The Spectra of Potassium, K IV and K V, and of Calcium Ca V and Ca VI

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From 19 to 36 new lines each have been identified in K IV, K V, Ca V and Ca VI. In K IV and Ca V these include singlet and intercombination lines. The presence in the nebulae of lines due to the forbidden ${}^3P-{}^1D$ transitions in S I, Cl II, A III, K IV and Ca V is discussed.

EKEFORS[1] has measured the spectra of potassium and calcium in the range below 1050A with a source capable of exciting all stages of ionization up to the ninth or tenth. In both K IV and Ca V, Ram[2] classified 30 to 40 lines each as triplet transitions and in K V noted one quartet multiplet of three lines.

In the course of the present investigation

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[1] E. Ekefors, Zeits. f. Physik **71**, 53 (1931).

[2] M. Ram, Ind. J. Phys. **8**, 163 (1933).

TABLE I. *Classified lines of K IV, K V, Ca V and Ca VI.*

Int.	λ	ν	Classification
Classified lines of K IV			
3	271.820	367891	$s^2p^4\,{}^3P_2-5s\ {}^3S$
2	273.065	366213	$s^2p^4\,{}^3P_1-5s\ {}^3S$
1	273.546	365569	$s^2p^4\,{}^3P_0-5s\ {}^3S$
2	354.139	282375	$s^2p^4\,{}^3P_2-4s\ {}^1D$
6	354.927	281748	$s^2p^4\,{}^1D-4s\ {}^1P$
3	356.260	280694	$s^2p^4\,{}^3P_1-4s\ {}^1D$
2	360.568	277340	$s^2p^4\,{}^1D-4s\ {}^3P_2$
6	375.955	265989	$s^2p^4\,{}^1D-4s\ {}^1D$
2	379.279	263658	$s^2p^4\,{}^3P_2-3d\ {}^3D_1$
5	380.477	262828	$s^2p^4\,{}^3P_2-3d\ {}^3D_2$
4	381.702	261985	$s^2p^4\,{}^3P_1-3d\ {}^3D_1$
3	382.487	261447	$s^2p^4\,{}^1D-4s\ {}^3D_2$
			$s^2p^4\,{}^3P_2-3d\ {}^1P$
4	382.646	261338	$s^2p^4\,{}^3P_0-3d\ {}^3D_1$
6	382.906	261161	$s^2p^4\,{}^3P_1-3d\ {}^3D_2$
3	384.956	259770	$s^2p^4\,{}^3P_1-3d\ {}^1P$
3	404.412	247273	$s^2p^4\,{}^1D-3d\ {}^3D_1$
2	405.773	246443	$s^2p^4\,{}^1D-3d\ {}^3D_2$
5	408.076	245052	$s^2p^4\,{}^1D-3d\ {}^1P$
3	417.280	239647	$s^2p^4\,{}^1D-3d\ {}^3P_2$
Classified lines of Ca V			
3	184.280	542652	$s^2p^4\,{}^3P_2-5s\ {}^3P_2$
1	184.415	542255	$s^2p^4\,{}^3P_2-5s\ {}^3P_1$
2	185.102	540243	$s^2p^4\,{}^3P_1-5s\ {}^3P_2$
1	185.288	539700	$s^2p^4\,{}^3P_1-5s\ {}^3P_{0,\,1}$
2	185.540	538967	$s^2p^4\,{}^3P_0-5s\ {}^3P_1$
4	190.363	525312	$s^2p^4\,{}^1D-5s\ {}^1P$
5	190.457	525053	$s^2p^4\,{}^3P_2-5s\ {}^3D_3$
3	190.558	524775	$s^2p^4\,{}^3P_2-5s\ {}^3D_2$
3	191.439	522360	$s^2p^4\,{}^3P_1-5s\ {}^3D_2$
2	191.480	522248	$s^2p^4\,{}^3P_1-5s\ {}^3D_1$
2	191.801	521374	$s^2p^4\,{}^3P_0-5s\ {}^3D_1$
5	196.970	507692	$s^2p^4\,{}^1D-5s\ {}^1D$
2	197.531	506250	$s^2p^4\,{}^1D-5s\ {}^3D_3$
2	197.648	505950	$s^2p^4\,{}^1D-5s\ {}^3D_2$
6	199.553	501120	$s^2p^4\,{}^3P_2-5s\ {}^3S$
3	199.890	500275	$s^2p^4\,{}^1S-5s\ {}^1P$
5	200.512	498723	$s^2p^4\,{}^3P_1-5s\ {}^3S$
3	200.860	497859	$s^2p^4\,{}^3P_0-5s\ {}^3S$
3	266.863	374724	$s^2p^4\,{}^3P_2-4s\ {}^1D$
8	267.772	373452	$s^2p^4\,{}^1D-4s\ {}^1P$
2	268.583	372328	$s^2p^4\,{}^3P_1-4s\ {}^1D$
2	270.570	369590	$s^2p^4\,{}^3P_2-4s\ {}^3D_1$
4	271.141	368812	$s^2p^4\,{}^1D-4s\ {}^3P_2$
1	271.440	368406	$s^2p^4\,{}^1D-4s\ {}^3P_1$
8	280.992	355882	$s^2p^4\,{}^1D-4s\ {}^1D$
2	284.794	351131	$s^2p^4\,{}^1D-4s\ {}^3D_3$
9*dB*	286.965	348475	$s^2p^4\,{}^1S-4s\ {}^1P$
0	301.139	332073	$s^2p^4\,{}^1D-4s\ {}^3S$
6	321.609	310937	$s^2p^4\,{}^3P_2-3d\ {}^3D_1$
6	330.937	302172	$s^2p^4\,{}^3P_2-3d\ {}^1P$
4	333.570	299787	$s^2p^4\,{}^3P_1-3d\ {}^1P$
6	334.545	298913	$s^2p^4\,{}^3P_0-3d\ {}^1P$
4	343.640	291002	$s^2p^4\,{}^1D-3d\ {}^3D_2$
9	352.915	283354	$s^2p^4\,{}^1D-3d\ {}^1P$
5	356.246	280705	$s^2p^4\,{}^1D-3d\ {}^3P_1$
5	387.077	258347	$s^2p^4\,{}^1S-3d\ {}^1P$
Classified lines of K V			
6	294.836	339172	$s^2p^3\,{}^4S-4s\ {}^4P_{2\frac{1}{2}}$
6	296.169	337645	$s^2p^3\,{}^4S-4s\ {}^4P_{1\frac{1}{2}}$
5	297.064	336628	$s^2p^3\,{}^4S-4s\ {}^4P_{\frac{1}{2}}$
7	300.252	333054	$s^2p^3\,{}^2D_{1\frac{1}{2}}-4s\ {}^2D_{1\frac{1}{2}}$
6	300.503	332775	$s^2p^3\,{}^2D_{2\frac{1}{2}}-4s\ {}^2D_{2\frac{1}{2}}$
6	311.243	321292	$s^2p^3\,{}^2D_{2\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
5	312.770	319724	$s^2p^3\,{}^2D_{1\frac{1}{2}}-4s\ {}^2P_{\frac{1}{2}}$
4	315.181	317278	$s^2p^3\,{}^2P_{\frac{1}{2}}-4s\ {}^2D_{1\frac{1}{2}}$
3	315.537	316920	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2D_{2\frac{1}{2}}$
2	327.031	305781	$s^2p^3\,{}^2P_{\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
4	327.376	305459	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
2	328.973	303976	$s^2p^3\,{}^2P_{\frac{1}{2}}-4s\ {}^2P_{\frac{1}{2}}$
0	329.307	303668	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2P_{\frac{1}{2}}$
5	422.178	236867	$s^2p^3\,{}^2D_{1\frac{1}{2}}-3d\ {}^2P_{\frac{1}{2}}$
5	425.159	235206	$s^2p^3\,{}^2D_{1\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
7	425.588	234969	$s^2p^3\,{}^2D_{2\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
2	452.227	221128	$s^2p^3\,{}^2P_{\frac{1}{2}}-3d\ {}^2P_{\frac{1}{2}}$
3	452.900	220799	$s^2p^3\,{}^2P_{1\frac{1}{2}}-3d\ {}^2P_{\frac{1}{2}}$
1	455.670	219457	$s^2p^3\,{}^2P_{\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
4	456.328	219141	$s^2p^3\,{}^2P_{1\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
7	580.319	172319.0	$s^2p^3\,{}^2D_{1\frac{1}{2}}-sp^4\,{}^2P_{\frac{1}{2}}$
5	585.510	170791.3	$s^2p^3\,{}^2D_{1\frac{1}{2}}-sp^4\,{}^2P_{1\frac{1}{2}}$
8	586.322	170554.8	$s^2p^3\,{}^2D_{2\frac{1}{2}}-sp^4\,{}^2P_{1\frac{1}{2}}$
5	638.668	156575.9	$s^2p^3\,{}^2P_{\frac{1}{2}}-sp^4\,{}^2P_{\frac{1}{2}}$
2	639.982	156254.4	$s^2p^3\,{}^2P_{1\frac{1}{2}}-sp^4\,{}^2P_{\frac{1}{2}}$
0	644.963	155047.7	$s^2p^3\,{}^2P_{\frac{1}{2}}-sp^4\,{}^2P_{1\frac{1}{2}}$
Classified lines of Ca VI			
7	228.628	437392	$s^2p^3\,{}^4S-4s\ {}^4P_{2\frac{1}{2}}$
7	229.734	435286	$s^2p^3\,{}^4S-4s\ {}^4P_{1\frac{1}{2}}$
5	230.495	433849	$s^2p^3\,{}^4S-4s\ {}^4P_{\frac{1}{2}}$
6	232.282	430511	$s^2p^3\,{}^2D_{1\frac{1}{2}}-4s\ {}^2D_{1\frac{1}{2}}$
5	232.531	430050	$s^2p^3\,{}^2D_{2\frac{1}{2}}-4s\ {}^2D_{2\frac{1}{2}}$
0	239.296	417892	$s^2p^3\,{}^2D_{1\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
7	239.535	417476	$s^2p^3\,{}^2D_{2\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
6	240.721	415419	$s^2p^3\,{}^2D_{1\frac{1}{2}}-4s\ {}^2P_{\frac{1}{2}}$
3	242.265	412771	$s^2p^3\,{}^2P_{\frac{1}{2}}-4s\ {}^2D_{1\frac{1}{2}}$
3	242.592	412215	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2D_{1\frac{1}{2}}$
5	242.631	412148	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2D_{2\frac{1}{2}}$
3	249.914	400138	$s^2p^3\,{}^2P_{\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
4	250.265	399576	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2P_{1\frac{1}{2}}$
4	251.465	397670	$s^2p^3\,{}^2P_{\frac{1}{2}}-4s\ {}^2P_{\frac{1}{2}}$
1	251.816	397115	$s^2p^3\,{}^2P_{1\frac{1}{2}}-4s\ {}^2P_{\frac{1}{2}}$
6	339.463	294583	$s^2p^3\,{}^2D_{1\frac{1}{2}}-3d\ {}^2D_{1\frac{1}{2}}$
4	339.940	294170	$s^2p^3\,{}^2D_{2\frac{1}{2}}-3d\ {}^2D_{1\frac{1}{2}}$
4	340.037	294086	$s^2p^3\,{}^2D_{1\frac{1}{2}}-3d\ {}^2D_{2\frac{1}{2}}$
8	340.528	293662	$s^2p^3\,{}^2D_{2\frac{1}{2}}-3d\ {}^2D_{2\frac{1}{2}}$
2	361.234	276829	$s^2p^3\,{}^2P_{\frac{1}{2}}-3d\ {}^2D_{1\frac{1}{2}}$
4	362.612	275777	$s^2p^3\,{}^2P_{1\frac{1}{2}}-3d\ {}^2D_{2\frac{1}{2}}$
7	370.022	270254	$s^2p^3\,{}^2D_{1\frac{1}{2}}-3d\ {}^2P_{\frac{1}{2}}$
5	373.418	267796	$s^2p^3\,{}^2D_{1\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
7	373.997	267382	$s^2p^3\,{}^2D_{2\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
2	396.055	252490	$s^2p^3\,{}^2P_{\frac{1}{2}}-3d\ {}^2P_{\frac{1}{2}}$
2	396.917	251942	$s^2p^3\,{}^2P_{1\frac{1}{2}}-3d\ {}^2P_{\frac{1}{2}}$
0	399.925	250047	$s^2p^3\,{}^2P_{\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
3	400.824	249486	$s^2p^3\,{}^2P_{1\frac{1}{2}}-3d\ {}^2P_{1\frac{1}{2}}$
2	629.594	158833	$s^2p^3\,{}^4S-sp^4\,{}^4P_{\frac{1}{2}}$
2	633.815	157775	$s^2p^3\,{}^4S-sp^4\,{}^4P_{1\frac{1}{2}}$
2	641.883	155792	$s^2p^3\,{}^4S-sp^4\,{}^4P_{2\frac{1}{2}}$

B, blend.

TABLE II. *Term values of K IV, K V, Ca V and Ca VI.*

Term values of K IV

$\Sigma l=3$		4		5	
		$s^2p^4\,^3P_2$	0	$sp^5\,^3P_2$	134181
$4s\,^3D_1$	277795	$s^2p^4\,^3P_1$	1673	$sp^5\,^3P_1$	135659
$4s\,^3D_2$	277851	$s^2p^4\,^3P_0$	2324	$sp^5\,^3P_0$	136453
$4s\,^3D_3$	277986	$s^2p^4\,^1D$	16386		
$4s\,^1D$	282373			$3d\ ^3P_2$	256034
$4s\,^3P_0$	293384			$3d\ ^3P_1$	257124
$4s\,^3P_1$	293473			$3d\ ^1P$	261445
$4s\,^3P_2$	293720			$3d\ ^3D_2$	262831
$4s\,^1P$	298134			$3d\ ^3D_1$	263659
$5s\,^3S$	367890				

Term values of K V

$\Sigma l=2$		3		4	
		$s^2p^3\,^4S$	0	$sp^4\,^4P_{2\frac{1}{2}}$	136639
$4s\,^4P_{\frac{1}{2}}$	336628	$s^2p^3\,^2D_{1\frac{1}{2}}$	24000	$sp^4\,^4P_{1\frac{1}{2}}$	138042
$4s\,^4P_{1\frac{1}{2}}$	337645	$s^2p^3\,^2D_{2\frac{1}{2}}$	24237	$sp^4\,^4P_{\frac{1}{2}}$	138806
$4s\,^4P_{2\frac{1}{2}}$	339172	$s^2p^3\,^2P_{\frac{1}{2}}$	39745	$sp^4\,^2P_{1\frac{1}{2}}$	194792
$4s\,^2P_{\frac{1}{2}}$	343726	$s^2p^3\,^2P_{1\frac{1}{2}}$	40064	$sp^4\,^2P_{\frac{1}{2}}$	196319
$4s\,^2P_{1\frac{1}{2}}$	345526				
$4s\,^2D_{2\frac{1}{2}}$	356993			$3d\ ^2P_{1\frac{1}{2}}$	259205
$4s\,^2D_{1\frac{1}{2}}$	357033			$3d\ ^2P_{\frac{1}{2}}$	260868

Term values of Ca V

$\Sigma l=3$		4		5	
		$s^2p^4\,^3P_2$	0	$sp^5\,^3P_2$	154664
$4s\,^3S$	350914	$s^2p^4\,^3P_1$	2404	$sp^5\,^3P_1$	156756
$4s\,^3D_1$	369590	$s^2p^4\,^3P_0$	3276	$sp^5\,^3P_0$	157897
$4s\,^3D_2$	369696	$s^2p^4\,^1D$	18831		
$4s\,^3D_3$	369959	$s^2p^4\,^1S$	43847	$3d\ ^3P_2$	298204
$4s\,^1D$	374728			$3d\ ^3P_1$	299535
$4s\,^3P_0$	387039			$3d\ ^1P$	302184
$4s\,^3P_1$	387226			$3d\ ^3D_2$	309834
$4s\,^3P_2$	387652			$3d\ ^3D_1$	310945
$4s\,^1P$	392283				
$5s\,^3S$	501127				
$5s\,^3D_1$	524651				
$5s\,^3D_2$	524770				
$5s\,^3D_3$	525053				
$5s\,^1D$	526523				
$5s\,^3P_1$	542249				
$5s\,^3P_2$	542650				
$5s\,^1P$	544143				

Term values of Ca VI

$\Sigma l=2$		3		4	
		$s^2p^3\,^4S$	0	$sp^4\,^4P_{2\frac{1}{2}}$	155792
$4s\,^4P_{\frac{1}{2}}$	433849	$s^2p^3\,^2D_{1\frac{1}{2}}$	27000	$sp^4\,^4P_{1\frac{1}{2}}$	157775
$4s\,^4P_{1\frac{1}{2}}$	435286	$s^2p^3\,^2D_{2\frac{1}{2}}$	27417	$sp^4\,^4P_{\frac{1}{2}}$	158833
$4s\,^4P_{2\frac{1}{2}}$	437392	$s^2p^3\,^2P_{\frac{1}{2}}$	44754		
$4s\,^2P_{\frac{1}{2}}$	442423	$s^2p^3\,^2P_{1\frac{1}{2}}$	45310	$3d\ ^2P_{1\frac{1}{2}}$	294798
$4s\,^2P_{1\frac{1}{2}}$	444890			$3d\ ^2P_{\frac{1}{2}}$	297250
$4s\,^2D_{2\frac{1}{2}}$	457458			$3d\ ^2D_{2\frac{1}{2}}$	321084
$4s\,^2D_{1\frac{1}{2}}$	457525			$3d\ ^2D_{1\frac{1}{2}}$	321584

plates of these spectra were taken in the region below 600A on a grazing incidence spectrograph of two meter focus. With the additional lines found on these long exposure plates to supplement the observations of Ekefors, it has been possible to make the further identifications of lines of K IV, K V, Ca V and Ca VI listed in Table I. All terms of these ions that have been fixed by either Ram's or the present identifications are given in Table II.

Since a large part of the K IV and Ca V lines, listed in the present paper, are singlet and intercombination lines it is now possible to fix accurately the relative positions of the ^1D and ^3P terms of the ground configuration of these ions. Ruedy[3] has likewise determined the relative positions of these terms in S I. Furthermore by interpolation between S I and K IV and Ca V the relative positions of these terms in Cl II and A III can now be predicted with an uncertainty of at most 200 cm^{-1}. The predicted wave-lengths of the forbidden transitions from the metastable $s^2p^4\,^1D$ state to the $s^2p^4\,^3P$ states corresponding to these relative positions are given in Table III. The only one of these wave-lengths that corresponds to an observed nebular line is $^3P_2-{}^1D$ of A III which falls near the strong unidentified line at 7135.6A. The decision as to the reality of this correlation will depend largely on whether the companion $^3P_1-{}^1D$ line, which should appear at 7755A, can be found. *Nova Pictoris*[4] shows unidentified lines at the positions of both the Ca V forbidden lines. However the ratio between the intensities of the two lines is neither constant nor at any time equal to the predicted ratio. Furthermore the observed lines persist with increasing intensity after other forbidden lines have disappeared. Since the $^3P_2-{}^1D$ and $^3P_1-{}^1D$ are, respectively, the strongest and second strongest forbidden lines that these ions emit, the failure of these lines to be observed points definitely to the low abundance of the ions involved.

TABLE III. *Forbidden transitions from metastable states.*

	$^3P_2-{}^1D$ λ	$^3P_1-{}^1D$ λ	$^3P_2-{}^3P_1$ $\Delta\nu$ (cm^{-1})
S I	10820.	11306. ± 10	397.4 ± 5
Cl II	8589.	9132. ±150	692. ± 5
A III	7141.	7761. ±100	1113. ± 5
K IV	6101.	6795. ± 5	1673. ± 8
Ca V	5309.	6086. ± 5	2404. ±10

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[3] J. E. Ruedy, Phys. Rev. **44**, 757 (1933).

[4] H. Spencer Jones, M. N. R. A. S. **91**, 777 (1931), **92** 728 (1932).