stand why helium does not experience plasma resonance in the pressure range between 150 and 300 Torr, where a doubly ionized plasma would be resonant. Because of the factor 10 difference in ionization cross section[15] and the factor 2 difference in ionization potential between He and He$^+$, the avalanche ionization rate for the two species will be vastly different. Therefore a large cone-shaped region of singly ionized, slightly underdense, plasma will first form in front of the focal spot. This will defocus the light and prevent it from reaching a high intensity for a long enough time to produce the doubly ionized plasma. This reasoning does not apply to nitrogen and argon, because the difference in ionization cross section[16] between successive stages of ionization is much less.

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Propagation of Ion-Acoustic Waves in a Two-Electron-Temperature Plasma*

W. D. Jones, A. Lee, S. M. Gleman, and H. J. Doucet†
Department of Physics, University of South Florida, Tampa, Florida 33620

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The propagation of ion-acoustic waves (IAW) in a double-electron-temperature plasma is investigated both experimentally and theoretically. It is found that the presence of even a small fraction of the lower-electron-temperature component can dominate the behavior of the waves. The results have important implications both for the use of IAW as a diagnostic tool for measuring electron temperature and for the interpretation of turbulent IAW spectra.

In this paper, we examine the propagation of linear ion-acoustic waves (IAW) in a plasma whose electron velocity distribution may be represented by the superposition of two Maxwellians.[1] Such electron distributions are rather frequently encountered. For example, hot turbulent plasmas of thermonuclear interest often have high-energy tails; strong electron-beam–plasma interactions can result in such electron distributions; and very often, simple hot-cathode discharge plasmas also have double-electron-temperature distributions.[1,2] The latter type of plasma is used in the present study because it is steady state, quiescent, and the plasma parameters are easily varied over a fairly wide range.

When two groups of electrons at different temperatures are present, the Langmuir-probe current characteristic shows a distinct break in the electron-retardation region. An example is given in Fig. 1. The procedure for determining both the temperatures and the densities of the two electron distributions is well known.[1]

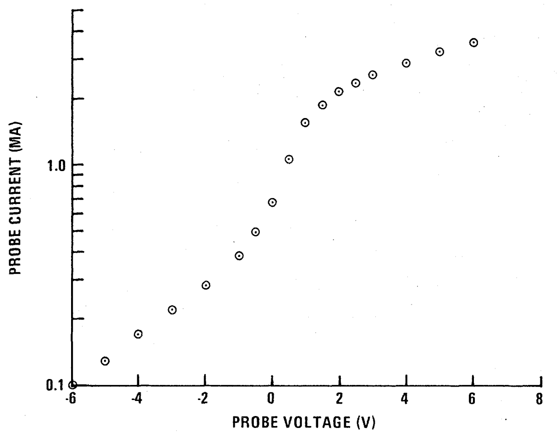

FIG. 1. An example of a Langmuir-probe characteristic for a plasma with a double-electron-temperature distribution.

Physically, one would expect IAW to be sensitive to the presence of another group of electrons with a different temperature, since, for plasmas having ions which are relatively cold compared to the electrons, the restoring force for IAW is provided by the pressure of the electrons. To see how the wave behavior is modified, it is necessary to calculate an "effective" electron temperature for the plasma. The calculation required is quite similar to the one for the one-electron-temperature case. For simplicity we use the fluid approach. This approach is well known and is found to provide the correct dispersion relation (except for collisionless damping, which is not of immediate interest here). We find theoretically that the IAW speed is more strongly influenced by the low-temperature electron component than by the high-temperature component, with the degree of domination by the low-temperature component becoming extreme as the two temperatures become far apart. Our experiments verify this result within the range of parameters available.

A brief outline of the calculation is presented below. The plasma is described by the one-dimensional multispecies fluid equations and Poisson's equation. They are

$$\partial n_s/\partial t + \partial(n_s v_s)/\partial x = 0,$$

$$\frac{\partial v_s}{\partial t} + \frac{1}{n_s m_s}\frac{\partial p_s}{\partial x} + v_s\frac{\partial v_s}{\partial x} = \frac{q_s}{m_s}E, \qquad (1)$$

and

$$\partial E/\partial x = (q/\epsilon_0)(n_i - n_{el} - n_{eh}),$$

where the subscript s refers to the species, l is for the low-temperature and h is for the high-temperature component, and the other symbols have their usual meanings. The validity of describing the electron components as two fluids is justified on the grounds that processes which produce such electron distributions have time scales much shorter than the relevant ion time scale. Equations (1) are linearized with the assumptions of no drift and that all first-order quantities vary as $\exp[i(kx - \omega t)]$. The following linear dispersion relation is found:

$$1 = \frac{\omega_{pi}^2}{\omega^2 - k^2 a_i^2} + \frac{\omega_{pel}^2}{\omega^2 - k^2 a_{el}^2} + \frac{\omega_{peh}^2}{\omega^2 - k^2 a_{eh}^2}, \qquad (2)$$

where a_s represent the respective rms velocities. This reduces to the usual linearized electrostatic-wave dispersion relation when only one electron temperature is present.[3] For IAW, we have $a_i \ll \omega/k \ll a_e$. Equation (2) may be reduced to

$$\omega/k = (\gamma K_B T_{\text{eff}}/m_i)^{1/2}, \qquad (3)$$

where

$$T_{\text{eff}} = n_e T_{el} T_{eh}/(n_{eh} T_{el} + n_{el} T_{eh}), \qquad (4)$$

k and K_B are the wave number and Boltzmann constant, respectively, and n_e is the total electron density. The expression given by Eq. (3) has the identical form of the one for a one-electron-temperature plasma, but with the effective electron temperature instead of the usual temperature of the single electron component. The effective temperature is seen to depend on both the temperatures and fractional densities of the two components.

To obtain a feel for the relative importance of the two electron groups for the IAW speed, we take a typical hot-cathode argon discharge plasma with $T_{eh} \sim 3T_{el}$, where $T_{el} \sim 1$ eV, and both groups are present in equal numbers. This gives $T_{\text{eff}} = 1.5$ eV, which is appreciably closer to the low temperature. As the temperature of the two components becomes further apart, the relative importance of the high-temperature component becomes even smaller. For example, if $T_{eh} \to \infty$ and n_{el}/n_{eh} is finite, the upper limit on the value which the effective temperature can assume is given by

$$T_{\text{eff}} = (n_{eh}/n_{el})T_{el}. \qquad (5)$$

Thus, even if the cold component makes up only 10% of the total electron density, T_{eff} cannot be higher than $10T_{el}$, regardless of how hot the other 90% of the electrons are!

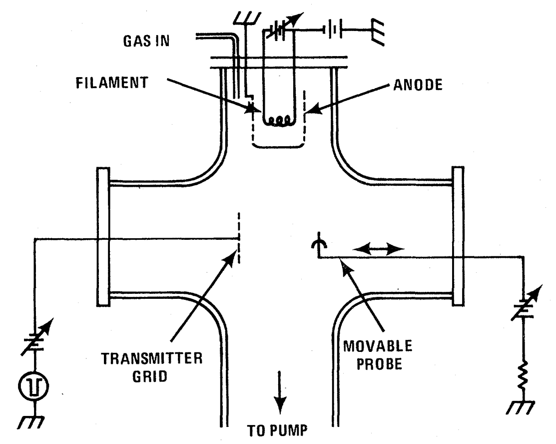

FIG. 2. Experimental apparatus for ion-acoustic-wave propagation studies.

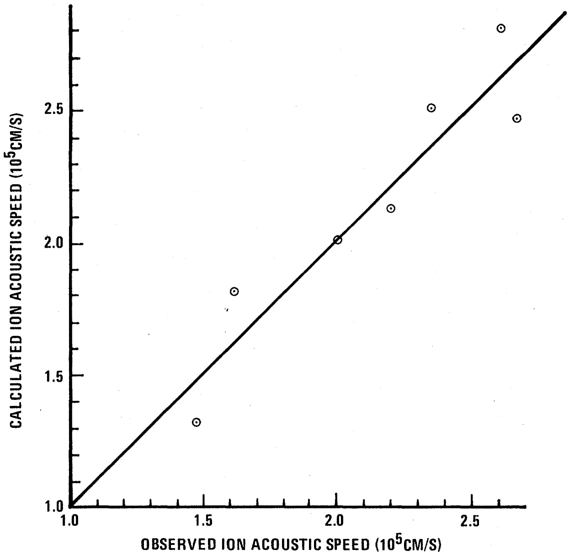

FIG. 3. Observed ion-acoustic speed versus that calculated from the effective electron temperature given by Eq. (4).

This result would seem to have important implications, for example, in the employment of IAW as a diagnostic tool in a hot-electron plasma which *might* have a cold component; or in the proper interpretation of the low-frequency IAW spectrum of a turbulent plasma having a low-temperature component; or in the utilization of IAW for ion heating by Landau damping, for example. In short, in any physical process or interactions where IAW play an important role, a small cold-electron component can be expected to have significant effects.

The experiment was performed in a weakly ionized, hot-cathode, discharge-type, quiescent argon plasma with typical densities between 10^8 and 10^9 cm^{-3} (see Fig. 2).[4] Plasma is created when energetic primary electrons from the filament have ionizing collisions with background neutral atoms. The plasma then diffuses into the center part of the glass cross to form a uniform region about 20 cm in diameter. Wave propagation takes place in this central region. The discharge conditions were varied to produce a wide range of variation of T_{eh}/T_{el} and n_{eh}/n_{el}.

IAW were excited by the application of a negative pulse to a planar copper grid immersed in the plasma.[5,6] A linear wave with $\delta n/n < 1\%$ was produced. A movable cylindrical probe detects the waves as they propagate through the plasma. A time-of-flight technique was used to measure the IAW phase velocity.[5,6] The results are summarized in Fig. 3. From the measured electron temperatures and densities of the two groups, an effective temperature is determined. The subsequently calculated IAW phase velocity given by Eq. (3) is plotted against the observed phase velocity. For perfect agreement, the slope of the curve should be 1. The solid line corresponds to the least-squares fit, and has a slope of 1.01. In our experiment, T_{eh}/T_{el} ranged from less than 2 to about 5, while n_{eh}/n_{el} ranged from about $\frac{1}{6}$ to 3. This gives a variation in T_{eff} of from less than 1 eV to almost 3.5 eV. Over this range, the agreement between theory and experiment is excellent.

With the range of variation of plasma parameters that can be readily obtained with our argon discharge plasma, we have verified the prediction of Eq. (3). We intend to test the theory over even wider ranges of T_{eh}/T_{el} and n_{eh}/n_{el}. The effect on the IAW dispersion by the low-temperature-electron group is overwhelming, even when this group represents only a small percentage of the total electron population. This effect may explain discrepancies observed between electron temperatures calculated from observed IAW speed and electron temperatures obtained by optical techniques which, in general, do not distinguish between the two groups of electrons with different temperatures. Furthermore, our results imply that a detailed knowledge of the electron distribution function is required for interpreting the turbulent IAW spectrum in hot turbulent plasmas. In summary, our results suggest that the presence of an electron group with a lower temperature has an important effect on IAW and waves in which electron pressure is the dominant restoring force.

A possible interesting application might be to use a cold-electron source to stabilize IAW instabilities via Landau damping due to the expected reduction of the wave phase velocity by the cold electrons. By the same token, such manipulation of the IAW dispersion by the introduction of a cold-electron component could lead to rapid ion heating due to preferential wave energy deposition into the ions.

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†Permanent address: Ecole Polytechnique, Paris, France.

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Temperature Dependence of the Far-Infrared Absorption Spectrum in Amorphous Dielectrics*

K. K. Mon, Y. J. Chabal, and A. J. Sievers
Laboratory of Atomic and Solid State Physics and Materials Science Center, Cornell University,
Ithaca, New York 14853
(Received 28 August 1975)

A study of the temperature dependence of the absorption coefficient in amorphous dielectrics below 10 cm^{-1} has enabled us to identify two level configurations from thermal population changes. We also find that the anomalous low-frequency modes in glasses consist of widely spaced manifolds of energy levels.

Measurement of the thermal properties of glasses at low temperatures has provided experimental evidence that anomalous low-frequency modes occur in amorphous materials.[1,2] The linear temperature dependence of the specific heat which occurs in glasses below a few degrees kelvin is interpreted as arising from these anomalous modes whose frequencies lie below 4 cm^{-1}. Both the nonlinear ultrasonic attenuation[3] around 0.1 cm^{-1} and the anomalous sound-velocity measurements[4] around 0.01 cm^{-1} at very low temperatures have established that the modes at those frequencies are very anharmonic and that the density of modes is consistent with the specific-heat measurements.[1,2] In addition to these special modes, Brillouin-scattering experiments[5] have shown that there are regular well-behaved transverse and longitudinal phonons in this frequency region as well. To account for these special modes a tunneling model has been proposed[6,7] in which atoms, ions, or groups of particles quantum mechanically tunnel between two or more equivalent sites. The linear dependence of the specific heat has been obtained from this model by including a statistical distribution of barrier heights and asymmetries for the local potential. One straightforward prediction which this model makes is that the temperature dependence of the far-infrared absorption coefficient should be determined by the occupation numbers of a small number of energy levels associated with the tunneling manifold. For example, a distribution of infrared-active two-level systems will produce an infrared absorption which decreases with increasing temperature in a well-defined way.

In this Letter, we describe the first measurements of the temperature-dependent absorption coefficient of amorphous dielectrics in the far infrared at frequencies between 2 and 10 cm^{-1}. We find the decrease in absorption expected for two-level systems in a restricted temperature and frequency range. Our more detailed measure-