strong fields are created therein To assume that electronic conduction must exist in the whole volume of the molded dielectric[7] does not have satisfactory grounds in our opinion, because such an assumption is found to be in contradiction with experimental data.

Translated by D. Lieberman
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SOVIET PHYSICS JETP VOLUME 2, NUMBER 2 MARCH, 1956

Investigation of the Isotope Effect in the Uranium Spectrum

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(Submitted to JETP editor May 10, 1955)
J. Exper. Theoret. Phys. USSR 29, 393-405 (October, 1955)

The isotope shift in the spectrum of uranium has been measured for 346 lines among the components of the isotopes U^{238} and U^{235}. The regularities obtained in the isotope shift have been employed for the extension of the classification of the uranium spectrum and for the establishment of the isotope shift in several terms of U I and U II.

Starting from the shift of the terms $5f^4\,7s^6\,I_{9/2}$ and $5f^3\,7s^2\,{}^4I_{9/2}$, it is found that the lowest electron configuration for U II is $5f^4 7s$.

THE isotope effect in the spectrum of uranium was first discovered by Anderson and White[1] and was later studied by a number of other investigators[2-4], including ourselves. As the problem of the present research, which was carried out in 1951, a much more complete investigation was conducted of the isotope shift in the lines of uranium, with the aim of establishing the dependence of the isotope shift on the electron configuration and the determination of the shift in the terms. It was also desirable to establish the presence of even-odd shift, which had not yet been observed in the uranium spectrum at that time.The results of these investigations are given below.

1. EXPERIMENTAL PART

Three spectrographs were used for the investigation of the isotope shift in the spectrum of uranium. The spectral region 2300-2700 A was obtained with the help of a large Hilger quartz spectrograph whose dispersion in this region ranged from 2.3 to 3.1 A/mm. The interval 3900-4400 A was spectrographed by means of a Zeiss three prism glass spectrometer with an autocollimating chamber $f = 1300$ mm. The dispersion of this apparatus in the given region varied from 1.3 to 2.6 A/mm. The intervals 2700-3900 A and 4400-6600 A were obtained with a Baird diffraction spectrograph with a concave grating of radius of curvature 3 m, with 600 lines/mm. Some parts of these intervals were spectrographed in second order (dispersion 2.6 A/mm) and some in third order (dispersion 1.8 A/mm).

An arc of variable current between graphite electrodes was used as an excitation source. The arc was fed by a generator DG-1. The current strength was 5 A.

In the investigations we used samples of enriched uranium which represented a mixture of two isotopes, U^{238} and U^{235}, and also samples of a three isotope mixture, U^{238}, U^{235}, U^{233}, or U^{238}, U^{235}, U^{234}. In addition to the spectra of these samples, we recorded the spectra of natural uranium and of iron. For a survey of the spectra of uranium from mixed oxides, we prepared aqueous solutions of uranium nitrate from a calculation of 0.06 cm^3 of distilled water per milligram of salt. This sample, in the form of an aqueous solution, was applied on the tips of the upper and lower graphite electrodes (length 50 mm, diameter, 5 mm) and dried out on the slab. For the survey of each spectrum we used 2 milligrams of material, the time of

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[1] D. E. Anderson and H. E. White, Phys. Rev. 71, 911 (1947)

[2] L. E. Burkhart, G. L. Stukenbrocker and S. Adams, Phys. Rev. 75, 83 (1949)

[3] J. K. McNally, J. Opt. Soc. Am. 39, 271 (1949)

[4] D. D. Smith, G. L. Stukenbrocker and J. K. McNally, Phys. Rev. 84, 383 (1951)

exposure being 2-3 minutes. In the case of the diffracting spectrograph, third order spectrum, the sample was increased to 6 milligrams, which were applied to the two pairs of graphite electrodes. Each pair of electrodes was arranged in series and was employed for the survey of a single spectrum; the total exposure was increased to 14 minutes for certain regions of the spectrum.

The isotope shift in the uranium spectrum was determined by linear interpolation between two nearby lines of iron. The mean relative error was approximately ± 5%.

2. THE RELATION OF THE ISOTOPE SHIFT TO THE ELECTRON CONFIGURATIONS OF U I AND U II

Making use of the spectrum of the two isotope sample (U^{238} and U^{235}) with 50% of each isotope, we measured the isotope shift for 346 lines. It turned out that of all the lines measured, 301 had negative shift (the component of the lighter isotope shifted in the direction of higher wave number) and 45 lines had a positive shift. Of the 45 positive shifts, 34 were in the visible portion of the spectrum. Of the most sensitive lines of uranium, two spark lines, 4244.372 A, ($\Delta\lambda = 0.246$ A) and 4689.074 A, ($\Delta\lambda = 0.219$ A) underwent significant shifts.

TABLE I

Arc Lines of Uranium

Line wavelength in Angstroms	Classification of the line[5]	Intensity		Shift $\Delta(U^{238}-U^{235})$	
		Arc	Spark	A	cm^{-1}
3454.617	$5f^36d7s^2\ {}^5K^0_5\ -295_6$	10	—	−0.058	−0.48
3489.371	$5f^36d7s^2\ {}^5L^0_6\ -287_5$	20	1	−0.059	−0.48
3644.245	$5f^36d7s^2\ {}^5K^0_5\ -280_6$	18	2	−0.044	−0.33
3679.375	$5f^36d7s^2\ {}^5K^0_5\ -278_5$	2	—	−0.050	−0.37
3904.299	$5f^36d7s^2\ {}^5K^0_5\ -262_6$	8	15	−0.062	−0.40
3918.065	$5f^36d7s^2\ {}^5K^0_6\ -297_7$	3	—	−0.086	−0.56
3923.054	$5f^36d7s^2\ {}^5K^0_5\ -261_6$	15	6	+0.110	+0.71
4246.261	$5f^36d7s^2\ {}^5L^0_6\ -235_7$	30	2	−0.051	−0.28
4266.331	$5f^36d7s^2\ {}^5L^0_6\ -234_5$	15	—	−0.082	−0.46
5329 223	$5f^36d7s^2\ {}^5L^0_6\ -187_6$	10	1	−0.118	−0.42
6395.446	$5f^36d7s^2\ {}^5L^0_6\ -156_7$	100	—	+0.117	+0.29
6502.59	$5f^36d7s^2\ {}^5K^0_6\ -196_5$	15	—	−0.099	−0.24
		Average		−0.071*	−0.40*
4285.232	$5f^36d7s\ {}^7K^0_6\ -301_6$	10	1	−0.098	−0.54
5997.329	$5f^36d7s\ {}^7M^0_6\ -229_7$	25	—	+0.106	+0.30
6246.550	$5f^36d7s\ {}^7K^0_6\ -217_6$	6	—	−0.146	−0.37
		Average		−0.122*	−0.44*

* The average value of the shift is taken without regard to sign.

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[5] C. O. Kiss, C. Hymphreys and D. D. Laun, J. Res. Nat. Bur. Stand. **37**, 57 (1946)

TABLE II

Spark Lines of Uranium

Line wavelength in Angstroms	Classification of the line[6]	Intensity		Shift $\Delta(U^{238}-U^{235})$	
		Arc	Spark	A	cm^{-1}
2556.194	$5f^37s^2\ {}^4I^0_{9/2} - 391_{11/2}$	15	12	—0.081	—1.24
2865.679	$5f^37s^2\ {}^4I^0_{9/2} - 349_{11/2}$	30	50	—0.080	—0.98
2923.174	$5f^37s^2\ {}^4I^0_{9/2} - 342_{11/2}$	8	10	—0.071	—0.84
2962.207	$5f^37s^2\ {}^4I^0_{9/2} - 337_{11/2}$	6	4	—0.074	—0.85
3216.201	$5f^37s^2\ {}^4I^0_{9/2} - 311_{11/2}$	5	3	—0.109	—1.06
3325.658	$5f^37s^2\ {}^4I^0_{9/2} - 300_{11/2}$			—0.104	—0.94
3339.446	$5f^37s^2\ {}^4I^0_{9/2} - 299_{11/2}$	5	1	—0.059	—0.52
3399.958	$5f^37s^2\ {}^4I^0_{9/2} - 294_{11/2}$	6	3	—0.07	—0.60
3476.293	$5f^37s^2\ {}^4I^0_{9/2} - 287_{11/2}$	4	3	—0.126	—1.05
3497.067	$5f^37s^2\ {}^4I^0_{9/2} - 286_{11/2}$	3	3	—0.123	—1.00
3550.822	$5f^37s^2\ {}^4I^0_{9/2} - 281_{11/2}$	12	20	—0.072	—0.64
3654.294	$5f^37s^2\ {}^4I^0_{9/2} - 272_{11/2}$	3	4	—0.141	—1.05
3895.272	$5f^37s^2\ {}^4I^0_{11/2} - 301_{11/2}$	12	20	—0.145	—0.96
3899.097	$5f^37s^2\ {}^4I^0_{11/2} - 300_{11/2}$	5	3	—0.149	—0.98
3918.065	$5f^37s^2\ {}^4I^0_{11/2} - 299_{11/2}$	3	8	—0.086	—0.56
3933.030	$5f^37s^2\ {}^4I^0_{9/2} - 254_{9/2}$	5	10	—0.097	—0.62
3989.953	$5f^37s^2\ {}^4I^0_{11/2} - 294_{13/2}$	4	6	—0.145	—0.91
4033.427	$5f^37s^2\ {}^4I^0_{11/2} - 292_{11/2}$	12	10	—0.140	—0.86
4050.039	$5f^37s^2\ {}^4I^0_{9/2} - 247_{9/2}$	25	35	—0.107	—0.65
4062.549	$5f^37s^2\ {}^4I^0_{9/2} - 246_{11/2}$	12	18	—0.120	—0.72
4088.254	$5f^37s^2\ {}^4I^0_{9/2} - 244_{9/2}$	25	18	—0.186	—1.11
4106.931	$5f^37s^2\ {}^4I^0_{9/2} - 243_{7/2}$	25	10	—0.102	—0.61
4116.097	$5f^37s^2\ {}^4I^0_{9/2} - 243_{11/2}$	25	35	—0.173	—1.02
4244.372	$5f^37s^2\ {}^4I^0_{9/2} - 235_{11/2}$	25	25	—0.249	—1.38
4287.869	$5f^37s^2\ {}^4I^0_{9/2} - 233_{9/2}$	15	18	—0.141	—0.76
4301.470	$5f^37s^2\ {}^4I^0_{9/2} - 232_{11/2}$	15	15	—0.081	—0.44
4415.241	$5f^37s^2\ {}^4I^0_{9/2} - 226_{11/2}$	12	12	—0.200	—1.02
4510.320	$5f^37s^2\ {}^4I^0_{9/2} - 222_{9/2}$	20	30	—0.187	—0.92
4689.074	$5f^37s^2\ {}^4I^0_{9/2} - 213_{7/2}$	30	40	—0.219	—1.00
4755.729	$5f^37s^2\ {}^4I^0_{9/2} - 210_{7/2}$	8	15	—0.178	—0.79
4769.260	$5f^37s^2\ {}^4I^0_{9/2} - 209_{7/2}$	6	15	—0.178	—0.78
4819.544	$5f^37s^2\ {}^4I^0_{4/2} - 251_{13/2}$	12	12	—0.209	—0.90
4859.750	$5f^37s^2\ {}^4I^0_{9/2} - 205_{7/2}$	8	8	—0.207	—0.88

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[6] J. C. van den Bosch, Physica **15**, 503 (1949)

TABLE II (continued)

Line wavelength in Angstroms	Classification of the line[6]	Intensity		Shift $\Delta(U^{238}-U^{235})$	
		Arc	Spark	A	cm^{-1}
4933.657	$5f^37s^2$ $^4I^0_{11/2}-247_{9/2}$	8	8	—0.151	—0.62
5311.881	$5f^37s^2$ $^4I^0_{11/2}-232_{11/2}$	18	18	—0.113	—0.40
		Average		—0.135	—0.84
3222.293	$5f^36d7s$ $^4L^0_{13/2}-373_{13/2}$	8	3	—0.049	—0.47
3370.134	$5f^36d7s$ $^6L^0_{15/2}-349_{13/2}$	6	4	—0.053	—0.47
3496.415	$5f^36d7s$ $^6L^0_{13/2}-303_{15/2}$	8	15	—0.059	—0.48
3826.514	$5f^36d7s$ $^6L^0_{11/2}-264_{13/2}$			—0.06	—0.41
3890.364	$5f^36d7s$ $^6L^0_{11/2}-260_{13/2}$	35	30	—0.055	—0.35
3978.159	$5f^36d7s$ $^6L^0_{13/2}-269_{11/2}$	4	—	—0.151	—0.95
3985.795	$5f^36d7s$ $^6L^0_{15/2}-303_{15/2}$	25	30	—0.089	—0.56
4004.063	$5f^36d7s$ $^6L^0_{13/2}-267_{13/2}$	15	20	—0.082	—0.51
4234.688	$5f^36d7s$ $^4L^0_{13/2}-253_{11/2}$	10	8	—0.114	—0.63
4297.112	$5f^36d7s$ $^6L^0_{11/2}-235_{11/2}$	18	18	—0.121	—0.66
4553.858	$5f^36d7s$ $^6K^0_{9/2}-228_{9/2}$	4	1	—0.085	—0.41
4584.847	$5f^36d7s$ $^6L^0_{13/2}-235_{11/2}$	10	15	—0.109	—0.52
4651.546	$5f^36d7s$ $^6L^0_{13/2}-232_{11/2}$			+0.096	+0.42
4702.517	$5f^36d7s$ $^6K^0_{11/2}-235_{11/2}$	10	20	—0.112	—0.50
4772.701	$5f^36d7s$ $^6K^0_{11/2}-232_{11/2}$	6	18	+0.077	+0.33
5247.352	$5f^36d7s$ $^6I^0_{7/2}-244_{9/2}$	6	6	—0.118	—0.43
5321.605	$5f^36d7s$ $^6H^0_{7/2}-244_{9/2}$	6	3	—0.099	—0.35
5400.951	$5f^36d7s$ $^6I^0_{7/2}-239_{9/2}$	10	6	—0.107	—0.36
5551.441	$5f^36d7s$ $^6I^0_{9/2}-244_{9/2}$	8	5	—0.133	—0.43
5581.610	$5f^36d7s$ $^6L^0_{11/2}-182_{9/2}$	12	5	+0.230	+0.74
5723.632	$5f^36d7s\begin{cases}{}^6I^0_{9/2}-239_{9/2}\\ {}^6I^0_{7/2}-228_{9/2}\end{cases}$	15	1	—0.159	—0.49
5843.294	$5f^36d7s$ $^6I^0_{9/2}-235_{11/2}$	3	—	—0.200	—0.58
5952.053	$5f^36d7s$ $^6I^0_{9/2}-232_{11/2}$	3	—	+0.121	+0.35
6087.338	$5f^36d7s$ $^6I^0_{9/2}-228_{9/2}$	10	—	—0.227	—0.61
		Average		—0.114*	-0.51*
3924.272	$5f^36d^2$ $^6M^0_{13/2}-300_{11/2}$	15	15	+0.059	+0.38
3943.498	$5f^36d^2$ $^6M^0_{13/2}-299_{11/2}$	6	10	+0.124	+0.8
4241.669	$5f^36d^2$ $^6M^0_{13/2}-281_{11/2}$	40	50	+0.069	+0.38
4992.940	$5f^36d^2$ $^6M^0_{13/2}-246_{11/2}$	4	4	+0.138	+0.55

TABLE II (continued)

Line wavelength in Angstroms	Classification of the line[6]	Intensity		Shift $\Delta(U^{238}-U^{235})$	
		Arc	Spark	A	cm^{-1}
5405.996	$5f^36d^2\ {}^6M^0_{15/2}\ —269_{15/2}$	5	6	+0.152	+0.52
5837.707	$5f^36d^2\ {}^6M^0_{13/2}\ —217_{13/2}$	30	1	+0.145	+0.42
		Average		+0.114	+0.51
3605.823	$5f^47s\ {}^6I_{9/2}\ —287^0_{11/2}$	8	8	—0.136	—1.05
3904.299	$5f^47s\ {}^6I_{11/2}\ —299^0_{11/2}$	8	15	—0.062	—0.40
3951.553	$5f^47s\ {}^4I_{9/2}\ —290^0_?$	1	8	—0.106	—0.67
3992.539	$5f^47s\ {}^4I_{9/2}\ —260^0_{9/2}$	10	8	—0.149	—0.93
		Average		—0.113	—0.76
5480.275	$5f^46d\ {}^6L_{11/2}\ —260^0_{9/2}$	15	25	+0.115	+0.38
5527.848	$5f^46d\ {}^6L_{11/2}\ —259^0_{9/2}$	25	40	+0.107	+0.35
6181.369	$5f^46d\ {}^6K_{9/2}\ —277^0_{7/2}$	2	—	+0.214	+0.56
		Average		+0.145	+0.43

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* The average value of the shift is taken without regard to sign.

The isotope shift for the classified lines of UI and U II, which are subdivided into groups according to the electron configurations of the lower term, are given in Tables I and II. It should be noted that the electron configurations of the higher terms have not yet been established. Therefore, these terms are denoted by the first three digits of their calculated value in cm^{-1} and the small interlinear number is their internal quantum number. The isotope shift for the unclassified lines is given in the separate table in the Appendix.

The average, maximum and minimum shift in the uranium lines for each electron configuration of the lowest term is given in Table III. The mean shift for all lines of the ionized atom amounts to 0.67 cm^{-1}, while the mean shift for the lines of the neutral atom amounts to 0.41 cm^{-1}. An especially large difference is observed for lines which refer to the terms of the lowest electron configuration of UII ($5f^3 7s^2$, $5f^4 7s$) and of UI ($5f^3 6d 7s^2$). The mean values of the shift of the lines of the two electron configurations

TABLE III

State of the atom and electron configuration of the lower term	$\Delta\nu\ (U^{238} - U^{235})$ in cm^{-1}		
	Mean	Maximum	Minimum
UI $5f^36d7s^2$	—0.40	—0.56	—0.24
UI $5f^36d^27s$	—0.44	—0.54	—0.37
UII $5f^37s^2$	—0.84	—1.37	—0.40
UII $5f^36d7s$	—0.51	—0.95	—0.35
UII $5f^36d^2$	+0.51	+0.80	+0.38
UII $5f^47s$	—0.76	—1.05	—0.40
UII $5f^46d$	+0.43	+0.56	+0.35

for U I ($5f^3 6d 7s^2$, $5f^3 6d^2 7s$) differ slightly from one another. The great majority of the lines connected with the two configurations have negative shift, and only three lines have a positive shift. The group of lines in U II which are related to the lowest configuration $5f^3 7s^2$ in system B with penetrating s^2 electrons undergo a very large average shift, equal to 0.84 cm^{-1}, while the shift for all the lines is directed one way, without exception. In system A the lines of the lowest configuration $5f^4 7s$ with a single penetrating s electron also have a large mean shift, equal to 0.76 cm^{-1}. All the lines of this configuration have a negative shift. The lines of the higher configurations ($5f^3 6d 7s$, $5f^3 6d^2$, $5f^4 6d$) of both systems, including the non penetrating d electron, have smaller and approximately uniform shift. The overwhelming majority of lines belonging to the configuration $5f^3 6d 7s$ have a negative shift and only four lines have a positive shift. All the lines of the two other higher configurations $5f^3 6d^2$ and $5f^4 6d$ with non penetrating d and f electrons have positive shifts.

These regularities in the isotope shift can serve for the further extension of the classification of the uranium spectrum. It is evident from the Table that all the lines of uranium with negative shift exceeding 0.56 cm^{-1} in absolute value belong to lines of the ionized atom. Furthermore, the lines with negative shift exceeding 1.05 cm^{-1} belong to the electron configuration $5f^3 7s^2$. Lines with negative shift which lie in the interval from 0.95 cm^{-1} to 1.05 cm^{-1} belong to one of the two lowest configurations $5f^3 7s^2$, $5f^4 7s$. Lines which undergo a positive shift belong generally to the two electron configurations $5f^3 6d^2$ and $5f^4 6d$ of the ionized atom, while those of them which have a positive shift greater than 0.56 cm^{-1} belong to the configuration $5f^3 6d^2$.

On the basis of the isotope shift we have once again established the connection of 220 lines to the ionized atom and have also determined the electron configuration of the lowest term for 153 transitions. These results are given in a Table (see Appendix), where the lines analyzed are designated in the fourth column either by the single symbol II (which denotes that the line belongs to the ion) or by this symbol and the electron configuration to which the lowest term of the given line belongs. It should be noted, however, that excitation in the levels has not been taken into account in establishing electron configurations by this method, so that errors are possible.

3. ISOTOPE SHIFT IN THE TERMS

Relying on the extensive experimental material on the isotope shift in the uranium spectrum, we have succeeded in determining the isotope shift

TABLE IV

Isotope Shift of the Terms of U I

Electron configuration and term[5]	Shift ΔT (U^{238}—U^{235}) in cm^{-1}	Initial term	Electron configuration and term [5]	Shift ΔT (U^{238}—U^{235}) in cm^{-1}	Initial term
$5f^3 6d 7s^2$ $^5L^0_6$	0.48	287_5	234_5	0.02	287_5
$5f^3 6d 7s^2$ $^5K^0_5$	0.48	295_6	235_7	0.20	287_5
$5f^3 6d 7s^2$ $^5K^0_6$	0.56	297_7	261_6	1.19	295_6
$5f^3 6d^2 7s$ $^7K^0_6$	0.54	301_6	262_6	0.08	295_6
$5f^3 6d^2 7s$ $^7M^0_6$	$\simeq$0.5	—	278_5	0.11	295_6
156_7	0.77	287_5	280_6	0.15	295_6
187_6	0.06	287_5	287_5	0	
196_5	0.32	297_7	295_6	0	
217_6	0.17	301_6	297_7	0	
229_7	$\simeq$0.8	$^7M^0_6$	301_6	0	

TABLE V

Isotope Shift of the Terms of U II

Electron configuration and terms [6]	Shift $\Delta T(U^{238}-U^{235})$ in cm^{-1}	Initial term	Electron configuration and terms [6]	Shift $\Delta T(U^{238}-U^{235})$ in cm^{-1}	Initial term
System *A*					
$5f^47s$ $^6I_{9/2}$	1.31	$^6L_{11/2}$	$260^0_{9/2}$	0.38	$^6L_{11/2}$
$5f^46d$ $^6K_{9/2}$	0		$277^0_{7/2}$	0.56	$^6K_{9/2}$
$5f^46d$ $^6L_{11/2}$	0		$287^0_{11/2}$	0.26	$^6L_{11/2}$
$259_{9/2}$	0.35	$^6L_{11/2}$	$290^0_?$	0.64	$^6L_{11/2}$
System *B*					
$5f^37s^2$ $^4I^0_{9/2}$	1.30	$^6M^0_{13/2}$	$244_{9/2}$	0.44	$^6M^0_{13/2}$
$5f^37s^2$ $^4I^0_{11/2}$	1.30	$^6M^0_{13/2}$	$246_{11/2}$	0.57	$^6M^0_{13/2}$
$5f^36d7s$ $^6I^0_{7/2}$	0.57	$^6M^0_{13/2}$	$247_{9/2}$	0.67	$^6M^0_{13/2}$
$5f^36d7s$ $^6I^0_{9/2}$	0.51	$^6M^0_{13/2}$	$251_{13/2}$	0.40	$^6M^0_{13/2}$
$5f^36d7s$ $^6K^0_{9/2}$	0.49	$^6M^0_{13/2}$	$254_{9/2}$	0.68	$^6M^0_{13/2}$
$5f^36d7s$ $^6K^0_{11/2}$	0.48	$^6M^0_{13/2}$	$260_{13/2}$	0.24	$^6M^0_{13/2}$
$5f^36d7s$ $^6K^0_{13/2}$	>0.35	$325_{13/2}$	$264_{13/2}$	0.18	$^6M^0_{13/2}$
$5f^36d7s$ $^6L^0_{11/2}$	0.59	$^6M^0_{13/2}$	$267_{13/2}$	—0.06	$^6M^0_{13/2}$
$5f^36d7s$ $^6L^0_{13/2}$	0.46	$^6M^0_{13/2}$	$269_{11/2}$	—0.50	$^6M^0_{13/2}$
$5f^36d7s$ $^6L^0_{15/2}$	0.53	$^6M^0_{13/2}$	$269_{15/2}$	0.52	$^6M^0_{15/2}$
$5f^36d7s$ $^6H^0_{7/2}$	0.49	$^6M^0_{13/2}$	$272_{11/2}$	0.25	$^6M^0_{13/2}$
$5f^36d^2$ $^6M^0_{13/2}$	0		$281_{11/2}$	0.38?	$^6M^0_{13/2}$
$5f^36d^2$ $^6M^0_{15/2}$	0		$286_{11/2}$	0.30	$^6M^0_{13/2}$
$182_{9/2}$	1.33	$^6M^0_{13/2}$	$287_{9/2}$	0.69	$^6M^0_{13/2}$
$205_{7/2}$	0.42	$^6M^0_{13/2}$	$287_{11/2}$	0.25	$^6M^0_{13/2}$
$209_{7/2}$	0.52	$^6M^0_{13/2}$	$292_{11/2}$	0.44	$^6M^0_{13/2}$
$210_{7/2}$	0.51	$^6M^0_{13/2}$	$294_{11/2}$	0.70	$^6M^0_{13/2}$
$213_{7/2}$	0.30	$^6M^0_{13/2}$	$294_{13/2}$	0.33	$^6M^0_{13/2}$
$217_{13/2}$	0.42	$^6M^0_{13/2}$	$299_{11/2}$	0.77	$^6M^0_{13/2}$
$222_{9/2}$	0.38	$^6M^0_{13/2}$	$300_{11/2}$	0.35	$^6M^0_{13/2}$
$226_{11/2}$	0.28	$^6M^0_{13/2}$	$301_{11/2}$	0.34	$^6M^0_{13/2}$
$228_{9/2}$	0.08	$^6M^0_{13/2}$	$303_{15/2}$	—0.03	$^6M^0_{13/2}$
$232_{11/2}$	0.86	$^6M^0_{13/2}$	$311_{11/2}$	0.24	$^6M^0_{13/2}$
$233_{9/2}$	0.54	$^6M^0_{13/2}$	$337_{11/2}$	0.45	$^6M^0_{13/2}$
$235_{11/2}$	—0.07	$^6M^0_{13/2}$	$342_{11/2}$	0.46	$^6M^0_{13/2}$
$239_{9/2}$	0.21	$^6M^0_{13/2}$	$349_{11/2}$	0.32	$^6M^0_{13/2}$
$243_{7/2}$	0.69	$^6M^0_{13/2}$	$349_{13/2}$	0.06	$^6M^0_{13/2}$
$243_{11/2}$	0.28	$^6M^0_{13/2}$	$391_{11/2}$	0.06	$^6M^0_{13/2}$

in the terms. The so-called initial terms were selected for this purpose. These terms take part in transitions in the case of certain spectral lines, but are known not to undergo isotope shift, or to undergo a shift which is small and, for all practical purposes, equal to zero. The isotope shift of the other term is completely determined in this case by the shift in the line. The relative shifts for the other terms have been found for other lines with measured isotope shift and with a known shift of one term, connected with this line. In order to obtain the correct sign, use is made of the relation

$$\Delta \nu = \Delta T_h - \Delta T_l$$

where $\Delta \nu$ is the shift in the line, ΔT_h and ΔT_l are the shifts in the higher and lower terms.

For initial terms among the arc lines, we used the highest part of the upper terms: 287_5, 295_6, 297_7, 301_6. The normalized results are given in Table IV, where the isotope shift for 20 terms of the neutral uranium atom are listed. For the spark spectra, ${}^6K_{9/2}$, ${}^6L_{11/2}$ were taken for the initial terms in system A and ${}^6M^0_{13/2}$, ${}^6M^0_{15/2}$ in system B. These terms do not undergo any noticeable isotope shift since they belong to the electron configurations $5f^4 6d$ and $5f^3 6d^2$, in which penetrating s electrons are absent. The isotope shift for 64 terms of single ionized uranium is listed in Table V. The isotope shift in the terms is established most reliably for the system B in U II.

TABLE VI

Isotope Shift for the Line 4244.372 A

Isotope	Our results		Reference 3		Reference 4	
	Δλ(Å)	Δν (cm^{-1})	Δλ (Å)	Δν (cm^{-1})	Δν (Å)	Δν (cm^{-1})
U^{238}	0.000	0.00	0.000	0.00	0.000	0.00
U^{236}	—	—	—	—	0.147	0.82
U^{235}	0.246	1.37	0.248	1.37	0.251	1·39
U^{234}	0.303	1.69	—	—	0.298	1.66
U^{233}	0.386	2.15	0.373	2.07	0.396	2·20

TABLE VII

Isotope Shift Per Unit Mass

wavelength of line in Angstroms	Δν (U^{238}—U^{235}) in cm^{-1}	Δν (U^{235}—U^{233}) in cm^{-1}	wavelength of line in Angstroms	Δν (U^{238}—U^{235}) in cm^{-1}	Δν(U^{235}—U^{233}) in cm^{-1}
3895.272	0·32	0.23	4088.254	0.37	0.41
3899.097	0.33	0·24	4225.369	0.39	0.36
3906.525	0·28	0.24	4231·676	0.26	0.22
3911.673	0.39	0.34	4234.688	0.21	0.38
3919.719	0·36	0·35	4244.372	0·46	0.38
3221.550	0.24	0.25	4252.426	0·29	0.22
3947·959	0.36	0·31	4261.505	0·36	0.28
3988·644	0.29	0.26	4422.984	0.40	0.32
4023·170	0·40	0·43			

A comparison of the lowest terms of U I and U II which belong to configurations with s^2 electrons ($5f^3 6d 7s^2$ and $5f^3 7s^2$), show that the isotope shift in the terms of the ionized atom is about 2.5 times larger than in the terms of the neutral atom. The largest shift in the limits of the system B is undergone by the term which belongs to the configuration with penetrating s^2 electrons. In comparison with these, the terms of configurations with a single s electron have about 2.5 times smaller shift. Most of the terms undergo a positive shift. This demonstrates that the term of the lighter isotope lies lower than the term of the heavier one.

It should be noted that, on the basis of these results, it is possible to establish a quantitative connection between the systems of terms A and B of the ionized atom. Actually, inasmuch as one of the lowest terms of the system A $(5f^4 7s\, {}^6I_{9/2})$ in the presence of a single s electron, undergoes the same isotope shift as does the lowest term of the system B $(5f^3 7s^2\, {}^4I_{9/2})$ with two s electrons, then, in accord with the data of Schurmans[7], we can regard the lowest electron configuration to be $5f^4 7s$. Hence, the ground state for U II is $5f^4 7s\, {}^6I_{7/2}$.

It must be noted that the magnitude of the isotope shift of the higher terms of uranium fluctuates widely, reaching comparatively large and comparatively small values. Furthermore, in system B of U II, there are 4 terms with negative shift for which the levels of the lighter isotope are higher. The difference in the shift of the higher term is by itself not unexpected. It is explained by the connection of the terms with different types of electron configurations and by the decrease in the shift with increasing principal quantum number n. However, to the anomalies in the form of very large or very small shift in the neighboring terms, and also their inverse distribution one must add the interaction of the close lying levels, of a similar quantum nature. This interaction reduces to the excitation of terms which have a significant effect on the magnitude of the shift, decreasing or increasing the purely isotope shift. By way of an example of strongly excited levels, we have the higher terms of U I: 156_7, 229_7, 261_6, 262_6 and of U II: $182_{9/2}$, $228_{9/2}$, $233_{9/2}$, $232_{11/2}$, $235_{11/2}$, $269_{11/2}$, $272_{11/2}$. Evidently, all the cases of positive shift that we have discovered in the lines for the configurations $5f^3 6d 7s^2$ and $5f^3 6d^2 7s$ (U I), and also $5f^3 6d 7s$ (U II) are related to transitions from the higher excited levels.

On the basis of the results that we have obtained from the shift of the terms, it is not difficult to see that all the negative shifts in the uranium lines are occasioned either by transitions from the less shifted higher terms to the more shifted lower terms, or by transitions from the higher inverted terms to the lower normal ones. All the positive shifts are obtained for transitions from the higher shifted (among these, the excited) terms to the lower, unshifted or less shifted term. The different cases of transitions are shown in Fig. 1. These permit the explanation of the isotope structure in the uranium spectrum.

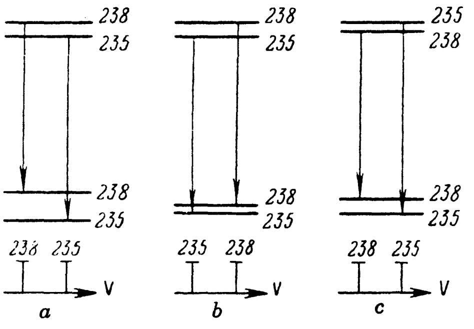

FIG. 1. Different cases of transitions between terms: a and c --- negative shift, b --- positive shift.

Comparison of the isotope shift in the terms of uranium with the shift in the terms of neighboring heavy elements (Hg, Tl, Pb) shows that the isotope shift for uranium is approximately twice as great. Thus, in accordance with our data, the isotope shift in the terms of U II which are related to the electron configurations $5f^3 7s^2$, is equal on the average to 0.42 cm^{-1} per unit atomic mass. The isotope shift in the terms of Hg II and Pb II for the configurations $5d^9 6s^2$ and $6s^2 7p$ are, respectively, 0.26 cm^{-1} and 0.22 cm^{-1} per unit mass[8]. Such a relatively large isotope shift in the terms of uranium cannot be fully explained by the single increase in charge and volume of the charge. Here, evidently, there is, along with the volume effect, an additional effect connected with large deformation of the shape of the nucleus[9]

4. THE ADDITIONAL EVEN-ODD SHIFT

For the detection of the even-odd shift, the spectra of three isotope samples (U^{238}, U^{235} and U^{233}) were photographed on the three prism spectrograph with the autocollimating chamber $f = 130$ cm, and measurements of the interval between the shifted components of the three isotopes were made on a series of lines. For measurement of the intervals a dispersion curve was constructed along the spectrum of iron. The position of each line was measured tenfold on a comparator with accuracy ±0.004 A (±0.02 cm^{-1}). One of the spectrograms is reproduced in Fig. 2 with the isotope structure of the line of U II 4244.372 A; the three components U^{238}, U^{235} U^{233} are clearly evident. A microphotometer trace of these lines is shown in Fig. 3.

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[7] Ph. Schurmans, Physica 11, 419 (1946); Ph. Schurmans, J. C. van den Bosch and Dijkwol, Physica 13, 117 (1947)

[8] P. Brix and H. Kopfermann (see Landolt-Börnstein, Vol. 1, part 5, pp. 1-59, Berlin, 1952)

[9] L. Wilets, D. L. Hill and W. Ford, Phys. Rev. 66, 1041 (1953); A. R. Bodmer, Proc. Phys. Soc. (London) A67, 622 (1954)

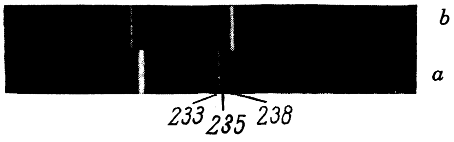

FIG. 2. The U II line 4244.372 A with components of three isotopes: *a*— spectrum of a mixture of three isotopes of uranium, *b*— spectrum of natural uranium.

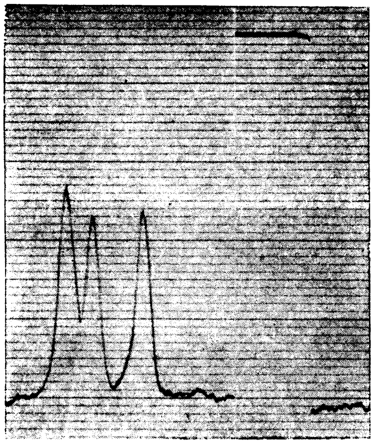

FIG. 3. Microphotograph of the U II line 4244.372 A.

The isotope structure of the line 4244.372 A of the three isotope sample U^{238}, U^{235}, U^{234} was spectrographed for the detection of the component of the isotope U^{234}. The shift between the components U^{235} and U^{234} was measured directly on the spectrum with the aid of a comparator, and then checked on a microphotogram obtained on a recording microphotometer. This shift was equal to 0.030 ±0.002 mm. If we take into consideration the dispersion in this region (1.907 A/mm), then the magnitude of the shift will be equal to 0.057 ±0.004 A or 0.32 ±0.013 cm^{-1}.

The results are given in Table VI along with the data of other investigators[3,4]. Comparing the isotope shift of the even isotopes with the odd, it can be noted that in the uranium spectrum the lines of odd isotopes undergo an additional shift (in comparison with the lines of the even isotopes) in the direction of the components of the isotopes of lower mass number. This additional shift, equal to 0.04 cm^{-1} (per unit mass) in the case of the U II line 4244.372 A shows that the *s* electrons of the odd isotope have a somewhat larger binding energy with the nucleus than the electrons of even isotopes.

The isotopes shifts referred to unit mass, for 17 lines between the isotopes U^{238} - U^{235} and U^{235} - U^{233}, are given in Table VII. For the major share of the lines, the magnitude of the isotope shift per unit mass between the even isotope U^{238} and the odd isotope U^{235} is larger than the corresponding magnitude of the shift between the odd isotopes U^{235} and U^{233}. This also points to the presence in the isotope shift in the case of the uranium spectrum of an additional even-odd shift. For five lines of uranium the shifts $\Delta\nu$ (U^{238}-U^{235}) and $\Delta\nu$(U^{235} - U^{233}) per unit mass appeared to be approximately equal or, on the other hand, the shift between odd isotopes U^{235} - U^{233} was larger than the shift between the isotopes U^{238}-U^{235} It can be assumed that these deviations from the usually ovserved regularities in the isotope shift for the spectra of the heavy elements are explained by excitations of close lying levels in the uranium atom.

CONCLUSIONS

1. Comparison of the isotope shift of the lines of uranium with the electron configuration of the lower term leads to the following conclusions:

a) The average shift of the lines of the ionized atom is larger than the average shift of the lines of the neutral atom.

b) The lines of the ionized atom, which are related to the lower configurations $5f^37s^2$ and $5f^47s$ have a negative and, on the average, a small shift; the lines belonging to the higher configurations $5f^36d^2$ and $5f^46d$ have a smaller and only positive shift; the lines which are related to the configuration $5f^36d7s$ have, as a rule, a negative shift and only four lines have a positive shift.

2. On the basis of the isotope shift, 220 lines of uranium have been associated with U II; the electron configurations of the lower terms have been found for 153 lines and the shift in the terms have been established for U I and U II.

3. The isotope shift in the terms of U II is generally 2.5 times larger than the shift in the terms of U I. If we exclude excited levels, then the terms undergo the largest shift which belong to configurations with s^2 electrons. The terms of configurations with a single *s* electron undergo a shift which is about 2.5 times smaller.

4. From the data obtained on the shift of the terms

it follows that all the negative shifts in the lines of uranium are determined either by transitions to a greater shifted lower term or to transitions from higher "inverted" terms to lower normal terms. All the positive shifts are obtained for transitions from higher shifted terms to lower unshifted or slightly shifted terms.

5. With the help of the investigation of isotope structure of the U II line 4244.372 A the presence of an additional shift of the components of even-odd isotopes in the direction of the isotopes of lower mass number has been established.

APPENDIX

Spectral Lines of Uranium with Isotope Shift‡

wavelength of line in Angstroms	Shift $\Delta\nu$ (U^{238}—U^{235}) in cm^{-1}	Electron configuration and atomic state, according to our results	wavelength of line in Anstroms	Shift $\Delta\nu$ (U^{238}—U^{235}) in cm^{-1}	Electron configuration and atomic state, according to our results
2390.11	—1.64	II, f^3s^2	2698.452	1.73	II, f^3s^2
2390.97	—1.28	II, f^3s^2	2700.96	—1.21	II, f^3s^2
2402.159*	—1.1	II, f^3s^2	2706.95	—1.12	II, f^3s^2
2407.599*	—1.59	II, f^3s^2	2733.772	—1.22	II, f^3s^2
2409.558*	—1.02	II, f^3s^2 or f^4s	2734.964	+1.84	II, f^3d^2
2414.56	—1.48	II, f^3s^2	2735.580	—0.96	II, f^3s^2 or f^4s
2419.573	—1.14	II, f^3s^2	2743.40	—1.17	II, f^3s^2
2424.971	—1.36	II, f^3s^2	2747.15	—1.09	II, f^3s^2
2427.454	—0.94	II	2747.362	—1.27	II, f^3s^2
2432.461*	—0.91	II	2757.554	—1.12	II, f^3s^2
2435.05*	—1.4	II, f^3s^2	2761.18	—1.34	II, f^3s^2
2438.007*	—1.8	II, f^3s^2	2765.40	—1.18	II, f^3s^2
2441.399*	—1.37	II, f^3s^2	2766.875	—1.19	II, f^3s^2
2442.895	—1.70	II, f^3s^2	2770.044	—1.06	II, f^3s^2
2448.931	—1.14	II, f^3s^2	2780.040	—1.10	II, f^3s^2
2450.443	—1.33	II, f^3s^2	2784.919	—0.85	II
2454.367	—1.26	II, f^3s^2	2831.169	+1.95	II, f^3d^2
2460.86	—1.17	II, f^3s^2	2840.940	—1.09	II, f^3s^2
2463.695*	—1.55	II, f^3s^2	2841.17	+1.54	II, f^3a^2
2468.261	—1.62	II, f^3s^2	2845.959	+1.32	II, f^3d^2
2470.645	—1.14	II, f^3s^2	2857.93	—1.04	II, f^3s^2 or f^4s
2477.178	—1.76	II, f^3s^2	2858.903	—0.91	II
2490.928	—1.24	II, f^3s^2	2865.14	—1.14	II, f^3s^2
2498.829	—1.68	II, f^3s^2	2866.986	—1.24	II, f^3s^2
2500 864	—1.24	II, f^3s^2	2873.298	—1.03	II, f^3s^2 or f^4s
2505.289	—1.58	II, f^3s^2	2874.083	—1.23	II, f^3s^2
2514.768	—1.71	II, f^3s^2	2877.569	—0.99	II, f^3s^2 or f^4s
2518.974	—1.31	II, f^3s^2	2878.2	+2.39	II, f^3d^2
2524.311	—2.05	II, f^3s^2	2880.4	—0.96	II, f^3s^2 or f^4s
2528.77	—2.16	II, f^3s^2	2882.345	—1.02	II, f^3s^2 or f^4s
2537.296	—1.58	II, f^3s^2	2882.741	—1.15	II, f^3s^2
2538.430	—1.25	II, f^3s^2	2887.907	—1.06	II, f^3s^2
2541.370	—1.29	II, f^3s^2	2888.380	—1 26	II, f^3s^2
2547.998	—1.88	II, f^3s^2	2888.741	—0.88	II
2548.328	—1.49	II, f^3s^2	2908.275	—0 78	II
2549.296	—1.59	II, f^3s^2	2910.201	—1.72	II, f^3s^2
2562.841	—1.76	II, f^3s^2	2931.891	—0.97	II, f^3s^2 or f^4s
2565.406	—1.33	II, f^3s^2	2935.615	—0.93	II
2567.108	—1.66	II, f^3s^2	2943.405	—1.08	II, f^3s^2
2567.955	—1.96	II, f^3s^2	2944.637	—0.93	II
2569.712	—1.6	II, f^3s^2	2946 772	—0.70	II
2583.480	—2.02	II, f^3s^2	2947.653	+0.92	II, f^3d^2
2584.420	—1.57	II, f^3s^2	2948.336	—0.32	II

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‡ The wavelengths of most of the lines are taken from the tables of Harrison. Lines not in these tables were either measured again (single asterisk) or taken from the tables of van der Bosch (double asterisk). Lines marked with a triple asterisk were referred[5] to arc lines while by our research they belong to spark lines. For all these lines the configuration of the lower term has not yet been established[5].

APPENDIX (continued)

wavelength of line in Angstroms	Shift $\Delta\nu$ (U^{238}—U^{235}) in cm^{-1}	Electron configuration and atomic state, according to our results	wavelength of line in Angstroms	Shift $\Delta\nu$ (U^{238}—U^{235}) in cm^{-1}	Electron configuration and atomic state, according to our results
2591.252	—1.46	II, f^3s^2	2951.07	—1.18	II, f^3s^2
2592.572	—1.54	II, f^3s^2	2956.060	—0.76	II
2593.571	—1.41	II, f^3s^2	2957.229	—1.22	II, f^3s^2
2597.689	—1.28	II, f^3s^2	2960.942	—1.28	II, f^3s^2
2624.915	—1.29	II, f^3s^2	2991.248	—0.92	II
2628.504	—1.32	II, f^3s^2	2993.355	—0.86	II
2628.928	—1.3	II, f^3s^2	3002.645	—0.61	II
2635.528	—1.25	II, f^3s^2	3009.42	—0.88	II
2648.789	—1.63	II, f^3s^2	3013.370	—1.05	II, f^3s^2 or f^4s
2652.828	—1.66	II, f^3s^2	3017.351	—1.09	II, f^3s^2
2691.038	—0.68	II	3022.753	—1.00	II, f^3s^2 or f^4s
2692.365	—0.98	II, f^3s^2 or f^4s	3025.406	—1.36	II, f^3s^2
3033.77	—1.23	II, f^3s^2	3733.752	—0.39	
3038.047	—1.08	II, f^3s^2	3761.961	—0.59	II
3049.584	—1.23	II, f^3s^2	3769.535	—0.42	
3050.198	—1.09	II, f^3s^2	3906.525	—0.85	II
3066.286	—1.14	II, f^3s^2	3911.673	—1.17	II, f^3s^2
3081.188	—0.78	II	3919.719	—1.09	II, f^3s^2
3081.666	—1.03	II, f^3s^2 or f^4s	3921.550	—0.71	II
3088.731	—1.16	II, f^3s^2	3930.982	—0.81	II
3090.554	—1.02	II, f^3s^2 or f^4s	3937.068	—0.84	II
3113.637	—0.93	II	3947.959	—1.08	II, f^3s^2
3115.795	—0.58	II	3973.234	+0.51	II, f^3d^2 or f^4d
3120.866	—0.42		3974.975	—1.05	II, f^3s^2 or f^4s
3121.330	—1.02	II, f^3s^2 or f^4s	3977.064	—0.92	II
3133.641	—1.28	II, f^3s^2	3988.644	—0.89	II
3138.513	—1.03	II, f^3s^2 or f^4s	4023.170	—1.2	II, f^3s^2
3153.120	—0.76	II	4026.999	+0.67	II, f^3d^2
3157.446	—0.96	II, f^3s^2 or f^4s	4064.165	—0.96	II, f^3s^2 or f^4s
3173.706	—1.08	II, f^3s^2	4071.108	+0.64	II, f^3d^2
3184.406	—1.26	II, f^3s^2	4086.145	+0.57	II, f^3d^2
3193.226	—0.92	II	4106.416	—0.69	II
3203.223	—0.58	II	4128.336	—1.03	II, f^3s^2 or f^4s
3221.103	—1.18	II, f^3s^2	4225.369***	—1.16	II, f^3s^2
3224.261	—0.50		4231.676***	—0.78	II
3229.502	—0.78	II	4252.426	—0.89	II
3239.614	—0.97	II, f^3s^2 or f^4s	4253.848	—0.76	II
3244.165	—0.40		4261.505	—1.09	II, f^3s^2
3253.351	—0.55		4263.419	—0.67	II
3267.638	—0.77	II	4270.89	—0.69	II
3279.096	—0.59	II	4289.556	—0.88	II
3280.004	—0.41		4313.147***	—0.65	II
3282.542	—0.81	II	4399.631	—1.00	II, f^3s^2 or f^4s
3284.368	—0.85	II	4405.952	—1.44	II, f^3s^2
3287.448	—0.43		4422.984	—1.21	II, f^3s^2
3288.209	—0.47		4468.895	—1.45	II, f^3s^2
3291.335	—0.62	II	4493.044	—1.08	II, f^3s^2
3322.350*	—0.75	II	4511.158	—1.09	II, f^3s^2
3337.929	—0.53		4513.373	—0.91	II
3367.896	—1.16	II, f^3s^2	4611.436	—1.17	II, f^3s^2
3371.292	—0.61	II	4614.678	—1.00	II, f^3s^2 or f^4s
3380.700	—0.74	II	4637.940	—1.05	II, f^3s^2
3381.95	—0.80	II	4684.644	—0.89	II
3401.213	—0.76	II	4713.943	—0.93	II
3403.546	—0.30		4844.716	—0.69	II
3424.810	—0.69	II	4911.668	—0.65	II
3426.393	—0.79	II	4934.105*	—0.69	II
3454.228	—0.31		5030.738	—1.17	II, f^3s^2
3455.742	—0.52		5200.667	—0.92	II
3458.683	—0.56		5204.316	+0.33	II, f^3d^2 or f^4d
3472.107	—0.80	II	5290.505	—0.34	

APPENDIX (continued)

wavelength of line in Angstroms	Shift $\Delta\nu$ (U^{238}—U^{235}) in cm^{-1}	Electron configuration and atomic state, according to our results	wavelength of line in Angstroms	Shift $\Delta\nu$ (U^{238}—U^{235}) in cm^{-1}	Electron configuration and atomic state, according to our results
3480.359	—0.67	II	5298.81	—1.01	II, f^3s^2 or f^4s
3488.815	—0.53		5310.038	—0.40	
3495.748	—0.29		5313.722	—0.84	II
3513.370	—0.50		5349.917	—0.99	II, f^3s^2 or f^4s
3591.560	—0.84	II	5352.320	+0.54	II, f^3d^2 or f^4d
3630.733	—0.35		5371.835	—0.79	II
3638.200***	—0.47		5409.096	—0.44	
3640.757	—0.81	II	5413.947	—0.81	II
3672.579	—0.42		5455.499	+0.43	II, f^3d^2 or f^4d
3697.93	—0.50		5479.935	+0.36	II, f^3d^2 or f^4d
3701.522	—0.35		5491.236	—0.38	
3704.099	—0.92	II	5513.386	+0.50	II, f^3d^2 or f^4d
3705.983	—0.74	II	5564.187***	—0.37	
3715.470	—0.27		5567.343	+0.70	II, f^3d^2
3733.069	—0.51		5733.262	—1.12	II, f^3s^2
5832.389	—0.51		6298.551***	—0.65	II
5845.272	+0.37	II, f^3d^2 or f^4d	6322.368	—0.71	II
5853.930	+0.42	II, f^3d^2 or f^4d	6347.671*	+0.57	II, f^3d^2
5986.122***	—0.34		6390.943	—0.37	
6051.745	+0.43	II, f^3d^2 or f^4d	6428.396*	+0.50	II, f^3d^2 or f^4d
6067.229	+0.36	II, f^3d^2 or f^4d	6428.870*	+0.35	II, f^3d^2 or f^4d
6132.613	—0.41		6465.005***	—0.44	I
6215.397***	—0.46		6470.550	+0.39	II, f^3d^2 or f^4d
6255.852*	+0.38	II, f^3d^2 or f^4d	6511.136*	+0.39	II, f^3d^2 or f^4d
6258.836*	—0.87	II	6557.581	+0.22	
6291.484	+0.35	II, f^3d^2 or f^4d			

Translated by R. T. Beyer
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