) | 94.6(5) | 91.0(4) | 89.1(4) | 84.8(5) | 82.8(4) | 81.8(3) | 79.3(5) |
| 3 | 136.6(4) | 131.9(4) | 127.3(3) | 122.2(4) | 120.0(3) | 116.7(4) | 113.0(3) | 110.3(5) |
| 4 | 173.3(4) | 168.0(4) | 161.3(2) | 158.6(3) | 151.7(3) | 149.7(2) | 145.3(4) | 142.4(4) |
| 5 | 210.6(2) | 201.5(2) | 199.7(3) | 192.1(1) | 185.8(1) | 183.3(1) | 178.5(1) | 172.1(2) |
| 6 | 247.5(3) | 241.3(2) | 230.8(1) | 225.4(2) | | 209.2(1) | | |

required $\Delta_2F$ values for $v=0$ and the vibrational term difference between the $v=0$ and $v=1$ levels. The data given by these authors are therefore used in combination with the data on the levels $v=1$ to 9 of the present study for extrapolation to $v=-\frac{1}{2}$ of the normal state.

The values of $B_v$ are given by the following least squares equations:

For the 1s $^1\Sigma$ state:

$$B_v=30.4286-1.04917(v+\tfrac{1}{2})+0.0057934(v+\tfrac{1}{2})^2-0.00027486(v+\tfrac{1}{2})^3\cdots. \quad (3)$$

In this equation the extrapolated value of $B_e=30.4286$ agrees sufficiently well with the value 30.430 obtained graphically and the value $B_0=29.905$ may be compared with the 29.906 obtained by the least squares method from the $\Delta_2F$ values of Teal and MacWood.

For the 2p $^1\Sigma$ state one obtains:

$$B_v=10.0018-0.350924(v+\tfrac{1}{2})+0.00921916(v+\tfrac{1}{2})^2+0.000199495(v+\tfrac{1}{2})^3\cdots. \quad (4)$$

This equation gives the values of $B_v$ from $v=0$ to $v=7$ inclusive but the curvature of the $B_v:v$ function is so pronounced that the least squares cubic does not give a good extrapolated value of $B_e$. A graphical solution together with difference tables gives the value $B_e=9.994$ cm$^{-1}$.

For the 2p $^1\Pi_{cd}$ states we have the equations:

$$(B_d^x)_v=15.857-0.5875(v+\tfrac{1}{2})+0.02070(v+\tfrac{1}{2})^2-0.003417(v+\tfrac{1}{2})^3\cdots \quad (5)$$

and

$$(B_c^x)_v=15.665-0.5739(v+\tfrac{1}{2})+0.009017(v+\tfrac{1}{2})^2-0.001500(v+\tfrac{1}{2})^3\cdots. \quad (6)$$

In each of the above equations the extrapolated values of $(B_i^x)_e$ agree with those obtained graphically. As before mentioned, the $(B_c^x)_v$ of the above equation is to be considered the "true" $B$ of the 2p $^1\Pi_{cd}$ state. The available data as given by the two equations above extend from $v=0$ to $v=4$ of the 2p $^1\Pi$ state.

The vibrational term differences are given by the least squares equations which follow:

For the 1s $^1\Sigma$ state:

$$\Delta G_v=3118.77-128.30(v+\tfrac{1}{2})+3.7627(v+\tfrac{1}{2})^2-0.42448(v+\tfrac{1}{2})^3+0.017133(v+\tfrac{1}{2})^4\cdots. \quad (7)$$

This equation fits the data to within the experimental error from $v=\frac{1}{2}$ to $v=8\frac{1}{2}$.

For the 2p $^1\Sigma$ state:

$$\Delta G_v=963.52-21.960(v+\tfrac{1}{2})+0.83907(v+\tfrac{1}{2})^2-0.04369(v+\tfrac{1}{2})^3\cdots. \quad (8)$$

In this equation the value of $\Delta G_v$ is given from $v=\frac{1}{2}$ to $6\frac{1}{2}$.

For the 2p $^1\Pi_{cd}$ state $\Delta G_v$ is given from $v=\frac{1}{2}$ to $v=3\frac{1}{2}$ by the equation:

TABLE IIC. $\Delta_2F$ values for 2p $^1\Pi_d$ state.

| $v=$ | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| $K$ | | | | | |
| 2 | 154.9(4) | 149.0(6) | 143.5(8) | 137.4(7) | 136.3(4) |
| 3 | 214.7(2) | 207.4(5) | 200.4(7) | 192.2(2) | 183.2(3) |
| 4 | 277.6(3) | 266.3(5) | 255.3(6) | 250.7(4) | 235.1(2) |
| 5 | 335.5(1) | 323.6(3) | 310.9(1) | 299.9(1) | 289.4(1) |
| 6 | 392.9(1) | 380.8(3) | 366.5(4) | | |

TABLE III. $B_v$ *values.*

|  | $1s\ ^1\Sigma$ |  | $2p\ ^1\Sigma$ |  | $2p\ ^1\Pi_c$ |  | $2p\ ^1\Pi_d$ |  |
|---|---|---|---|---|---|---|---|---|
| $v$ | Obs. $B$ | Calc. $B$ | Obs. $B$ | Calc. $B$ | Obs. $B$ | Calc. $B$ | Obs. $B$ | Calc. $B$ |
| 0 | 29.906 | 29.905 | 9.827 | 9.828 | 15.451 | 15.380 | 15.560 | 15.567 |
| 1 | 28.834 | 28.867 | 9.495 | 9.497 | 14.805 | 14.820 | 15.021 | 15.010 |
| 2 | 27.838 | 27.837 | 9.196 | 9.185 | 14.283 | 14.264 | 14.453 | 14.464 |
| 3 | 26.817 | 26.816 | 8.898 | 8.895 | 13.724 | 13.703 | 13.960 | 13.908 |
| 4 | 25.850 | 25.800 | 8.582 | 8.628 | 13.056 | 13.130 | 13.381 | 13.321 |
| 5 | 24.754 | 24.788 | 8.390 | 8.384 |  |  |  |  |
| 6 | 23.761 | 23.778 | 8.178 | 8.165 |  |  |  |  |
| 7 | 22.773 | 22.770 | 7.966 | 7.973 |  |  |  |  |
| 8 | 21.780 | 21.760 |  |  |  |  |  |  |
| 9 | 20.739 | 20.748 |  |  |  |  |  |  |

TABLE IV. $\Delta G_v$ *values.*

|  | $1s\ ^1\Sigma$ |  | $2p\ ^1\Sigma$ |  | $2p\ ^1\Pi_{cd}$ |  |
|---|---|---|---|---|---|---|
| $v$ | Obs. $\Delta G$ | Calc. $\Delta G$ | Obs. $\Delta G$ | Calc. $\Delta G$ | Obs. $\Delta G$ | Calc. $\Delta G$ |
| $\frac{1}{2}$ | 2993.5 | 2993.8 | 942.4 | 942.4 | 1736.2 | 1736.2 |
| $1\frac{1}{2}$ | 2874.1 | 2874.1 | 922.6 | 922.6 | 1661.4 | 1661.6 |
| $2\frac{1}{2}$ | 2758.0 | 2757.7 | 903.8 | 904.0 | 1592.8 | 1592.7 |
| $3\frac{1}{2}$ | 2643.0 | 2643.0 | 886.3 | 886.3 | 1527.0 | 1527.1 |
| $4\frac{1}{2}$ | 2527.8 | 2529.0 | 869.2 | 869.2 | 1462.5 | 1462.5 |
| $5\frac{1}{2}$ | 2413.9 | 2415.0 | 853.7 | 852.5 |  |  |
| $6\frac{1}{2}$ | 2300.6 | 2300.6 | 835.8 | 835.9 |  |  |
| $7\frac{1}{2}$ | 2186.3 | 2186.0 |  |  |  |  |
| $8\frac{1}{2}$ | 2071.7 | 2071.8 |  |  |  |  |

$$\Delta G_v = 1736.18 - 78.215(v+\tfrac{1}{2}) + 4.0143(v+\tfrac{1}{2})^2 - 0.39167(v+\tfrac{1}{2})^3 \cdots; \quad (9)$$

in each of the above three equations for $\Delta G_v$ the extrapolated values of $\Delta G_e$ were determined by difference tables and graphs.

In Table II are given values of $\Delta_2 F$ for the three states under consideration. The integer in parentheses following each entry indicates the number of independent values of which the entry is the average. Table III gives the values of $B_v$ as determined by the analytic least squares method[6] together with calculated values from Eqs. (3), (4), (5) and (6). The values of $\Delta G_v$ as determined directly from the data and as calculated from Eqs. (7), (8), and (9) are given in Table IV. Values of the band origins for both systems are collected in Table V.

The program of research on the visible spectra of HD and $D_2$ being carried out in this laboratory by Professor Dieke will give additional data on the $2p\ ^1\Sigma$ and $2p\ ^1\Pi_{cd}$ states and the accuracy of the results should be increased. Comparison between the data of this paper and the unfinished work in the visible and infrared regions indicate satisfactory agreement.

## COMPARISON OF THE $H_2$ AND $D_2$ DATA

The well-known theory of the isotope effect in diatomic molecules required the equality of certain ratios between corresponding constants of the two isotopic substances. The constants for $H_2$ have been previously[1] determined, but in this former work the difference between $(K+\frac{1}{2})^2$ and $K(K+1)$ in the rotational energy function was neglected. Also in the case of the $^1\Pi$-level the $\Lambda$ in the equation for the rotational energy was not taken into consideration.

In the case of the $1s\ ^1\Sigma$-state, in addition to correcting for the above differences, the Raman effect measurements[7] of Teal and MacWood together with a re-examination of the data have slightly changed the extrapolation of the $\Delta G_v : v$ function to $v = -\frac{1}{2}$ giving $\Delta G_e = 4406.4$ cm$^{-1}$. Teal and MacWood obtain 4405.3 cm$^{-1}$. Considering the uncertainty of extrapolation together with the error of measurement the two values agree as closely as should be expected. For the

TABLE VA. *Origins of the $2p\ ^1\Sigma - 1s\ ^1\Sigma$ bands.*

| $v''$ \ $v'$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 0 |  |  |  |  |  |  |  |  |
| 1 |  |  |  |  | 91293.1 | 92163.5 | 93017.6 |  |
| 2 |  | 85704.9 | 86629.9 | 87533.1 | 88419.0 |  |  |  |
| 3 |  | 82949.4 |  | 84775.0 |  |  |  |  |
| 4 |  | 80304.2 | 81229.0 |  |  | 83889.0 | 84742.8 | 85579.3 |
| 5 | 76836.0 | 77778.5 |  |  | 80492.7 |  |  |  |
| 6 | 74421.1 |  | 76286.9 | 77191.4 |  |  |  | 80637.3 |
| 7 | 72121.8 | 73063.8 | 73985.8 |  | 75777.4 | 76646.9 | 77500.5 |  |
| 8 | 69936.2 | 70877.8 |  |  | 73590.8 |  |  | 76149.3 |
| 9 |  | 68806.2 |  | 70632.3 |  | 72387.7 | 73241.2 | 74076.8 |

TABLE VB. *Origins of the $2p\ ^1\Pi - 1s\ ^1\Sigma$ bands.*

| $v''$ \ $v'$ | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 |  |  |  |  |  |
| 1 | 96413.4 | 98075.5 | 99666.9 |  |  |
| 2 | 93539.7 | 95200.4 | 96793.4 | 98320.9 |  |
| 3 | 90779.4 | 92442.1 | 94035.8 | 95562.4 |  |
| 4 | 88138.0 | 89798.1 | 91392.2 | 92919.7 | 94382.5 |
| 5 |  | 87271.7 | 88863.0 | 90389.7 |  |
| 6 |  | 84857.1 | 86450.6 |  |  |
| 7 |  |  | 84148.9 | 85675.9 | 87137.5 |
| 8 |  |  | 81963.4 | 83488.3 | 84950.8 |
| 9 |  |  |  | 81416.6 | 8287.79 |

TABLE VI. *Spectroscopic constant of the deuterium molecule.*

| | $1s\,^1\Sigma$ | $2p\,^1\Sigma$ | $2p\,^1\Pi_{cd}$ |
|---|---|---|---|
| $B_e(\mathrm{cm}^{-1})$ | 30.429 | 10.186 | 15.665 |
| $B_e^x(\mathrm{cm}^{-1})$ | | 9.994 | 15.857 |
| $D_e(\mathrm{cm}^{-1})$ | −0.011586 | | −0.005154 |
| $D_e^x(\mathrm{cm}^{-1})$ | | −0.004301 | −0.005291 |
| $F_e(\mathrm{cm}^{-1})$ | $6.22\times 10^{-6}$ | | $2.24\times 10^{-6}$ |
| $F_e^x(\mathrm{cm}^{-1})$ | | $2.66\times 10^{-6}$ | $2.34\times 10^{-6}$ |
| $\alpha_e(\mathrm{cm}^{-1})$ | 1.0492 | | 0.5739 |
| $\alpha_e^x(\mathrm{cm}^{-1})$ | | 0.35092 | 0.5875 |
| $G_0(\mathrm{cm}^{-1})$ | 1543.5 | 479.0 | 858.4 |
| $\omega_e(\mathrm{cm}^{-1})$ | 3118.8 | 963.5 | 1736.2 |
| $2x_e\omega_e(\mathrm{cm}^{-1})$ | 128.3 | 21.96 | 78.215 |
| $T_e(\mathrm{cm}^{-1})$ | 0 | 91698.4 | 100092.1 |
| $B_e^i/B_e$ | 0.49989 | 0.49848 | 0.50067 |
| calc. $\rho^2$ | 0.50035 | | |
| $\omega_e^i/\omega_e$ | 0.70777 | 0.70946 | 0.70348 |
| calc. $\rho$ | 0.70735 | | |

$2p\,^1\Sigma$ and $2p\,^1\Pi_{cd}$ states we have $\Delta G_e = 1358.0$ and 2468.0, respectively. The corrected values of $\nu_e$ are 91694.4 $\mathrm{cm}^{-1}$ for the $2p\,^1\Sigma - 1s\,^1\Sigma$ system and 100069.3 for the $2p\,^1\Pi - 1s\,^1\Sigma$ system.

Values of the constants for the $D_2$ molecule are collected in Table VI. In this table the $B_e$ given for the $2p\,^1\Pi_{cd}$ state is the $(B_c^x)e$ of Eq. (6), since this determines the true moment of inertia. The $B_e^x$ of the table is the "effective" $(B_d^x)e$ of Eq. (5).

The presence of a $l$ vector in the $2p\,^1\Sigma$ state gives rise to uncoupling terms because of quantum mechanical interaction with the neighboring $2p\,^1\Pi$ state. The $B_v$ determined from the experimental data for this state is therefore also an "effective" $B_v$ and should be denoted by $B_v^x$. This is not commonly done, however, since for nearly all practical purposes, such as the calculation of term values, the $B_v^x$ is required. It has thus become customary for the sake of simplicity to call this $B_v$. In addition the correction that must be applied to $B_v^x$ to obtain $B_v$ is often not known with any degree of accuracy. In our particular case, however, the correction can be made, as indicated in a paper[8] by Professor Dieke. Accordingly for the $2p\,^1\Sigma$ state values of both $B_e^x$ and $B_e$ are given in Table VI. Because of the method that must be used to calculate the correction, the value of $B_e^x$ is more accurate than that of $B_e$. This is especially true in the case of $H_2$ where there is a great number of perturbations in the perturbing $2p\,^1\Pi$ state the data of which must be used to obtain the difference between $B_e^x$ and $B_e$.

When the ratio of the $B_e$ values for the two isotopes are to be compared with the calculated $\rho^2$ it is of course the true $B_e$ rather than $B_e^x$ that must be used. It is for this reason that both values are given here.

The calculated value of $\rho$ given in the table is obtained from the mass spectrograph measurements of Aston.[9] There are several other corrections as discussed by Dieke[10] that should be applied to some of the constants of Table VI. These are all so small, however, that in view of the very unfavorable ratio of wave number intervals to differences of wave-length in the extreme ultraviolet as well as the comparatively larger error of measurement, these corrections are found to be inappreciable.

A comparison of the electronic term values listed in the table with those given above for $H_2$ indicates that for the $2p\,^1\Pi - 1s\,^1\Sigma$ system the electronic shift is 23 $\mathrm{cm}^{-1}$ and for the $2p\,^1\Sigma - 1s\,^1\Sigma$ system is 4 $\mathrm{cm}^{-1}$. The probable error in these values is perhaps 3 or 4 $\mathrm{cm}^{-1}$.

The value of the shift for the latter system is rather surprising since it is considerably less than the corresponding shift between $H_2$ and HD. In the case of the $2p\,^1\Pi - 1s\,^1\Sigma$ system the shift is approximately twice that for HD. The value given in a previous paper[2] for this shift in the $2p\,^1\Pi_{cd} - 1s\,^1\Sigma$ system of HD, as has been pointed out several times, is in error. The corrected value is 9 $\mathrm{cm}^{-1}$ units.

If the values given by Mie and Fujioka and Wada are corrected to take into account the $\Lambda$ as well as the difference between $(K+\frac{1}{2})^2$ and $K(K+1)$ in the rotational energy function, one obtains 9 $\mathrm{cm}^{-1}$ from the data of each of these investigations also. For the $2p\,^1\Sigma - 1s\,^1\Sigma$ system of HD the data of Mie and of Fujioka and Wada give, when corrected for the difference between $(K+\frac{1}{2})^2$ and $K(K+1)$ a value of the shift equal to 14 $\mathrm{cm}^{-1}$.

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[8] G. H. Dieke, Phys. Rev. **44**, 610 (1935).

[9] F. W. Aston, Nature **135**, 541 (1935).

[10] G. H. Dieke, Phys. Rev. **47**, 661 (1935).