not occur. Experiments of this type using DyAlG doped with Er^{3+} are being carried out.

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MAGNETIC BIREFRINGENCE OF EuSe

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Magnetically ordered EuSe exhibits very large magneto-optical effects in a wavelength region where the material is exceptionally transparent. We have previously reported Faraday rotation and absorption of EuSe in the paramagnetic region.[1] This paper describes measurements of Faraday rotation (magnetic circular birefringence) and Cotton-Mouton phase difference (magnetic linear birefringence) made at 4.2°K where EuSe is ferromagnetic in high magnetic fields and antiferromagnetic in low magnetic fields.

The Curie point measured in an applied field and the Néel point measured in zero field by neutron diffraction are both approximately 7°K.[2] Neutron diffraction also has shown that the zero-field magnetic structure consists of a basic component having the second kind of fcc antiferromagnetic ordering and an additional square-wave-modulated ferromagnetic component. Application of a moderate field (1750 Oe at 1.9°K) aligns the modulated component, causing the appearance of a partially saturated ferromagnetic moment, and a high field (8000 Oe at 1.9°K) eliminates the basic antiferromagnetic component, leaving pure ferromagnetism.

EuSe has the NaCl crystal structure and is semiconducting with a low Hall mobility.[3] A sharp optical absorption edge is observed at about 670 mμ. Some values of room-temperature absorption coefficient (neglecting reflection losses) are 293 cm^{-1} at $\lambda = 660$ mμ, 89 cm^{-1} at $\lambda = 700$ mμ, and 66 cm^{-1} at $\lambda = 750$ mμ. Due to the strong absorption at shorter wavelengths, even very thin bulk crystals could not be measured at wavelengths less than 600 mμ. Absorption measurements made on evaporated thin films of EuSe showed[1] that the absorption edge observed with bulk crystals of 670 mμ is actually the long-wavelength edge of a broad absorption band with a peak at 460 mμ. It has been suggested that this absorption peak at 460 mμ is due to a charge-transfer transition $(4f^7)(4f^7) \rightarrow (4f^6)(4f^7 5d)$ between neighboring Eu^{++} ions.[4]

The magnetic birefringence was measured on a single crystal approximately 2 mm square, with a thickness of 157 μ (±5% error). The sample was directly immersed in liquid helium. The light source is a Bausch and Lomb monochromator with a tungsten lamp and an output of about 60 Å half-width. The remainder of the experimental apparatus includes a 12-in. magnet with axial hole, 150-cps light chopper, Glan-Thomson prisms, several lenses, Soleil compensator, RCA 7102 photomultiplier, and a lock-in detector.

In the Faraday configuration H is applied parallel to the light beam, and the two eigenmodes of propagation in the crystal are right- and left-handed circularly polarized light (for magnetization M parallel to H). The difference in index of refraction for these modes $\Delta n_F = n_r - n_l$ gives rise to Faraday rotation, and the difference in extinction coefficients $\Delta k_F = k_r - k_l$ results in circular dichroism. In the Cot-

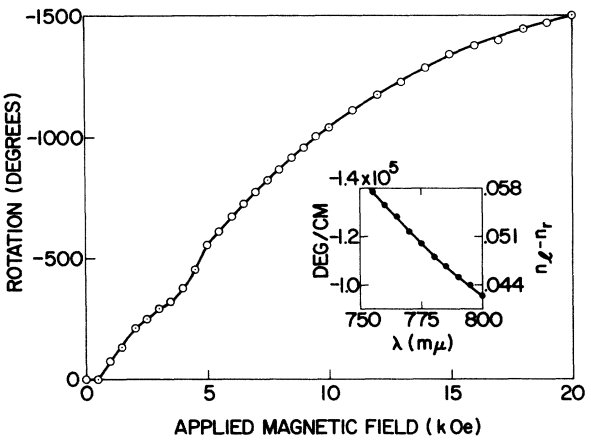

FIG. 1. Field dependence of Faraday rotation of EuSe single crystal (thickness 157 μ) at 4.2°K and 800-mμ wavelength. Insert: Wavelength dependence of specific rotation at 4.2°K for 20-kOe applied field.

ton-Mouton configuration,[5] H is applied perpendicular to the light beam, and the two eigenmodes of propagation in the crystal are linearly polarized light polarized parallel and perpendicular to H (for M parallel to H). The difference in index of refraction $\Delta n_{CM} = n_{\parallel} - n_{\perp}$ is the Cotton-Mouton birefringence, and the difference in extinction coefficients $\Delta k_{CM} = k_{\parallel} - k_{\perp}$ results in linear dichroism.

Figure 1 shows the field dependence of the Faraday rotation for EuSe at 4.2°K for a wavelength of 800 mμ. The dispersion of the specific rotation (degrees of rotation/sample thickness) for 20-kOe applied field is indicated by the insert. The circular birefringence is also indicated. At 20 kOe the magnetization is approximately 83% of saturation.

The rotation is large: At 755 mμ we measure approximately six complete revolutions of the plane of polarization of the light. This occurs in a wavelength region where the sample is still relatively transparent. Comparison of EuSe with $CrBr_3$[6] shows that for 37% transmission of the incident light the saturation rotation of $CrBr_3$ is about 110° ($\lambda = 480$ mμ), whereas the saturation rotation of EuSe is about 2000° ($\lambda = 755$ mμ). The saturation rotation of iron (again for 37% transmission) is about 0.5°.

The data of Fig. 1 were compared with magnetization data taken on a different sample of EuSe. It was found that the rotation was linearly proportional to magnetization for H between 13 and 20 kOe. Extrapolating this linear region to saturation magnetization gives a saturation rotation of 115 000 deg/cm for $\lambda = 800$ mμ and 166 000 deg/cm for $\lambda = 755$ mμ. Small deviations from linearity occurred at lower fields where the sample is in the antiferromagnetic region, as well as in a region where sample alignment may be important. For high fields there is very little circular dichroism (~5%) associated with the Faraday rotation for wavelengths between 755 and 800 mμ. Measuring Faraday rotation at shorter wavelengths is difficult presumably because of inhomogeneity in the sample thickness; e.g., a 5% variation in sample thickness will cause a variation in rotation of 75° (at 20 kOe and 800 mμ) which will almost completely depolarize the light.

The experimental dependence of the Cotton-Mouton phase difference upon H is plotted in Fig. 2, along with corresponding values of Δn_{CM}. To the best of our knowledge, all previous measurements of Cotton-Mouton birefringence have been made on paramagnetic materials and have shown Δn_{CM} to be proportional to H^2. This is clearly not the case here. It is found that Δn_{CM} is proportional to M^2 for $H > 8$ kOe at 725 mμ (and for $H > 6$ kOe at 750 mμ). Extrapolating to saturation magnetization gives a saturation value of $\Delta n_{CM} = 2.0 \times 10^{-2}$ at 725 mμ. It should be mentioned that for $0 < H < 2$ kOe, Δn_{CM} is difficult to measure because the emergent light is largely depolarized. We are presently measuring the magnetic dichroism, Δk_F and Δk_{CM}, which for wavelengths shorter than about 700 mμ is found to be exceptionally large.

We wish to thank F. Holtzberg for kindly giving us the single crystal, R. W. Kaplan for

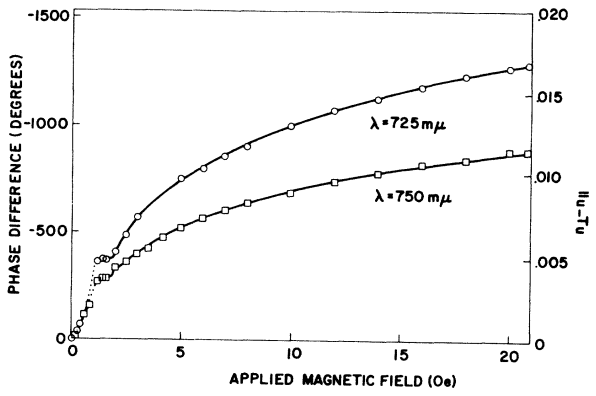

FIG. 2. Field dependence of Cotton-Mouton phase difference of EuSe single crystal (thickness 157 μ) at 4.2°K.

valuable assistance in making the measurements, and M. J. Freiser for valuable discussions.

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PHOTOCARRIER GENERATION IN ANTHRACENE DUE TO EXCITON INTERACTION OF TWO-PHOTON EXCITED SINGLETS

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This Letter is concerned with an investigation of photocurrents in anthracene excited by a Q-switched ruby laser. Recently two-photon absorption in anthracene has been indirectly observed by several workers.[1-3] We have reported[4] that the photocarriers excited by a Q-switched ruby laser increase with the square of the light intensity, and this fact strongly suggests carrier production through two-photon absorption. On decreasing the laser intensity, however, the induced charges do not follow the square dependence as shown in Fig. 1. The induced charges have been obtained by a crystal counter technique.[4] In Fig. 1 the photocurrent peak values are also plotted against the laser intensity. In the low-intensity region the peak currents tend to show a fourth-power dependence. Figure 2 shows the transient wave form of the photocurrent. A very rapid decay is seen from the figure.

Two-photon excited photocurrents may be two carrier streams of electrons and holes (this implies considerably high probability of direct recombination of two carriers when the density of charge carriers is very high). Since the decay rate of the photocurrent pulse is much larger than that in the case of high-intensity weakly absorbed light reported by Silver et al.,[5] this decay may be due neither to trapping nor to the bulk generation effect.

Let us assume that photocarriers are produced by singlet-singlet interaction in anthracene,[6,7] and that carrier density decreases only through recombination of electrons and holes (neglecting the trapping process). Then the rate of

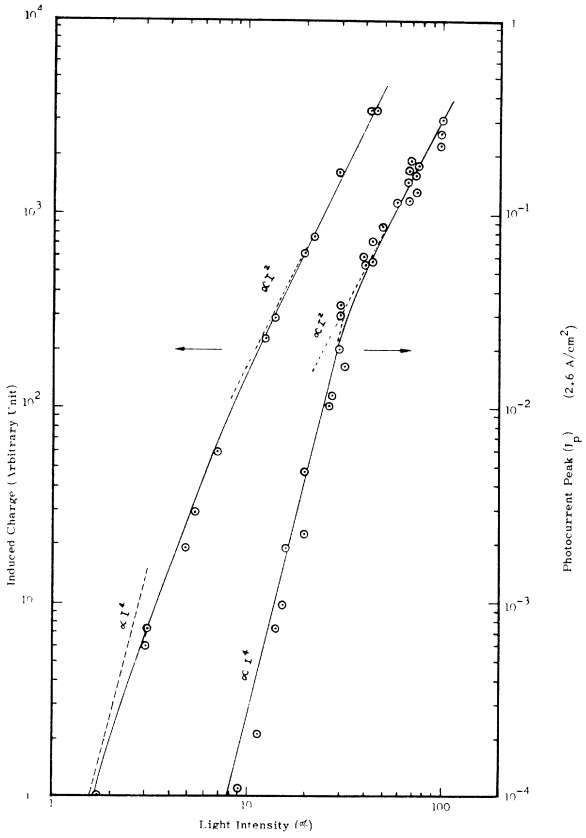

FIG. 1. Photocurrent peak and induced charge versus incident laser intensity. 100% light intensity means 6.8×10^{26} photons cm^{-2} sec^{-1}. The applied voltage is 1300 V across a crystal 10^{-1} cm in thickness.

increase of charge carriers is

$$dn/dt=\beta N^2-\gamma n^2, \tag{1}$$

where n is the density of conduction carriers,