gold, using the second-harmonic radiation from the ruby laser. The photon energy of this radiation is 3.57 eV, which is lower than the work function W of gold. Two such photons, however, have total energy of 7.14 eV, much higher than W. Figure 3 shows the photoelectric current versus intensity and reveals a two-photon photoelectric effect. We may write $J=bI^2$ for the current density, where b has a physical meaning similar to c in $J=cI^3$. From the data we obtain $b=2.35\times10^{-3}$ (A/MW)/(MW/cm^2). The quantum yield is plotted also as a function of intensity in Fig. 3. A calculation similar to that for the three-photon effect gives an estimate of the absorption constant of the two-photon effect at the surface: $\alpha_2=3.6\times10^{-6}(2\alpha_1+1/D)bI$. For an incident laser intensity $I=0.77$ MW/cm^2, for example, we obtain $\eta_2=6.5\times10^{-9}$ electrons/photon and $\alpha_2=2.6\times10^{-2}$ cm^{-1} at 7.14-eV total photon energy.

We are presently working on a theoretical calculation of the three-photon photoelectric effect.

We would like to thank Professor H. Mahr for helpful discussions.

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[3]A possible two-photon absorption is neglected since its contribution to the attenuation of the light with depth into the metal is negligible compared with the one-photon absorption.

[4]The effect of reflectivity is neglected in this estimate of the absorption constant.

NOTE ON TRANSIENT CURRENT MEASUREMENTS IN LIQUID CRYSTALS AND RELATED SYSTEMS

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(Received 23 December 1966)

The purpose of this note is to present the results of some measurements of transient currents in nematic liquid crystals and some structurally related non-nematic compounds of ultrahigh purity.

The experimental procedure consisted of melting the nematic substance between two pieces of glass possessing evaporated metal electrodes on their surfaces. The area of these cells was typically 1.3 cm^2. The thickness of the cell was determined by Mylar spacers and ranged from 6 to 25 μm in our experiments. Provisions were made for maintaining the cell at constant temperature within its nematic liquid crystalline range. Currents were observed through a series load resistor by means of an oscilloscope. The applied voltage step was generated by means of a mercury relay and a variable dc supply. The materials which we have investigated include p-azoxyanisole (nematic range 120-136°C), and azobenzene, a structurally similar but nonmesomorphic compound which melts at 69°C. Although the data presented are for p-azoxyanisole, similar behavior was found for azobenzene.

Figure 1 shows a typical current transient. The initial portion of the curve is due to the normal charging current. The secondary peak is striking and is the subject of our investigation. We note that this type of transient has been frequently observed for space charge injection into insulators.[1]

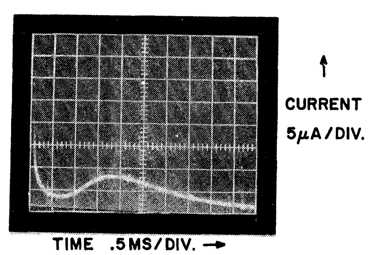

FIG. 1. Typical current transient—nematic p-azoxyanisole.

A plot of the time occurrence of this secondary peak or "cusp" versus the reciprocal of the applied voltage yields a straight line as seen in Fig. 2. A plot of the magnitude of the "cusp" as a function of applied voltage over the rather limited range of voltages typically yields $I \propto V^n$, where $1.5 < n < 2$. This is shown in Fig. 3. Wider voltage ranges are not possible. When one of the electrodes is covered with a suitable thickness of Teflon which has about the same dielectric constant as the compounds which we are investigating, no secondary peak or "cusp" is found. The initial charging current peak remains. Increasing the conductivity of our materials [$\sigma \approx 10^{-10}$-10^{-11} $(\Omega\ \mathrm{cm})^{-1}$ (undoped)] by doping with an ionizable organic salt, i.e., dodecyl isoquinolonium bromide, caused the "cusp" to disappear when the dielectric relaxation time was reduced to a value below a realistic estimate of the transit time for charge motion in a liquid. An attempt was made to investigate the thickness dependence of the time and amplitude of the "cusp." The data are admittedly crude but we find that $t_{\mathrm{cusp}} \propto L^{1.3}$, where L is the spacer thickness. We also find that

$$I_{\mathrm{peak}} \propto 1/L^{2.4}.$$

Although the crude thickness-dependence measurements do not yield definite support, one possible interpretation of our results might be based on space-charge-limited currents. Because of the relatively short lifetimes of free electrons in liquids compared with the transit times in our experiments (10^{-6} to 10^{-8} sec vs 10^{-3} sec) an injected electron would probably be captured by a neutral molecule forming a negative ion. The excess electron would then be removed at the anode yielding the neutral molecule. Alternatively, the negative ion could be directly produced by a field-dependent ionization process at the contact.[2] If we assume that the proportionality of t_{cusp} to $1/V$ is related to a transit time as it would be in the space charge case, a mobility can be calculated[3]:

$$\mu = 0.8L^2/Vt_{\mathrm{cusp}},$$

where L is the spacer thickness and V is the applied voltage. A value of approximately 2.5×10^{-4} $\mathrm{cm^2/V\ sec}$ is found for the mobility of negative ions in p-azoxyanisole which is typical for ions of this size.

In summary, transient current measurements have been made on the nematic liquid crystal p-azoxyanisole and the related nonmesomorphic compound azobenzene. Several features associated with transient space-charge-limited currents in solids were observed, i.e., (1) a "cusp," (2) the proportionality of the time occurrence of the cusp to the reciprocal of the applied voltage, and (3) the near proportionality of the magnitude of the current cusp to the square of the applied voltage. Doped samples with much shorter dielectric relaxation times and samples with ideal blocking contacts do not exhibit the "cusp."

The authors wish to thank Dr. R. Williams,

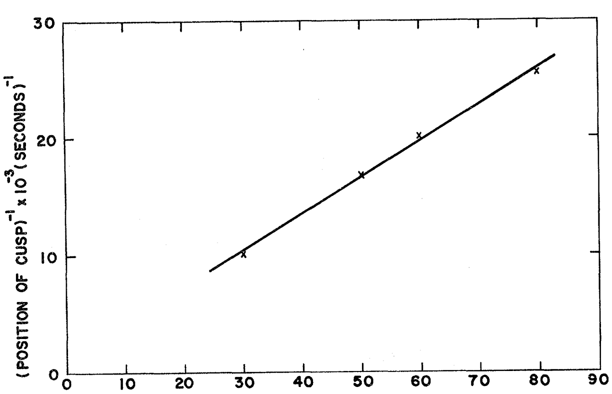

FIG. 2. (Position of cusp)$^{-1}$ versus voltage—nematic p-azoxyanisole. Sample thickness ≈25 μm.

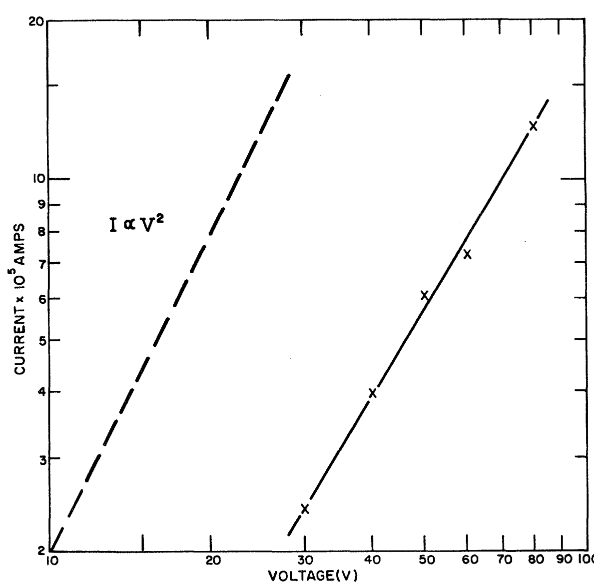

FIG. 3. Peak transient current versus voltage—nematic p-azoxyanisole. Sample thickness ≈25 μm.

Dr. P. Mark, and Dr. G. Warfield for helpful discussions and Mr. L. A. Zanoni for technical assistance.

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[3]See Ref. 1.

SOME NEW STABLE TOROIDAL PLASMA CONFIGURATIONS*

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(Received 1 March 1967)

In a recent paper we showed that plasma containment in a toroidal geometry is likely to be poor unless the geometry is axially symmetric or the particle distribution function $f(\epsilon, \mu)$ is the same on all flux surfaces.[1] In this Letter we explore the second possibility.

In a mirror geometry, Taylor has shown that this special distribution function (under certain mild additional restrictions) yields satisfactory containment and stability when it is combined with a minimum B field.[2,3] We show that exactly the same situation holds in a torus. To do this we must exhibit a toroidal vacuum field with flux surfaces in a magnetic well. This is commonly thought to be impossible. We have given previously examples of toroidal magnetic wells which depend on internal plasma currents.[4] We now extend these results by presenting several simple explicit examples of vacuum magnetic wells in a toroidal geometry. These configurations have all the advantages of containment and stability which are attributed to magnetic wells in open-ended systems; in addition, they have lower loss rates and are less sensitive to loss-cone instabilities. We also indicate how one might be able to construct similar stable, contained, high-β toroidal plasmas, e.g., as in a toroidal θ pinch.

We note that minimum average B ($\int dl/B$, V'', etc.), commonly considered to be a compromise necessitated by the "impossibility" of minimum B, requires more complex coil systems than we find necessary for a true minimum B. Actually, minimum average B and minimum B are not comparable,[4] the primary (but not exclusive) application of the former being to scalar pressure and the latter to anisotropic equilibria. And the present indications are that anisotropy may play a vital role even in toroidal plasmas.

The relation of magnetic-well fields to plasma stability is not at all simple. In a mirror machine it has been shown that stability depends on a complex correspondence between the field and the particle distribution.[5] The essence of Taylor's contribution[2] is not minimum B (which was long known to combine the features of adiabatic containment and a tendency toward stability[6]), but the special particle distribution $f(\epsilon, \mu)$. In this particular combination, it is the particle distribution that provides stability, while the minimum B field is primarily for containment. It is easy to find many other particle distributions which are unstable in a well. On the other hand, the special distribution $f(\epsilon, \mu)$ is absolutely stable (within this theory) when it is placed in any magnetic field (say, enclosed by physical walls to make the problem definite). We can compare $f(\epsilon, \mu)$, which is stable but can be confined only in a well, with the more special Maxwellian distribution, which is even more stable than $f(\epsilon, \mu)$ but which cannot be contained in any field. To find a useful distribution function requires a compromise between ease of containment and stability. Because of the containment advantage of a magnetic well (a particle with given ϵ and μ cannot reach a location where $B > \epsilon/\mu$), the class of distribution functions that can be contained in a well is greater than in many other types of field. Thus it is not surprising that within the subclass of stable distributions, we find more that are contained in a well than otherwise.[5]

The proof usually quoted that there can be no magnetic well in a toroidal force-free or vacuum magnetic field[7] (and which is identical to the proof that there is no stable plasma with a smooth boundary at $\beta = 1$)[8] is based on a specific definition of magnetic well; viz. that the plasma end on a flux surface on which $\partial B^2/\partial n > 0$. This definition differs from the one that is conventional in open-ended systems, viz.

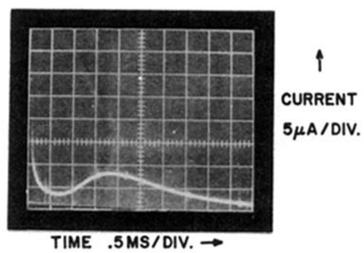

FIG. 1. Typical current transient—nematic *p*-azoxyanisole.