The term value of the $^2S_{1/2}$ state is given as 74461 cm^{-1} by McLennan and McLay. This corresponds to a value of n_e of 1.21. The value of Z_0 is unity for Au I, and the value of a is 0.214/2 or 0.107 cm^{-1}. The relativity correction K can be calculated from the results of Racah.[16] For $Z_i = 79$, $j = \frac{1}{2}$, the value is 2.19. The value for g thus determined is 0.130, which for a spin of 3/2 results in a nuclear moment of 0.195 proton magnetons.

Because of the intermediate coupling present in the complex electronic configurations, no determination of the magnetic moment can at present be made from the splitting observed in the levels corresponding to these configurations.

The $7s$ electron of the $^2S_{1/2}$ state of λ5837A must possess a small interval factor since no splitting has been observed in this line. This is not surprising in view of the rapidity with which the a factor decreases with increasing total quantum number. In the case of Tl II, the ratio of the a factor for the $6s$ and $7s$ electrons is over eight to one; and in Bi I, over thirteen to one. The ratio in the case of Au I is probably at least five to one—how much greater we cannot say.

In conclusion, the present work shows that the nuclear spin of gold is 3/2 and the magnetic moment 0.195 proton-magneton within an experimental error of two percent, disregarding inadequacies in the theory. No indications of an abnormally large $^2P_{1/2}$ separation or of an isotope shift have been found. Electron configurations of McLennan and McLay have been confirmed for several states.

[16] G. Racah, Nuovo Cimento **8**, 178 (1931); and Zeits. f. Physik **71**, 431 (1931).

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The Fine Structure of the Line λ4686 of Ionized Helium

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The fine structure of the line λ4686 of ionized helium emitted from a discharge tube with hollow cathode cooled by liquid air was measured with a Fabry-Perot interferometer. The formula for the pattern obtained with this instrument expressed in Fourier series was applied in the analysis. Of the eight components predicted by theory, four were definitely observed, while the remaining weak ones were inferred from the pattern to be present. Relative intensities and positions of the eight components were found to be in general agreement with theory. The separation between the two strongest components was 0.0095 ± 0.0024 IA or 0.4529 ± 0.0109 cm^{-1}. The Rydberg constant for helium was calculated to be $109{,}722.430 \pm 0.030$.

ALTHOUGH the fine structure of the lines of ionized helium is of equal interest with that of hydrogen and deuterium, there has been relatively little study made of it. This paper is the report of the use of a Fabry-Perot interferometer, instead of the customary diffraction grating, for this purpose. The difficulty, of course, lies in the overlapping of the orders, but by using a variety of plate separations, the errors caused by this can be minimized.

Experimental Arrangement

The light came from a hollow cathode glow, excited by direct current. The cathode, made of a copper cylinder 3.4 cm in diameter and eight cm in length, formed the bottom of the discharge tube. Its inside was aluminized by evaporation in order to avoid the emission of ionized copper lines, one of which has a wave-length 4682 so close to the line 4686 that it could not be separated by the prism. The cathode was immersed in liquid air whose level was kept a little lower than the junction where the tapering top of the cathode was sealed to the glass tube. The anode was an aluminum ring just above the cathode and was of such a size that it would not intercept the light from the cathode to the window of the tube. The distance between the anode and

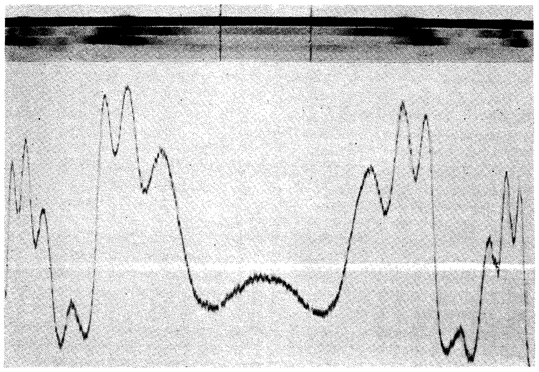

FIG. 1. A sample plate and microphotometer tracing. The upper strip of the plate represents λ4713 of He, the middle strip λ4686, and the bottom strip λ4663 of Al and a portion of the reflected image of 4686.

the cathode was made as small as possible to reduce the space in which the spectrum of neutral helium appeared. The length of the tube, about 36 cm, and the diameter of its top, about 10 cm, were so designed that the solid angle subtended at the collimeter slit by the lens which closed the top of the tube was nearly equal to that subtended by the collimator lens. The diameter of the cathode was such that the image on the slit was sufficiently large to secure fairly uniform illumination.

The discharge was produced at a pressure around 0.3 mm. The helium was kept purified during the exposure by circulation through charcoal traps immersed in liquid air.

The spectrograph consisted of a half-prism silvered on the back and a two-meter camera. The ratio of the focal length of the camera lens to that of the collimator lens was about 5.5 so that the slit image on the plate was wide enough to lessen the effect of photographic grain. Between the collimator and the prism was interposed a Fabry-Perot interferometer with plates 11 cm in diameter separated by three Invar posts held in a brass ring. Intensity marks on each plate were made with essentially the same arrangement as that used by Houston and Hsieh.[1]

In order to detect any shift of fringes that might have occurred during exposure the following method was devised. Two short exposures of about one or two minutes were made on a second plate, one just before and the other immediately after the main exposure which was about 50 minutes. The two pictures lay side by side on the same plate and any shift of fringes during the exposure was easily observed. Plates on which a shift could be definitely detected were rejected.

METHOD OF MEASUREMENT

For each plate to be measured, a microphotometric tracing was taken of the line 4686. (A sample of the line and its tracing is shown in Fig. 1, where four components are readily seen.) The ordinates and abscissae of the tracing were measured on a comparator and used in conjunction with tracings from the intensity marks to obtain a curve of intensity as a function of the square of the distance from the center of the pattern. Corrections were then applied for the deviations from uniform slit illumination and an average of one, two or three orders on each side of the center was taken. This average curve was

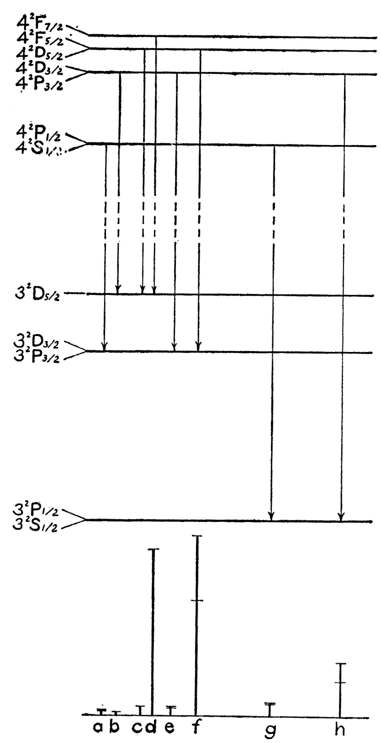

FIG. 2. Energy level diagram for He 4686.

[1] W. V. Houston and Y. M. Hsieh, Phys. Rev. **45**, 263 (1934).

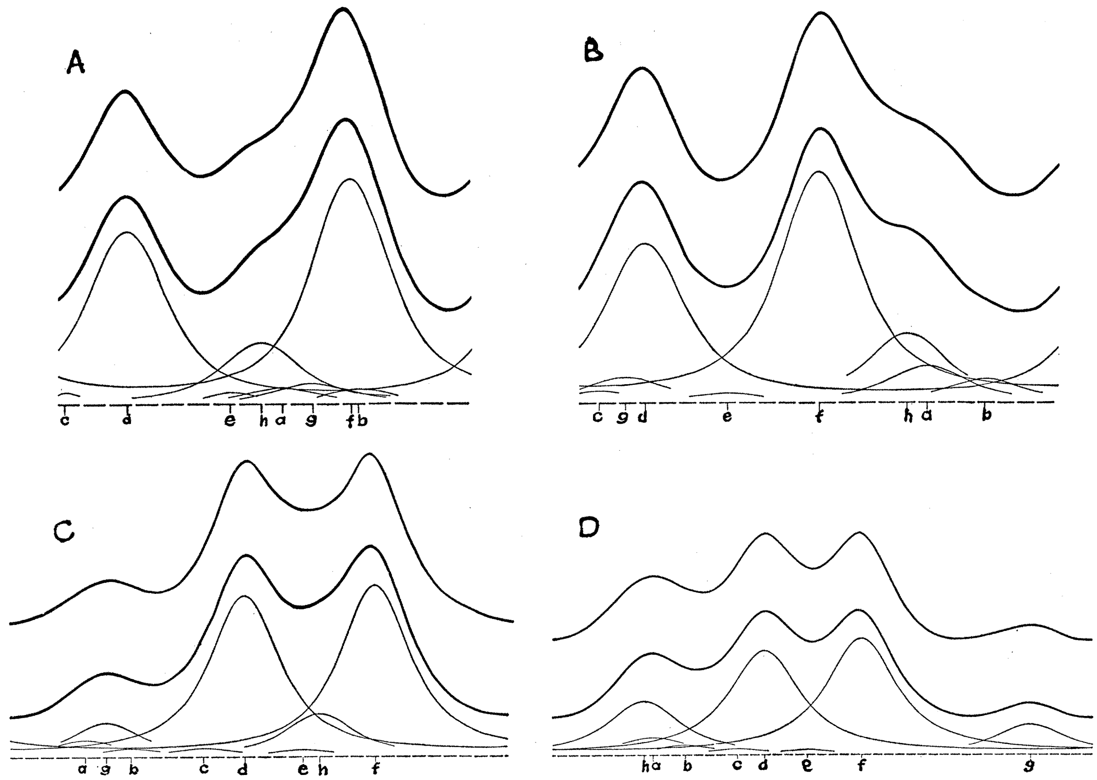

FIG. 3. In each of the drawings the upper heavy curve is the experimental curve, the lower heavy curve is the theoretical one obtained by summing the light curves representing the eight components *a, b, c, d, e, f, g, h*. Of the component curves only a part of the whole period is shown, except those of the two strongest components *d, f*. *A*. For plate 118 of which $s=5.9814$ mm; *B*. For plate 124 of which $s=3.9794$ mm; *C*. For plate 126 of which $s=2.9878$ mm; and *D*. For plate 134 of which $s=1.9780$ mm.

TABLE I. *Relative intensities and positions. In the second column are given the interferometer separations; in the third, the pressures both at the start and at the end of exposure; in the fourth, the current. I denotes intensity, that of component f being taken as 1.00. The theoretical intensities* are also given in the second row from the bottom. The theoretical positions calculated by using 1/137.0 for the fine structure constant** are given in the last row, all referred to f. P denotes the position. When no value is given, it means that the position is assumed to have the theoretical value.*

PLATE	*s* mm	*p* mm Hg	*c* ma		*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
118	5.9814	0.33–0.29	140	*I*	0.07	0.06	0.05	0.77	0.05	1.00	0.09	0.27
				P	—	—	—	−0.4528	—	0	0.7593	1.4907
124	3.9794	0.31–0.28	145	*I*	0.15	0.10	0.05	0.70	0.04	1.00	0.11	0.30
				P	—	—	—	−0.4555	—	0	0.7486	1.4868
126	2.9878	0.33–0.30	145	*I*	0.10	0.05	0.05	0.94	0.04	1.00	0.20	0.25
				P	—	—	—	−0.4393	—	0	0.7671	1.4854
134	1.9780	0.23–0.18	130	*I*	0.15	0.08	0.05	0.89	0.04	1.00	0.25	0.45
				P	—	—	—	−0.4529	—	0	0.8005	1.5167
Theoretical *I*					0.026	0.010	0.046	0.924	0.041	1.00	0.062	0.299
Theoretical *P*, cm^{-1}					−0.9744	−0.8210	−0.5774	−0.4556	−0.2436	0	0.7577	1.4885

* A. Sommerfeld and A. Unsöld, Zeits. f. Physik **36**, 259 (1926); **38**, 237 (1926); M. Saha and A. C. Banerji, Zeits. f. Physik **68**, 704 (1931).
** R. T. Birge, Phys. Rev. **48**, 918 (1935); R. Ladenburg, Ann. d. Physik **28**, 458 (1937).

TABLE II. *Wave-lengths*, IA.

PLATE	λ_f FROM MAX.	COR.	λ	WT.	λ_d FROM MAX.	COR.	λ	WT.
118	4685.7030±0.0013	−0.0015	.7015±0.0013	4	.8011±0.0011	0	.8011±0.0011	3
124	.7001±0.0013	+0.0012	.7015±0.0013	3	.8031±0.0010	−0.0015	.8016±0.0010	3
126	.7048±0.0017	−0.0029	.7019±0.0017	2	.7962±0.0020	0.0018	.7980±0.0020	1
134	.7052±0.0016	−0.0028	.7024±0.0016	2	.8013±0.0014	0.0012	.8025±0.0014	2
Mean	4685.7017±0.0014				4685.8012±0.0020			
$\Delta\lambda_{fd}$	$\Delta\lambda_{fd}=0.0995\pm0.0024$ IA				$\Delta\nu_{fd}=0.4529\pm0.0109$ cm^{-1}			

used in the analysis for the relative intensities and positions of the components.

The line 4686 consists of eight components resulting from the transitions as shown in Fig. 2. If their positions and relative intensities are given, the theoretical pattern can be constructed by means of the expression in Fourier series for the pattern of a single component.[2] The method of analysis was to construct such a pattern with assumed values of the positions and relative intensities and to compare it with the experimental intensity curve. After several trials, each with a set of assumed values, a pattern for each plate was finally obtained which fitted the experimental curve best. It was in this way that the intensities I and positions P given in Table I were obtained. Fig. 3(A–D) shows both the experimental and theoretical curves as well as the component curves for four different plates (s represents the interferometer separation).

In the Fourier series used the parameters α and r, which gave the broadening caused by Doppler effect and reflecting power of the silver surfaces of interferometer plates, respectively, were determined from another single line. This was because the structure of the line 4686 was so complex that it would be extremely tedious if besides the relative intensities and positions we had to change α and r in trying to get a theoretical pattern to fit the experimental one. The reflecting powers, r, obtained in this way were in the neighborhood of 0.61, since the source was not very intense and a thicker silver could not be used. Under these circumstances the contribution of the interferometer to the shape of the line cannot be ignored and the Fourier series for the individual components need to be used in order to take this into account. The values of α corresponded to temperatures around 180°K.

The measurements of wave-lengths were referred to other helium lines such as 5048, 5016, 4922, 4713, 4471, 4437 and 4388 of which the line 5016 was taken as standard and was assumed to be 5015.6750 IA. In the determination of the interferometer separations from which the wave-lengths were calculated corrections were made for the phase change on reflection at the silvered surfaces and for the deviation from standard conditions of the temperature and pressure under which the exposure was taken.

RESULTS

Four plates of different interferometer separations were measured. Because of the overlapping not all of the eight components could be observed. On plate 134 four components d, f, g, h were manifestly present, while on the other plates only three components could be definitely resolved. The existence of the four weak components a, b, c, e could be inferred only by the fact that the theoretical patterns deviated too much from the experimental curves when they were assumed absent. Of these four, c and e were the weakest and were always assumed to have the

TABLE III. *Computation of* R_{He}. $(\mu-1)10^7=2789.9$.

λ_{air}	$(\mu-1)\lambda$	ν	R_{He}
4685.7017	1.3072	21335.5686	109722.423±0.032
4685.8012	1.3072	21335.1157	109722.437±0.047
		Mean	109722.430±0.040

[2] W. V. Houston, Phys. Rev. **51**, 446 (1937).

theoretical intensities throughout the analysis. The intensities of the other components were found to have the values given in Table I. Of course these values are not unique, since the intensity of one component was so related to its neighbors that increasing the one must decrease the other in order to fit the experimental curve. For example, the component a was very close to the component g (next order) on plate 126, to the component h on plates 124, 134, and was between g, h on plate 118. Thus its true intensity might be different from the values given in Table I. For the two strongest components f, d, however, the intensities could be ascertained with certainty, except in the case of plate 124 where d was too close to g.

As to positions, those of the components a, b, c, e could not be determined with certainty, and they were assumed to have the theoretical values in the analysis. The components g, h were found to have separations from f greater than those predicted by theory on plate 134, but appear not to be displaced on the other plates. The two strongest components were found to have a separation in agreement with theory, except in the case of plate 126 where d was too close to f. This was probably caused by experimental error, for the positions of maxima corresponding to this component were uncertain on the microphotometric tracing.

Table II gives the wave-lengths of the two strongest components d, f. They were first calculated from the maxima on the intensity curves. The errors were estimated from the uncertainties of the positions of these maxima. Then the corrections due to the displacement of the maxima by neighboring components were accurately determined and given in the columns "Cor." The weights were taken from the number of maxima from which the wave-lengths were calculated. The uncertainties in the mean values of wave-lengths are estimated values rather than the mean deviations which, 0.0003 for λ_f and 0.0008 for λ_d, are too small to be taken as representing the precision.

The wave-length of the component g could be calculated from only two plates. It was

$$\lambda_g = 4685.5330 \pm 0.0030 \text{ from plate 126,}$$

$$\text{and } \lambda_g = 4685.5266 \pm 0.0050 \text{ from plate 134.}$$

The uncertainties in this are great because on plate 126 the position of the maximum corresponding to g was considerably affected by its neighboring components a, b, and on plate 134 the maximum was broad and uncertain. However, the separation between g and f, which is 0.1719 IA, does not deviate from the theoretical value, 0.1665 IA as much as it does in the measurements of Paschen and Leo who found it to be 0.154 IA and 0.152 IA, respectively.

From the calculated wave-lengths of the two strongest components d, f, the Rydberg constant for helium was calculated (Table III) under the assumption that $\alpha = 1/137.0$. In reducing the wave-lengths in IA to those in vacuum, the index of refraction μ from the formula of Meggers and Peters[3] was used in order that the calculated R_{He} may be comparable with R_H calculated by using the same value of the index of refraction.[4] If we use the latest value of the index of refraction which gives $(\mu-1)\lambda = 1.3175$,[5] R_{He} will be 109722.189 ± 0.030, which is considerably smaller than the above value. The uncertainty of the mean in Table III is not the mean deviation but the mean of the individual uncertainties calculated from the uncertainties of the wave-lengths. The uncertainty here as well as elsewhere in this paper can be regarded as an estimated limit of error. The corresponding probable error would be perhaps about one-fourth of this.

Conclusions

The results of this work show that the positions of the components generally agree with the theory, in particular those of the two strongest components. The separation between these has an average value of 0.0995 IA, which is smaller than the values of 0.106, 0.1023 and 0.104 obtained by Paschen,[6] Kunze[7] and Leo,[8] respectively. It is also a little smaller than 0.1001 which is the calculated value when $\alpha = 1/137.0$. Since only one of the plates showed an appreciable

[3] W. F. Meggers and C. G. Peters, Nat. Bur. Stand. Bull. **14**, 697 (1918).
[4] W. V. Houston, Phys. Rev. **30**, 612 (1927).
[5] D. Bender, Phys. Rev. **54**, 179 (1938).
[6] F. Paschen, Ann. d. Physik **50**, 901 (1916). His later value obtained from the microphotometer curve, 0.098 (see F. Paschen, Ann. d. Physik **82**, 689 (1927)) is close to, but a little smaller than, our value.
[7] P. Kunze, Ann. d. Physik **79**, 610 (1926).
[8] W. Leo, Ann. d. Physik **81**, 757 (1926).

deviation from the value 0.1001, it must be concluded that there is no evidence for a departure from the theory which can be expressed as a change in scale of the whole pattern. Departures which produce a displacement of components which are of small intensity in this line are not, however, excluded.

The relative intensities are different for different plates and not in precise agreement with the theoretically calculated values, yet the deviations are not more than can be attributed to uncertainties in the conditions of excitations and to photometric errors. The too high intensities of the components g, a, b suggest the hypothesis that the $4p$ state is more populous than the others because of the absorption of radiation $1s-4p$. On the other hand, component h does not seem to be sufficiently strong for this to be correct. The unusually high intensities of components g, h on plate 134 are perhaps associated with the low pressure in the same way in which corresponding variations of relative intensity with pressure are observed in hydrogen.[9] That the intensity of f is always greater than that of d is in agreement with Paschen's measurement rather than with that of Leo, who found them equal, and is also in agreement with theory.

The wave-lengths of the two strongest components are smaller than the values obtained by Paschen, Leo and Houston. It is believed, however, that the present measurement is more accurate than the previous ones not only because of the accuracy which is usually attained by the interferometer, but also because of the careful consideration being taken in the correction for displacement of maxima by neighboring components.

The author wishes to express his deepest gratitude to Professor W. V. Houston for his suggestion of the problem, constant direction and helpful guidance throughout the course of the work. The author also wishes to thank Professor I. S. Bowen for his valuable suggestions.

[9] C. D. Shane and F. H. Spedding, Phys. Rev. **47**, 36 (1935).

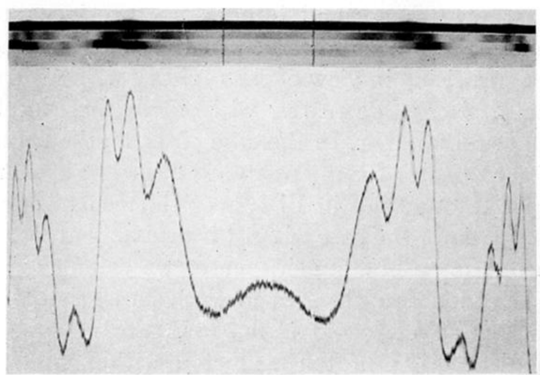

FIG. 1. A sample plate and microphotometer tracing. The upper strip of the plate represents λ4713 of He, the middle strip λ4686, and the bottom strip λ4663 of Al and a portion of the reflected image of 4686.