COPPER-CUPROUS OXIDE RECTIFIER

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NUMEROUS "Sperrschicht Cells" or "Barrier layer" rectifiers are in commercial use; but no material appears to have been more extensively studied or utilised than the copper-cuprous oxide rectifier. These rectifiers satisfy the demands for the direct current and are used in battery-charging, in electroplating, in preparing A.C. measuring instruments, in tele-communications and as photo-electric cells. The practice has far outrun our knowledge of the fundamental nature of the problem and we are forced to follow the trial-error and inferential methods of procedure. Our present knowledge appears to indicate that the rectification is governed by statistical laws. Scientific interest has been stimulated mainly by the ever-increasing use of the effect in industry. We have undertaken to study systematically the various factors which alter the rectification of cuprous oxide layers, with a view that such a systematic knowledge will enable us to understand the mechanism of the rectifying action. This paper gives a short summary of the work we have done so far, but for the sake of giving the readers a complete picture we have included some work done by others.

In general when voltage is applied to a conductor the current which flows is independent of the direction of the voltage. But some composite conductors show asymmetric conduction, that is, the property of passing currents more freely in one direction than in the opposite direction. The direction in which more current flows is usually called the forward or the conducting direction and the other the reverse or non-conducting direction. The rectification occurs at the contact between the two dissimilar substances.

In 1926 Grondahl observed that a plate of copper upon which a thin film of cuprous oxide has been formed could be used for the rectification of currents of considerable magnitude. The rectifier was made by partially oxidizing a sheet of copper in air at about 1000° C. and then by allowing the oxidized sheet to cool to room temperature. When one electrical contact was made to the copper sheet and another to the oxide by a metal foil applied under pressure, it was found that the element passed current readily from oxide to copper but much less freely in the other direction. The process which is used to-day in preparing the cuprous oxide rectifier is similar to the Grondahl's original process.

For best effects the copper needs to be of exceptional purity, it was supposed at one time that it should be completely free from silver but later experiments have disproved this. Since it is the surface of the metal which is used in making the rectifier it is essential that it should be clean and with a perfect finish. Pure copper (to which suitable amounts of inclusions can be added) is poured in a molten state, then it is rolled (or hammered) in strips of 1 mm. thickness, from this is punched the blank, to be oxidized. It is established that grain-size, hardness, etc., are of no importance. There is no test of the suitability of rectifier copper other than the preparation of rectifiers from it.

The blanks are oxidized in pure air at about 1020° C. Cupric oxide formed at lower temperatures becomes unstable at 970° C. and is reduced to cuprous oxide. The furnace temperature must not exceed 1040° C. Upto an oxidation temperature of 1020° C. the higher the temperature the lower the forward resistance of the rectifier. The temperature of the furnace is allowed to remain at 1020° C. for about 12 minutes and an oxide film of about 0·1 mm. thickness is formed. The annealing is done in two stages upto 600° C. in 15 minutes in the furnace and then it is removed and cooled to the room temperature. Some physical deformation is produced, in the oxidizing and annealing process, but if copper is oxidized on both sides the element remains flat. The cuprous oxide is in the form of a hard bright red crystalline layer adhering very firmly to the mother copper but covered by a very thin film of black cupric oxide which has been formed during annealing. The insulating film of black oxide was originally removed by mechanical means, but later a concentrated solution of sodium cyanide was employed, now this has been superseded by a mineral acid process. These changes have been accompanied by marked improvements in the magnitude of the reverse resistance. If now an efficient electrical contact is made with the cuprous oxide the rectifier element becomes ready for use. If a soft metal is simply pressed in contact with the oxide layer the contact resistance is very high; so powdered carbon is rubbed into the surface and a soft metal foil is pressed on. Or colloidal graphite in aqueous suspension is painted on the surface and is dried; contact may be made with graphite either by soft metal under pressure or by spraying, vaporising or cathode sputtering a metal electrode which gives good contact without the use of pressure.

The resistance of the rectifier either in the forward or reverse direction depends on the applied voltage, that is, the rectifier does not obey Ohm's law. The resistance varies with the applied voltage, temperature and time. The most important electrical property of a rectifier is its self-capacitance which is of the order of $0·02 \mu F.$ per $cm.^2$ This value varies with the voltage and current in the rectifier but is practically independent of the frequency. The capacitance has the effect of increasing the reverse leakage when the rectifier is used at high frequencies. The electrical properties of the rectifiers can be varied considerably at the will of the manufacturer.

Cuprous oxide layer formed in this way exhibits photoconducting properties and can be used as a cell showing photovoltaic effects. In the normal cuprous oxide rectifier, when

light falls upon the oxide surface the photo-current flows from copper to oxide internally, that is, in the reverse direction, and it may be expected that the magnitude of the current would be related to the reverse characteristic of the rectifier. There is, however, no evidence to support this. The cell has a red and infra-red colour response and the cut-off at the end of the visible spectrum corresponds exactly to the commencement of the light transmission of the cuprous oxide, which, therefore, must be acting as a filter. Maximum colour response is approximately in the middle of the visible spectrum.

SPERMATELEOSIS AND NUCLEINATION

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SINCE the early studies of Miescher[1] followed by those of Steudel and Peiser[2] on the chemical constituents of the sperm-heads, it has been known that these, which represent so far as we know, the consolidated essence of nuclear matter, contain a large percentage of nucleo-proteins which make up much of the chromosomes of the nucleus. In fact, our knowledge of the chemistry of the nucleus has largely been based on these pioneer studies, and as a result, it has now been clear that the chromosomes are in the nature of complex salt-like compounds of proteins and nucleic acids called nucleo-proteins. The two conditions of the nucleus, that of rest and that of division, differ mainly in the polymerization of nucleotides on the protein framework of the chromosomes. It is surmised that most, if not all, nucleic acid of the chromosome comes from the cytoplasm where it exists as isolated nucleotides and which are transferred to the chromosomes at the beginning of every mitosis. In fact, one of the important changes associated with mitosis is the nucleination of the chromosomes, whose fixability, and visibility under the microscope are due to the accumulation of nucleotides on the protein framework of the chromosome, which is the permanent part of the chromosome, the nucleic acid varying in amount at different stages of the mitotic cycle. It has even been suggested that the sudden increase of nucleic acid in the chromosomes at pro-metaphase, of mitosis is due to the breaking down of the nuclear membrane at this stage and the free transference of material from the cytoplasm to the chromosomes (White[3]). So the idea has gained ground that the mitotic process is a necessary prerequisite for the organization of the chromosomes in a recognizable form, and for their nucleination. For, at no other stage the chromosome is visible in the nucleus, nor is thymonucleic acid identifiable in the nucleus at any other time.

But that leaves the sperm-head, which has formed the important source of our information on the chemistry of the chromosome, out of the picture. The sperm-head is analogous to the metaphase chromosome in that it represents the synthesis and accumulation of the maximum amount of nucleic acid in relation with the protein; but while in the latter case, this synthesis has been achieved with reference to mitosis, in the former, the synthesis of nucleic acid has taken place without any reference to division and indeed, without any reference to the chromosomes. The sperm-head, therefore, offers the only example of the synthesis and accumulation of desoxyribose nucleic acid outside its relation with the definitive chromosome.
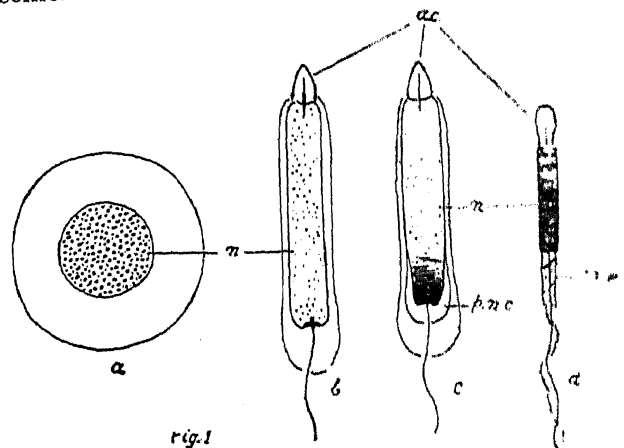

FIG. 1. Four stages in the spermateleosis in *Ichthyophis glutinosus*, × 600.

a. Resting nucleus of the spermatid

b. Elongation of the nucleus during sperm-teleosis.

c. Beginning of nucleination from the posterior end.

d. Fully formed spermatozoon.

ac. acrosome; m.p. middle piece; n. nucleus; p.n.c. post-nuclear cavity (which later becomes the middle piece).

The process of spermateleosis confirms this. The animal spermatid has a resting nucleus, and associated with changes* which vary in different animals, this nucleus begins gradually to synthesize nucleic acid within it till in the fully formed sperm, the nucleus is the packed essence of nucleo-protein. If the mitotic cycle involves the transference of cytoplasmic nucleotides into the nucleus and their conversion from ribose to desoxyribose nucleotides, then the same process must take place during spermateleosis also, where, however, without changes associated with mitosis and without the formation of organized visible chromosomes, the essentials of the same process of deposition of desoxyribose nucleic acid takes place in the nucleus.

There is yet another parallel between the development of the metaphase chromosome and that of the spermatozoon. In both it is probable that important changes occur in the