DECEMBER 1, 1934 PHYSICAL REVIEW VOLUME 46

The Spectrum and Ionization Potential of Radium

HENRY NORRIS RUSSELL, *Carnegie Institution of Washington, Mount Wilson Observatory*

(Received October 15, 1934)

A new interpretation of the connection between the two groups of terms in Ra I found by Rasmussen is suggested and confirmed by new observations which he has courteously communicated. Certain term-designations are altered. The first ionization potential is 5.252 volts.

RASMUSSEN, in his admirable analysis of the arc spectrum of radium[1] has conclusively identified two groups of lines—one resulting from transitions from ^3D and ^1D terms to higher odd levels and the other from $^3P^0$ and $^1P^0$ to higher even levels and the ground-term $^1S_0$. Absolute term-values for the first group are well determined from a series of four $^3F^0$ terms. The only series available in the other consists of two ^3S terms, and gives but a rough limit. Connection between the two groups should occur through the ultraviolet line λ3101.80 which must arise from the ^1S level. Rasmussen assigns this as $1^1S_1-3^1P_1$.[2] The combination $3^1D_2-3^1P_1$ should lie in the red and he adopts the strongest unclassified line at 6336.90. All terms are thus referred to an accurately known limit, giving $1^1S_0=41{,}949.19$ and 5.176 volts for the ionization potential: but this arrangement is not confirmed by any other combinations. An independent determination of the term-values for the P^0 terms and those which combine with them may be made by combining the low ^1S and the two higher ^3S terms in a single series. This apparently crazy method—first suggested to the writer some time ago by Professor A. G. Shenstone in connection with another spectrum—works very well, as is illustrated by Table I which gives the Rydberg denominators n^* for the other alkaline earths.

TABLE I. *Rydberg denominators for alkaline earths.*

Term	1^1S_0		2^3S_1		3^3S_1
Element	n^*	Δn^*	n^*	Δn^*	n^*
Be	1.208	0.971	2.179	1.026	3.205
Mg	1.334	0.981	2.315	1.031	3.346
Ca	1.492	0.993	2.485	1.040	3.525
Sr	1.546	1.003	2.549	1.044	3.593
Ba	1.616	1.014	2.630	1.045	3.675
Ra(est.)		1.025 ± 0.005		1.050 ± 0.003	
Ra(obs.)	1.605	1.028	2.633	1.047	3.680

The progression of these values is very regular and leads to the estimates for Ra I given in the corresponding line. The estimated tolerances represent the probable limit of error provided that the progression remains regular. The "observed" values are discussed below. With Rasmussen's value $^1S_0=41{,}950$ the values of Δn^* come out 1.070 ($^1S-{}^3S$) and 1.145 ($^3S-{}^3S$). Increasing the assumed limit by 500 reduces these to 1.036 and 1.066; by 200 more, to 1.024 and 1.036. The two estimated values of Δn^* for Ra I therefore require the additions of 683±80 and 606±20 to Rasmussen's limit,—or, in the mean, 630±30. With the new value of $^1S_0$, the term which combines with it to give λ3101 comes out 10,350±30.

Now Rasmussen has already identified a level $dp^3D_1{}^0$ at 10,347.38. The corresponding level in Ba I combines strongly with $^1S_0$, and it appears very probable that the radium line is homologous. Upon communicating this suggestion to Dr. Rasmussen the writer received a cordial letter stating he had found upon his plates another ultraviolet line which confirms the new arrangement; λ2955.65, intensity 2. As the further investigation upon this spectrum, which he plans, may take some time, he generously suggested that this evidence should be presented in the present paper. The new combination, together with some others whose interpretation has been altered, are exhibited in Table II. The intensities are given before the wave numbers, and the differences of the observed and computed values below. It is evident that the true connection between the two parts of the spectrum has been found. Retaining Rasmussen's values for the

---

[1] Rasmussen, Zeits. f. Physik **87**, 607 (1934).

[2] These serial numbers are "Laufzahlen" beginning with 1, 2, 3, 4 for the *S*, *P*, *D* and *F* series. They are retained here for comparison with Rasmussen's tables.

TABLE II. *Term values in Ra I.*

		3^1D_2 25495.95	3^3D_3 27870.00	3^3D_2 28583.38	3^3D_1 28861.50	1^1S_0 42577.35
$dp^3D_1{}^0$	10347.38	(3) 15148.55 -0.02		(8) 18236.03 $+0.03$	(10) 18514.07 -0.05	(6) 32230.02 $+0.05$
$dp^3P_2{}^0$	8194.44	(5) 17301.40 -0.11	(6) 19675.58 $+0.02$	(4) 20389.00 $+0.06$	(3) 20667.06 0.00	
$^3P_1{}^0$	8753.65			(5) 19829.62 -0.11	(5) 20107.96 $+0.11$	(2) 33823.65 -0.05
$^3P_0{}^0$	8794.94				(4) 20066.56 (0.00)	

first set (3^3D, etc.) those of his second set (given in his Table IV) should be increased by 627.66. The corresponding values of n^* for the S terms are given in the last line of Table I.

The ionization potential corresponding to the new data is *5.252 volts.*

The adoption of the term $dp^3P_1{}^0$, as here given, accounts for the unclassified line at λ4982 ($^3D_1-{}^3P_0$) and removes from the list Rasmussen's doubtful level at 5431.68 combining with 2^3P^0. His levels at 10,702.91 and 11,014.06 may then be interpreted as $3^3P_2{}^0$ and $3^3P_1{}^0$. The isolated line at λ5755.45 ($\nu=17{,}370.03$) then gives $3^3P_0{}^0=11{,}491.47$. This interpretation differs from Rasmussen's mainly in the choice between alternatives which he mentioned as possible. It puts dp^3P^0 higher than dp^3D^0, as in the case of Ca, Sr and Ba, and 3^3P^0 between dp^3F^0 and dp^3D^0, as is true in Ca and Sr (but not in Ba, where the limits of the normal and displaced series are closer together). Apart from some effects of this difference, the similarity of the spectra of the alkaline earths is remarkably detailed. For example, dp^1D^0 is superposed on dp^3F^0 in all four spectra, and the separation $dp(^3P_1{}^0-{}^3P_0{}^0)$ is abnormally small in every case.

Some revision of the assignments of the high level even terms appears also to be desirable. Table III gives the new and old term-values and designations. The slight inversion of 4^3D_1 appears preferable to the very large interval demanded by the old assignment. The outstanding levels are attributed to the p^2, rather than the d^2, configuration, since the former is lower in Ca and Sr (which resemble Ra more closely than Ba does). Which of the last two levels is $^3P_2$ is doubtful: the present assignment assumes that the difference $^3P_2-{}^3P_1$ is likely to be large. Further identifications must be postponed till the fainter lines have been more fully observed.

TABLE III. *Term values and designations.*

Old		New	
2^3P_0 2^3P_1 2^3P_2	28,871.25 27,950.31 25,261.15	$2^3P_0{}^0$ $2^3P_1{}^0$ $2^3P_2{}^0$	29,498.91 28,577.97 25,888.81
2^1P_1	21,233.98	$2^1P_1{}^0$	21,861.64
dd^3P_1 4^3D_2 4^3D_3	9948.87 9956.28 9752.41	4^3D_1 4^3D_2 4^3D_3	10,576.53 10,583.94 10,380.07
4^3D_1	10,701.08 9008.56 9734.85	$p^2\,{}^3P_1$ $p^2\,{}^3P_2$ $p^2\,{}^1D_2$	11,328.74 9636.22 10,362.51

In conclusion, the writer desires to express his hearty thanks to Dr. Rasmussen for his generous communication of the new data and his permission to refer to them here.