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OBSERVATION OF STIMULATED COMPTON SCATTERING OF ELECTRONS BY LASER BEAM*

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We have observed the scattering of electrons by standing light waves and believe our experiment represents the first direct observation of stimulated Compton scattering, a phenomenon predicted by Kapitza and Dirac in 1933.[1] Kapitza and Dirac proposed that a standing light wave with periodic maxima of photon density could serve as a diffraction grating for an electron beam. The prediction that Bragg's law,

$$n\lambda_{\mathrm{el}} = 2(\lambda_{\mathrm{phot}}/2)\sin\theta,$$

should be satisfied follows either from a simple wave picture or from the following quantum picture. As a suitably aimed electron passes through the Bragg planes of the standing wave from a vertical reflector, it may absorb a photon. Stimulated emission at 0° or 180°, induced by the incoming or outgoing wave trains, leaves the electron with a horizontal change in momentum of 0 or $2h/\lambda_{\mathrm{phot}}$. These possibilities correspond to zero-order or first-order Bragg reflections. For a single scattering it can be shown that both the wave and particle pictures rule out higher order reflections.

In contrast to ordinary Compton scattering in which electrons recoil in arbitrary directions with a collision probability proportional to the first power of photon density, the stimulated Compton effect induces directed recoils with a probability increasing with the square of photon density. At conventional intensities ordinary scattering predominates, but inside our laser cavity, according to calculation, stimulated scattering exceeds ordinary scattering by several orders of magnitude.

In our experiment a beam of 1.65-kV electrons was passed through the cavity of a 30-J Korad ruby laser equipped with 99.9% reflecting external mirrors. This arrangement made it possible, even without Q spoiling, to work with enormously higher photon densities than are obtained from normal laser outputs. The electron beam was passed through the laser beam at right angles, and scattering angles were measured by scanning the electrons past the slit of a scintillation detector.[2] Since the scattering angle 2θ is only 10^{-4} radian, the problem of collimating the beam and preserving its quality during the laser discharge is not trivial. In our apparatus it was possible to reduce disturbances to a small fraction of 2θ during a given scan of the beam.

We have consistently observed the recoil of a surprising fraction of the electron beam in over 200 laser bursts. The effect does not occur during laser activity if a narrow metal strip is placed in the laser cavity so as to cast a shadow along the electron beam. The effect reappears if the metal strip is rotated about the laser beam axis so that its shadow no longer masks the entire electron beam. This and other evidence would seem to eliminate the possibility that the observed electron deflections were spurious rather than a result of direct electron-photon interactions. Typical oscilloscope traces illustrating the effect are shown in Fig. 1.

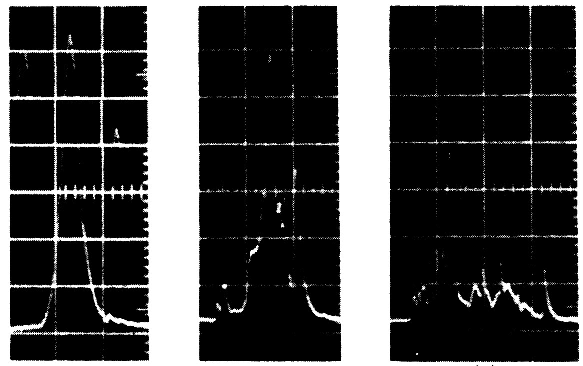
A conservative estimate of individual spike intensities inside our laser cavity is 10^{14} to 10^{15} erg-sec cm^2. According to the relation of Kapitza and Dirac, this is enough to deflect most electrons, provided the inhomogeneity of wavelength of the laser photons is no greater than that usually reported and provided the angle of incidence is correct. This intensity still is far short of that required to produce an observable effect in our apparatus by ordinary Compton scattering.

Unfortunately, it has not yet been possible to make unequivocal measurements testing whether scattering angles follow Bragg's law accurately. Our apparatus at the present time does not measure time and electron scattering angles independently. The signals showing depletion of the main beam and the appearance of the scattered beam correspond to angles (and hence to scanning times) which are dictated by the haphazard occurrence of very strong laser spikes. Electron intensities are no doubt modulated by the Bragg interference condition, but the laser spikes are too random and brief to permit sensitive tests with the individual patterns we observe. The angular distribution of our electron beam is sharp enough to allow resolution of 10^{-4} radian under favorable conditions, but the breadth of the beam at its foot is comparable to the expected Bragg deflection.

Perhaps the most interesting observation is the remarkably high probability with which electrons are deflected by the stronger laser modes. Indeed, the main electron beam is often so severely depleted at irregular but close intervals that it is impossible to recognize its center. Electrons are thrown out to angles corresponding to diffraction orders of four or more, indicating momentum exchanges with four or more photons. Although there is no evidence that the Laue interference condition

$$\lambda_{el} = (\lambda_{phot}/2)(\sin\theta_{inc} + \sin\theta_{refl})$$

is violated, it is evident that the more strict Bragg condition (with $\theta_{inc} = \theta_{refl}$) is not rigidly adhered to.



(a) (b) (c)

FIG. 1. Contour of electron beam: (a) during flashtube discharge with laser cavity blocked; (b), (c) during laser pulse. Oscilloscope sweep 0.067 m/cm. Electron-beam sweep past detector slit equivalent to 10^{-4} rad/cm.

Kapitza and Dirac[1] derived a probability for the stimulated effect from the known cross section for ordinary Compton scattering by identifying the ratio between the two probabilities with the ratio between Einstein's coefficients for stimulated and spontaneous emission. An essentially identical equation for the probability can be derived by calculating the perturbing effect on an electron wave of the term $(e^2/2mc^2)|\vec{A}|^2$ in the Hamiltonian operator for an electron in a classical radiation field.

Our apparatus is being modified to permit more definitive tests of the relation of Kapitza and Dirac. It is planned to describe experimental details, potential applications, and the results of our alternative perturbation approach in forthcoming papers.

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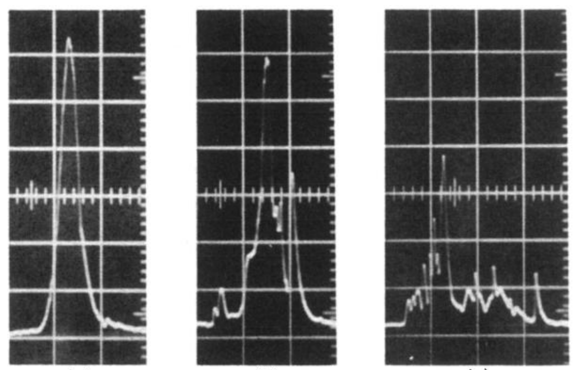
[1]P. L. Kapitza and P. A. M. Dirac, Proc. Cambridge Phil. Soc. 29, 297 (1933).

[2]T. E. Everhart and R. F. M. Thornley, J. Sci. Instr. 37, 246 (1960).



(a) (b) (c)

FIG. 1. Contour of electron beam: (a) during flash-tube discharge with laser cavity blocked; (b), (c) during laser pulse. Oscilloscope sweep 0.067 m/cm. Electron-beam sweep past detector slit equivalent to 10^{-4} rad/cm.