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DEPENDENCE OF THE TRANSVERSE DIFFUSION OF DRIFTING ELECTRONS ON MAGNETIC FIELD

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ABSTRACT

It is shown that the constant D of transverse diffusion of drifting electrons in gases depends on the magnetic field B or the cyclotron frequency $\omega = (e/m)B$ in such a way that the reduction factor is $D(0)/D(B) = 1 + \omega^2\tau_1^2$ for small B and $D(0)/D(B) = C + \omega^2\tau_2^2$ for large B. The measurements were done between B = 0 and B = 7 kG, using a time projection chamber. The gas was 91% argon and 9% methane at 1 atm, the drift field 115 V/cm.

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1. INTRODUCTION

The transverse diffusion of the electrons from an ionising track in a time projection chamber (TPC) has two effects on the coordinate measurement: it sets a limit to the achievable accuracy and it has an influence on the response of neighbouring electrodes. Using this response, we have measured the variation of the diffusion with magnetic field in our chamber gas, a mixture of 91% argon and 9% CH_4.

We show in this paper that the influence of the magnetic field on diffusion can be characterised by three constants, two of which have the meaning of average collision times.

2. PAD RESPONSE FUNCTION

Particle tracks in the TPC are drifted onto the wire plane where the three coordinates of each track segment are measured through signals induced in cathode pads. The coordinates x and y, in the cathode plane, are given by the positions of the pads involved; z, the coordinate along the drift direction, is given by the drift time and the drift velocity. A precision measurement in the plane is obtained by interpolation between the pulses of neighbouring pads arranged in a pad row along y. For this interpolation one must know the precise form of the Pad Response Function (PRF) which describes the size of the electrical signal P_i induced in a pad i as a function of the distance $(y-y_i)$ between the centre of the avalanches on the proportional wires and the centre y_i of the pad. The PRF depends on the electrode configuration and on the spread of the ionisation on the wires. In the absence of diffusion, and for tracks at right angles to the pad rows, with our electrode configuration and amplifier (see Fig. 1) the PRF is known [1] to have the Gaussian form

$$P_i = A\, e^{-(y-y_i)^2/2\sigma_0^2} \qquad (1)$$

When interpolating between the pulses of two neighbouring pads, the normalisation constant A will drop out, whereas the width σ_0 needs to be known.

3. DIFFUSION

If the ionisation on the wires is spread out due to the diffusion of the drifting electrons and has an r.m.s. width σ_d along y, then the PRF is the result of a convolution with the Gaussian shape of the diffused ionisation. It is again a Gaussian with the parameter

$$\sigma_1^2 = \sigma_0^2 + \sigma_d^2. \tag{2}$$

σ_d^2 is given by the drift length L of the electrons, their drift velocity v and transverse diffusion constant D and is

$$\sigma_d^2 = 2DL/v. \tag{3}$$

Experimentally, σ_d^2 can be separated from σ_0^2 because it is proportional to L.

4. MEASUREMENT OF THE DIFFUSION CONSTANT D AT DIFFERENT B-FIELDS

For our measurements we used TPC90, a prototype for the ALEPH TPC [2]. It has a maximum drift length of 1.3 m, and the electrode configuration shown in Fig. 1. (The pads were arranged in 7 concentric circular arcs with radii varying between 0.4 and 0.8 m).

A UV laser beam with diameter of ≈2 mm was used to produce ionising tracks in the drift volume. Quartz windows in the field cage, aligned with small slots between the coils of the magnet, allowed the light to enter into the drift volume and to exit from it. Some earlier work and some related technical details were reported in Ref. [2].

The pulsed laser ray was directed into the sensitive volume of the TPC90, parallel to the wire plane and at three different drift distances, so that it crossed the seven rows of pads orthogonally. For each laser shot, the ionisation corresponded to approximately 3 to 15 times that of a minimum ionising particle. The ionisation track was drifted towards the wire planes, and we evaluated the pad pulses P_i above threshold for all pad rows k (k=1, ..., 7) where three neighbouring pads gave signals (i=1,2,3). From each triplet of neighbouring pads we calculated the "observed σ_1" according to

$$\left(\frac{\sigma_1^{obs}}{\Delta}\right)^2 = \frac{1}{\log\,(P_2^2/P_1P_3)} \tag{4}$$

where $\Delta \equiv y_1 - y_2 = y_2 - y_3$. Each time the measurement was repeated, with another laser shot, the observed $(\sigma_1/\Delta)^2$ was slightly different due to the electronic amplifier noise and other causes. A typical distribution is seen in Fig. 2. The average of 300 shots taken at some B and L is called $(\sigma_1(B,L)/\Delta)^2$. Measurements were taken at three different values of L and 13 different B values of both polarities as well as at B=0. The gas was 91% Ar + 9% CH_4 at atmospheric pressure. The E field 115 V/cm was chosen to maximize the electron drift velocity, which was 5.05 cm/μsec.

In Fig. 3 we depict $\sigma_1^2(B,L)$ vs L for some selected magnetic field values. The errors were calculated based on the approximation of a constant relative error $\delta\sigma_1^2/\sigma_1^2$ which was put equal to ±4% so that $\sigma_1^2(B,L)$ is a linear function of L always inside the errors (all $\chi^2 \leq 1$). The fitted slopes are the measured values of 2D(B)/v. They are plotted in Fig. 4. We observe the well-known reduction of D with increasing B. Before we discuss this functional dependence we would like to remark on the measurement errors. The method is insensitive to contributions from the width of the laser beam and the E×B effect near the sense wire. The positions of the laser beams were uncertain to within a few mm and contribute ≤ 0.5% to $\delta\sigma_1^2/\sigma_1^2$. The two values of σ_1^2 determined for equal and opposite magnet currents were always the same to within, typically, 1%. σ_1^2 appeared to depend slightly on y (varying by ≈ ±5% between symmetric and asymmetric track positions over the three pads), but this largely cancelled when taking averages over all seven pad rows. The stated relative error of $\delta\sigma_1^2/\sigma_1^2 = 4\%$ is a safe upper limit to contain these systematic errors.

5. INTERPRETATION OF THE DIFFUSION MEASUREMENT

The coefficient D of transverse diffusion of electrons in a gas and in the presence of electric and magnetic fields can be calculated from the isotropic distribution function f_0^0 of electron velocities v [3]:

$$D = \frac{4\pi}{3n} \int \frac{\nu}{\nu^2 + \omega^2} v^4 f_0^0 \, dv \qquad (5)$$

where ν is the collision frequency, n the normalisation of the distribution function and ω = eB/m the electron cyclotron frequency. This expression can be evaluated in the two cases of ω^2 small and ω^2 large compared to the square of a typical collision frequency ν_0. For this we take the value derived from the electron mobility μ in the limit in which ν is independent of v:

$$\nu_0 = \frac{e}{m} \cdot \frac{1}{\mu} \tag{6}$$

At our conditions we have $\nu_0 = 4.2 \times 10^{10}$ sec $^{-1}$ or $\omega/\nu_0 = 1$ at 2.3 kGauss. From equation (5) follows:

$$\left.\begin{array}{l}\omega^2 \ll \nu_0^2 \\ \text{or } B^2 \ll (2.3\text{ kG})^2\end{array}\right\} \quad \frac{D(0)}{D(B)} = 1 + \omega^2\tau_1^2$$

$$\left.\begin{array}{l}\omega^2 \gg \nu_0^2 \\ \text{or } B^2 \gg (2.3\text{ kG})^2\end{array}\right\} \quad \frac{D(0)}{D(B)} = C + \omega^2\tau_2^2 \tag{7}$$

where

$$\tau_1^2 = \int \frac{1}{\nu^3} v^4 f_0^0 \, dv \Big/ \int \frac{1}{\nu} v^4 f_0^0 \, dv,$$

$$\tau_2^2 = \int \frac{1}{\nu} v^4 f_0^0 \, dv \Big/ \int \nu \, v^4 f_0^0 \, dv, \tag{8}$$

and

$$C = \left[\int \frac{1}{\nu} v^4 f_0^0 \, dv \cdot \int \nu^3 v^4 f_0^0 \, dv\right] \Big/ \left[\int \nu v^4 f_0^0 \, dv\right]^2$$

τ_1 τ_2 and C are independent of ω^2.

Therefore, we have plotted our data in Figs. 5a and 5b in the form of D(O)/D(B) vs B^2. One observes that this quantity shows the expected linear behaviour above B=4 kG and below B=1 kG. The linear fit yields the following results:

τ_1 = (0.41 ±0.02) × 10^{-10} sec or $\omega\tau_1/B$ = 0.72 ±0.03 kG^{-1},
τ_2 = (0.266±0.006) × 10^{-10} sec or $\omega\tau_2/B$ = 0.468±0.010 kG^{-1},
C = 2.8 ± 0.2.

We note that the values of τ_1 and τ_2 which have the meaning of average collision times are almost a factor of 1.5 apart. Two previous measurements of diffusion are consistent with our values of τ_2 and C. The Berkeley measurement [4] with 10% CH_4 + 90% Ar of 600 Torr at 20.4 kG is equivalent to 760 Torr at 25.8 kG. They obtained $D(0)/D(25.8) \approx (10.5)^2$. The Orsay measurement with 9% CH_4 + 91% Ar at normal pressure gave [5] $D(0)/D(12) = (5.46 \pm 0.30)^2$. Our extrapolated values are $(12.2 \pm 0.3)^2$ and $(5.86 \pm 0.12)^2$, respectively.

6. CONCLUSION

These measurements show that the influence of the magnetic field on the transverse electron diffusion is different below and above a characteristic B-field given by the equality of the electron cyclotron frequency with the mean collision frequency. Below (as is well known) the diffusion is reduced in the ratio

$$D(0)/D(B) = 1 + \omega^2 \tau_1{}^2 .$$

Above, two other constants are needed, because there the reduction is

$$D(0)/D(B) = C + \omega^2 \tau_2{}^2 .$$

REFERENCES

1. D.L. Faucher and A.C. Schaffer, I.E.E.E. Transactions on Nucl. Sc., Vol. NS26, 150 (1979) and literature quoted there.

2. M. Benetta et al., I.E.E.E. Transactions on Nucl. Sc., Vol. NS-32, 605 (1985).

3. W.P. Allis in Fluegge (editor), Handbuch der Physik, Vol. 23, p. 383 (1956).

4. PEP4-Proposal, SLAC PUB-5012 (1976), Appendix 6; data read from Fig. A6.5.

5. F. Fulda-Quenzer et al., Nucl. Instr. and Methods A235, 517 (1985). Value for 115 V/cm interpolated from values in their Table 1.

FIGURE CAPTIONS

Fig. 1 Electrode structure. Units are in mm unless indicated.

Fig. 2 Typical frequency distribution of $(\sigma_1/\Delta)^2$.

Fig. 3 Measured dependence of σ_1^2 on B and L.

Fig. 4 Measured dependence of 2D/v on B.

Fig. 5 Experimental evidence that the factor by which the magnetic field reduces the diffusion constant, is a linear function of B^2 in the limit of low B^2 (a) and in the limit of high B^2 (b).

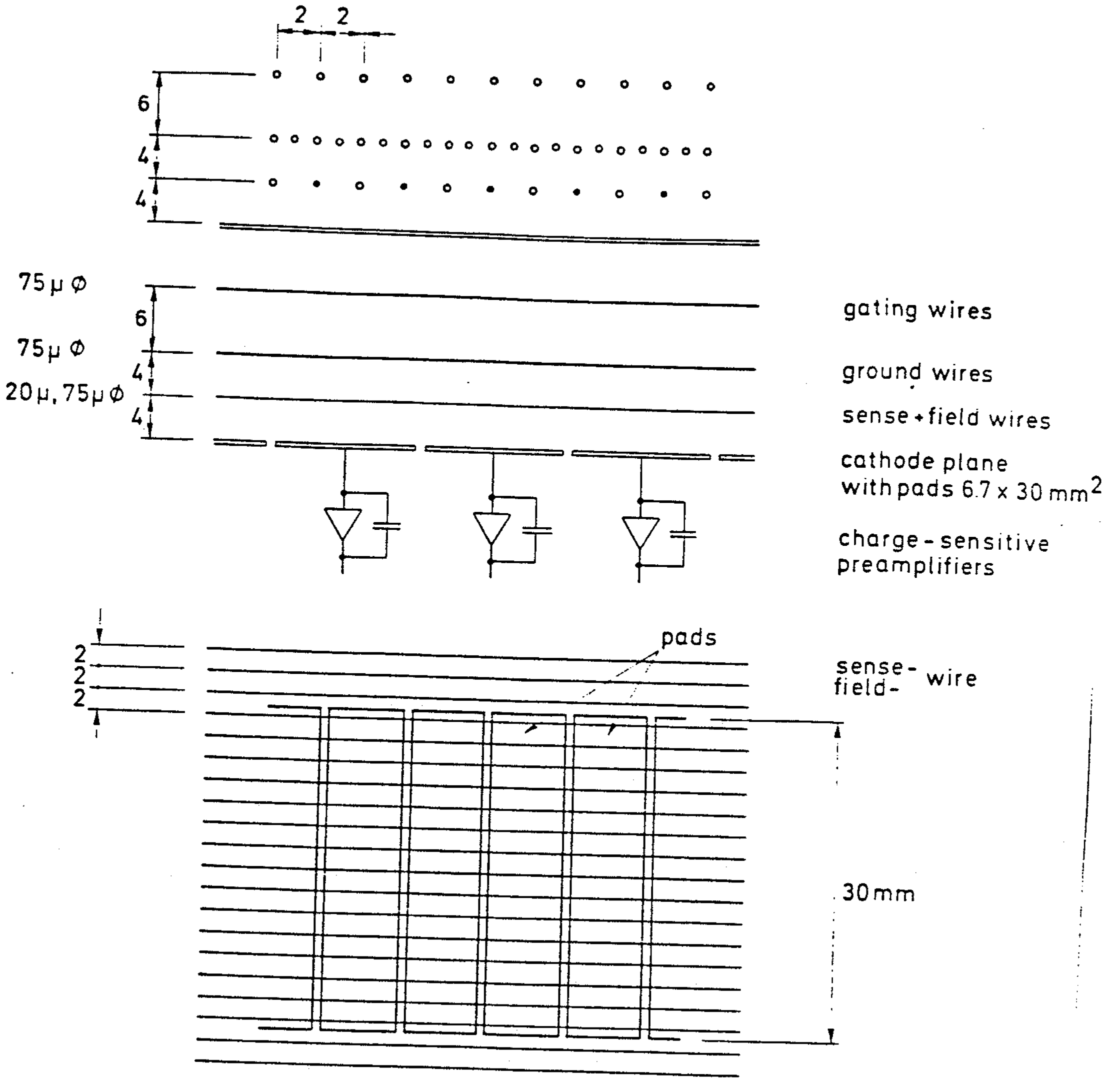
2
2
6
4
4
75μ Ø
6
75μ Ø
4
20μ, 75μ Ø
4
gating wires
ground wires
sense + field wires
cathode plane
with pads 6.7 x 30 mm2
charge - sensitive
preamplifiers
2
2
2
pads
sense-
field- wire
30mm

Fig. 1

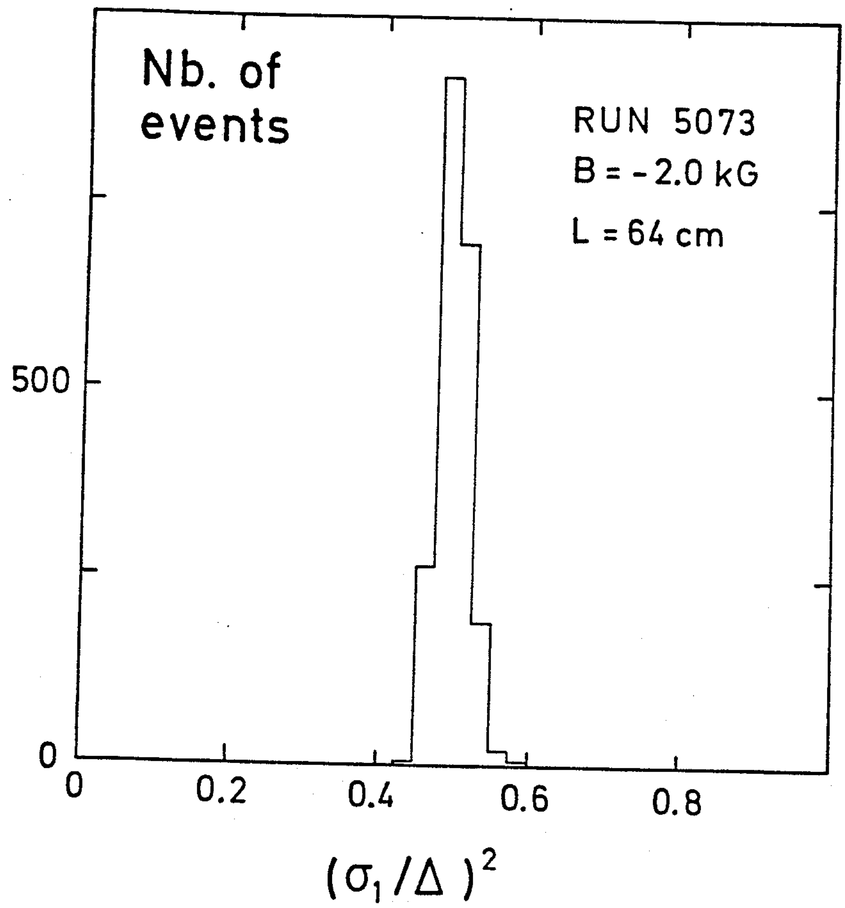

Fig. 2

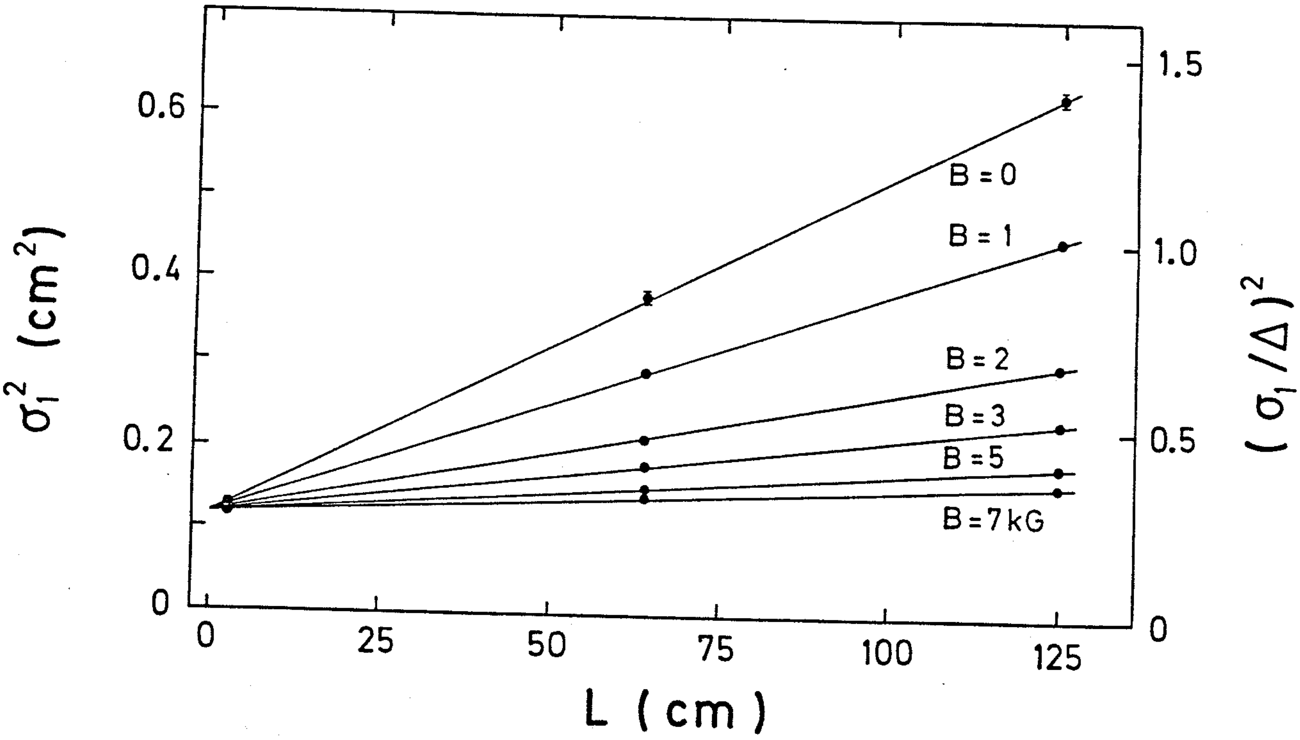
0.6
0.4
0.2
0
σ₁² (cm²)
1.5
1.0
0.5
0
(σ₁ / Δ)²
B = 0
B = 1
B = 2
B = 3
B = 5
B = 7 kG
0
25
50
75
100
125
L (cm)

Fig. 3

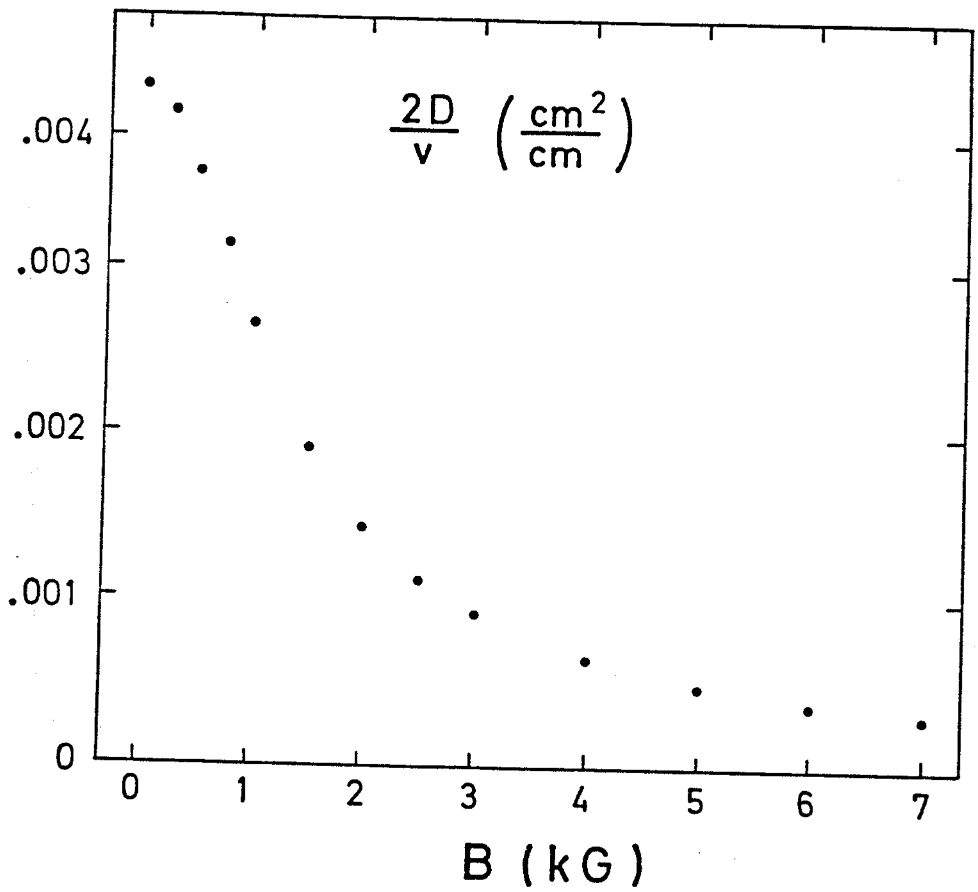

Fig. 4

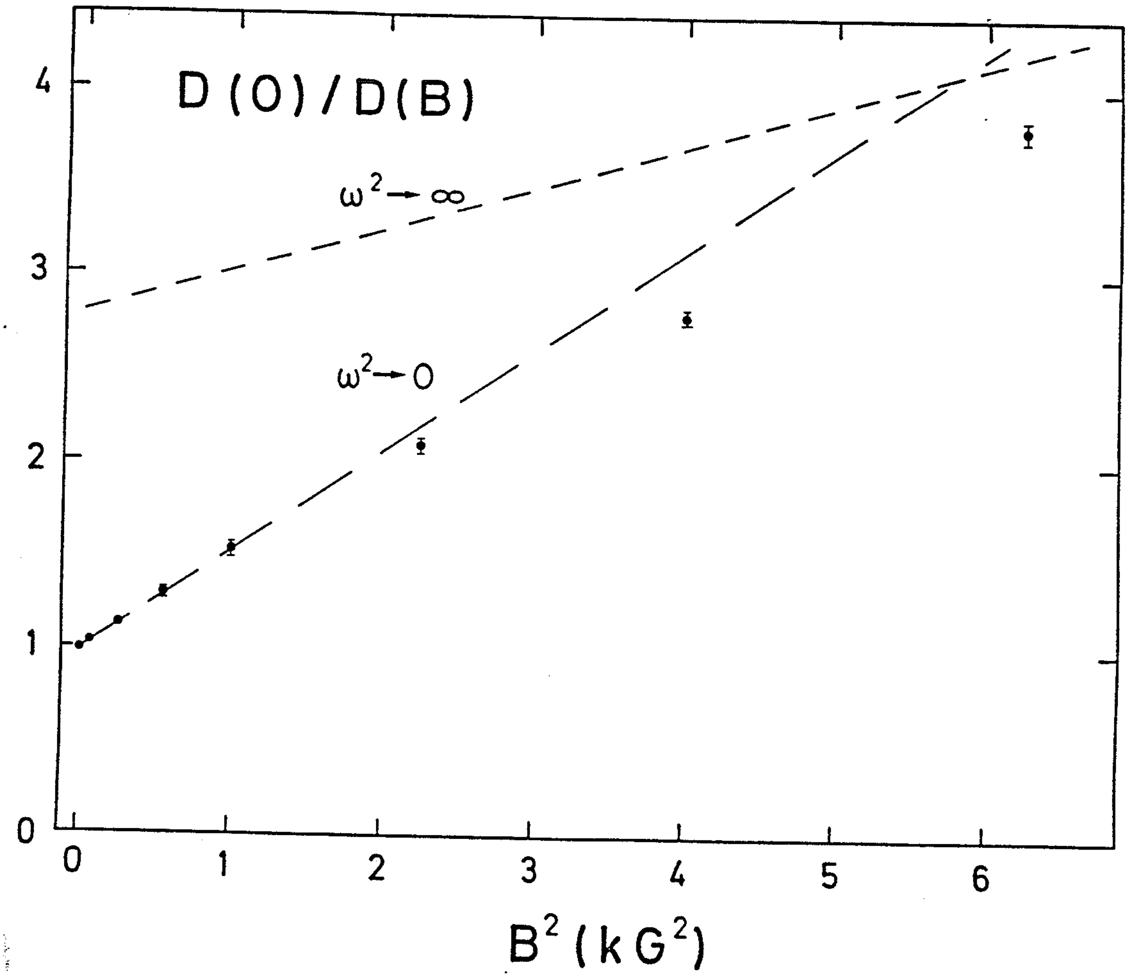

Fig. 5a

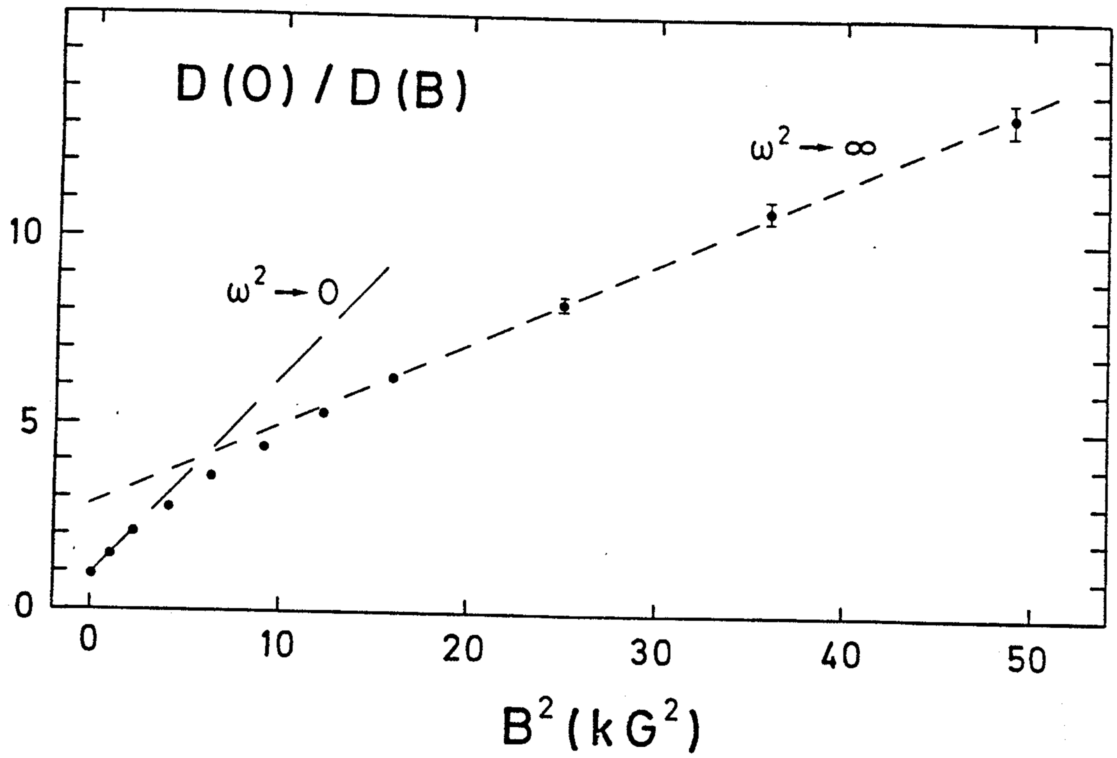

Fig. 5b