formalism. This has enabled us to take an average over different parametrizations and obtain reparametrization-invariant results. Although the results are yet incomplete, they appear encouraging. I hope that some of the long-standing difficulties of the string theory may be resolved by this quantization method.

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Photodisintegration of ^{3}H

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Measurements of the two-body and three-body photodisintegration cross sections for tritium are reported. The measurements were done with monoenergetic photons, high-pressure gas samples, and neutron-multiplicity detection. Presently available theoretical calculations are not adequate to explain the results.

The study of the photodisintegration of the three-body nuclei is of fundamental importance to nuclear physics, since knowledge of these cross sections can throw light upon the nature of nuclear forces in nuclei by testing the application of theories of the nucleon-nucleon force to the structure of the simplest of many-body nuclei. We report here a simultaneous measurement of both the two-body and the three-body photodisintegration cross sections for ^{3}H; this is the first measurement of these cross sections across the energy region of their maxima.

Prior to this experiment, almost no experimental work had been done on the photodisintegration of ^{3}H, primarily because of the difficulties of handling radioactive tritium, but also because of the low cross sections involved. In fact, there have been only two previous measurements with incident photons: Bosch *et al.*[1] used fixed-energy monoenergetic photons and a low-pressure gas sample to measure $\sigma(\gamma,n)$ at three low-energy points and $\sigma(\gamma, 2n)$ at one point; and Kosiek *et al.*[2] used bremsstrahlung and a low-pressure gas sample to measure $\sigma(\gamma, d)$ above the peak of the cross section. There also was an early measurement of the capture cross section for 14.4-MeV neutrons by ^{2}H reported by Cerineo *et al.*[3] The two-body data of Refs. 1 and 2 are shown in Fig. 1.

The results of certain theoretical calculations are shown in Figs. 1 and 2. For ^{3}H(γ,n), the early results of Bosch *et al.*[1] are representative of calculations using an *ad hoc* Gunn-Irving bound state, assuming no final-state interaction, and combining several multipole contributions. The

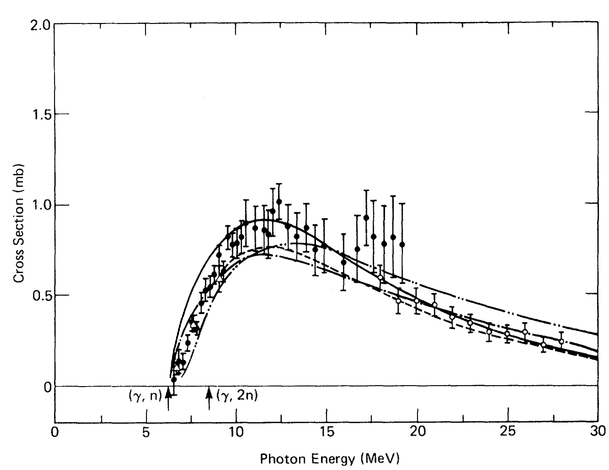

FIG. 1. Two-body photodisintegration cross section, for ^{3}H$(\gamma,n)^2$H: filled circles, present data; triangles, data of Ref. 1; open circles, data of Ref. 2; solid curve and dashed curve, Ref. 4; dash-dot-dash curve, Ref. 1; dash-dot-dot-dash curve, Ref. 5. The error flags indicate statistical uncertainties only. The arrows indicate the reaction thresholds.

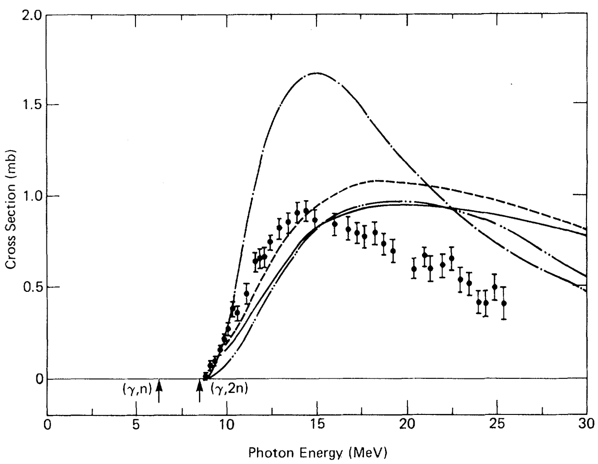

FIG. 2. Three-body photodisintegration cross section, for $^3H(\gamma, 2n)^1H$: filled circles, present data; solid curve and dashed curve, Ref. 6; dash-dot-dash curve and dash-dot-dot-dash curve, Ref. 7.

two results of Rahman, Sen Gupta, and Husain[4] were for the $E1$ transition using a modified Gunn-Irving initial state (whose parameters were fixed in a simple variational procedure) and a final-state wave function which reproduced the $l=1$ n-d phase shift data; there was no coupling to the three-body channel. The $E1$ results of Gibson and Lehman[5] were calculated using a complete Faddeev theory for the initial and final states and an s-wave separable-potential representation of the N-N interaction; a significant enhancement (over the plane-wave Born approximation) results from the transfer of cross section from the three-body breakup channel.

For $^3H(\gamma, 2n)$, Fig. 2 shows the hyperspherical-harmonics results of Vostrikov and Zhukov[6] using Eikemeier-Hackenbroich and super-soft-core potentials, and of Levinger and Fitzgibbon[7] using Volkov and V^x potentials. The hyperspherical-harmonics results are only for the $T=\frac{3}{2}$ component of the cross section; it is not yet understood how to handle (in this formalism) the mixed boundary condition required for the treatment of the $T=\frac{1}{2}$ coupled n-d and n-n-p channels. However, from the work on $^3He(\gamma, 2p)$ of Barbour and Phillips[8] or Gibson and Lehman,[9] it can be inferred that the $T=\frac{3}{2}$ part of $^3H(\gamma, 2n)$ should be about 90% of the complete cross section. Faddeev calculations for $^3H(\gamma, 2n)$ have not been published, and it is not appropriate here to attempt to adjust the $^3He(\gamma, 2p)$ results to compare with the present data because of the T_z dependence of the mixed-symmetry (S') state effects.

The general features, as well as many specific details, of the apparatus and procedures used for measuring photoneutron cross sections at Lawrence Livermore Laboratory (LLL) have appeared elsewhere in the recent literature.[10,11] The source of radiation was the annihilation-photon beam produced by fast positrons from the LLL electron-positron linear accelerator passing through a 0.76-mm-thick beryllium annihilation target. The photon beam was collimated by a series of three thick 9.5-mm-diam nickel collimators, and then allowed to pass through the high-pressure gas sample container located inside an efficient paraffin-and-BF_3-tube neutron detector. The photon-beam flux was measured by a cylindrical xenon-filled thin-walled ionization chamber, which in turn was calibrated against a large NaI photon spectrometer. This calculation was rechecked after the experiment; the old and new calibrations agreed to within 2%. This calibration of the absolute photon flux [together with the knowledge of the neutron detector efficiency and the other parameters of the experiment (see below)] makes the cross-section scale reported here independent of all other photoneutron cross-section measurements. The sample containers are stainless steel cylindrical tubes 1 m long and 2.54 cm i.d. with welded end caps whose window thickness is 0.76 mm. A sample container was mounted inside the secondary containment vessel, a large evacuated stainless steel tank, also with 0.76-mm-thick windows, capable of holding all the sample gas at less than atmospheric pressure. This secondary containment vessel in turn was moved into place inside the neutron detector (and its associated shielding). The alignment was checked *in situ* with the aid of x-ray photographs made with the primary electron beam from the linac. The 6.22-atom-mole tritium gas sample (about 200 000 Ci) was contained at a pressure of 16.92 MPa.

Background measurements with annihilation target in place were made before and after each data run, and background measurements during a delayed gate were made simultaneously with each data run. Beam-off background measurements also were performed, and the drifts of both the ionization chamber and neutron detector were checked at frequent intervals with standard ^{60}Co and Am-Be radioactive sources. No rapid drifts, erratic behavior, or unusual effects of any other kind were encountered during the course of the experiment. Neutron-yield measurements for all samples (see below) were made with electrons, as well as with positrons, incident upon the annihilation target. Neutron-yield measurements were made with an empty sample container as well.

The data-analysis procedures for this experiment were largely the same as have been developed and used for many other photoneutron measurements at Lawrence Livermore Laboratory.[11] Corrections to the data were made for pileup effects and for the various backgrounds and drifts. Neutron yields resulting from positron bremsstrahlung were subtracted with the aid of the data runs performed with incident electrons. Yields from the empty-sample runs then were subtracted, and the resulting net neutron yields per unit photon flux were ready for conversion into cross sections. The other factors necessary were the attenuation of the photon beam in passing through the sample (and windows), the functional dependence of the neutron-detector efficiency upon neutron energy and (for the gas samples) upon position along the beam line, and the effective number of atoms in the samples (see below). The photon attenuation was small and easily accounted for. The energy dependence of the detector efficiency is known well at the center of the detector,[11] and its position dependence was measured (for neutrons having an average energy of 2.1 and 4.2 MeV) with standard ^{252}Cf and Pu-Be neutron sources.

In order to determine the effective number of atoms in the ^{3}H sample intercepting the photon beam, three measurements using oxygen were made. The first was a new measurement of the absolute $^{16}O(\gamma,n)$ cross section done in the usual way[10,11] using a water sample. The results of this measurement, reported by Jury *et al.*, were found to agree very well with previous Livermore data[13] (except for a slight energy shift) and with more recent data from Giessen.[14] Next, the results of another water-sample oxygen measurement which was performed under the same (restricted) collimation condition as was used with the ^{3}H sample were normalized to these results; this determined the number of atoms in the beam (at the center of the neutron detector) for this collimation condition. Third, the results of a measurement using a high-pressure sample of oxygen gas were normalized to the water-sample data; this determined the effective number of atoms in the oxygen gas sample intercepting the photon beam. Finally, the effective number of atoms in the ^{3}H sample was computed from the ratio of the number of moles of ^{3}H and ^{16}O in the two gas samples, determined gravimetrically to high accuracy ($<0.3\%$). It should be emphasized that this procedure does not depend upon knowledge of the $^{16}O(\gamma,n)$ cross section, although the agreement of these new results[12] with previous data yields added confidence in the present results. It should be noted that because these oxygen data were taken over a significant range of photon (and neutron) energies, they serve to check that no strong energy-dependent systematic error is present.

The cross-section results for the present measurements also are shown in Figs. 1 and 2. The $^3H(\gamma,n)$ cross section (Fig. 1) rises sharply from threshold to a maximum value of about 0.9 mb at about 12 MeV, then decreases only slightly, to about 0.8 mb at 19 MeV. The rise is as steep as the data of Ref. 1, and the cross section at 18 to 19 MeV is somewhat higher than that reported in Ref. 2. None of the theoretical results in Fig. 1 can be excluded by the present data alone; however, it would appear that the addition of a tensor force to the separable-potential Faddeev calculation might improve the agreement with the data.[15]

The $^3H(\gamma,2n)$ cross section (Fig. 2) rises sharply from threshold [unlike the case for the three-body breakup of ^{3}He (see Ref. 16)] to a maximum

TABLE I. Integrated cross sections and moments.

Nucleus, reaction	$E_{\gamma\max}$ [a] (MeV)	σ_{int} (MeV mb)	σ_{-1} (mb)	σ_{-2} (mb MeV^{-1})
$^3H(\gamma,n)$ [b]	19.2	9.2	0.73	0.062
$^3H(\gamma,2n)$ [c]	19.2	6.9	0.48	0.035
$^3H(\gamma,2n)$ [c]	25.4	10.4	0.64	0.042

[a]The energy up to which the integrations are carried out.

[b]The statistical uncertainties are less than 4%; systematic uncertainties might be as large as 15%.

[c]The statistical uncertainties are less than 2%; systematic uncertainties might be as large as 10%.

value of 0.9 mb at about 14 MeV, then falls smoothly to about 0.4 mb at 26 MeV. The hyperspherical-harmonics calculations yield cross sections which appear either to peak at too high an energy or else to attain too high a peak value at the maximum, although it should be noted that the dash-dot-dash curve[7] is for a Volkov force with no spin dependence and never was intended to be compared with experiment.

The measured integrated cross sections and their first and second moments for the reactions $^3H(\gamma,n)$ and $^3H(\gamma,2n)$ are given in Table I. Up to a photon energy of 19.2 MeV, the values for the reaction $^3H(\gamma,n)$ are the larger.

We hope that these data stimulate the additional theoretical work necessary to understand these fundamental cross sections, particularly the three-body photodisintegration cross section, for which no presently available calculation is adequate.

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Quadrupole Moment of a High-Spin Yrast Trap in ^{147}Gd

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Static quadrupole interactions of three ^{147}Gd isomers in single crystals of hexagonal gadolinium have been observed. The quadrupole moments increase with increasing spin and imply a substantial (oblate) deformation ($\beta \sim -0.2$) for the 500-ns high-spin yrast trap.

The discrete yrast states with spins between $14\hbar$ and $36\hbar$ that have recently been observed in the neutron-deficient rare-earth nuclei ^{152}Dy (Ref. 1) and ^{154}Er (Ref. 2) exhibit a new kind of collective motion. Many individual particles align their angular momenta along the symmetry axis producing an oblate deformation. It had been predicted by Bohr and Mottelson[3] that the yrast energies of such nuclei, when plotted versus $I(I+1)$, should follow closely a straight line corresponding to an effective moment of inertia, $\mathcal{I}$, of about the rigid-body value. In ^{152}Dy, $\mathcal{I}$ exceeds $\mathcal{I}_{\rm rigid}$ by about 10%,[1] which may be taken as an indication that the valence particles induce a sizable oblate deformation of the core. Experimental attempts to verify this speculation have

