ural oscillations of the plasma are too feeble to be detected with a conventional floating probe and microwave spectrum analyzer.

That this unperturbed plasma fluctuation spectrum should peak at the natural resonances of the plasma follows from applying the Nyquist theorem to the space-charge modes of the plasma. Dougherty and Farley[5] have used this theorem to calculate the fluctuation spectrum of an unbouded plasma and have obtained agreement with theories based on equilibrium statistics of the plasma. The Nyquist theorem qualitatively predicts that the absorption spectrum as determined by the measurement of Fig. 1(a) should contain the same structure as that resulting from thermal fluctuations. This is borne out by Fig. 1(c).

Combination scattering makes possible the probing of natural and driven electrostatic oscillations of laboratory magnetoplasmas. Since it has been proposed that the perturbing effects of drifting electrons, electron beams, etc., are coupled into the plasma via electrostatic waves, we look toward using the scattering of microwaves to monitor the onset of plasma instabilities in the presence of these perturbations.

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ELECTRON MOBILITIES IN LIQUID ARGON

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Malkin and Schultz,[1] Williams,[2] and Swan[3] have previously measured electron drift velocities in liquid argon. Their measurements were made at electric-field strengths in excess of 1 kV/cm, where the electron drift velocity is definitely nonlinear with respect to the electric-field strength. Swan[3] summarizes the data on drift velocities in liquid argon as measured by various investigators in Fig. 2 of his paper. All of the curves in this figure are cut off at electric-field strengths of the order of a few kV/cm. Although the drift-velocity–versus–electric-field curve must pass through the origin, the correct extrapolation to the origin for each of these curves is difficult, and it leads to a number of different limiting slopes (the mobility) as E, the electric-field strength, approaches zero. For this reason we believed that it was of considerable importance to extend the measurements of electron drift velocities in liquid argon into the low field region so as to obtain insight into low-energy electron-scattering processes in dense, disordered systems. Indeed, at low field strengths we observe a field-independent electron mobility, which may be used to test the theory of Davis, Rice, and Meyer,[4] while at the same field strengths and at 145°K in Ar we observe a field dependence of the mobility. In this note we focus attention on the low field limit.

The time-of-flight mobility apparatus and its mode of operation is very similar to that used by Meyer and Reif in their experiments in superfluid helium, and has been described elsewhere.[5] Two different types of electron source were used in our experiments. In the first series of experimental runs, we used a Po^{210} alpha-emitting source (approximately 400 microcuries). In our most recent runs we have used a tungsten field emission tip.[6] The currents collected from these sources were in the range from 10^{-12} to 10^{-11} A.

Swan[7] has estimated from electron attachment coefficient measurements in liquid argon that at field strengths of the order of 100 to 200 V/cm, the oxygen impurity content would have to be less than one part in 10^9 in order to observe drift velocities of electrons, and not negative ions as observed by Davis, Rice, and Meyer.[8] The first step in the purification procedure we have used involves the passage of the argon gas through 45 g of activated cocoanut charcoal at dry-ice temperature. This charcoal had previously been degassed by heating to temperatures between 400 to 500°C for 45 minutes while pumping to a pressure less than 10^{-5} mm Hg with a liquid-nitrogen-baffled oil diffusion pump. The argon was passed through the charcoal trap at a rate of approximately 2 liters (NTP) per minute on route to liquefaction in the cell. The second and most important stage in the purification is the electrolysis of the liquid argon for approximately two hours at an electric-field strength of −100 V/cm to remove electron trapping impurities present in the liquid in the form of negative ions (presumably O_2^-).

An elementary expression for the electron mobility in a liquid, in the limit of weak scattering, is

$$\mu = \frac{e}{m^*}\left\langle \frac{1}{V_T} \right\rangle \frac{1}{\rho_N Q} = \frac{e}{2\sqrt{2}\,\pi^{3/2}(m^*)^{1/2}k^{3/2}\rho_N{}^2 a^2 K_T T^{3/2}}, \quad (1)$$

where e is the electronic charge and m^* the electron effective mass, ρ_N is the number density of the liquid, k is Boltzmann's constant, T the absolute temperature, K_T the isothermal compressibility of the liquid, $\langle V_T{}^{-1} \rangle$ is the average of the reciprocal of the group velocity for the electron wave packet over the Boltzmann distribution, and Q is the elastic-scattering cross section. The quantity a is the scattering length, and is defined in terms of the s-wave phase shift of the scattering potential. Equation (1) is based on the following physical picture: The electron is represented as a free particle weakly scattered by the atoms of the fluid. Whether the electron is represented by a plane-wave function or a wave packet, the coherence between scattering centers determined by the statistical geometry of the liquid leads to phase relations between nearby scattering centers.

It can be shown that the cross section for long-wavelength elastic scattering of electrons is given by the relation $Q = 4\pi a^2 a(0)$, where $a(0)$ is the zero wave-vector limit of the Fourier transform of the radial distribution function.[9] For a fluid such as Ar, $a(0) = \rho_N k T K_T$, whence these thermodynamic parameters appear in Eq. (1).

In Fig. 1, we display the experimental temperature dependence of μ at a pressure of 7.0 atm and at electric-field strengths of −150 V/cm and −200 V/cm. The temperature is known to within ±0.3°K. In Fig. 2, the pressure dependence of μ is given at a temperature of 100.3°K and a constant electric field of −200 V/cm. The pressures are known to within ±0.5 atm. The dashed lines in Figs. 1 and 2 represent values for the mobility calculated from Eq. (1) multiplied by a common scale factor of 1.8. The scattering length used in these calculations was obtained from O'Malley's paper,[10] and the thermodynamic data were calculated from polynomial fits to the PV data

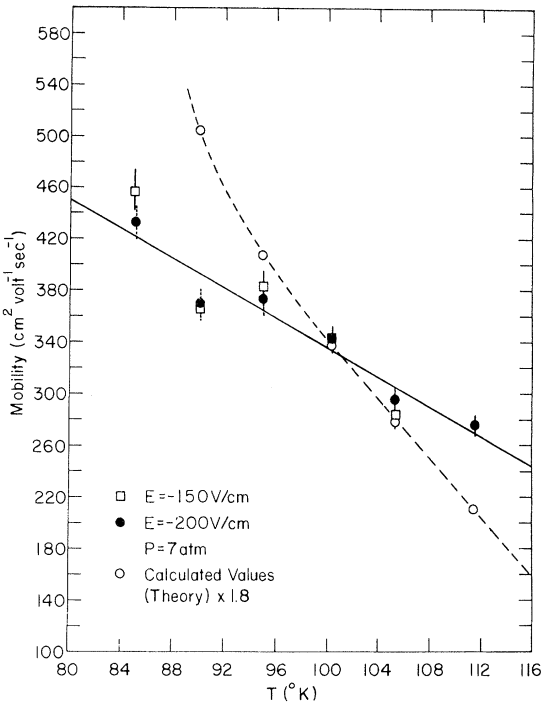

FIG. 1. Electron mobilities in liquid argon as a function of temperature at a pressure of 7 atm. The open squares represent experimental points observed at a constant electric field of −150 V/cm. The solid circles represent experimental points observed at a constant electric field of −200 V/cm. The dashed line is drawn through points calculated from Eq. (1) and multiplied by a common scale factor of 1.8.

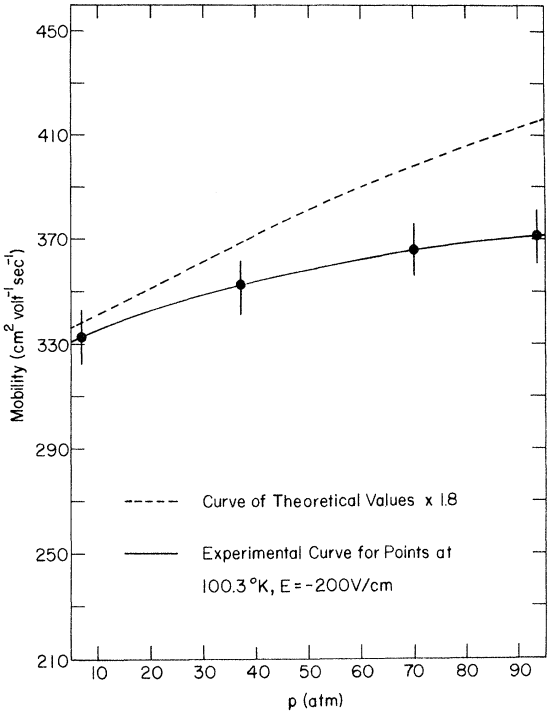

FIG. 2. Electron mobilities in liquid argon as a function of pressure at a constant electric field of −200 V/cm and a temperature of 100.3°K. The dashed line is drawn through points calculated from Eq. (1) and multiplied by a common scale factor of 1.8.

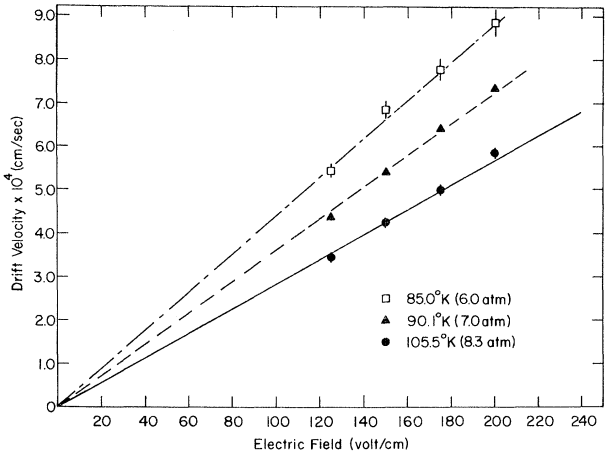

FIG. 3. Electron drift velocities in liquid argon as a function of electric-field strength. The symbols representing experimental points observed on a given isotherm are as follows: open squares, 85.0°K; solid triangles, 90.1°K; and solid circles, 105.5°K. Notice that the points fall on straight lines which pass through the origin.

of Levelt Sengers.[11] In Fig. 3, the electric-field dependence of the electron drift velocity, v_d, is shown. It is important to notice that the experimental values of v_d fall on straight lines which pass through the origin. In this linear region, μ is a constant, as it must be according to Eq. (1), and one can appropriately discuss a mobility.

From the data displayed we note the following:

(a) If m^* is assumed to be the free-electron mass, then a scaling factor of 1.8 is needed to bring both the pressure and temperature dependences of the mobility into rough agreement with experiment. It is interesting that the major part of the discrepancy between experimental and theoretical slopes in Figs. 1 and 2 can be traced to the temperature and pressure dependence of ρ_N and K_T.

(b) If for m^* we adopt the value $0.4m_e$, as determined from the exciton spectra of the solid,[12] then $(m^*)^{-1/2}=1.6$, and the discrepancy in magnitude between theory and experiment is removed. However, it is not certain if the optical effective mass should be used for low-energy electrons or, more importantly, in the liquid.

We conclude that a zero-order description of excess electrons in liquid Ar as free particles occasionally scattered by the atoms of the fluid is a reasonable approximation. This deduction has important implications for the description of the excited electronic states of liquids. Assuming the remaining discrepancy between model and observation to be real, we may question the suitability of isolated-atom electron-scattering cross sections to describe scattering in a dense medium where many-body effects may alter the effective single-atom-scattering cross section.

Further studies of electrons in liquid Ar and other rare-gas liquids are in progress, and will be reported in the near future.

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OPTICALLY-INDUCED MAGNETIZATION RESULTING FROM THE INVERSE FARADAY EFFECT*

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The application of high-intensity laser radiation to various materials has produced a number of nonlinear effects which in turn have prompted a reformulation of the laws of optics.[1] One consequence of this reformulation was to establish relations between seemingly different phenomena. The first example of these relations to be experimentally observed has been between the linear electro-optic effect and induction of a dc polarization proportional to the intensity of a light beam (i.e., optical rectification) in crystals which lack inversion centers.[2] General phenomenological considerations, however, do predict other relations,[3] but to date only effects of electric rather than magnetic origin have been observed. The purpose of this Letter is to describe the first observation of an optically-induced magnetization in a nonabsorbing material, and to demonstrate the relationship between this effect, which we will call the inverse Faraday effect (IFE), and the Faraday effect in the same material.

The IFE follows from the existence of a potential function F, which for cubic or isotropic media has the form[3]

$$F = \chi \mathcal{H}\left\{ \mathcal{E}_R \mathcal{E}_R^* - \mathcal{E}_L \mathcal{E}_L^* \right\}, \tag{1}$$

where χ is a constant characteristic of the material, and $\mathcal{H}$ is the dc magnetic field whose positive sense is taken in the direction of light propagation. The $\mathcal{E}_R$ and $\mathcal{E}_L$ are amplitudes of right and left circularly polarized light, respectively. For example, the electric field for right circularly polarized light is written

$$E(t) = 2\,\mathrm{Re}[(2)^{-1/2}(\tilde{x} + i\tilde{y})\mathcal{E}_R \exp i(\omega t - kz)].$$

In the presence of a magnetic field, Eq. (1) yields a contribution to the optical dielectric constants. For right and left circularly polarized light we have[4]

$$\Delta\epsilon_R = -\partial^2 F/\partial \mathcal{E}_R \partial \mathcal{E}_R^* = -\chi\mathcal{H},$$
$$\Delta\epsilon_L = -\partial^2 F/\partial \mathcal{E}_L \partial \mathcal{E}_L^* = +\chi\mathcal{H}, \tag{2}$$

which can be shown to lead to a rotation of the plane of polarization of linearly polarized light (Faraday rotation) through an angle $\theta/d = VH$ per unit length. The Verdet constant V is

$$V = -4\pi^2\chi/n_0\lambda_0\ [\text{rad Oe}^{-1}\ \text{cm}^{-1}], \tag{3}$$

n_0 is the refraction index in the absence of a dc field, and λ_0 is the vacuum wavelength of the light in cm.

On the other hand, in zero applied magnetic field there is a magnetization

$$M = -\partial F/\partial\mathcal{H} = -\chi(\mathcal{E}_R \mathcal{E}_R^* - \mathcal{E}_L \mathcal{E}_L^*),$$

or in terms of measurable quantities,

$$M = \lambda_0 V (2\pi c)^{-1}[I_R - I_L], \tag{4}$$

where I_R and I_L are the intensities of right and left circularly polarized light inside the medium in cgs units [ergs sec^{-1} cm^{-2}] and M is in G cm^{-3}.

The IFE has been observed in Eu^{+2}:CaF_2,[5] a number of diamagnetic glasses, and several organic and inorganic liquids. Radiation from a Q-switched ruby laser, 0.1 J with a half-amplitude pulse width of 3×10^{-8} sec, was circularly polarized by a quartz $\lambda/4$ plate. The magnetization was detected by a 30-turn pickup coil wound on a phenolic cylinder and slipped over either the cylindrically ground samples, in the case of Eu^{+2}:CaF_2 and the glasses, or the cylindrical sample holder in the case of liquids. All measurements described here were done in zero applied dc magnetic field.