light patterns: a two-mode pulse, and a seven-mode pulse. $g^{(k)}$ values are given with a large error which is due to an uncertainty in the value of k, and an additional uncertainty in the position of the average straight line passing through scattered experimental points as shown in Figs. 1(c) and 2(c). When the number of modes becomes increasingly large, the value of the $g^{(k)}$ has been calculated to be $K!$,[8,12] i.e., $10^{7.6}$ for $K=11$, and $10^{20.8}$ for $K=22$.

The third point is relative to the influence of mode locking of seven modes of the laser pulse. This experiment was carried out by placing in the oscillator cavity a solvent cell containing a dye to phase lock the seven modes [Fig. 2(d)], and without the dye [Fig. 2(c)]. The number of ions is found to be enhanced by a factor of 10^2 when the seven modes have the same phase in comparison with the same average laser intensity when the seven modes have random phase from 0 to 2π. Thus the locking of modes by the dye very significantly changes the statistical properties of the laser pulse, and increases the temporal peaks of the laser intensity.

In conclusion, it seems that the multiphoton ionization probability for xenon atoms with a Nd-glass laser pulse is $g^{(k)}$ times as large as that obtained when the excitation source is an ideal single-mode laser pulse. Thus, in comparing calculated and experimental multiphoton ionization probabilities, a $g^{(k)}$ correction factor has to be applied when experimental results are obtained with a multimode laser pulse.

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Measurement of *S-P* Coherence in the Beam-Foil–Excited $n = 2$ State of Atomic Hydrogen*

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The intensity of beam-foil–excited Ly-α radiation has been measured in electric fields alternately parallel and antiparallel to the beam. Measurements were made at three energies—110, 165, and 210 keV—and three field strengths. From these data the *S-P* coherence term σ_{SP} has been determined. The magnitude of σ_{SP} is found to be 0.07 at 110 keV, 0.19 at 160 keV, and 0.22 at 210 keV. These results establish that beam-foil–excited hydrogen atoms have a nonzero electric dipole moment.

Since the observation by Bashkin and co-workers[1,2] and by Sellin *et al.*[3] of electric-field–induced modulations in the time decay of beam-foil–excited hydrogen atoms, the study of modulated decays has proved to be of considerable importance in the field of beam-foil spectroscopy. In particular, the discovery of zero-field quantum beats by Andrä,[4] indicating that foil-excited atoms are frequently aligned, prepared the way for the introduction of a large number of high-resolution techniques into the field of beam-foil spectroscopy. Essentially, the excited atoms must possess a nonzero quadrupole moment $\langle 3L_z^2 - L^2\rangle$, where $\vec{L}$ is the orbital angular momentum, in order to observe the zero-field beats. Measurable modulations have now been observed for a variety of beam-foil–excited transitions in light atoms, and the coherence implied by $\langle 3L_z^2 - L^2\rangle \neq 0$ is now well established as a significant feature of the excitation process.

Early discussions[5] of beam-foil–excited atoms recognized that another type of coherence, namely coherence between states of different orbital angular momentum L but with the same M_L, could produce observable modulations in atomic hydrogen. Two types of coherence may be distinguished, that involving states of the same parity, for example, S-D coherence, and that involving states of opposite parity, for example, S-P coherence. Even-parity coherence results in zero-field modulations of transitions from $n \geq 3$ to $n \geq 2$ levels. Such coherence has been observed by Burns and Hancock.[6] At present their measurement of the S-D coherence term represents the only reported observation of $\Delta L \neq 0$ coherence in beam-foil–excited atoms. Their results seem well established, however, since the S-D coherence term they measure is quite large.

In contrast to even-parity coherence, odd-parity coherence has observable effects on the intensity of decay radiation only when the hydrogen atom decays in an external field which mixes even- and odd-parity states. Eck[7] has pointed out that it should be possible to observe such coherence by comparing the radiation intensity I_+, observed when the electric field E is parallel to the beam velocity $\vec{v}$, with the intensity I_- observed when $\vec{E}$ is antiparallel to $\vec{v}$. Eck shows that, in a weak-field perturbation treatment of Ly-α radiation, the difference $I_+ - I_-$ is proportional to the S-P coherence term. This could then provide a sensitive probe for $\Delta L \neq 0$ coherence.

In addition to directly probing the $\Delta L \neq 0$ coherence, observation of $I_+ - I_- \neq 0$ would be important because it would indicate that the foil-excited hydrogen atoms have an electric dipole moment along $\vec{v}$. The sign of the moment indicates whether the electron charge distribution is predominantly pointing toward or away from the foil, a piece of potentially important information for understanding the foil excitation mechanism. Equally important, however, is the possibility that application of an electric field $\vec{E}$ perpendicular to the dipole moment rotates the dipole, thereby orienting the originally unoriented atoms.[8] Here an atom is said to be oriented if the average of the electronic angular momentum $\langle\vec{J}\rangle$ over a group of atomic eigenstates, in this case the $n=2$ eigenstates, is nonzero.[9]

This result may be easily seen from the equation of motion $\dot{\vec{J}} = e\vec{E} \times \vec{r}$ for the electronic angular momentum $\vec{J}$ of a hydrogen atom in an electric field. If observations establish that the mean dipole moment $e\langle\vec{r}\rangle$ is nonzero, then beam-foil excitation in conjunction with electric fields can produce an oriented beam. Normally, foil-excited atoms are partially aligned, but unoriented.[10]

Ordinary beam-foil experiments with side-on detection geometry were performed using proton beams of energy 110, 160, and 210 keV and currents of 3 μA directed through 3-μg/cm^2-thick self-supporting carbon foils 3 mm in diameter at pressures below 10^{-5} Torr. The foil holder was grounded and used as one electrode to apply electric fields of 220, 295, and 370 V/cm parallel and antiparallel to the beam. Ly-α photons were detected by a Channeltron multiplier with a MgF_2 window. The beam section viewed by the tube was defined by two vertical slits with a full width at half-maximum of 0.8 mm, thus averaging over oscillations due to fine structure in the $n=2$ level. The detection efficiency is assumed to be independent of polarization.

To assure a highly homogeneous electric field parallel to the beam, intermediate potential plates connected to a resistor chain were inserted and the entrance slit of the detection system was put at the same potential as the beam section viewed by using a second resistor chain.

Only foils showing little or no wrinkles after floating have been used. A new foil was used for each 1-h run during which the polarity of the electric field was changed in the order I_-, I_+, I_+, I_-, while a typical foil lifetime under the given conditions is 10 h. The first few minutes of foil exposure to the beam were not used for data taking. After a preset charge was collected in a Faraday cup the foil together with the field electrodes was moved by one step of 0.2 mm relative to the detection system.

The result of one run at 110 keV and 295 V/cm is shown in Fig. 1. Shadowing by the foil holder is apparent in the initial part of the curve. Expressions for $I_+ + I_-$ and $I_+ - I_-$ as functions of time have been derived neglecting hyperfine structure, and using previously measured values for the ratio[11] $\sigma_{P_1}/\sigma_{P_0} = 1.1$ and the ratio[12] $\sigma_S/\sigma_{P_0} = 4.0$, where the subscripts 0 and 1 refer to the m_L quantum numbers for the P states. The Stark effect has been taken into account by numerically diagonalizing the energy matrix. In the fields used here the perturbation approach of Eck does not apply; however, it can be shown quite generally that $I_+ - I_-$ is proportional to the magnitude of the S-P coherence term σ_{SP}.

The data were added and subtracted to give I_+

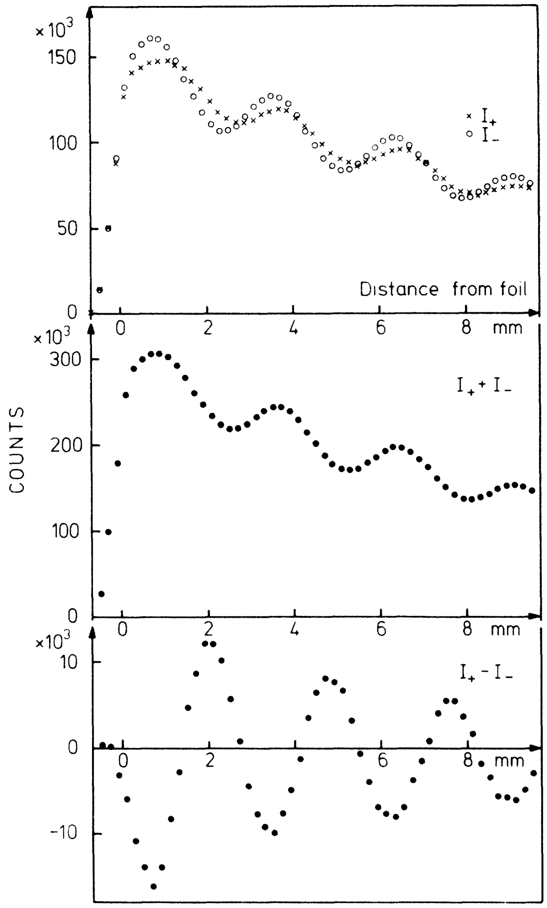

FIG. 1. Stark beats in hydrogen Ly-α radiation for field parallel, I_+, and antiparallel, I_-, to the beam at 110-keV H^+ energy and 295 V/cm electric field strength. Statistical errors in the I_+, I_-, and $I_+ + I_-$ curves are less than the size of the symbols used. Statistical errors in the $I_+ - I_-$ curve are of the order of 10%. The curves exhibit shadowing by the foil holder near the 0-mm position.

$+I_-$ and $I_+ - I_-$. These curves were fitted with the function $A\exp(-\gamma t)[1+B\cos 2\pi\nu(t-t_0)]$ by a weighted least-squares method; for $I_+ - I_-$ the cosine was replaced by the sine. Since this is not the correct expression, which would contain three exponentials and an oscillating term, the values for σ_{SP} are only approximate. Comparing with the theoretical expression for $I_+ + I_-$, which is independent of σ_{SP}, gives agreement within 20% for the modulation depth, justifying the applied procedure. From the overall normalization relative to $I_+ + I_-$, and from the amplitude and phase of the fitted expression for $I_+ - I_-$, values for Reσ_{SP} and Imσ_{SP} were extracted. Here $2\sigma_{P1} + \sigma_{P0} + \sigma_S$ is normalized to unity.

TABLE I. Measured values of σ_{SP}.

H^+ energy (keV)	Reσ_{SP}	Imσ_{SP}	$\lvert\sigma_{SP}\rvert$
110	− 0.03	0.06	0.07
160	− 0.09	0.17	0.19
210	− 0.10	0.19	0.22

The obtained values show no dependence on field strength when corrected for the resolution function according to the calculations of Wittmann *et al.*[13] The results given in Table I are averages over the three different field strengths. Uncertainties are of the order of 30%.

The sign of Reσ_{SP} indicated that the electron is in front of the proton on leaving the foil. The overall displacement of the electron cloud relative to the nucleus is between $+0.2a_0$ and $+0.6a_0$, where $a_0 = 0.527\times10^{-8}$ cm is the Bohr radius.

Our measurements effectively complete the determination of the density matrix for foil-excited hydrogen for the three energies used here. It is instructive to write this matrix explicitly for one particular energy. For 210 keV the $n=2$ density matrix σ_{ij} $(i,j=S,P1,P0,P-1)$ is

$$\sigma = \begin{pmatrix} 0.56 & 0 & 0.22e^{2.06i} & 0 \\ 0 & 0.15 & 0 & 0 \\ 0.22e^{-2.06i} & 0 & 0.14 & 0 \\ 0 & 0 & 0 & 0.15 \end{pmatrix}.$$

The maximum value that $\lvert\sigma_{SP}\rvert$ can have is $(\sigma_S \times\sigma_{P0})^{1/2}$ which equals 0.28 on the basis of previously measured values for σ_{P0} and σ_S. We see that σ_{SP} equals 0.22 at 210 keV showing that the S-P coherence is very nearly as large as it can be. This is consistent with the similarly large S-D coherence observed by Burns and Hancock.[6]

In summary our measurements establish the presence of significant S-P coherence in the beam-foil–excited $n=2$ state of hydrogen. In view of this positive result, further investigations of orientation of beam-foil–excited hydrogen atoms induced by fields perpendicular to $\vec{v}$ should be feasible. Quantities sensitive to orientation include circular polarization of decay radiation, spin polarization of hydrogen atoms, and proton spin polarization. Since our work was completed, essentially similar but less completely analyzed measurements have been reported by Sellin *et al.*[14]

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Observation of Electron Spin Resonance of Negative Ions in Liquid Helium

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We have observed ESR signals of negative ions in liquid helium. The linewidth and g value have been measured. Electrons injected into helium by field emission from ferromagnetic tips are shown to be polarized. We propose a new technique for the measurement of electron spin polarization.

Excess electrons injected into liquid helium form a uniquely simple system which has been the object of extensive study over the past decade. The wealth of experimental data so far accumulated has been interpreted using the generally accepted model of the electron trapped in a helium void, a bubble of radius ~17 Å.[1] Such an isolated unpaired electron will form a two-level system when placed in an external uniform magnetic field, and transitions between these two states should be detectable by standard magnetic-resonance techniques. Such measurements probably would have been made long ago if it were not for the extremely low ion densities one can reasonably obtain because of space-charge limitations ($\sim 10^{10}$ spins/cm^3) and the predicted long spin-lattice relaxation times of this bubble state.[2]

This Letter reports the first measurements of a single, unsplit, ESR absorption line from negative ions injected into helium by field emission from both ferromagnetic (iron) and nonferromagnetic (tungsten) tips. Recent experiments have demonstrated that electrons ejected from ferromagnetic tips by field emission are polarized.[3]

Our spectrometer was a superheterodyne type operating in the K_u band. The pressure-sealed TE_{102}-mode rectangular cavity had special microwave chokes which prevented leakage of microwave radiation. They also provided support and electrical insulation for both an electrolytically etched metallic tip and a collector electrode. The collector served to focus the ion beam into the region of the maximum microwave magnetic field. Typical operating conditions were the following: negative 5000 V on the tip, positive 2500 V on the collector, tip current $I_t = 2.5\ \mu$A,