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Constant Drift Velocity of Carriers in Organic Compounds

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S u m m a r y

It has been found in some organic compounds that the drift mobility of carriers decreases with the increasing electric field (HANSEL et al. 1978, HALADYJ et al. 1980, KANIA 1980, KONDRASIUK and SZYMANSKI 1972, MYCIELSKI and LIPINSKI 1978). All these experimental results can be interpreted on the assumption that the time of flight of carriers across a sample is controlled by one "difficult" jump. For such a system the Einstein equation is not valid and the drift velocity of carriers is independent of the electric field.

1. D i f f u s i v e s y s t e m s

Let us take a piece of semiconductor placed between the plates of a charged condenser. The plates do not touch the semiconductor, so no current is allowed to flow in the system. The carrier density in such a system is given by the Maxwell-Boltzmann distribution. The picture of the carrier distribution in equilibrium in such a sample is shown in Fig.1. On equating the diffusion current and the drift current in the system we obtain the well-known Einstein relation:

$$\mu = \frac{eD}{kT} \qquad (1)$$

where μ is the drift mobility, e is the electron charge, D is the diffusion coeficient, k is the Boltzmann constant and T is the temperature. The relation is often used to estimate the drift mobility in hopping systems.

2. N o n - d i f f u s i v e s y s t e m s

At first let us assume that the probability of a "difficult" jump is equal to zero and that each hopping path of a hopping system contains one "difficult" jump. In such a system the distribution of carriers is not given by the Maxwell-Boltzmann statistics, as there is no possibility of a jump between the two localized states which form the "difficult" jump.The distribution of carriers in a system containing "difficult" jumps is shown in Fig.1. The function of the distribution is not continuous, so the diffusion equation:

$$j = -De\frac{\partial n(x)}{\partial x} \qquad (2)$$

cannot be used. In the light of this statement the Einstein relation is not valid for such systems. The time of flight of carriers flowing across a sample containing "difficult" jumps is given by the time of a single jump between the two states forming the "difficult" jump.

In real systems there can be no such difficult jumps, the probability

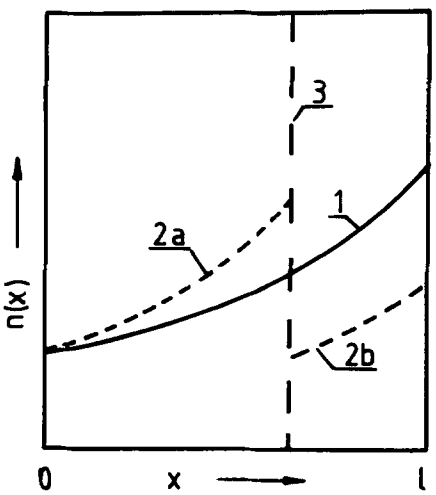

Fig.1.Concentration of carriers in a sample;1-sample without "difficult jumps, 2a and 2b-two parts of a sample containing "difficult" jumps,3-plane of "difficult" jumps 1-thickness of a sample.

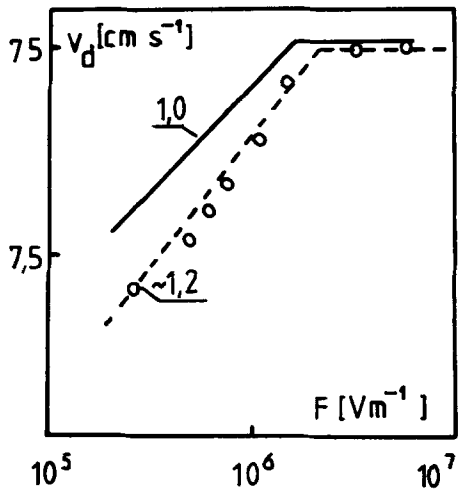

Fig.2.Comparison of experimental results (full curve) with the theory results (dashed curve).

of which is equal to zero, but a simple criterion which enables us to find out whether the system can be regarded as a non-diffusive one, can be formulated. When the average time of a single "difficult" jump is greater then the time of flight of carrier across the rest of sample, the system can be considered to be controlled by "difficult" jumps. As the Einstein equation is not valid for such a system, the drift mobility is not proportional to the diffusion coefficient that is to the probability of a single jump. In the case of existence of "difficult" jumps the drift velocity is proportional to the probability of a single jump because the time of "difficult" jumps is inversly proportional to its probability. When the probability of a "difficult" jump is independent of the electric field, the drift velocity becomes independent of the field as well.

The dependence of the probability of a single "difficult" jump was discussed earlier (BAK 1982). It was suggested that the hopping paths are formed up to the field of 3×10^6 Vm^{-1}, because a number of new localized states become available to the hopping transport with the increasing electric field. Above the field of 3×10^6 Vm^{-1} the hopping paths become stable and the probability of a single jump is independent of the field.

The case of existence of one "difficult" jump is shown in Fig.1. It may be supposed that the drift velocity remains independent of the field even if the number of the "difficult" jumps is greater than one, provided that the Maxwell-Boltzmann distribution is not obeyed in the system.

It was suggested that the hopping paths in polycrystalline simple aromatic hydrocarbon layers are formed below the border value of an electric field (BAK 1982, BAK 1983ab). It is clear that in the case of existence of "difficult" jumps in hopping paths, the distance between the two states forming the "difficult" jump is the most sensitive place of the path to new available localized states, which appear in the path. It may be shown (BAK 1983a) that the field-dependence of the drift-velocity in the case of non-diffusive systems containing "difficult" jumps is given by:

$$v_d \propto \exp\left[-2\alpha R(F)\left(k^o - \frac{3k^{o2}|\Delta R(F)|}{4R(F)}\right)\right] \qquad (3)$$

where α is the exponential decay parameter of the localized state wave function, $R(F)$ is the average distance between localized states forming hopping paths and k^o is the ratio of the lenght of the most difficult jump to that of the average jump, taken at zero electric field. The comparison of the drift velocity obtained by using (3) with experimental results is shown in fig.2.

The field-dependent drift mobility of carriers has been observed in a few various compounds, such as polycrystalline tetracene and p-quaterphenyl (MYCIELSKI and LIPINSKI 1978, KANIA 1980), crystalline tetracene (KONDRASIUK and SZYMANSKI 1972), polycrystalline and crystalline tetrabenzofulvalene (HALADYJ et al. 1981) and some polymers (HANSEL et al. 1978). The nature of "difficult" jumps in the compounds may be expected to be various. The idea of "difficult" jumps may prove to be only a thought abbreviation, which must be supplemented according to new experimental results, but it seems to be a way of better understanding the phenomenon of the field-dependent drift mobility, which has not been explained in another way so far.

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