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[21]Another "sensitive" candidate is $\Gamma_{25'} \rightarrow \Gamma_{2'}$. However, from second-order perturbation theory we believe this edge shifts rapidly only for crystals such as Ge, GaAs, etc., where $\Gamma_{2'}$ is near the bottom of the conduction band. When $\Gamma_{2'}$ is near $\Gamma_{15}$, its temperature dependence should be similar to that of $\Gamma_{15}$ itself.

[22]Another question that arises is why $L_{3'} \rightarrow L_1$ is detected as a saddle-point edge in Si, but not as a threshold in Ge. But note that the strength of either edge is roughly proportional to $(\mu_l)^{1/2}$, where $\mu_l$ is the reduced interband mass along (111) axes near $L$. Si-Ge alloy data [J. Tauc and A. Abraham, J. Phys. Chem. Solids 20, 190 (1961)] show that $\mu_l \rightarrow \infty$ near 0.8-0.9 Si, which suggests much stronger intensities for $\Delta R/R$ in Si than in Ge.

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# SCHUBNIKOW-de HAAS TYPE PHENOMENA IN PYROLYTIC CARBONS AT LIQUID-NITROGEN TEMPERATURES

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Two years ago, we noticed some unusual behavior in the low-temperature galvanomagnetic effects in pyrolytic carbons.[1,2] One of the features we noticed then was that the field dependance of the negative magnetoresistance $\Delta\rho/\rho_0$ observed in pyrolytic carbons is not monotonic, as had been reported, but turns to positive at higher fields. It was found that the character of field dependence is sensitive to the crystalline structure, varying from sample to sample.

Later work revealed that the curves are also nonmonotonic in the positive magnetoresistance region; as the field intensity increases the values of $\Delta\rho/\rho_0$ in all samples begin to show evidence of gradual saturation. In some samples we could even observe the magnetoresistance reaching peak values and then falling off to negative values. At the same time, further precise measurements along this line revealed the detailed shape of the curves in the low-field region. The over-all shape of the field dependence seems to be of oscillatory nature (Fig. 1).

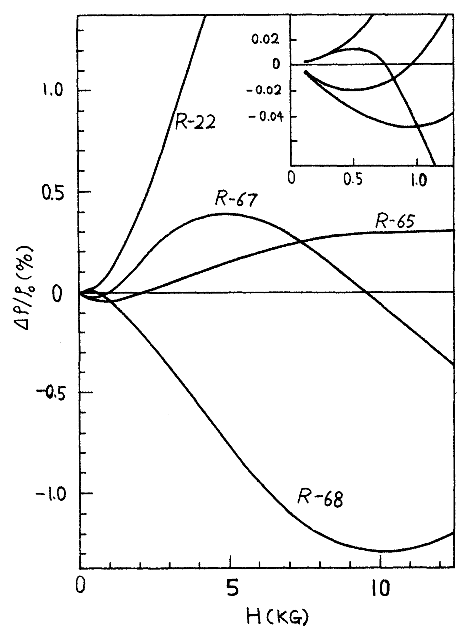


FIG. 1. Field dependence of the magnetoresistance in pyrolytic carbons. Note a small positive magnetoresistance region at low field strengths observed in sample No. R-68. These curves suggest an oscillatory nature for the over-all shapes.

The fabricating conditions of the deposits used in these experiments are listed in Table I. The samples are cut in a bridge shape 30 mm long with the flat faces parallel to the layer planes of the deposits. Most of our measurements were made with current densities of 100 mA/mm$^2$ or less.

Just as in the case of negative magnetoresistance, so in the case of positive magnetoresistance the character of the field dependence is structure sensitive. The field intensities for which the peak values are observed vary from

Table I. Preparation history of the samples.

| Sample No. | Gas | Deposition temperature (C°) | Remarks |
|---|---|---|---|
| R-22 | methane | 2300 | heat treated at 2500°C for 1 h |
| R-65 | propane | 1900 | |
| R-67 | propane | 1800 | deposited in $N_2$ gas atmosphere |
| R-68 | propane | 2200 | deposited in $N_2$ gas atmosphere |

sample to sample. It seems very likely that more samples would show a decrease of the magnetoresistance if we could extend experiments to still higher fields.

So far, we have observed the sign of the magnetoresistance of some samples to change from positive to negative and then back to positive, and in other samples from negative to positive and then back to negative. Although we have not yet succeeded in obtaining two peaks for either one of the signs, it seems to be very likely that the whole picture of the field-dependence character might be oscillatory.

We can conclude nothing decisively at the present stage, but the uniqueness of the observed field dependence of the magnetoresistance is interesting. Furthermore, since we have some reasons to believe that the effective masses of the charge carriers in some pyrolytic carbons of turbostratic nature are extremely small,[3] it seems very probable that the observed phenomena are caused by the Schubnikow–de Haas effect. If this conjecture is valid, the observation of a Schubnikow–de Haas effect at such high temperature is quite stimulating.

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# EVIDENCE FOR THE EXISTENCE OF EXTREMELY LIGHT CARRIERS IN PYROLYTIC CARBONS

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In the preceding Letter we reported on an observation of oscillatory magnetoresistance of pyrolytic carbons. A possible explanation of this unusual behavior might be the Schubnikow–de Haas effect. So far, the Schubnikow–de Haas effect has been observed in a few materials, only at liquid-helium temperature, and the period in terms of $(1/H)$ is of the order of $10^{-5}$ at most. But if $m^*$ is of the order of $10^{-3}m_0$, there is the possibility of observing the effect even at the liquid-nitrogen temperature, with a much longer period.

Assuming a simple parabolic band, the necessary condition for the oscillatory part to be sufficiently large is, as is well known,

$$\pi^2kT/\mu_B^*H = 2\pi^2m^*ckT/eH \lesssim 1, \qquad (1)$$

while the period is expressed as

$$P = \Delta(1/H) = eh/m^*cE_F. \qquad (2)$$

Although the observed behavior is somewhat different from the usually reported de Haas effect, both as to the temperature range and as to the oscillation period, both observed tendencies are consistent in indicating an extremely small mass of carriers.

So far the only element that has been used for doping carbons substitutionally is boron. As has been reported elsewhere, we have succeeded in doping pyrolytic carbons with nitrogen up to a content of several hundred ppm.[1,2] Some of the electronic properties of these new doped materials have been reported already, and a somewhat more detailed report will be