tude without altering the Zeeman-exchange relaxation rate. The quantity τ_{XL} is roughly independent of ^{4}He concentration at 1°K, but it is less strongly dependent on temperature—i.e., has a lower activation energy (6)—for the more impure samples.

We observe at least three relaxation times in the more impure samples below 0.7°K; so the three-bath model does not provide a complete description at the lowest temperatures. Because of this, we cannot perform a meaningful analysis of the nonexponential recoveries at the lowest temperatures. However, it may be noted that the difference between recoveries following short and long saturation periods is even more marked at these low temperatures than shown in Fig. 3. The mechanism for this additional bottleneck is at present unknown to us. It occurs at higher temperatures than those for which the ^{3}He-^{4}He phase separation has been observed.[9]

An extensive program of measurement is currently in progress.

Mr. H. Glyde very kindly analyzed the samples for ^{4}He content. Maintenance grants from the Department of Scientific Industrial Research (to B. T. B. and M. G. R.) and from the States of Guernsey (to R. P. C.) are also gratefully acknowledged.

*The research reported in this paper has been made possible through the support and sponsorship of the U. S. Department of Army, through its European Research Office.

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[5]With some electronic modifications we have now been able to observe nonexponential recoveries in region II for a molar volume of 20.6 cm^3. The recoveries are similar to those shown in Fig. 3, having the characteristic features of the three-bath model and not of a mixed phase. Values of ρ obtained from an analysis of the double-exponential recovery are in rough agreement with the observed frequency dependence of T_1 in the region where Eq. (4) is applicable.

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DIFFERENTIAL MOTION OF EXCITED He^+ IONS IN A HOLLOW CATHODE PLASMA*

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(Received 17 January 1964)

In a recent study[1,2] of the HeII $(3s,p,d)$ - $(4s,p,d,f)$ line complex excited in a liquid helium-cooled hollow cathode plasma at pressures between 0.12 and 0.06 Torr and current densities of about 5 mA/cm^2, an important shift of the position of the lines was discovered. It appears that the most likely origin of the shift of the lines is a Doppler effect caused by a drift of the ions in the direction of the small axial electric field in the plasma. A comparison of measurements of the relative line positions with the calculated positions and with those measured by Series[3] indicates a possible differential shift apparently arising from different drift velocities for ions in the $4s$, $4p$, $4d$, and $4f$ states. Because of the importance of this type of shift for spectroscopic measurements, and because of its potential use as a tool for studying the hollow cathode plasma and atomic properties, an investigation of this effect has been begun. This note is a report of the preliminary experiments.

The discharge tube consisted of three cylindrical copper electrodes held coaxially one above the other by insulating glass spacers. The assembly was closed at the bottom by a glass light trap, and attached at the top to a 40-cm long conical tube with an end window for viewing the plasma along the axis of the electrodes. The middle electrode, which had an 8-cm bore, was the cathode within which the plasma was contained. The two identical, symmetrically placed extremal electrodes were alternately made anodes so that the plasma could be viewed with the electric field either toward or away from the observer. The discharge was operated under conditions similar to those of the first study.

The faint light from the HeII $(3s,p,d)$ - $(4s,p,d,f)$ complex ($\lambda = 4686$ Å, $\sigma = 21\,335$ cm^{-1}) was analyzed by a high-luminosity pressure-scanned photoelectric Fabry-Perot spectrometer of the Bellevue type.[4,1] A Fabry-Perot etalon with a 2.1-mm spacer was employed to provide a resolution of about 225 000. This arrangement provided sufficient resolution and free spectral range to study the fine-structure lines $3p\,^2P_{1/2}$-$4s\,^2S_{1/2}$, $3s\,^2S_{1/2}$-$4p\,^2P_{1/2}$, and $3d\,^2D_{5/2}$-$4f\,^2F_{7/2}$, hereafter called lines No. 3, No. 4, and No. 9, respectively, in accordance with previous work.[2] The output of the photomultiplier was recorded on the first channel of a two-channel recorder. Reference fringes from a widely spaced Fabry-Perot connected in parallel with the main Fabry-Perot and illuminated by a ^{198}Hg lamp were recorded on the second channel of the recorder to provide a fixed background against which to measure shifts of the lines under study. These fringes could be measured to within ±0.1 mK, but measurements of the HeII lines were limited by low signal-to-noise ratio. A possible instrumental shift was checked by measuring the shift of the neutral helium line $2p\,^3P_0$ - $4s\,^3S_1$, which in previous work[2] showed a 1-mk shift corresponding to motion opposite the field direction. The measurements were of sufficient accuracy to verify that the instrumental shift was less than 2 mK.

The results of the measurements are shown in Table I. It is clear from Table Ia that the separation of lines No. 3 and No. 4 depends strongly on the direction of the field. The average separation, however, is close to the calculated separation. It is not surprising that the average lies below the calculated value because of the reduction in the apparent separation of the recorded peaks brought about by the incompleteness of their resolution. This reduction is estimated to be between 1.5 and 3 mK in the direction of decreased separation.

Table Ib shows the shift between the two field directions for each measurable component. The shift was taken as positive if the lines were shifted to the violet when the field was towards the observer. It is clear from these measurements that there is a significant differential shift of the lines.

The observed shifts are inconsistent with the assumption that they are caused by Stark shifts of the levels. In particular, any electric field would push lines No. 3 and No. 4 apart and the shift of line No. 4 should be equal and opposite to that of line No. 3.[5,2]

We are led to postulate that the shift is a Doppler shift caused by motion of the ions along the small axial electric field in the plasma, and that the differential shift is caused by a dependence of the probable velocity of an ion at the time of emission upon its l value. An elementary explanation can be given using the information in Table II. Assume that on the average all ions excited to $n = 4$ have the same velocity immediately after excitation. This is probable if ionization and excitation occur in a single step.

Then: (1) In the absence of collisions with neutral atoms, the increment in the velocity of an ion up to the time of emission is dependent upon the lifetime of the upper ($n = 4$) state since the ion accelerates in the electric field. Thus the ions in the short-lived $4P$ state have a much smaller velocity in the direction of the field than those in the relatively long-lived $4S$ and $4F$ states and show a correspondingly smaller line shift. The electric fields of about 1 V/cm expected in the hollow cathode are sufficient to explain the shifts.

Table Ia. Experimental results. The separation $\Delta\sigma$ = No. $3(3p\,^2P_{1/2}-4s\,^2S_{1/2})$ - No. $4(3s\,^2S_{1/2}-4p\,^2P_{1/2})$.

Field direction	$\Delta\sigma$ (mK) Observed[a]	Average[a]	Calculated[b]
Toward spectrometer	202.7 ± 2.5	196.7 ± 2.5	198.6
Away from spectrometer	190.0 ± 2.5		

[a]Errors are estimates of the probable error.
[b]See reference 2.

Table Ib. Shifts of individual lines with field reversal.

No.	Line transition	l value of upper state	Shift[a, b, c] (mK)	Ion velocity (m/sec)
3	$(3p\,^2P_{1/2}-4s\,^2S_{1/2})$	0 (S)	+ 9.5 ± 2.5	+ 67
4	$(3s\,^2S_{1/2}-4p\,^2P_{1/2})$	1 (P)	- 3.0 ± 2.5	- 21
9	$(3d\,^2D-4f\,^2F)$	3 (F)	+19.2 ± 1.5	+135

[a]Errors are estimates of the probable error.
[b]Plus sign indicates positive ions drift in the direction of the electric field.
[c]These shifts may be subject to a small instrumental shift. See text.

Table II. Properties of He II, $n=4$.

l	Relative lifetime[a] (t_0/t_l) $t_0=1.4154\times10^{-8}$ sec	Atomic radius[b] $\langle r_l\rangle$ (atomic units)	Relative mean free path in He[c]
0 (4*s*)	1	12	1
1 (4*p*)	0.05431	$11\frac{1}{2}$	1.082
2 (4*d*)	0.15953	$10\frac{1}{2}$	1.279
3 (4*f*)	0.32012	9	1.695

[a]G. Herzberg, Z. Physik 146, 269 (1956).
[b]E. U. Condon and G. H. Shortley, Theory of Atomic Spectra (Cambridge University Press, New York, 1953), 2nd ed., p. 117.
[c]See text.

(2) If the ions have sufficiently long lifetimes, their velocities are limited by atomic collisions. In this case the drift velocity, and hence the line shift, is proportional to the mean free path of the ions in the He gas.[6] In the hard-sphere approximation the mean free path is inversely proportional to the square of the sum of the radii of the He^+ ion and the neutral He atom. Taking for the radius of the ion the appropriate expectation value $\langle r_l\rangle$ listed in Table II, and for the radius of the neutral atom the value $\langle r_1\rangle = 0.929a_0$ calculated by Pekeris[7] for the He I $1s^2\,{}^1S_0$ state, one obtains the relative mean free paths listed in Table II. This ratio is expected to be equal to the line-shift ratio when the velocity is limited by atomic collisions. For lines No. 3 and No. 9, which have relatively long-lived upper states, this ratio is 2.0 ± 0.5, in good agreement with the mean-free-path ratio of 1.695. For the conditions of this experiment, the collision time for the excited He ions is estimated to be $<10^{-8}$ sec.

It is possible that the apparent backward shift of the 4*P* ions is a result of the impact of the exciting electrons. In reference 2, a backward shift of the neutral atoms was observed, and it is reasonable to expect a similar shift for the ions. The backward shift of the ions might be larger than that of the neutral atoms because on the average higher energy electrons are involved in the excitation. Only the lines emitted from the short-lived 4*P* levels of He II would be expected to show directly the recoil shift because their lifetime is too short for the weak electric field to cause an appreciable velocity change.

The authors wish to express their gratitude to Professor J. E. Mack for his help and advice.

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*Work supported by the National Science Foundation and by the Research Committee of the Graduate School of the University with funds supplied by the Wisconsin Alumni Research Foundation.

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