In view of the above results, we did not compute CI effects in higher excited states. Going back to Eq. (4), we see that $\rho$ must be very near 1, even when all discrete states are included. We conclude that the experimental results remain in disagreement with the Weinberg-Salam theory.

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## Electron Acceleration during Resonant Absorption

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When an oscillating electric field is applied along a plasma density gradient, an enhanced field is resonantly excited where the electron plasma frequency approximately equals the frequency of the applied field. The measured, time-averaged distribution function of the electrons accelerated by the enhanced field in a plasma-filled capacitor includes a high-energy component that agrees with calculations.

When a temporally oscillating electric field is applied along a plasma density gradient, an enhanced electric field is resonantly excited in the region where the electron plasma frequency is approximately equal to the frequency of the applied field. Recent studies of this phenomenon, resonant absorption, include experiments at microwave[1-3] and optical frequencies.[4,5] The resonant localized field accelerates electrons in the directions parallel and antiparallel to the plasma density gradient, and particular interest has been focused on the energy carried by the fastest electrons, since it may impede the laser-produced compression of a pellet to a thermonuclear temperature and density.[6] Fast electrons were first noted in the microwave experiments of Wong and Stenzel.[2] More recently they have been observed in laser experiments.[4,5]

This Letter is a report of the first direct measurement of (a) the distribution function of electrons that are accelerated solely because of resonant absorption, and of (b) the dependence of the distribution function on the localized field parameters. The accelerated electrons constitute a high-energy component of the total distribution function, which falls off exponentially with increasing electron energy. The principal result of the experiments described in this Letter is that the exponential-decay constant of the distribution function at high energy depends linearly on the ratio of the field strength to the field width, as predicted by a simple model.

Figure 1 is a schematic drawing of the apparatus. The device is essentially the same as the one used by Kim, Stenzel, and Wong[1] to study the formation of resonantly excited, localized electric fields and density depressions ("cavitons"). An unmagnetized plasma with a density gradient ($n^{-1}dn/dx \approx 0.4$ cm$^{-1}$) is created by a multicathode discharge at one end of the vacuum chamber.

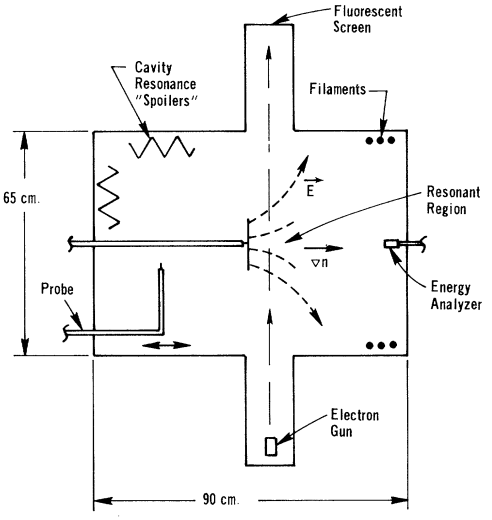


FIG. 1. Schematic drawing of the apparatus.

The temperature of the main body of electrons (contained by the plasma potential) is 2 eV, and the argon background pressure is $2\times10^{-4}$ Torr.

A 470-MHz signal (rf) is applied to the capacitor comprised of a 15-cm-diam plate and the vacuum chamber, so that the oscillating electric field has a component along the density gradient. As in a previous, low-field experiment,[7] the quasistatic field resonantly drives a 470-MHz localized electric field where the electron density is approximately $2.5\times10^{9}$ cm$^{-3}$ (1–2 cm from the plate). This field accelerates a low-density component of electrons in both directions along the density gradient. The electrons accelerated into the high-density region are sampled using a gridded, retarding-field energy analyzer located 40 cm from the plate. The measurements described here were made after the resonantly excited oscillations had reached constant amplitude, 50 $\mu$sec after the driving electric field is applied. Because the electron transit times through the experiment are less than the field decay time, the applied field is on during the measurements of the distribution function of accelerated electrons. Ionization by the rf is negligible.

Various tests show that the accelerated electrons come from the resonant region and are not, for example, (a) artifacts of an rf-produced change in the overall plasma properties or (b) accelerated by the nonresonant near fields of the capacitor plate. One check is that no rf-produced change in the current to the analyzer is observed when the maximum plasma density is less than required for resonance. Also, a small grid (5 cm diam, 80% transparency) was located several centimeters in front of the analyzer so that electrons accelerated from the resonant region could be reflected. Since the measured electron distribution function of the "test plasma" between the biased grid and the analyzer does not change when the resonant field is driven, (a) the background plasma at this end of the device is not disturbed by the rf, (b) the analyzer operation is not affected by the rf, and (c) the accelerated electrons come from the solid angle blocked by the grid.

Placing a thin probe (0.1 mm o.d.) at any point in the vicinity of the resonant region significantly changes the number of accelerated electrons collected in the analyzer. Consequqntly, all measurements of the electric-field strength and width were made by observing the deflection of a nonperturbing electron beam (8 keV, less than 0.1 $\mu$A, 1 mm diam) directed as shown in Fig. 1 and viewed on a fluorescent screen.[8,7,1] The maximum deflection (< 1 cm) is an average measurement of the field strength along part of the beam trajectory. The field profile, measured by deflecting the beam slightly at the electron gun, shows that the field is less than the resolution limit of 8 V/cm everywhere outside the resonant region. The measurements of the resonant field will be related to the measured fast-electron distribution.

Over the energy range of most electrons in the background plasma (< 20 eV) no effect of the rf on the distribution function is resolvable. Since a slow electron (with a transit time through the field that is many oscillation periods) encounters an effectively static ponderomotive potential,[9] its energy is unchanged. Faster electrons can gain or lose energy, depending on the phases of the field as they pass through. The small number of electrons that are accelerated in this way is represented in the data shown in Fig. 2. Because of the presence in the background plasma of primary ionizing electrons[10] with energies up to 45 eV, the difference between the time-averaged, steady-state currents to the analyzer with and without a signal applied to the capacitor is shown as a function of electron energy $W$. Data are shown for several values of the absorbed power, which depends on the oscillating voltage applied to the capacitor.

The current shown in the top curve of Fig. 2 corresponds to an electron component that is less than 0.01% of the density of the background plasma at the resonant location, and it carries a heat flux of 0.3 mW/cm$^2$ at the analyzer. To charac-

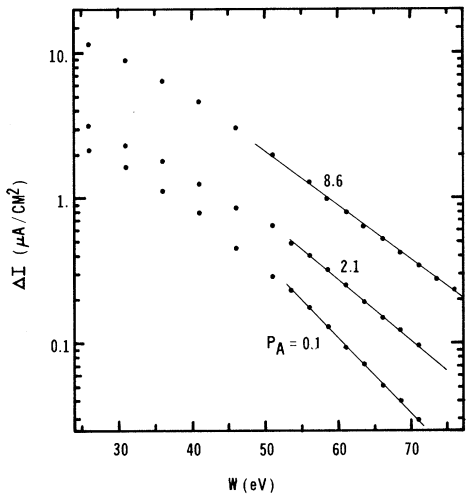


FIG. 2. Difference current density is shown vs electron energy for three values of total absorbed power $P_A$.

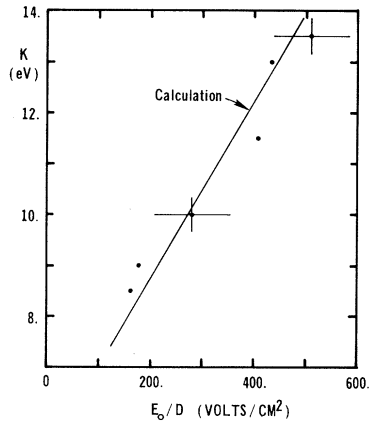


FIG. 3. Solid points show measurements listed in Table I (exponential decay constant of difference distribution for various values of field strength divided by field half-width). The line shows calculated results from Ref. 11, normalized to data using $\langle T\rangle = K_0 = 7.5$ eV.

terize the high-energy electrons, which carry most of the energy for field strengths characteristic of laser fusion, we note that above 50 eV the difference distribution $\Delta f$ [$\sim d(\Delta I)/dW$] can be approximated by the exponential decrease with energy shown as a solid line. [The logarithmic plot of $\Delta I$ is the most accurate presentation for determining the decay constant, but it can also be confusing. The decreasing slope of $\ln(\Delta I)$ at energies below 50 eV is in a region where $\Delta f$ is approaching an absolute maximum. Also, although $\Delta f$ has a beamlike maximum, the combined distribution function—dense background plasma plus the accelerated component $\Delta f$—has no local maximum at these high energies.] In Table I the decay constant $K$ [$\Delta f \sim \exp(-W/K)$] that fits the data is shown with the corresponding measured field strength $E_0$ and width $2D$ and the absorbed power $P_A$.

Figure 3 shows the principal new result of these experiments: $K$ is a linear function of the ratio $E_0/D$ over the range of $P_A$ studied. To corroborate this result, single-particle orbits were computed numerically in a one-dimensional model of the resonant electric field. The field profiles in these experiments are like those presented in Ref. 1 and are approximately Gaussian, $E(x,t) = E_0 \exp(-x^2/D^2)\sin(\omega t)$. By regarding the unheated distribution of electrons that are incident on the field as a collection of monoenergetic beams of test electrons, the time-averaged distribution function $\Delta f$ was found to have a decay constant that also increases linearly with $E_0/D$. Details of this calculation have been published elsewhere.[11] To compare the calculation and the data, the decay constant of the distribution function of resonant electrons incident on the field must be known. (The density of resonant electrons does not affect $K$.[11]) Because of the presence of primary (ionizing) electrons,[10] the incident electron distribution falls off as $\exp(-W/K_0)$, with $K_0 > 2$ eV for $W > 10$ eV. Since probe measurements near the resonant region are questionable, $K_0$ was determined to be 7.5 eV by fitting the calculation to the datum point at $K = 10$ eV in Fig. 3. [As might be expected because of the local heating, $K_0$ is approximately 20% larger than that measured with a probe before rf is applied. Also, although the calculated values of $K$ are linearly dependent on $E_0/D$ for the range of field parameters studied here, $K$ increases nonlinearly at very low values[11] of $E_0/D$, so that $K_0$ is not simply the extrapolated value of $K$ at $E_0/D = 0$.] The calculation (solid line) correctly predicts the

TABLE I. The decay constant $K$ extracted from the fit to the data for various absorbed powers $P_A$, field strengths $E_0$, and field widths $2D$.

| $P_A$ (W) | $E_0$ (V/cm) | $2D$ (cm) | $K$ (eV) |
|---|---|---|---|
| 0.1 | 57.0 | 0.72 | 8.5 |
| 1.0 | 62 | 0.70 | 9.0 |
| 2.4 | 84 | 0.60 | 10.0 |
| 4.4 | 74 | 0.34 | 13.0 |
| 8.6 | 118 | 0.58 | 11.5 |
| 11.0 | 143 | 0.56 | 13.5 |

slope of the data in Fig. 3.

In conclusion, this Letter reports the first direct measurement of the distribution function of electrons accelerated solely due to resonant absorption. These electrons constitute a very low-density, high-energy component of the distribution function, which falls off exponentially at high energy. The decay constant $K$ [$\Delta f \sim \exp(-W/K)$] increases linearly with the field strength to field width ratio of the localized resonant field. Calculations using a simple model of the field agree with these low-power experiments and suggest that the high-energy tail studied here is cut off at higher electron energies, falling off exponentially with the decay constant of the resonant electrons incident on the field. Higher-power experiments will resolve $\Delta f$ at higher electron energies to test this prediction.

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# Role of Rotational and Translational Local Modes in Vibrational Relaxation in Solids: A Study of NH and ND in Solid Ar

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A quantitative model for vibrational relaxation of impurity molecules in host crystals is presented, and applied to the vibrational relaxation of NH and ND in solid Ar. Realistic impurity-host interaction and impurity-cage geometry are employed. It is shown that impurity rotation is the dominant receiving mode in the relaxation, and only a small fraction of the energy released goes directly into phonon modes. The results explain the faster relaxation of NH compared with ND and the temperature independence of the measured decay rates.

The important recent progress in experimental studies of vibrational relaxation of impurity molecules in solids[1] led to observation of several interesting effects that could not be interpreted with existing theoretical models[2-5] in this field. Several difficulties arose: (1) It was found that deuterides generally relax more slowly than the corresponding hydrides [e.g., NH($A^3\Pi$, $v=1$) and ND in Ar [6]; NH($\chi^3\Sigma^-$, $v=1$) and ND in Ar [7]; $CH_3F$($v=1$) and $CD_3F$ in Kr [8]]. This result is in marked contrast with the theoretical prediction that the relaxation rate should decrease with an increase of the vibrational-energy gap.[2-5] (2) The experimental relaxation rates were found to be tempera-