In Fig. 3, the inverse of laser power necessary to achieve stimulated scattering is compared to the calculated Stokes gain[6] which is a function of the polarizability matrix element for the transition, the population difference between the transition levels, and the transition linewidth. Because the linewidths of the transitions have not been measured with sufficient resolution, they are considered as an adjustable parameter to fit the threshold data. Reasonably consistent agreement can be achieved by assuming that the vibrational transitions for even J had linewidths a factor of 2 larger than all other transitions.[7]

The rotational Raman transition $S_0(0)$ has also been stimulated in hydrogen (1 atm, 80°K) using a laser beam of either linear or circular polarization. Because in both D_2 and H_2 the vibrational transitions were always stimulated when the laser was plane polarized, it was not possible to measure the polarization dependence of threshold power for the rotational transitions.

During these and other studies, large pulses of Stokes radiation were observed in the reverse direction. The time duration of these pulses were instrument limited (<1 nsec) while the forward Stokes radiation followed the modulation in the laser source (~4 nsec). The ratio of peak powers front to back varied with experimental conditions, but was typically 3:1 for both the rotational and vibrational lines. Stimulated Brillouin scattering was neither expected nor observed during these experiments.[8]

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REFLECTION OF ATOMS FROM STANDING LIGHT WAVES

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It was predicted in 1933 by Dirac and Kapitza[1] that electrons could undergo Bragg reflection from standing light waves. This phenomenon of electron-wave scattering is analogous to the ordinary scattering of light waves by periodic structures such as diffraction gratings and crystals. Recent interest[2] has been stimulated by the increased possibility of observing the effect using the intense light beams now available as a result of laser technology.

We wish to point out that Bragg reflection by standing light waves is not restricted to electrons, but should occur for all particles capable of scattering photons, including neutral atoms. The Dirac-Kapitza analysis results in the expression for the scattering probability per unit length k of the electron traversing the region occupied by the standing waves,

$$k=\frac{4\pi^3 n^2 c^4}{\omega^2 \gamma v}\frac{d\sigma(\pi)}{d\Omega}, \tag{1}$$

where n is the photon number density, ω is the angular frequency, γ is the spectral width of the electromagnetic radiation, v is the electron velocity, and $d\sigma(\pi)/d\Omega$ is the Thomson differential cross section for backscatter of a photon by a free electron. Although the original analysis and all of the subsequent references have been concerned explicitly with electrons, it is of considerable interest to note that the same analysis applies regardless of the nature of the incident particle. Equation (1) remains valid provided only that $d\sigma(\pi)d\Omega$ be interpreted as the differential cross section for backscatter of a photon from the particle in question.

Dirac and Kapitza regard the standing wave as a superposition of two traveling waves. The essence of their analysis is then the computation of the stimulated backscatter rate, viz., that corresponding to scattering a traveling-wave photon from a mode associated with one propagation direction into the mode associated with the opposite direction. Because photons obey Bose statistics, this rate is proportional not only to the radiation density in the mode from which the photon is absorbed, but also to the radiation density in the mode into which the photon is emitted.[3] It is to be emphasized, however, that this proportionality to the photon density in the final-state mode is a consequence of only the Bose statistics obeyed by the photons, and is independent of the nature of the scatterer. It is for this reason that the Dirac-Kapitza analysis is directly generalizable from electrons to arbitrary scatterers.

Equation (1) applies only if the Bragg condition is satisfied, i.e., the particle must be incident at an angle θ_B relative to the direction normal to the photon-propagation vector. The Bragg angle is given by $\theta_B = \hbar\omega/Mcv$, where M is the particle mass. The particle is deflected through an angle $2\theta_B$; however, if the Bragg condition is not satisfied, there is essentially no scattering.

As an illustration of the magnitude of the effects, let us consider the scattering of a neutral atom of atomic mass of about 20 and kinetic energy of 1 eV. We shall choose the radiation frequency to be that appropriate to a ruby laser ($\omega = \pi \times 10^{15}$ sec^{-1}), a power density of one megawatt per cm^2, and a typical cavity loss rate γ of 10^7 sec^{-1}. For the back-scattering cross section, $d\sigma(\pi)/d\Omega$, we choose a typical value of 10^{-28} cm^2 corresponding to Rayleigh scattering. It should be observed, however, that $d\sigma/d\Omega$ for atoms is strongly frequency dependent, and at or near resonances can be many orders of magnitude larger than the value for Rayleigh scattering. For the numbers we have chosen, the deflection angle is quite small, namely, $2\theta_B = 2\times 10^{-5}$ rad. However, the interaction is quite strong; the scattering probability per unit length is $k = 6.2$ cm^{-1}, and, as we have just indicated, it can be enormously greater near a resonance. This strong interaction suggests that a large net scattering angle may be attainable with a succession of individual Bragg scatterings by an appropriate arrangement of successive standing-wave cavity orientations.

Finally, it should be mentioned that the above reasoning can be readily extended to multiple-photon events. That is, to every N-photon scattering process occurring in free space there corresponds an N-photon stimulated scattering process for which the Bragg angle is $N\hbar\omega/Mcv$, the scattering angle is $2N\hbar\omega/Mcv$, and the scattering probability per unit length is proportional to the $2N$th power of the photon density n^{2N}.

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