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PRODUCED BY PASSING PROTONS THROUGH THIN CARBON TARGETS

by

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MEASUREMENT OF THE $n=2$ DENSITY OPERATOR FOR HYDROGEN ATOMS PRODUCED BY PASSING PROTONS THROUGH THIN CARBON TARGETS

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Résumé. Nous avons mesuré les éléments du matrice d'excitation de l'état $n=2$ hydrogène après passage d'un cible mince de carbone aux énergies entre 20 et 1000 keV par nucléon.

Abstract. We report measurements of the $n=2$ density operator and the probability for $n=2$ production, for hydrogen atoms produced by passing 20 to 1000 keV protons through thin carbon targets.

A proton beam, collimated by a $3/16$ " collimator, passed through a grid used to monitor the beam current and then passed a second foil which was $1/4$ " in diameter. The grid sampled only the beam which would pass through the second foil, since the collimator was smaller than foil 2. The alignment of collimators and foils was verified by a darkened grid pattern which could be seen centered on foil 2 when it was held up to a light following a run.

The second foil was mounted upon a stainless steel field plate which measured $4" \times 2"$ and was machined to a tolerance of $.002"$. Two similar $1/8"$ stainless plates, containing $3/8"$ holes to pass the beam, were mounted downstream from the foil plate using $3/4"$ long plexiglass spacers located near the four corners of the plates. The foil plate was grounded and a voltage applied to the second and third plates via two resistors. The sole purpose of the third plate was to minimize the fringing field due to the hole in the second plate. We were able to reverse kilovolt potentials with a time constant of microseconds, and a digital voltmeter continuously monitored the potential difference between the foil plate and plate 2. We used electric fields of 140 and 250 volts/cm.

We measured the intensity of Lyman α photons emitted perpendicular to the beam axis, between the foil plate and field plate 2. More precisely, we measured the number of Ly α photons which passed through two vertical slits of width to allow a usable count rate and so that the high frequency fine structure interference oscillations would be averaged out, leaving only the Lamb shift interference oscillations as modified by the electric field. An EMR photomultiplier (model 541F-08-18) with a cesium telluride photocathode detected the $1215 \text{ \AA}$ Ly α photons with a quantum efficiency of about 5%.

A Ly α intensity measurement was made with an electric field parallel, $I(F, t)$, and antiparallel, $I(-F, t)$, to

the beam direction. The field plate assembly was then stepped up beam by approximately .11 mm, and the Ly α intensity measurements repeated.

Fig. 1. Unpolarized Ly α radiation intensity as a function of distance and time from the foil surface as observed during a measurement.

We measured the movement of the foil caused by the ion beam and the electric fields we applied, by

reflecting a laser beam from the foil's surface onto a screen. We found that reversing our electric fields changed the foil position by less than .04 mm, (about .4 of a channel). The ion beam moved the foil surface downbeam from the beam-off position by less than .16 mm. Although this limit is nearly 2 channels, we measured the foil position automatically during every run and hence were insensitive to small beam-induced displacements.

The hydrogen $n=2$ density operator has 16 independent components in general, assuming unpolarized spins. The axial symmetry of the beam-foil interaction about the beam direction (taken to be the positive z axis) requires that average values of all but the $q=0$ tensor components be zero. The reflection symmetry of the interaction in all planes which contain the beam axis, requires that the non-vanishing components be average values of tensors which transform identically under parity transformations and rotation of 180° about $\hat{y}$. As a result, the proton-target interaction produces a $n=2$ density operator for $t=0$, which has only the 5 non-zero components.

Fig. 2. The $n=2$ density matrix elements, normalized to unit probability for $n=2$ production, as functions of inverse velocity of the hydrogen atoms.

The results were fit directly to four of these five parameters using a non-linear least squares fitting program which is detailed elsewhere.¹ Included in this analysis are the finite time-resolution of the observing system, the hyperfine structure of the transition and effects of cascading. The alignment of the $2p$ state as defined by the ratio of the density matrix components ρ_{p0} and ρ_{p1} was taken from the measurements of Winter and Bukow.² The final results, consisting of average values of many measurements, for the five density matrix components are shown in Fig. 2.

We choose to show Fig. 2 in units of inverse velocity because any molecular phenomena would depend upon the time spent near the foil surface and, if present, would thus be periodic in $1/v$. The density matrix elements we plot are proportional to the tensor components of the density operator except for ρ_{2p0} and ρ_{2p1} . We plot these matrix elements rather than tensor components, because ρ_{2p1} is nearly constant over the measured energy range. The other striking feature of the measured density operator is the increased relative probability of $2s$ excitation at the highest energies. The vector components, ρ_{sp0}^R and ρ_{sp0}^I , indicate that the bound electron leads the proton and is moving faster, consistent with conclusions based upon earlier more qualitative measurements.

References

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1. G. Gabrielse, Ph.D. Thesis, to be published.
2. H. Winter and H. Bukow, *Z. Physik*, **277**, 27 (1976).
3. A. Gaupp, H. Andr, and J. Macek, *Phys. Rev. Lett.*, **32**, 268 (1974).