in samples of larger L because $N_q \propto nL$. We have estimated the values of n at which the deviation begins for the different samples and they are in reasonable agreement with the theory.

For the smallest sample, the values of the $F_\alpha^{(i)}$ are in the range for which the calculations carried out above apply. At the very highest fields it is found that j varies essentially as $E^{0.5}$. Since saturation should certainly have been obtained by these fields, this indicates that μ decreases essentially as $E^{-0.5}$, in agreement with the theory. Variation of μ as $E^{-0.5}$ under similar experimental conditions has been found previously for both n-Ge[3] and p-Ge.[4]

To test the predicted dependence of μ on L we note that at 50 V/cm, the ratio of current densities of the two smallest samples is 1.7, while the $-\frac{3}{4}$ power of the ratio of their transverse dimensions is 2.2. This is in reasonable agreement with the theory, particularly since for the larger of the two samples the $F_\alpha^{(i)}$ are large enough so that the dependence of Φ on L has some effect.

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*On leave from General Telephone & Electronics Laboratories, Bayside, New York.

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TWO-STEP RAMAN SCATTERING IN NITROBENZENE

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We have observed emission as a function of angle of coherent Stokes and anti-Stokes radiation from the nitrobenzene in the Kerr cell shutter of a Q-switched ruby laser. Careful measurements of the angular distribution of the three Stokes lines (S_1, S_2, and S_3) and one anti-Stokes line (AS_1) have allowed a clear-cut distinction between two possible mechanisms that could produce coherent anti-Stokes radiation—namely, a four-photon process and a two-step Raman scattering process. Our data can be explained in terms of the two-step Raman scattering process and is inconsistent with the four-photon model.

In the four-photon process, two laser quanta are annihilated with the emission of a phase-matched Stokes and anti-Stokes quantum. In the two-step Raman scattering process, the laser parametrically stimulates the emission of a distribution of Raman Stokes quanta and associated distributed optical phonons; this is followed by a secondary anti-Stokes Raman scattering process, the annihilation of both laser radiation and the appropriate optical phonons to create phase-matched anti-Stokes radiation. The first of these processes has been suggested by Terhune[1] to explain his observation of anti-Stokes rings in Raman scattering. The importance of the excitations of optical phonons in stimulated Raman emission was suggested by two of the authors[2]; and the two-step process for the creation of anti-Stokes radiation has been considered within the framework of a formalism similar to the optical-phonon picture.[3]

In our arrangement the sample is simply the nitrobenzene in the Kerr cell shutter of a standard Q-switched ruby laser with an external reflector. This contrasts with the earlier observation of Terhune, who focused the the primary laser beam on an external sample cell. The experiment consists of measurement of the angular distribution of three Stokes and one anti-Stokes lines that were observable with our system. The angular distribution results, obtained with a spectrometer and photomultiplier detector, are shown in Fig. 1. The significant features of the data are these:

(1) The first Stokes line (S_1) peaks up in the forward direction, and shows no other major peaks as a function of angle.

(2) The first anti-Stokes line (AS_1) does not

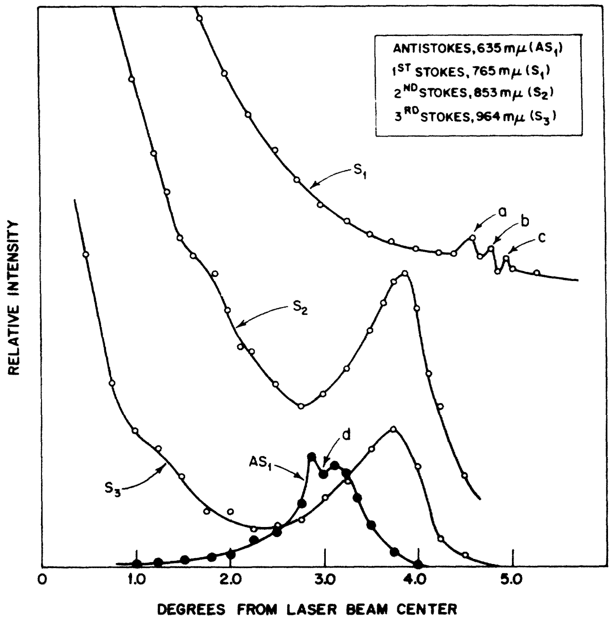

FIG. 1. Experimental angular distribution of the first three Stokes lines and first anti-Stokes line. The relative intensities are only roughly to scale. Fine structure *a*, *b*, and *c* on S_1 and the entire AS_1 curve have been drawn enlarged by approximately an order of magnitude in order to show detail. Data are not corrected for refraction at cell surface.

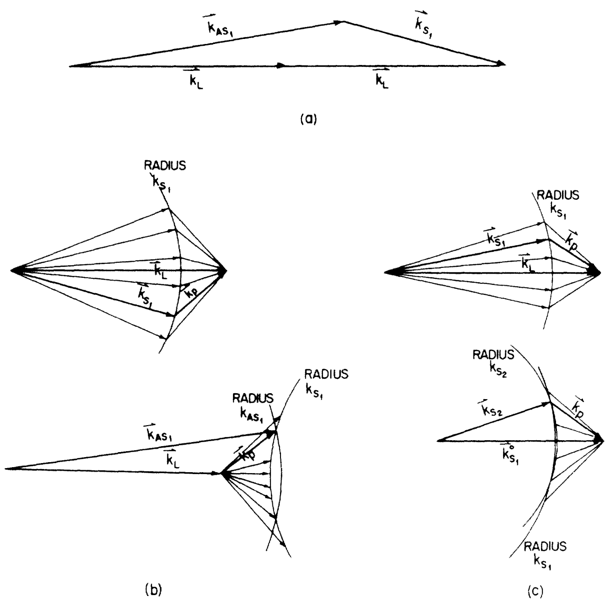

FIG. 2. Phase-matching conditions for (a) production of angularly peaked AS_1 by a four-photon process; (b) production of angularly peaked AS_1 by a two-step Raman process; (c) production of angularly peaked S_2.

peak up in the forward direction but does peak up at a well-defined angle.

(3) Stokes lines S_2 and S_3 peak up at well-defined angles in addition to the forward direction.

It is experimentally difficult to measure small variations in the signal because of random fluctuations in the primary Q-switched laser intensity and perhaps also fluctuations in the distribution of power into the different Raman modes. To show that a peak in intensity comparable to the AS_1 peak did not occur on the large background of distributed first Stokes emission, it was necessary to reduce the scatter in the S_1 data by a two-spectrometer balancing method. One spectrometer measured the angular distribution while the second one remained fixed in position; both were tuned to the S_1 line, balancing out fluctuations in S_1 intensity.

The explanation of the process for the production of the forward peaks of S_1, S_2, and S_3 has been discussed previously[4,2]; they result from a chain of stimulated Raman processes each shifted by a vibrational excitation of the nitrobenzene at 1344 cm^{-1}, due to the high-Q optical structure. The Stokes radiation away from the forward direction is produced by the parametric excitation of growing Stokes photon and optical-phonon waves,[5] and dies off with increasing angle because of the decrease of effective path length in the active region of the nitrobenzene.

The four-photon and two-step Raman process for the production of anti-Stokes emission are kinematically equivalent except for the intermediate presence of optical phonons. The four-photon process for production of AS_1 radiation must satisfy the phase-matching condition

$$\vec{k}_{AS_1} = 2\vec{k}_L - \vec{k}_{S_1} \tag{1}$$

[see Fig. 2(a)]. On the other hand, the corresponding two-step Raman process satisfies the coherence conditions,

$$\vec{k}_L = \vec{k}_{S_1} + \vec{k}_P, \tag{2a}$$

$$\vec{k}_L + \vec{k}_P = \vec{k}_{AS_1}, \tag{2b}$$

where $\vec{k}_{S_1}$ and $\vec{k}_P$ are the associated distributed first Stokes and optical-phonon $\vec{k}$ vectors [see Fig. 2(b)]. (The ω vs k of the optical-phonon spectrum is taken to be flat in this region.) The four-photon process requires the emission of S_1 radiation peaked in angle, superposed on the distributed S_1 emission, and of the same intensity as the AS_1 peak. On the other hand, the two-step Raman process requires the absorption of a distributed optical phonon for every AS_1 photon emitted, resulting in at most a small dip in S_1 at the matching angle due to a decrease in stimulated S_1 emission. The absence of an S_1 peak comparable in intensity to the AS_1 peak at the matching angle therefore demonstrates that the four-photon process cannot be the source of the AS_1 radiation. The small wiggles on the S_1 curve of Fig. 1 appear to be real but do not occur at the proper angle to be the matching peaks for AS_1. This fine structure and that on the AS_1 peak will be discussed below.

On the basis of two-step Raman scattering, a reasonable explanation for the angular peaks in the S_2 and S_3 emission can also be given. The S_2 peak is due to the process characterized by the phase-matching condition,

$$\vec{k}_L = \vec{k}_{S_1} + \vec{k}_P, \tag{3a}$$

$$\vec{k}_{S_1}{}^0 = \vec{k}_{S_2} + \vec{k}_P, \tag{3b}$$

where $\vec{k}_{S_1}{}^0$ is the k vector of S_1 radiation emitted in the forward direction [see Fig. 2(c)]. An additional process leading to the same phase-matching condition is

$$\begin{aligned}\vec{k}_L &= \vec{k}_{S_1}{}^0 + \vec{k}_P{}^0,\\ \vec{k}_{S_1} &= \vec{k}_{S_2} + \vec{k}_P{}^0,\end{aligned} \tag{4}$$

where $\vec{k}_P{}^0$ is the k vector of the forward-directed optical phonon accompanying the emission of $\vec{k}_{S_1}{}^0$. In the second steps of Eqs. (3) and (4), Stokes scattering takes place, stimulated by the presence of optical phonons produced in the first step. In a similar way, the S_3 angular peak is produced by the Stokes scattering of $\vec{k}_{S_2}{}^0$ from $\vec{k}_P$ and $\vec{k}_{S_2}$ from $\vec{k}_P{}^0$. It is interesting that the only likely process for producing a peak in S_1 comparable to those in S_2 and S_3 is the phase-matched anti-Stokes scattering of forward-directed S_2 quanta off the distributed optical phonons. This phase-matching condition is incompatible with that for the production of the S_3 peak.

The exact values of the S_2 and S_3 peak angles are exceedingly sensitive to the dispersion characteristic of nitrobenzene, which is not accurately known for wavelengths longer than the laser wavelength. Using the known values of the index of refraction[6] at the laser frequency and AS_1, and the measured peak angles of AS_1, S_2, and S_3, values for the index of refraction at S_1, S_2, and S_3 have been calculated (see Fig. 3). While the absolute values are not to be taken as accurate, the shape of this dispersion curve is similar to that of many materials which have dielectric anomalies in the ultraviolet and infrared; in fact, extrapolation from the available dispersion data in the visible region indicates the observed trend in the infrared.

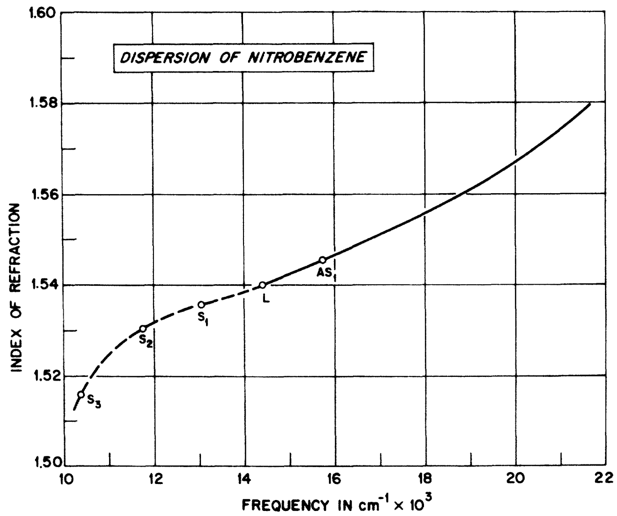

FIG. 3. Dispersion characteristic of nitrobenzene. Solid portion of curve is measured index of refraction; dashed portion is drawn through points calculated from angular peaks of AS_1, S_2, and S_3.

The following explanation of the fine structure a and b in Fig. 1 is consistent with the previously proposed model. The optical phonons emitted in process (3b) cause a small enhancement of stimulated emission of S_1 radiation in (3a) resulting in a phase-matched S_1 peak at a. The angles at which the S_2 and a peaks occur are consistent within experimental error with this explanation. Fine-structure peak b is associated in an analogous way with the phase-matched emission of S_3 radiation. c could similarly be associated with S_4 emission, but this has not been verified experimentally; while dip d could be the result of phase-matched depletion of the optical phonon or S_1 spectrum.

The optical phonons in the nitrobenzene that are excited by stimulated S_1 emission are analogous to optical phonons in solids. In a more general case such as a crystal containing ions, the Raman processes described could still occur, with a polarization wave associated with ionic excitation replacing the optical phonons of nitrobenzene.

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INTERMEDIATE STRUCTURE IN THE ENERGY DEPENDENCE OF NUCLEAR CROSS SECTIONS*

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Low-energy, low-resolution neutron scattering experiments exhibit a well-known broad resonance structure. It is commonly assumed that as the energy resolution improves one will see additional structure only when the experiment is able to resolve the sharp resonances characteristic of the compound system. However, there is growing evidence for the existence of an intermediate structure which is observed on all target nuclei. The most striking illustration is recent high-resolution data[1] on total neutron cross sections over the full range of target mass values for neutron energies from 2.5 to 15 MeV. These data show regular oscillations with characteristic widths of 100 kilovolts and separations of 300 kilovolts at all mass values for energies up to about 8 MeV. Similar structure has been seen in elastic scattering[2] and in other processes such as (p,p') and (α,p) reactions.[3] In this note we wish to argue that this intermediate structure can be interpreted in terms of the excitation of particularly simple configurations of the compound system and to suggest that this be exploited for nuclear structure studies.

In describing resonance processes in nuclear reactions it has been customary to consider two limiting situations. In one limit one attempts to describe nuclear processes observed in low-resolution experiments which average over many resonances of the compound system. The broad shape resonances that are observed experimentally can be understood in terms of single-particle excited states of the compound system and can be related to an energy-independent complex potential model. This implies that the interaction between the incident particle and the target nucleons is not so strong as to destroy all dependence upon the incident state and upon the gross properties of the target nucleus.

In the other limit the scattering process is described as passing through the actual states of this system as defined by suitable boundary conditions. The states of the compound system are numerous and, at excitations of about ten MeV or more, overlap considerably. The description of the scattering process which invokes these states of the compound nucleus has usually assumed a strong interaction between the incident particle and the nucleons of the target, but it is now recognized that this description is also compatible with a weaker interaction.[4]

Even in this description, however, there are expected to be fluctuations in the cross section at several MeV incident energy because of interferences between neighboring compound states.