UNITED STATES DEPARTMENT OF COMMERCE, Charles Sawyer, Secretary
NATIONAL BUREAU OF STANDARDS, E. U. Condon, Director

ATOMIC ENERGY LEVELS

As Derived From the Analyses of Optical Spectra

Volume I

The Spectra of Hydrogen, Deuterium, Tritium, Helium, Lithium, Beryllium, Boron, Carbon, Nitrogen, Oxygen, Fluorine, Neon, Sodium, Magnesium, Aluminum, Silicon, Phosphorus, Sulfur, Chlorine, Argon, Potassium, Calcium, Scandium, Titanium, and Vanadium

By Charlotte E. Moore

Circular of the National Bureau of Standards 467

Issued June 15, 1949

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price $5.50

HELIUM

He I

2 electrons $Z=2$

Ground state $1s^2\ ^1S_0$

$1s^2\ ^1S_0$ **198305±15 cm^{-1}** I. P. 24.580 volts

Most of the terms are taken from Paschen-Götze with the term values subtracted from Paschen's limit as quoted by Robinson in 1937. Higher members of the $^1F^{\circ}$ and $^3F^{\circ}$ series are taken from Meggers and Dieke. The term $2p\ ^3P^{\circ}$ has been calculated from its combination with $2s\ ^3S_1$, using the resolved triplet as observed by Meggers, the intervals being -0.078 cm^{-1} and -0.996 cm^{-1}. The components of $3p\ ^3P^{\circ}$ are based on Paschen's value of $3p\ ^3P_2^{\circ}$ and the intervals observed by Gibbs and Kruger; -0.165 cm^{-1} and -0.192 cm^{-1}.

Some doubt exists regarding the correct classifications of lines attributed to doubly excited helium, such as those observed at 309.04 A and 320.38 A by Compton and Boyce, and at 320.392 A and 357.507 A by Kruger. Approximate theoretical computations of the energies of doubly excited levels have been made by a number of authors and are summarized by Wu. His classification of the line observed at 320.4 A as $2p\ ^3P^{\circ}-2p^2\ ^3P$ has been adopted and used for the calculation of $2p^2\ ^3P$.

Several references deal with intercombinations in He I, namely, those by Lyman, Hopfield, Paschen, Suga, and others. The term values based on the excellent long series have been adopted in the table, since it is believed that they are the most accurate.

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He I

Config.	Desig.	J	Level
$1s^2$	$1s^2\ ^1S$	0	0±15
$1s\,2s$	$2s\ ^3S$	1	159850. 318
$1s\,2s$	$2s\ ^1S$	0	166271. 70
$1s\,2p$	$2p\ ^3P^{\circ}$	2	*169081. 111*
		1	*169081. 189*
		0	*169082. 185*
$1s\,2p$	$2p\ ^1P^{\circ}$	1	*171129. 148*
$1s\,3s$	$3s\ ^3S$	1	183231. 08
$1s\,3s$	$3s\ ^1S$	0	184859. 06
$1s\,3p$	$3p\ ^3P^{\circ}$	2	*185558. 92*
		1	*185559. 085*
		0	*185559. 277*
$1s\,3d$	$3d\ ^3D$	3, 2, 1	186095. 90
$1s\,3d$	$3d\ ^1D$	2	186099. 22
$1s\,3p$	$3p\ ^1P^{\circ}$	1	*186203. 62*
$1s\,4s$	$4s\ ^3S$	1	190292. 46
$1s\,4s$	$4s\ ^1S$	0	190934. 50
$1s\,4p$	$4p\ ^3P^{\circ}$	2, 1, 0	*191211. 42*
$1s\,4d$	$4d\ ^3D$	3, 2, 1	191438. 83
$1s\,4d$	$4d\ ^1D$	2	191440. 71
$1s\,4f$	$4f\ ^3F^{\circ}$	4, 3, 2	*191446. 61*
$1s\,4f$	$4f\ ^1F^{\circ}$	3	*191447. 24*
$1s\,4p$	$4p\ ^1P^{\circ}$	1	*191486. 95*
$1s\,5s$	$5s\ ^3S$	1	193341. 33
$1s\,5s$	$5s\ ^1S$	0	193657. 78
$1s\,5p$	$5p\ ^3P^{\circ}$	2, 1, 0	*193795. 07*
$1s\,5d$	$5d\ ^3D$	3, 2, 1	193911. 48
$1s\,5d$	$5d\ ^1D$	2	193912. 54
$1s\,5f$	$5f\ ^1F^{\circ}$	3	*193914. 31*
$1s\,5f$	$5f\ ^3F^{\circ}$	4, 3, 2	*193915. 79*
$1s\,5p$	$5p\ ^1P^{\circ}$	1	*193936. 75*
$1s\,6s$	$6s\ ^3S$	1	194930. 46
$1s\,6s$	$6s\ ^1S$	0	195109. 17
$1s\,6p$	$6p\ ^3P^{\circ}$	2, 1, 0	*195187. 21*
$1s\,6d$	$6d\ ^3D$	3, 2, 1	195254. 37
$1s\,6d$	$6d\ ^1D$	2	195255. 02
$1s\,6f$	$6f\ ^1F^{\circ}$	3	*195256. 7*
$1s\,6f$	$6f\ ^3F^{\circ}$	4, 3, 2	*195256. 82*
$1s\,6p$	$6p\ ^1P^{\circ}$	1	*195269. 17*
$1s\,7s$	$7s\ ^3S$	1	195862. 63

He I

Config.	Desig.	J	Level
$1s\,7s$	$7s\ ^1S$	0	195973. 19
$1s\,7p$	$7p\ ^3P^{\circ}$	2, 1, 0	*196021. 72*
$1s\,7d$	$7d\ ^3D$	3, 2, 1	196064. 00
$1s\,7d$	$7d\ ^1D$	2	196064. 31
$1s\,7f$	$7f\ ^1F^{\circ}$	3	*196065. 4*
$1s\,7f$	$7f\ ^3F^{\circ}$	4, 3, 2	*196065. 51*
$1s\,7p$	$7p\ ^1P^{\circ}$	1	*196073. 41*
$1s\,8s$	$8s\ ^3S$	1	196455. 79
$1s\,8s$	$8s\ ^1S$	0	196529. 03
$1s\,8p$	$8p\ ^3P^{\circ}$	2, 1, 0	*196561. 08*
$1s\,8d$	$8d\ ^3D$	3, 2, 1	196589. 42
$1s\,8d$	$8d\ ^1D$	2	196589. 73
$1s\,8f$	$8f\ ^1F^{\circ}$	3	*196590. 3*
$1s\,8f$	$8f\ ^3F^{\circ}$	4, 3, 2	*196590. 42*
$1s\,8p$	$8p\ ^1P^{\circ}$	1	*196595. 56*
$1s\,9s$	$9s\ ^3S$	1	196856. 37
$1s\,9s$	$9s\ ^1S$	0	196907. 13
$1s\,9p$	$9p\ ^3P^{\circ}$	2, 1, 0	*196929. 68*
$1s\,9d$	$9d\ ^1D$	2	196949. 49
$1s\,9d$	$9d\ ^3D$	3, 2, 1	196949. 63
$1s\,9f$	$9f\ ^1F^{\circ}$	3	*196950. 3*
$1s\,9f$	$9f\ ^3F^{\circ}$	4, 3, 2	*196950. 36*
$1s\,9p$	$9p\ ^1P^{\circ}$	1	*196953. 95*
$1s\,10s$	$10s\ ^3S$	1	197139. 76
$1s\,10s$	$10s\ ^1S$	0	197176. 36
$1s\,10p$	$10p\ ^3P^{\circ}$	2, 1, 0	*197192. 63*
$1s\,10d$	$10d\ ^1D$	2	197207. 08
$1s\,10d$	$10d\ ^3D$	3, 2, 1	197207. 30
$1s\,10f$	$10f\ ^3F^{\circ}$	4, 3, 2	*197208. 0*
$1s\,10p$	$10p\ ^1P^{\circ}$	1	*197210. 41*
$1s\,11s$	$11s\ ^3S$	1	197347. 05
$1s\,11p$	$11p\ ^3P^{\circ}$	2, 1, 0	*197386. 98*
$1s\,11d$	$11d\ ^1D$	2	197397. 62
$1s\,11d$	$11d\ ^3D$	3, 2, 1	197397. 75
$1s\,11f$	$11f\ ^3F^{\circ}$	4, 3, 2	*197398. 6*
$1s\,11p$	$11p\ ^1P^{\circ}$	1	*197400. 18*
$1s\,12s$	$12s\ ^3S$	1	197503. 69
$1s\,12s$	$12s\ ^1S$	0	197524. 26

He I—Continued

Config.	Desig.	J	Level	Config.	Desig.	J	Level
1s 12p	$12p\ ^3P^\circ$	2, 1, 0	*197534. 44*	1s 16d	$16d\ ^3D$	3, 2, 1	197876. 41
1s 12d	$12d\ ^1D$	2	197542. 54	1s 16p	$16p\ ^1P^\circ$	1	*197877. 04*
1s 12d	$12d\ ^3D$	3, 2, 1	197542. 67	1s 17p	$17p\ ^3P^\circ$	2, 1, 0	*197922. 51*
1s 12p	$12p\ ^1P^\circ$	1	*197544. 56*	1s 17d	$17d\ ^3D$	3, 2, 1	197925. 33
1s 13s	$13s\ ^3S$	1	197624. 98	1s 17p	$17p\ ^1P^\circ$	1	*197925. 87*
1s 13p	$13p\ ^3P^\circ$	2, 1, 0	*197649. 07*	1s 18p	$18p\ ^3P^\circ$	2, 1, 0	*197964. 02*
1s 13s	$13s\ ^1S$	0	197649. 78	1s 18d	$18d\ ^3D$	3, 2, 1	197966. 75
1s 13d	$13d\ ^1D$	2	197655. 19	1s 18p	$18p\ ^1P^\circ$	1	*197966. 80*
1s 13d	$13d\ ^3D$	3, 2, 1	197655. 47	1s 19p	$19p\ ^3P^\circ$	2, 1, 0	*197999. 12*
1s 13p	$13p\ ^1P^\circ$	1	*197656. 95*	1s 19d	$19d\ ^3D$	3, 2, 1	198001. 43
1s 14s	$14s\ ^3S$	1	197721. 13	1s 19p	$19p\ ^1P^\circ$	1	*198001. 44*
1s 14p	$14p\ ^3P^\circ$	2, 1, 0	*197739. 90*	1s 20p	$20p\ ^3P^\circ$	2, 1, 0	*198029. 07*
1s 14d	$14d\ ^1D$	2	197744. 918	1s 20p	$20p\ ^1P^\circ$	1	*198031. 02*
1s 14d	$14d\ ^3D$	3, 2, 1	197744. 94	1s 20d	$20d\ ^3D$	3, 2, 1	198031. 41
1s 14p	$14p\ ^1P^\circ$	1	*197746. 15*	1s 21p	$21p\ ^3P^\circ$	2, 1, 0	*198054. 83*
1s 15s	$15s\ ^3S$	1	197796. 63	1s 21d	$21d\ ^3D$	3, 2, 1	198056. 50
1s 15p	$15p\ ^3P^\circ$	2, 1, 0	*197813. 11*	1s 22p	$22p\ ^3P^\circ$	2, 1, 0	*198077. 15*
1s 15d	$15d\ ^3D$	3, 2, 1	197817. 05				
1s 15p	$15p\ ^1P^\circ$	1	*197818. 12*	He II ($^2S_{½}$)	***Limit***	----------	**198305**
1s 16p	$16p\ ^3P^\circ$	2, 1, 0	*197872. 95*	$2p^2$	$2p^2\ ^3P$	2, 1, 0	481198

August 1946.

He II

(H sequence; 1 electron) $Z=2$

Ground state 1s $^2S_{½}$

1s $^2S_{½}$ He^3 **438889.040** cm^{-1} I. P. He^3 54.400 volts

1s $^2S_{½}$ He^4 **438908.670** cm^{-1} I. P. He^4 54.403 volts

The levels have been calculated by J. E. Mack, "using $R_{He^4}=109722.264$ and taking into account the fine structure as in hydrogen, but with $\Lambda=0.0402\pm0.009$, from the work of Skinner and Lamb on the 2s-level. The tentative experimental indication that Λ decreases with increasing n has been neglected. Assuming $R_{He^3}=109717.344$, the levels of He^3 may be calculated to a close approximation from those of He^4 by the equation

$$\text{Level}_{He^3 II}-\text{Level}_{He^4 II}=-(1-n^{-2})19.630\ \text{cm}^{-1}."$$

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			He^3 II	He^4 II	
Config.	Desig.	J	Level	Level	Interval
1s	$1s\ ^2S$	½	0.000	0.000	
2p	$2p\ ^2P^\circ$	½	329164.390	329179.102	0.470
2s	$2s\ ^2S$	½	329164.860	329179.572	5.8434
2p	$2p\ ^2P^\circ$	1½	329170.135	329184.945	
3p	$3p\ ^2P^\circ$	½	390123.179	390140.622	0.14
3s	$3s\ ^2S$	½	390123.318	390140.761	1.7314
3p, 3d	$3d\ ^2D$, $3p\ ^2P^\circ$	1½	390124.910	390142.353	0.5771
3d	$3d\ ^2D$	2½	390125.487	390142.930	
4p	$4p\ ^2P^\circ$	½	411458.517	411476.917	0.06
4s	$4s\ ^2S$	½	411458.576	411476.976	0.7304
4p, 4d	$4d\ ^2D$, $4p\ ^2P^\circ$	1½	411459.248	411477.648	0.2435
4d, 4f	$4d\ ^2D$, $4f\ ^2F^\circ$	2½	411459.491	411477.891	0.1217
4f	$4f\ ^2F^\circ$	3½	411459.613	411478.013	
5p	$5p\ ^2P^\circ$	½	421333.629	421352.472	0.03
5s	$5s\ ^2S$	½	421333.659	421352.502	0.3740
5p, 5d	$5d\ ^2D$, $5p\ ^2P^\circ$	1½	421334.003	421352.846	0.1247
5d, 5f	$5d\ ^2D$, $5f\ ^2F^\circ$	2½	421334.128	421352.971	0.0624
5f, 5g	$5g\ ^2G$, $5f\ ^2F^\circ$	3½	421334.190	421353.033	0.0374
5g	$5g\ ^2G$,	4½	421334.228	421353.071	
6p	$6p\ ^2P^\circ$	½	426697.845	426716.928	0.02
6s	$6s\ ^2S$	½	426697.862	426716.945	0.2164
6p, 6d	$6d\ ^2D$, $6p\ ^2P^\circ$	1½	426698.062	426717.145	0.0721
6d, 6f	$6d\ ^2D$, $6f\ ^2F^\circ$	2½	426698.134	426717.217	0.0361
6f, 6g	$6g\ ^2G$, $6f\ ^2F^\circ$	3½	426698.170	426717.253	0.0216
6g, 6h	$6g\ ^2G$, $6h\ ^2H^\circ$	4½	426698.192	246717.275	0.0144
6h	$6h\ ^2H^\circ$	5½	426698.206	426717.289	
7s, etc.	$7s\ ^2S$, etc.	½, etc.	----------	429951.508 to .741	
8s, etc.	$8s\ ^2S$, etc.	½, etc.	----------	432050.863 to1.023	
9s, etc.	$9s\ ^2S$, etc.	½, etc.	----------	433490.169 to .283	
10s, etc.	$10s\ ^2S$, etc.	½, etc.	----------	434519.693 to .777	
11s, etc.	$11s\ ^2S$, etc.	½, etc.	----------	435281.423 to .486	
12s, etc.	$12s\ ^2S$, etc.	½, etc.	----------	435860.778 to .828	
13s, etc.	$13s\ ^2S$, etc.	½, etc.	----------	436311.653 to .692	
14s, etc.	$14s\ ^2S$, etc.	½, etc.	----------	436669.407 to .439	
15s, etc.	$15s\ ^2S$, etc.	½, etc.	----------	436957.026 to 8.052	
	∞=***Limit***	----------	----------	**438908. 670**	

February 1949.