Note on the Ionization Potential of Fe II

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Two new high terms, e^6D and e^4D, have been found in the spark spectrum of iron which are in series with known low terms. The principal ionization potential for Fe II is thus found to be 16.16 volts.

IN the course of analysis of the unclassified lines of Fe II which is now being undertaken at the Solar Physics Observatory, Cambridge, England, with a view to the extension of the multiplet scheme started by H. N. Russell,[1] two new high-lying terms, $e^6D(77{,}861.4)$ and $e^4D(79{,}439.3)$ have been identified.

The arrangements of the multiplets which these terms, belonging to the configuration $d^{n-2}\cdot s$, form by their combinations with the odd triad $d^{n-2}p\ z^4P^\circ$, D°, F° are set out in Tables I and II. The intensities, placed after the wave-length, have been estimated on an arbitrary scale. The theoretical wave number is shown in brackets below the observed.

The measurements of these new multiplet lines have been made from plates, taken by Mr. Moss, of the polar lines of iron. They appear on these plates most strongly at the positive pole and faintly in the core in the case of the stronger lines and not at all in the case of the weaker lines. In Exner and Haschek's spark spectrum of iron the lines in question either do not appear or are broad and diffuse.

Many hundreds of unclassified lines of Fe II appear on our plates as polar lines of all degrees of enhancement ranging from those which are nearly as strong in the core as at the poles (i.e., high level lines of Fe I) to those which are very strong at the pole compared with the core (i.e., lines corresponding to transitions from high terms in Fe II such as those recorded in this note).

Since the new terms $d^{n-2}\cdot s\ e^6D$ and $d^{n-2}\cdot s\ e^4D$ are the second members of their respective series, the first members being the low-lying $d^{n-2}s\ a^6D$ and $d^{n-2}s\ a^4D$ terms, the ionization potential of Fe II may be calculated with a fair degree of accuracy.

Taking the levels of highest inner quantum number $a^4D_{3\frac{1}{2}}(7955.3)$ and $e^4D_{3\frac{1}{2}}(79{,}439.3)$ as representing the first two terms of the quartet series and expressing the difference 71,484.0 as the difference between two Rydberg terms, we find

$$71{,}484.0 = 4\times 109{,}737.1\{1/(1.877783)^2 - 1/(2.877783)^2\}$$
$$= 124{,}486.6 - 53{,}002.6,$$

where the value 109,737.1 has been taken for the Rydberg constant.[2]

The series limit becomes $7955.3+124{,}486.6 = 132{,}441.9$. From a comparison of the limits obtained from a Ritz formula for series in which more than two terms are known, with those obtained from a Rydberg formula from the first two terms, Russell[3] finds that in the case of the neutral elements of the iron group the limit obtained from a Rydberg formula is higher than that obtained from a Ritz formula and that a fair correction may be made to the former by assuming a percentage error of $4.5\times 10^{-5}\times$ length of series.

In the case of the ionized elements he shows that the computed percentage error

$$0.25\times 4.5\times 10^{-5}\times \text{length of series}$$

is in good agreement with the actual error for Ca II and Zn II to which elements the Ritz formula is applicable.

[1] H. N. Russell, Astrophys. J. **64**, 194 (1926).

[2] Bacher and Goudsmit, *Atomic Energy States*, page 544.

[3] H. N. Russell, Astrophys. J. **66**, 233 (1927).

TABLE I.

		$e^6D_{4\frac{1}{2}}$ 77861.4	376.2	$e^6D_{3\frac{1}{2}}$ 78237.6	287.7	$e^6D_{2\frac{1}{2}}$ 78525.3	200.3	$e^6D_{1\frac{1}{2}}$ 78725.6	118.3	$e^6D_{\frac{1}{2}}$ 78843.9
$z^6F^\circ_{5\frac{1}{2}}$	41968.08	2785.21(15) 35893.3 (3.4)								
$z^6F^\circ_{4\frac{1}{2}}$	42114.86	2796.65(7) 35746.6 (6.6)		2767.52(20)[a] 36123.0 (2.7)						
$z^6F^\circ_{3\frac{1}{2}}$	42237.06	—		2776.92(8) 36000.4 (0.5)		2754.90(10) 36288.0 (8.2)				
$z^6F^\circ_{2\frac{1}{2}}$	42334.86			2784.48(2) 35902.8 (2.7)		2762.35(7) 36190.6 (0.5)		2747.14(6) 36390.8 (0.7)		
$z^6F^\circ_{1\frac{1}{2}}$	42401.33					—		2752.17(7) 36324.1 (4.3)		—[b]
$z^6F^\circ_{\frac{1}{2}}$	42439.87							2755.09(0) 36285.5 (5.7)		2746.14(4) 36403.8 (4.1)
$z^6D^\circ_{4\frac{1}{2}}$	38459.02	2537.15(8)[c] 39402.6 (2.4)		2513.16(3) 39778.6 (8.6)						
$z^6D^\circ_{3\frac{1}{2}}$	38660.06	2550.16(5) 39201.5 (1.4)		2525.93(6) 39577.5 (7.5)		2507.69(3) 39865.3 (5.2)				
$z^6D^\circ_{2\frac{1}{2}}$	38858.99			2538.69(4) 39378.7 (8.6)		2520.27(3) 39666.3 (6.3)		2507.61(5) 39866.8 (6.6)		
$z^6D^\circ_{1\frac{1}{2}}$	39013.23					2530.11(10) 39512.3 (2.1)		—		2509.87(4) 39830.7 (0.7)
$z^6D^\circ_{\frac{1}{2}}$	39109.33							2523.46(3) 39616.4 (6.3)		2515.94(1) 39734.8 (4.6)
$z^6P^\circ_{3\frac{1}{2}}$	42658.26	2839.82(10) 35203.1 (3.2)		2809.79(8) 35579.2 (9.3)		2787.25(5) 35866.9 (7.0)				
$z^6P^\circ_{2\frac{1}{2}}$	43238.61			2856.40(8) 34999.0 (9.0)		2833.10(8) 35286.7 (6.7)		2817.11(6) 35487.0 (7.0)		
$z^6P^\circ_{1\frac{1}{2}}$	43620.98					2864.13(5) 34904.3 (4.3)		2847.79(6) 35104.6 (4.6)		2838.22(8) 35222.8 (3.0)

[a] A blend. [b] Covered by the Fe II line 2743.196. [c] Very diffuse core line slightly enhanced.

Applying this correction, therefore, to the value 132,441.9 found above for the series limit in the case of the quartets, we obtain for the corrected limit the value 130,698.

The length of the series now becomes

$$130{,}698 - 7955 = 122{,}743,$$

which value represents the energy (15.14 volts) required to remove an s electron from the $d^{n-2}s\ a^4D_{3\frac{1}{2}}$ state or 16.12 from the ground state $a^6D_{4\frac{1}{2}}$.

TABLE II.

		$e^4D_{3\frac{1}{2}}$ 79439.3	446.1	$e^4D_{2\frac{1}{2}}$ 79885.4	292.5	$e^4D_{1\frac{1}{2}}$ 80177.9	168.1	$e^4D_{\frac{1}{2}}$ 80346.0
$z^4F^\circ_{4\frac{1}{2}}$	44232.55	2839.53(12) 35206.6 (6.7)						
$z^4F^\circ_{3\frac{1}{2}}$	44753.83	—		2845.61(15)[a] 35131.6 (1.6)				
$z^4F^\circ_{2\frac{1}{2}}$	45079.87	—		—		2848.33(8) 35098.0 (8.0)		
$z^4F^\circ_{1\frac{1}{2}}$	45289.86			—		2865.47(3) 34888.1 (8.0)		2851.73(10)[b] 35056.1 (6.1)
$z^4D^\circ_{3\frac{1}{2}}$	44446.91	2856.93(9) 34992.3 (2.4)		—				
$z^4D^\circ_{2\frac{1}{2}}$	44784.80	2884.78(7) 34654.5 (4.5)		2848.12(8) 35100.5 (0.6)		2824.58(2) 35393.0 (3.1)		
$z^4D^\circ_{1\frac{1}{2}}$	45044.23			—		2845.44(7) 35133.6 (3.7)		2831.89(3) 35301.8 (1.8)
$z^4D^\circ_{\frac{1}{2}}$	45206.55					2858.65(5) 34971.5 (1.4)		2844.97(6) 35139.4 (9.4)
$z^4P^\circ_{2\frac{1}{2}}$	46967.52	3078.71(9) 32471.9 (1.8)		3036.98(7) 32917.8 (7.9)		3010.23(3) 33210.5 (0.4)		
$z^4P^\circ_{1\frac{1}{2}}$	47389.88			3076.46(8) 32495.5 (5.5)		3049.01(7) 32787.9 (8.0)		3033.46(3) 32956.2 (6.1)
$z^4P^\circ_{\frac{1}{2}}$	47626.18					3071.14(5) 32551.7 (1.7)		3055.37(8) 32719.7 (9.8)

[a] Blended with the Fe I line 2845.595.

[b] Blended with the Fe I line 2851.797.

In the case of the sextet series, the empirically corrected length of series becomes 131,259 representing an ionization potential of 16.19 volts.

The mean of these, 16.16 volts, may be adopted as the "principal ionization potential" which represents the difference in energy between the normal states of the Fe II and of the Fe III atom.

The values 16.19 volts for the sextet series and 15.14 volts for the quartet series are in excellent agreement with the values 16.15 volts and 15.12 volts found by Russell[3] from the empirical formulae

$$C=0.601Z+0.13M$$

and

$$D=0.601Z-0.13M,$$

where C and D represent the second ionization potentials of the atoms of the iron group obtained by the removal of an s electron from the $d^{n-2}s$ state for higher and lower multiplicities, respectively. In these formulae Z is the atomic number of the neutral element and M the magnetic moment of the incomplete shell of d electrons, which increases from a single magneton in Sc II to five in Mn II and then diminishes to one in Cu II.