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ANGULAR DISTRIBUTION OF LYMAN-α RADIATION EMITTED BY H (2S) ATOMS IN WEAK ELECTRIC FIELDS

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H atoms in the 2S state are known to be metastable in a field-free region.[1] Application of an electric field perturbs the atoms, causing them to emit Lyman-α radiation and to decay to the 1S ground state. It is the purpose of this Letter to point out that the angular distribution of the radiation is isotropic and to examine the consequences of this conclusion for interpretation of certain electron-scattering experiments.

The electric-field-induced emission process can be considered as arising from a perturbation of the $2\,{}^2S_{1/2}$ state by the nearby $2\,{}^2P_{1/2}$ levels only. Since the $2\,{}^2P_{3/2}$ levels are energetically much farther away from 2S, their effect can be neglected. The effect of the perturbation of each $P_{1/2}$ level can be considered separately unless the coupling by the electric field is too strong, or unless there is accidental level crossing.[2] If one assumes that the latter condition is not present, the former can occur only if the perturbing matrix element V is comparable to the energy separation $h\nu$ between the $S_{1/2}$ and $P_{1/2}$ levels. Here $\nu = [E(S_{1/2}) - E(P_{1/2})]/h \sim 10^9$ cps; $V/h \sim ea_0E/h \sim 10^8$ cps for a typical laboratory quenching field of 50 v/cm, and the condition of weak coupling is well fulfilled.

Thus, it is only necessary to consider separately the angular distribution of the radiation emitted by an H atom in either of the two $P_{1/2}$ states. The well-known formulas[3] for the relative strengths of the π and σ lines give

$$I(\pi)/I(\sigma) = 4m^2/(J \pm m)(J \mp m + 1).$$

In the present case $J = \frac{1}{2}$, $m = +\frac{1}{2}$, and $I(\pi)/I(\sigma) = 1$. Thus the radiation is completely unpolarized and the angular distribution is isotropic.

Recently a controversy has arisen over the absolute magnitude of the cross section $\sigma(2S)$ for excitation of the 2S state of H by electron impact. Schultz and the writer[4] measured $\sigma(2S)$ from threshold (10.2 ev) to about 45 ev. The maximum value for $\sigma(2S)$ was $(0.35+0.05)\pi a_0^2$. Since the results depended primarily on normalization of the data to the Born approximation, the conclusions are unaffected by the present paper. A considerably less precise confirmatory absolute determination measured the number of photons emitted by electrostatic quenching. Since, in the latter experiment, the data were treated by assuming isotropic angular distribution of the photons, the conclusions of Schultz and the author rest unchanged.

Subsequently, Fite and co-workers[5] have measured $\sigma(2S)$ by comparing the intensity of photons emitted from quenched H (2S) atoms with the intensity arising from excited 2P atoms. [$\sigma(2P)$ had been measured previously by normalization to the Born approximation.] The measured $\sigma(2S)$ was consistently about one third of the results of Schultz and the writer over the common energy range. Fite et al. extended the observations to energies as high as 700 ev. Above 300 ev, the results agreed with the Born approximation. Fite et al. stated that this agreement was "thought to be undeniable evidence" for the correctness of the lower value for $\sigma(2S)$.

However, Fite et al. assumed 100% polarization of the radiation parallel to the electric field and perpendicular to the direction of observation. They multiplied their results by a factor of 2/3 to correct for anisotropy. According to the result of the present paper, this correction should not be made, since the radiation is isotropic. Thus the results of Fite et al. should be raised by 50%. This would bring their maximum cross section to $0.16\,\pi a_0^2$, in better agreement with the higher value of Schultz and the writer. Nevertheless, the disagreement is still substantial and exceeds the combined errors.

The most probable values of Fite et al. now exceed the Born approximation by 50% above 300 ev. Their results agree fairly well with a calculation by Marriott.[6] However, very recently Smith[7] has pointed out that the partial wave analysis of Marriott omitted important p- and d-wave contributions. When these and other terms are included, the calculations of Smith[7] are in disagreement with the results of Fite et al. The new theoretical results agree with the measurements of Schultz and the writer within the quoted experimental error.

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10-Mev PROTON REACTION CROSS SECTIONS FOR Cu^{63} AND Cu^{65}[†]

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Recently, Meyer and Hintz[1] have reported results obtained on the reaction cross sections, σ_R, for several nuclei (including Cu^{63} and Cu^{65}) with incident protons of 9.85 Mev. The results were obtained using the following relation for σ_R:

$$\sigma_R = \sigma(p,q) + \sigma(p,n), \qquad (1)$$

where $\sigma(p,q)$ is the sum of the (p,p') and (p,α) cross sections which they have measured, and $\sigma(p,n)$ is a weighted sum of (p,n) cross sections which others have measured.[2-5] The expression (1) for σ_R neglects contributions from proton capture and compound elastic scattering which are believed to be small at this energy. Other reactions including multiple particle emission are either energetically forbidden or greatly reduced by the Coulomb barrier.

These authors[1] find that the proton reaction cross sections they obtain using expression (1) are significantly larger than the optical model calculations obtained using parameters that fit proton elastic scattering and polarization measurements. This is a strong statement since, as they point out, the reaction cross sections obtained with (1) are always lower limits. They also find that the two copper isotopes Cu^{63} and Cu^{65} have considerably different reaction cross sections (845^{+92}_{-67} and 974 ± 76 millibarns, respectively). This is difficult to justify using optical model theory which predicts them to be nearly the same. They feel that this difference may not be real but rather due to large errors in the (p,n) measurements.

We have recently measured (p,n) cross sections for Cu^{63} and Cu^{65} using variable energy protons from the Livermore 90-in. cyclotron and detecting neutrons by a "long counter" technique previously described.[6] Targets were in the form of metallic foils approximately 1.5 mg/cm^2 thick.

We obtain (p,n) cross sections for Cu^{63} and Cu^{65} at 9.85 Mev (510 and 700 millibarns, respectively) which differ appreciably from the weighted sums (480^{+90}_{-65} and 819 ± 75 millibarns, respectively) used by Meyer and Hintz.[1] The estimated absolute error in these (p,n) cross sections is 7%. When these (p,n) cross sections are combined with the (p,q) cross sections of Meyer and Hintz[1] [measurements by Benveniste, Booth, and Mitchell[7] of this laboratory agree within the errors quoted with these (p,q) cross sections], we obtain for the reaction cross sections, σ_R, of Cu^{63} and Cu^{65}, 875 and 855 millibarns, respectively. These agree within a few percent as predicted by the optical model.

Our results were compared with a surface-absorption optical-model calculation of Bjorklund