around the hypocotyl, as a band around the first internode, as a thin layer along the midrib of one primary leaf, or as a thin layer on the cotyledons of each plant. Comparable controls were similarly treated with lanolin containing 20% of Tween 20 but no 2,4-DNCl.

Ten days after treatment there were marked differences in the way the plants had responded. Treatment of the first internode reduced stem length by 33.5%. An equal amount of 2,4-DNCl applied to the hypocotyl reduced stem length by 22.8%, while the same amount of chemical applied to the leaf brought about only a 7% reduction in stem elongation. Treatment of the cotyledon had no significant effect on stem elongation, although the cotyledons were fleshy when treated and remained attached for several days following treatment. It is obvious from these results that the effectiveness of 2,4-DNCl in inhibiting internodal elongation varied, depending upon the part of the plant treated.

Bean plants in different stages of development were used to compare the effect of 2,4-DNCl on stem elongation of plants in different stages of maturity. Seedlings selected for the first group were about 3 in. tall and their hypocotyls were still increasing in length. Plants in the second group were 4–5 in. tall, their hypocotyls had nearly completed elongation, and the first internodes were elongating. Plants in the third group were 6–7 in. tall, the hypocotyls had reached maximum length, and the first trifoliate leaf was beginning to unfold. Part of the plants in each group were treated by applying 50 mg of the paste containing 2,4-DNCl as a band around the hypocotyl of each plant. The remaining plants in each age group were left untreated for comparison.

During the following 10 days, stem elongation of the youngest treated plants was reduced by 35.8% and of those in the medium age group by 28.6%, whereas treatment of the oldest plants reduced stem length only 6.2% in comparison with elongation of comparable untreated plants in each age group.

With respect to molecular configuration of the compounds used, there was a statistically significant difference between the activity of the three chlorides. Parachlorobenzylnicotinium chloride was least effective, 3,4-dichlorobenzylnicotinium chloride was somewhat more effective than the para form, and 2,4-dichlorobenzylnicotinium chloride was very effective in reducing internodal elongation. The three compounds assumed the same order of activity when classified on the basis of their effect on stem diameter. Differences between the activity of the compounds evaluated on this basis were highly significant from the statistical standpoint.

With respect to the two bromides used, the substitution of one chlorine atom in the ortho position in the benzene ring significantly increased activity when evaluated either on the basis of the inhibition of stem elongation or increase in stem diameter.

In preliminary experiments the following coal tar derivatives[1] have been found to bring about responses in bean plants similar to those that resulted when the nicotinium compounds were applied: 2,4-dichlorobenzylpyridinium chloride, 2,4-dichlorobenzyl-2-picolinium chloride, 2,4-dichlorobenzyl-3-picolinium chloride, and 2,4-dichlorobenzyl-4-picolinium chloride. The effect of these coal tar derivatives on plant growth is being studied further.

[1] Coal tar derivatives prepared by Dr. C. F. Woodward and Dr. D. H. Saunders, Eastern Regional Research Laboratory, Wyndmoor, Pennsylvania.

Conduction in Photoconductive PbS Films

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Sosnowski, Starkiewicz, and Simpson (*2*) have produced photoconductive PbS films which contain both Pb and O atoms as impurities, in concentrations ($10^{19}/cm^3$) that are, for semiconductors, relatively high. The Pb and O atoms tend to make the film an n-type or p-type semiconductor, respectively. Photoconductive sensitivity demands a very careful balance of these impurities to make the conductivity a minimum; this occurs, presumably, when Pb and O impurities are present in equal numbers. Variations in the densities of the two impurities will then cause the film to consist of p and n regions interspersed. The very high resistance of the film is attributed to the p-n barriers, and the photoconductive effect to the reduction in height of these barriers by the redistribution of electronic charge produced by illumination (photovoltaic effect).

This note presents some extensions of these ideas, and conclusions as to the film structure desired for maximum photosensitivity.

First, it must be noted that purely random fluctuations in the densities of the two types of impurities can produce important fluctuations of the conductivity and potential within the film. Consider, for instance, the most homogeneous possible film containing 10^{19} O atoms and 10^{19} excess Pb atoms per cm^3. A 1-μ cube will then contain about 10^7 atoms of each type. Random fluctuations in these numbers, from cube to cube, will be of the order of $\sqrt{10^7}$. The excess of one impurity over the other (net impurity density), which determines the character of the conduction in a region, will be on the average some $\sqrt{2\times10^7}=4.5\times10^3$ atoms, or about the number of impurity atoms in an equal volume of an ordinary semiconductor with 5×10^{15} impurities/cm^3. For larger regions the fluctuations in net impurity density will be less; in smaller regions the potential fluctuations discussed in the next pararaph cannot follow closely the fluctuations in impurity density. The "homogeneous" film considered here will thus in effect consist of n and p regions, of the order of 1 μ in diameter, with conductivities ranging from the intrinsic level to values of the order of those produced by 10^{16} impurities of one type per cm^3.

Fluctuations in net impurity density may cause important fluctuations of potential in the film, even when they do not involve the appearance of n-p barriers. In an ideal homogeneous semiconductor the Fermi ζ-level is extremely sensitive to changes in the relative numbers of

n and p impurities, when these are present in nearly equal numbers. At low temperatures this sensitivity is particularly great: a very small preponderance of one impurity over the other will shift the ζ-level to the neighborhood of the corresponding impurity level. In an inhomogeneous semiconductor in equilibrium the ζ-level is fixed, but the electrical potential undergoes corresponding fluctuations as the relative number of impurities shifts. The variations in potential will be larger the lower the temperature (Fig. 1a, b) becoming important when the number of thermally excited carriers falls below the net impurity density. Taking the width of the forbidden band in PbS as 0.385 ev, and the effective electronic mass equal to the real electronic mass, one finds the number of intrinsic electrons to be $1.5 \times 10^{16}/cm^3$ at 300° K, and $2.16 \times 10^{15}/cm^3$ at 250° K. In the film considered above,

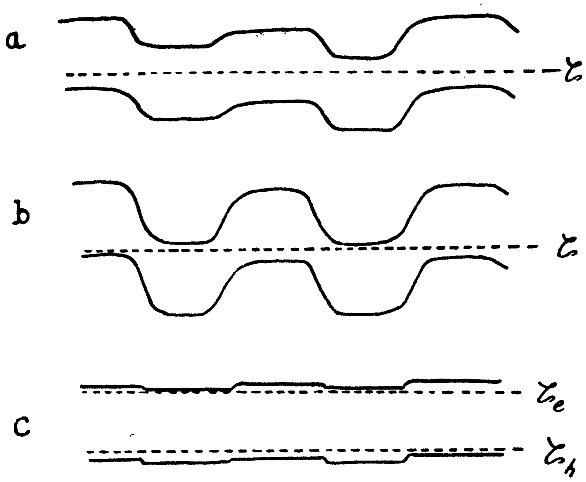

FIG. 1. Schematic representation of edges of forbidden band between the full band and the conduction band. (a) Moderate temperature, no illumination. (b) Low temperature, no illumination. (c) Strong illumination.

the potential fluctuations would become important around room temperature, and would increase significantly with decreasing temperature through the next 100° C.

With inhomogeneous materials, the conductivity of films may be very different from that of bulk material. In either case charges will tend to move through potential valleys, along paths of minimum potential change; in the films here considered current will flow most easily along chains of n-regions or of p-regions. A film of thickness 1 μ will be essentially one region thick, and current flow in it will be essentially two-dimensional. If n- and p-regions are present in equal numbers, the probability that there will exist a continuous n-path across a region in the direction of current flow is equal to the probability that there will be a continuous p-path at right angles to it. These two events are mutually exclusive, and each will occur with very small probability if the region considered is large. Only when one type of region is present in considerable excess will continuous n-paths or p-paths be available in the film; in other cases p-n barriers must be traversed by the current. In bulk material, on the other hand, there can simultaneously exist networks of p- and n-regions along which conduction can take place, even when the two types of regions are present in equal numbers. If inhomogeneities in PbS arise only from fluctuations, the conductivity of a film will be of a lower order of magnitude than that of the bulk material when the two types of impurity are present in equal amount; the two conductivities will, however, be comparable when one type of impurity is so much in excess that fluctuations will not cause the appearance of regions of opposite type.

It is thus evident that PbS films with large, equal numbers of Pb and O impurities will have high resistances, because (a) the number of conductors in any given region depends on the net, rather than the total, impurity concentration; and (b) p-n barriers, as well as smaller fluctuations of potential, impede the flow of current. The conductivity decreases with decreasing temperature because the number of available conductors is decreased, but, more importantly, because the potential barriers become higher. Inequality in the average density of p- and n-impurities will decrease the importance of the density fluctuations, and decrease the potential fluctuations, as well as increase the number of carriers. Maximizing the resistance of the film, as described in reference *2*, thus provides a very sensitive means of assuring equality in numbers of the two types of impurities, especially if the resistance is measured at a low temperature.

This picture of the conductivity of PbS films is supported by the observations of Chasmar (*1*), who found that the resistance of the films falls with increasing frequency, because of capacitative shorting of the p-n barriers. The high frequency conductivity, due to current flow within individual regions, remains of the order of a thousand times less than that of other PbS semiconductors. This is due to the fact, apparently overlooked by Chasmar, that the conductivity of the individual regions depends on the carefully minimized difference in concentrations of the two impurity types; it would be a thousand times greater if one impurity or the other were absent.

Illumination of the PbS film increases the number of electrons in the conduction band and of holes in the full band, throughout the material. The distribution in energy of the holes and electrons will not, however, be the same as if this effect were produced by rise in temperature. Indeed, if interactions of electrons and holes with the lattice are sufficiently frequent (as compared with the creation and annihilation of holes), the distribution in energy of holes alone, and of electrons alone, will continue to be those corresponding to the temperature of the crystal lattice. The probability that an electronic state, or a hole state, will be occupied can then be written, as usual, as

$$p(\varepsilon) = \left[e^{\frac{\varepsilon - \zeta}{kT}} + 1 \right]^{-1},$$

but it will be necessary to take different ζ-values for the holes and for the electrons. As the number of electrons and holes is increased by increasing illumination, these ζ-values approach the edges of the conduction and full bands, respectively, whatever the impurity density. Since each of these ζ-levels will be constant through the crystal, this involves a leveling-out of the potential fluctuations (Fig. 1c), which will become marked when the concentration of holes and electrons introduced by illumination becomes comparable with the net concentration maintained by impurities and thermal excitation. This leveling of the potential barriers, and the attendant decrease in resistivity, will thus occur for lower illumination the more exact the balancing of the two types of impurities, and the lower the temperature. The observation of Chasmar (*1*), that high frequency conductivity is little affected by illumination, indicates that this, rather than any increase in the number of available carriers, is the important factor in the photoconductivity of these films. Very pure PbS films should also show photoconductivity, their low intrinsic conductivity being increased by the carriers produced by illumination; their sensitivity to illumination, should, however, be markedly less.

It appears, then, that high photosensitivity of PbS films is to be sought by careful balancing of fairly high contents of *n*- and *p*-impurity atoms in films of the order of 1 μ thick, made as homogeneous as possible; random fluctuations in impurity distribution will suffice to produce the required potential fluctuations in the film. Use of the films at low temperatures is also indicated.

A theoretical study of the potential distribution and conductivity in these films, as it depends on temperature and illumination, is now in progress.

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On the Direct Fermentation of Maltose[1]

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During the course of isolating and identifying bacteria of the genus *Neisseria* from the nasopharynx of humans, several strains were encountered which fermented maltose with acid production while glucose was not fermented. The fermentation of a disaccharide without fermentation of either of its constituent monosaccharides (direct fermentation) by bacteria has been reported by Wilson and Smith (*5*). Wright (*6*), Douderoff *et al.* (*1*), and Snell *et al.* (*3*), have reported on a strain of *Lactobacillus bulgaricus* which utilized lactose but not glucose or galactose. such observations are not in accord with the generally accepted concept of indirect fermentation, which presupposes a cleavage of the disaccharide to its monose constituents, which are fermented as such. The subject of direct and indirect fermentation has been reviewed by Liebowitz and Hestrin (*2*).

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TABLE 1

pH VALUES PRODUCED IN GLUCOSE AND MALTOSE BROTH BY SEVERAL STRAINS OF *Neisseria*

Culture	Media*	
	Glucose broth	Maltose broth
	pH	pH
No. 4	8.3	6.0
" 12	8.1	5.7
" 55	8.3	6.3
" 876	7.9	5.6

* BBL phenol red broth containing peptone and meat extract, pH 7.2–7.4. The glucose and maltose were sterilized by filtration and added aseptically to sterile phenol red broth to give a final concentration of 0.5%. The pH values were determined after 7 days' incubation at 35° C.

The results obtained with four cultures of *Neisseria*, when cultivated in glucose and maltose broth, are shown in Table 1. In each instance, the organisms produced acid from maltose while an alkaline reaction developed in the glucose medium. It may be noted that an acid reaction in the vicinity of pH 6.0 is a limiting factor for the growth of most *Neisseria.*

Further observations were made comparing culture No. 12 to a strain of *Neisseria sicca,* which ferments both glucose and maltose. Each of these organisms was cultivated in glucose and maltose broth for a 5-day period, after which the residual sugar was determined by the method of Somogyi (*4*). The culture of *N. sicca* effected complete utilization of both carbohydrates, while culture No. 12 utilized approximately 75% of the maltose and little, if any, of the glucose. In addition, experiments employing the Warburg manometric technic showed that the oxygen uptake with cells of *N. sicca* was approximately the same for both glucose and maltose. For culture No. 12, the oxygen uptake with maltose was approximately that obtained with *N. sicca*; with the glucose, the uptake was only slightly greater than that of endogenous respiration.

The maltose used in the above experiments was chemically pure (Pfanstiehl). All determinations have been repeated using maltose recrystallized from chemically pure maltose and treated with norite five times. No differences in results were obtained.

These results suggest that the *Neisseria* described are capable of a direct fermentation of maltose.

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