

THE BREAKDOWN OF ACCOMMODATION—NERVE AS MODEL SENSE-ORGAN

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IN EVERY highly developed sense-organ it is possible to distinguish a primary recipient mechanism, adjusted for maximal sensitivity to the adequate stimulus, and a secondary "generator" mechanism firing the nerve or perhaps ganglion cells directly. The very special problem as to how different forms of energy are translated into a physiological stimulus capable of exciting the generator mechanism will not be considered in this paper. We shall only be dealing with the nature of this secondary mechanism, a problem belonging to the general physiology of the special senses.

At present it is only possible to attack this general problem with the aid of hypotheses to be tested experimentally. The hypothesis to be chosen in the first instance is one which is suggested by the relatively extensive work on the retina. From this work it is known that the simpler the retina or the better the isolation of components of the response of complex retinae, the more definite the evidence for the conclusion that the generator mechanism is a slowly rising potential preceding excitation or inhibition, as the case may be (see Adrian and Matthews, 1928, Hartline and Graham, 1932, Hartline, 1938, Granit, 1933, 1938, Granit and Therman, 1935, Bernhard, 1941). There is enough evidence for the reasonableness of this general assumption to be found in the exciting properties of "local" potentials in nerve (Hodgkin, 1938), muscular end-plates (Göpfert and Schaefer, 1936), Eccles, Katz and Kuffler, 1941, Eccles and Kuffler, 1941), salivary glands (Langenskiöld, 1941), spinal neurons (Umrath, 1933, Barron and Matthews, 1938) to make the earlier results with the retina in no way exceptional. From the point of view of neurons and sense-organs, however, the main question is how repetitive firing is brought about by this potential difference. Thus "accommodation" enters the problem.

The work on accommodation shows that a non-accommodative nerve reacts to a rising current with a stream of impulses (Fessard, 1936, Erlanger and Blair, 1936, 1938) much as an adequately stimulated sense-organ would do, and that any nerve can be made to acquire such properties *e.g.* by suitable treatment with citrate or Ca-free Ringer (Solandt, 1935-36, Katz, 1936, Lehmann 1937, Schriever and Cebulla, 1938). It then tends to fire spontaneously. The same holds good for ganglions (Bronk, 1939) and sense-organs (Matthews, 1931 for muscle-spindle, Talaat, 1933 for sense-organs in the skin), many of which discharge spontaneously without having been subject to treatment of any kind. We have found (unpublished work) the retina also to increase its normal spontaneous activity after treatment with citrate-Ringer.

If sense-organs set up repetitive discharges as a consequence of "local"

potentials arising in them, then the question of *breakdown* of accommodation in nerve in response to slowly rising currents deserves a separate study. Beyond the general knowledge that a strong catelectrotonus causes a nerve to fire repetitively there is very little information concerning repetitive firing in normal vertebrate nerve. Such use of nerve as model sense-organ should show to what an extent imitation of the "generator" potential imitates some of the known properties of sensory discharges. Thus, for instance, the retina has a long latent period, 10–20 times any possible synaptic delay. It can react with excitation or inhibition, gives grouped or otherwise synchronized discharges, etc.

METHOD

For slowly rising currents of different time constants an apparatus built by our physicist, Mr. T. Helme, was available. The principle of this instrument is a release of an initially blocked anode current by charging the grid over condensers. Kahlson and v. Werz (1936) among others have utilized this principle before. An improvement in our apparatus consists in the use of a suitable resistance connected to the cathode-side of the H.T. circuit in order to eliminate deformation of the H.T. current rise owing to the characteristic of the valve. The form of the rise of the current in the stimulating anode circuit was determined oscillographically. In the diagrams plotted below, however, the actual rising times have not been used but a factor proportional to the $C \times R$ products of the condensers charging the grid. The reason for this was our original intention to calculate Hill's constant λ (Hill, 1936, and below). The stimulating currents remain at the level to which they have risen until broken off manually. A description of the technique together with observations on the breakdown of accommodation has been given in Swedish by Granit and Skoglund (1941).

Silver-silver chloride electrodes placed in the anode circuit were held to be satisfactory on account of the high internal resistance of the H.T. circuit relative to that of the tissue. The nerves were stimulated monopolarly through these electrodes. A Lapique-circuit similar to the one used by Solandt (1935–36) for slowly rising stimuli was also available.

Decerebrate cats, sometimes frogs, were used for work on peripheral nerve. In the former case the animals were kept in a heated and shielded box with a cistern of boiling water supplying the moist atmosphere needed. A number of experiments were also carried out with the retina and optic ganglion of *Dytiscus*.

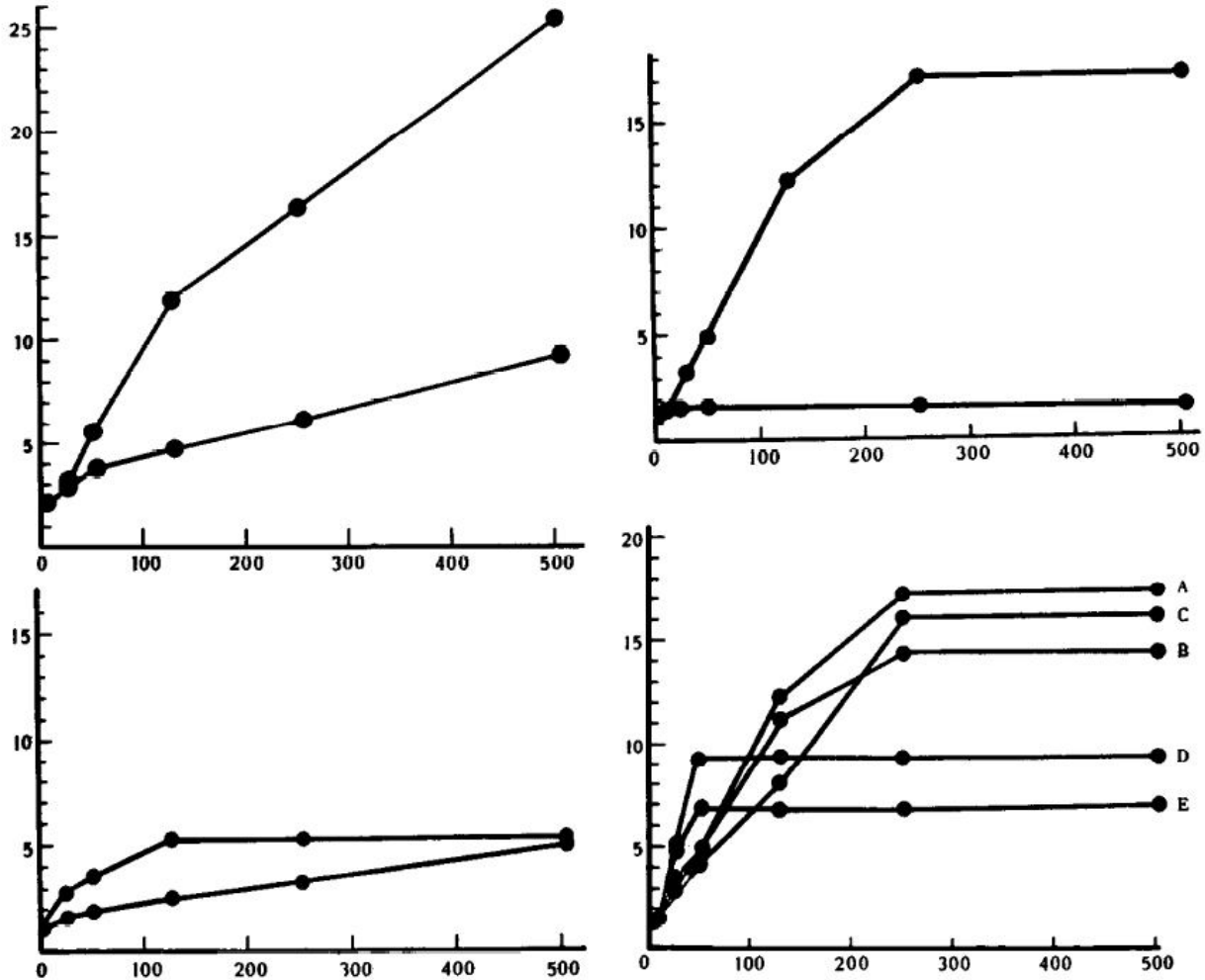
Cathode ray oscillograph and condenser coupled amplifier were used for recording from nerve or muscle.

RESULTS

1. *The index for accommodation measurements*

In 1884 it was shown by von Kries that, as the rate of rise of the stimulus decreased, the currents had to be made stronger in order to excite. He also plotted curves showing current strength as ordinates against rising time as abscissae. Following Hill's (1936) theory Solandt (1935–36) and Katz (1936) plot their results in the same manner but using multiples of rheobasic strength as ordinates and a factor proportional to rising times as abscissae. As a consequence Hill's accommodation constant λ appears as the inverse value of the slope of these curves which for the short rising times in which they were interested were rectilinear. Thus, with little accommodation, λ is great, the curves approach horizontality, and the nerves even tend to fire repetitively (Katz, 1936). Index in these measurements was a threshold muscle contraction.

In actual practice these measurements may be made in several different ways and we also began by using a threshold muscle contraction as index and determined the current strength necessary for a given rate of rise. Such experiments showed that what we have called "breakdown" of accommodation can be demonstrated already by observing the curves obtained in this



FIGS. 1-4. "Accommodation curves" for mammalian nerves with threshold muscle contraction as index. Abscissae: Rising time of stimulus in msec. (see text). Ordinates: Multiples of rheobase. Rheobase unit = 1 in all curves, but curves not always continued to this unit. *Fig. 1*: upper curve transected sciatic, lower curve transected peroneal nerve. *Fig. 2*: upper curve, unsevered peroneal nerve, lower curve, *n. aurient. magn.* *Fig. 3*: A-C: unsevered peroneal nerve, A immediately, B after 4 min., C after 25 min. D-E: same nerve severed and electrodes near cut end. *Fig. 4*: severed sciatic: upper curve electrode about 4-5 cm. from cut end, lower curve at cut end.

manner. Some curves selected from a large number of experiments are given below.

Figure 1 shows two curves for the sciatic and the peroneal nerve, both severed, Fig. 2, two intact nerves, *n. peroneus* and *n. auricularis magnus*, in the latter case with a reflex muscle contraction (pinna reflex) as index. The auricular nerve generally gave curves of this type. In Fig. 3 the three upper curves (A, B, C) were taken in this order during half an hour with the elec-

trode on an intact peroneal nerve. Then the nerve was severed and the electrodes placed near the cut surface. The curves D and E were obtained. The results are typical. Finally, in Fig. 4, a sciatic nerve, sectioned from the beginning, was used, but at a relatively late stage, the lower curve showing the result of putting the stimulating electrode near the cut end of the nerve.

According to Hill (1936) and his collaborators, whose interest was restricted to the early part of these curves, the inverse value of the slope is a measure of accommodation. Thus, the more the curves approach horizontality, the less the capacity of the nerve to accommodate. At the outset we shall define complete breakdown of accommodation by taking from the diagrams the strength of current at which the curves turn round to become horizontal. Beyond this point the nerve responds to any current above the strength of this ordinate independently of its rate of rise. In the sample curves of Figs. 1-4 breakdown occurs with different degrees of completeness and at different strengths in terms of multiples of rheobase.

A glance at these curves shows that accommodation in mammalian nerves is extremely sensitive to interference with the tissue (cf. also Schriever 1932, Liesse, 1938, a, b for blood supply etc. and frog nerve.) But there must also be unknown physiological factors to account for variations which certainly are not caused by maltreatment of the nerves. It seemed worth while investigating whether such variations had something to do with the observation that the muscle contraction was an unsatisfactory index. For rapidly rising currents the threshold contraction was brief and precise, but with slowly rising stimuli it also became slow, looking then more like a contracture. Hoffmann in 1910 had already found that the action currents then indicated repetitive firing. Schriever and Cebulla (1938) have repeated and confirmed these observations using frog's nerve which apparently in the normal state accommodates much better than mammalian nerves.

In repeating this work with leads to the amplifier from the stimulated nerve we found that the index for accommodation was equally uncertain in this case. There is no doubt repetitive firing from the nerve (cf. also Rosenblueth, 1941), developed more with slowly rising stimuli, but the question as to when and how the breakdown of accommodation takes place, is still unsolved, except that it is clear that, as predicted by Hill's theory (1936), in a general manner there is less accommodation when the slope is smaller. But it is obvious that the difficulty of deciding whether a brief or a protracted muscular contraction should be used as the constant index, necessary for obtaining the accommodation curves, is by no means solved by exchanging it for the difficulty of deciding what kind of nervous discharge to use as index, since the latter also is far from being constant but varies with respect to duration, number of spikes and amount of potential. For whole nerve such records have been published by Schriever and Cebulla (1938) who also found in frog's nerve the bend of the curve noted by us, although it was not so marked.

2. Accommodation in motor units

The next step in the work clearly required some kind of restriction of the activity to smaller populations and the simplest method (Skoglund, 1942) seemed to be to insert fine electrodes in the muscle. Silver pins in a glass tube, drawn out in a flame with the glass to a thin point, were used as different electrodes (*musc. tib. ant.*, cat) the indifferent electrode being on the bone clamped to the myograph drill. The stimulating electrodes were on the peripheral stump of the severed sciatic.

To judge from the literature on "muscle spikes" many workers are under the impression that small electrodes restrict the discharge to single motor units. But it can easily be shown, if a motor nerve be stimulated with a neon-stimulator at different strengths, that the seemingly isolated spikes of activity of constant size increase in size within a range of

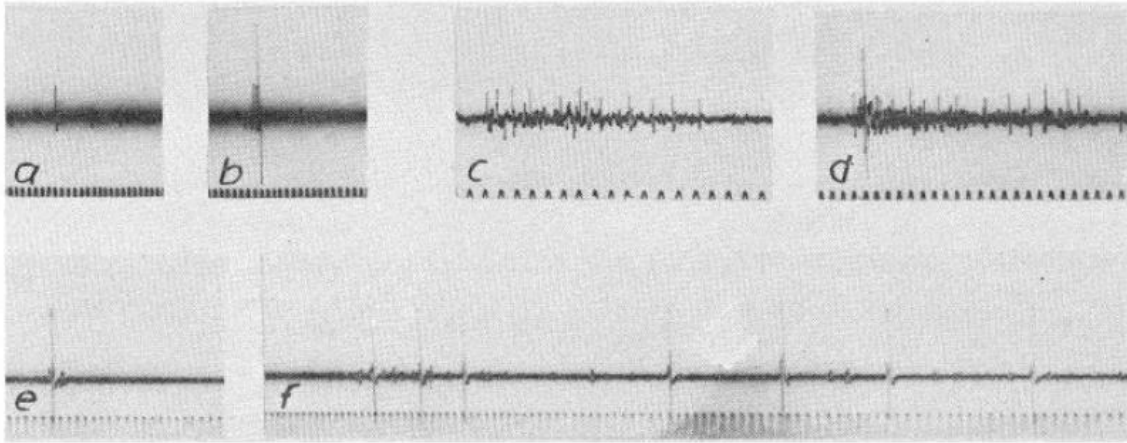


FIG. 5. Spikes recorded with microelectrode in cat's *tib. ant.* and stimulating electrodes on severed sciatic nerve. Time in 1/50 sec. Full description in text. (We regret that good films have not been obtainable.)

10 times or more when the stimuli are strengthened. Obviously therefore synchronized activity can throw into action a greater or smaller number of muscle fibres and we have no means of deciding by merely relying upon the electrode whether these fibres belong to the same motor unit or not. The all-or-none law is no reliable criterion since well synchronized spikes keep constant for a given current strength. The same holds good for recording with concentric needle electrodes (cf. Blake, Pritchard, 1930). Despite this microelectrodes are a definite improvement and some restriction of activity is obtained with them.

With this method one of us (C. R. S.) found that the motor nerve typically activates small or large spikes in the muscle (see Fig. 5) and that these have different properties with regard to accommodation. His analysis of the properties of the "spike patterns" will be published separately (Skoglund, 1942), and we shall here merely discuss *breakdown* of accommodation in relation to this new index of activity.

Figure 5a shows a single small spike at relative threshold-strength 8 and time 10, in fact the first point plotted on the lower curve of Fig. 6. Keeping the same spike as constant index this lower curve was traced in the usual manner. If at 10 msec. the strength of current was increased, the response b of Fig. 5 was obtained. This shows a large spike. The small spike now

reacts repetitively. But it is of course also possible to trace an accommodation curve with the single large spike as index. This is the upper curve of Fig. 6. The kind of response obtained for 20 msec. with the large spike at the threshold is shown in Fig. 5d. Somewhat below the threshold for the large spike, that is at strength 9.5 for 20 msec., only small spikes are seen, and there is definite repetitive firing (5c).

It would be a mistake to believe that only the small spikes are repeated. The lower curve of Fig. 5 is from another experiment, in which for 200 msec. a large spike appears at the threshold (e). The small spikes are here very

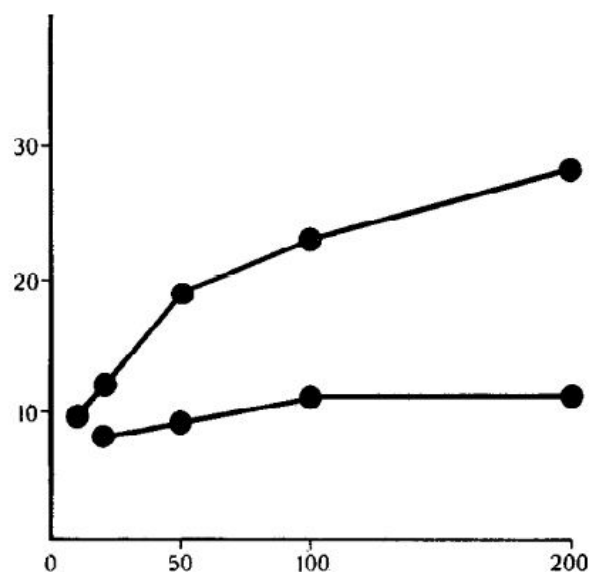


FIG. 6. "Accommodation curves" with (lower curve) small spike (a in Fig. 5) and (upper curve) large spike (b in Fig. 5) as index. Abscissae as in Fig. 1-4. Ordinates: relative current strength (not multiples of rheobase) in order to show relative threshold.

small. Record f shows a small increase of current strength, from 35 in record e to 40 in f. The large spike now has become repetitive. Thus, it is only necessary to increase current strength for a given rate of rise a little above the value given by the ordinate on the accommodation curve to find a repetitive discharge in the nerve.

Accepting the result of Skoglund's (1942) analysis, *viz.* that the difference between large and small spikes depends upon the degree of "grouped action" of the stimulated fibres, we have now to reconsider repetitive firing and the breakdown of accommodation from this point of view. It is clear that *in general* repetitive firing takes place in the region above the accommodation curve, provided that relatively slowly rising stimuli

be used. This proviso is necessary because with strong and rapidly rising stimuli there is an *alternative* to repetitive firing in the possibility of grouped action, or, rather, increased degree of grouped action, the small spikes probably also being due to smaller groups. The consequence of this alternative is that it is possible to plot a new and steeper accommodation curve for the grouped fibres with consequent smaller value for λ . Breakdown of accommodation as well as accommodation itself is therefore influenced by the manner in which the fibres co-operate.

The new "constant" λ which, as we now may suggest, is constant only for relatively brief rising times means that the grouped fibres resist breakdown better than relatively isolated elements,—a conclusion with many significant consequences, among them that the theoretically correct value for λ with mammalian nerves can be obtained only with isolated fibres under the electrodes.—From the point of view of sense-organs we must conclude

that *an end-organ, developing generator potential, has a much better chance of causing breakdown than any electrical stimulus over a group of elements. It has a chance of exciting a single axon in a highly adequate manner by electrotonic spread designed to minimize accommodative resistance.*

Returning now to the curves of Fig. 1-4, obtained in the usual manner with a threshold muscle contraction as index, it is clear that the variability which is so obvious a feature of such measurements to a large extent must be due to the uncertainty of the index which in turn also depends upon the degree of "grouped action," a factor so far definable only with respect to the strength of the stimulus but probably influenced by a number of other variables, among them temperature, maltreatment of the nerve etc. Thus, it is reasonable to suggest that, when in Fig. 3 a shift of the stimulating electrodes to the cut end of the nerve leads to steeper initial rise of the curves followed by sudden breakdown of accommodation, the cause behind this change is, that grouped action with consequent steeper rise is favoured by the injury potential but that at the same time the strength of catelectrotonus necessary for complete breakdown has decreased.

This raises the question as to what extent the breakdown obtained with mammalian nerves is a normal phenomenon. The small and large spikes, forming a whole "spike spectrum" and the main phenomena are certainly obtained also with unsevered nerve, just isolated and put on the electrodes. But there is no doubt but that breakdown of accommodation and small slopes of the curves are favoured by a departure of the nerve from "normality."

3. *Definition of breakdown of accommodation*

In the discussion following upon the publication of Hill's theory (1936) it has been emphasized by M. and L. Lapicque (1937, a, b, 1938) that the autorhythmic activity of nerve may have complicated measurements of accommodation, particularly in citrated-nerve, and that stimuli of long duration alter the state of the tissue. The latter objection need not be true. If care be taken to preserve an accurate index of accommodation the curves obtained with mammalian nerves are constant for hours.

But the rhythmic activity does introduce complications (cf. v. Kries, 1884, Hoffmann, 1910, Schriever and Cebulla, 1938) inasmuch as it complicates evaluation of the index, and probably, as held by Fabre (1931, 1936), represents a physicochemical system with properties very different from those tested by the usual shock technique. It is no exaggeration to state that this latter technique, as applied to whole nerve and muscle, has served to keep the facts connected with repetitive firing out of focus.

From the point of view of the problem "generator potential-repetitively firing axon," so clearly raised by all the work on the retina (cf. particularly Bernhard, 1941), the breakdown of accommodation in nerve is of interest as a model. Its definition by the aid of our results is based on the change of slope of a curve which *as a whole* serves to characterize these properties of the excitable tissue. The inverse value of the initial part, Hill's constant λ ,

may still serve as a useful approach to many problems as it has done to our own work. Looking very generally upon accommodation as a process tending to counteract the effect of a maintained stimulus, our curves mean that this process, so to speak, breaks down during the time the stimulus is applied, provided that it has reached a certain level of strength, and that finally there is so little accommodation left that the stimulus always excites, no matter how slowly it reaches this level. The slope of the curve then becomes horizontal. By following our curves far enough we reach the point when cat-electrotonus excites independently of and not counteracted by accommodation. Above our curves lies the region of repetitive firing of the particular single unit or grouped unit concerned. We do not believe ourselves that spikes of the small type represent single fibres.

4. Inhibition

In looking for a model reproducing retinal inhibition it has been necessary to discard the idea that it could be explained as a subnormal phase according to Gasser (in Erlanger and Gasser, 1937).

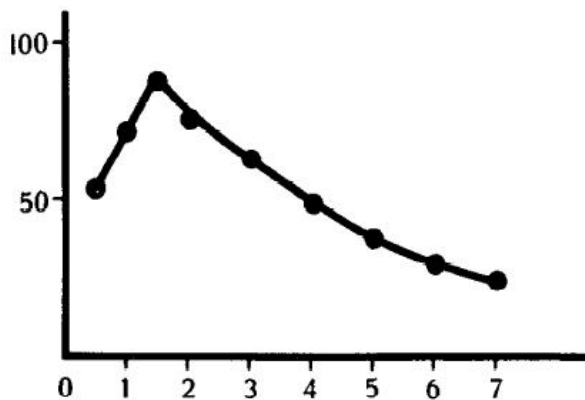


FIG. 7. Frequency of discharge in frog's nerve following removal of anelectrotonic block. Abscissae: time in sec. Ordinates: frequency per sec.

In 1935 Granit and Therman showed that inhibition of the discharge in the optic nerve is preceded by a slow potential belonging to the component PIII of the retinal response. This result was subsequently confirmed by Hartline (1938). A full discussion of retinal inhibition is found in a summary by Granit (1938). Since then Therman (1938) has shown that the retinal component does not agree with subnormality by any of the chemical tests selectively influencing the positive after-potential. Bernhard and

Skoglund (1941) have found that alcohol selectively diminishes the negative component PIII and that at the same time inhibition also diminishes. The connexion between PIII and inhibition has thus been confirmed. This does not necessarily mean that PIII could be excluded as factor causing excitation. This potential precedes PII at both "on" and "off" as we have now definitely proved (Bernhard, unpublished work).

If PIII were an anelectrotonic state developing during illumination, then the off-effect could be regarded as the consequence of the release of anelectrotonus which during illumination had piled up inhibition influencing certain retinal neurons. Our model would then be an anelectrotonic block. Actually, after an anelectrotonic block across a frog's nerve, the impulse frequency of the ensuing discharge often follows a curve of the type given by the retinal off-effect. This is shown in the example of Fig. 7.

On the other hand, it is known that a sufficiently strong catelectrotonus also may block nerve fibres (see *e.g.* Bugnard and Hill, 1935). In our experiments catelectrotonic inhibition has often been seen when for some reason or other the nerve fires spontaneously as in the record of Fig. 8. Here the discharge is inhibited by a catelectrotonus. The component PIII could also just as well be imitated by this model. It is known that the retina is oppositely influenced by opposite polarizing potentials across it (Granit and Helme, 1939). At the moment it is hardly necessary to go beyond the general hypothesis that a generator potential, capable of causing excitation, may also be capable of causing inhibition. Below we shall show that the same polarizing current gives excitation *or* inhibition in the optic ganglion of *Dytiscus* depending upon whether it is silent or discharges spontaneously at the time of applying the current.

5. Latent period and adaptation

Both phenomena are reproduced by the model. The slower the rise of the current the later the initiation of the iterative discharge. This follows directly

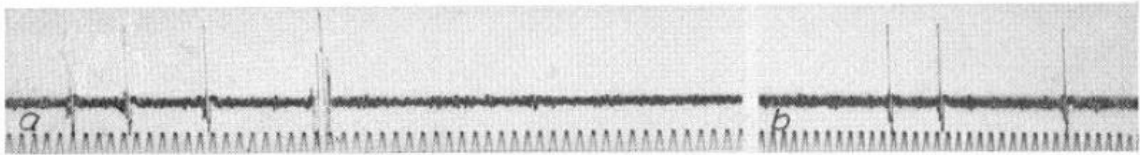


FIG. 8. Spontaneous discharge (a) in cat's *tib. ant.* muscle. Catelectrotonus on sciatic nerve leading to an outburst of muscle spikes followed by inhibition for the time the stimulus remains on. Afterwards (b) renewal of spontaneous discharge.

from the fact that a certain minimal strength of current is necessary for it, and that it is possible, by delaying the rate of rise of the current, to postpone the moment at which this level of excitation is reached. When passing beyond the strength of current necessary for iterative firing anywhere above the accommodation curve, it is seen that iterative firing does not continue indefinitely but stops after some time (Skoglund, 1942). There is thus a parallel to adaptation, which, of course, in addition may be determined by the properties of the primary mechanism which precedes the generator potential of the end-organ.

6. Application of model to eye of *Dytiscus*

The primary visual cells of both vertebrate and invertebrate eyes are homologous and have been carried through the whole progress of evolution (Kappers, Huber, and Crosby, 1936). In the water-beetle Bernhard's recent work (1941) has shown that the visual cells easily can be separated from the optic ganglion lying behind them and that the isolated retina gives a large smooth action potential reminiscent of the simple response of *Limulus* (Hartline, 1928, Hartline and Graham, 1932), and preceding the discharge in the nerve. If the ganglion is included spikes or synchronized waves appear on the response (*cf.* Adrian, 1932, 1937).

Where in this sense-organ are impulses generated? In order to answer this question we attempted to record from various parts of the retina by means of microelectrodes, *e.g.* through openings in the chitinous cover of the lenses and from behind. But from nowhere in the retina can any trace of impulses be obtained, not even if the microelectrode is forced in between optic ganglion and retina with tip towards the latter. In contradistinction to this stands the fact that impulses are obtained practically everywhere from the ganglion or on the optic nerve emanating from it.

From the work of Granit and Therman (1938) and that of Bernhard (1940, 1941) we know that the large potential difference developing across

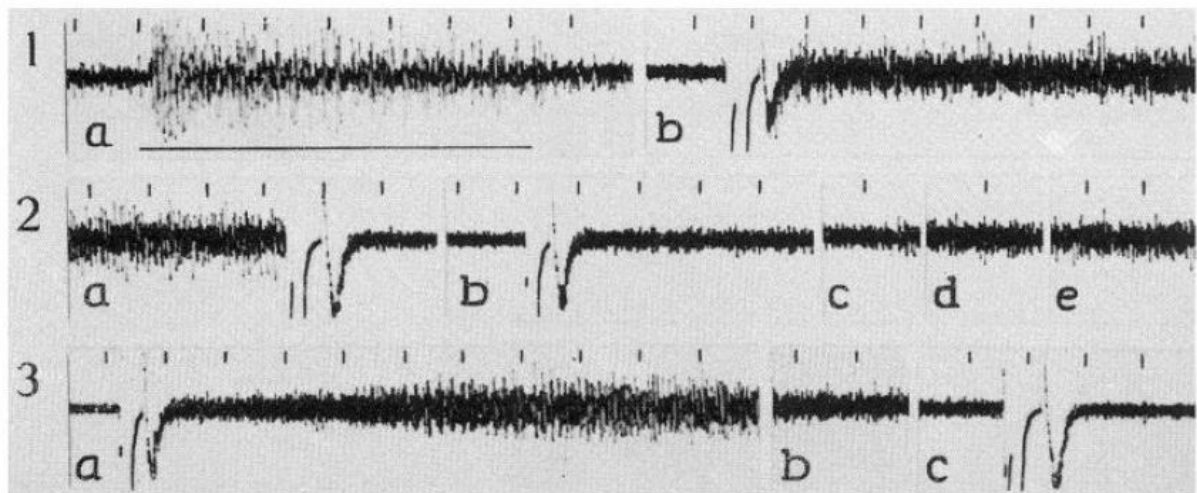


FIG. 9. Eye of *Dytiscus*. 1a, whole eye illuminated, optic nerve. 1b, isolated silent ganglion stimulated cathodally (at artefact). 2a, activity in isolated spontaneously active optic ganglion inhibited by cathodal stimulation, 2b, removal of catelectrotonus, 2c, d, e, f, gradually recovering spontaneous discharge. 3a, silent isolated optic ganglion stimulated anodally, 3b, gradual diminution of frequency, 3c, removal of anelectrotonus. All records taken with small metal electrodes. Time in $\frac{1}{2}$ sec.

the retina upon illumination is carried down electrotonically to and over the ganglion. On our hypothesis this would serve as generator mechanism for impulses, provided that the threshold for breakdown of accommodation were low. That this must be the case is shown by the tendency of the eye to discharge spontaneously. Fig. 9 shows an experiment with a cathode or anode on the ganglion isolated in air and the other electrode on the supraoesophageal ganglion. Microelectrodes are used for picking up the impulses from the ganglion.

First follows a control with illumination (1a) showing that the retina was alive before isolated from its ganglion. There is a small spontaneous discharge before illumination sets in. After separation from the retina the optic ganglion is stimulated cathodally with anode on the supraoesophageal ganglion. This leads to a discharge (1b). Record 2a shows another spontaneously active ganglion. Cathodal stimulation in this case immediately blocks the discharge which slowly reappears when the current is cut off (2b, c, d, e). Finally anodal stimulation (3a) is applied onto another isolated optic gan-

gion which was silent from the start but began to discharge upon stimulation. This discharge gradually diminished and did not reappear when the stimulus was removed (3c).

Now a preparation of this type consisting of ganglion cells surrounding a bundle of nerves emanating at one end as an optic nerve cannot be precisely stimulated anodally or cathodally. But the experiments nevertheless show that in both cases both inhibitory and excitatory effects were obtained. The only rule observed was the one illustrated, *viz.* that silent ganglions began to discharge and active ones were inhibited by the polarizing current.

Actually in this eye both effects are also observed by stimulation with light. When the "generator" potential develops across the visual cells upon illumination, there follows a heavy outburst of impulses which instantaneously stops at "off." But if the preparation is discharging spontaneously it can be seen that the drop of potential at "off" leads to an additional slow potential from the ganglion accompanied by a temporary inhibition of the spontaneous discharge (Bernhard, 1941). It is therefore possible that the abrupt stop of the normal discharge following cessation of illumination also is brought about by active inhibition.

These experiments together with those of Bernhard (1941b) show: (i) the sensory cells themselves develop only generator potential but no impulses, (ii) the generator potential is carried down electrotonically to the optic ganglion, where both a slow stationary potential difference as well as an impulse discharge is initiated, (iii) in some cases inhibition turns up instead of excitation, and (iv) these phenomena all can be imitated by polarizing currents (cf. also Granit and Helme, 1939). Whether the large potential difference across the sensory cells initiates impulses directly or *via* the slow potential in the ganglion cells (Bernhard, 1941), cannot be discussed without further experimentation.

Other sense-organs may be working on the same principles, unless so primitive that breakdown of accommodation takes place directly in free thin nerve-endings influenced by changes in ion balance or the concentration of surface-active substances released around them. (*e.g.* pain).

SUMMARY

The work described serves the twofold aim of clarifying some elementary questions regarding accommodation in nerve relative to repetitive firing and of finding out to what extent a nerve discharging repetitively in response to slowly rising electrical stimuli can serve as model sense-organ.

"Accommodation curves" obtained by plotting rising time of the stimulus (to a motor nerve) as abscissae against multiples of rheobase as ordinates for a constant effect show that a muscle contraction or a discharge from whole nerve are unsuitable as indicators for the constant effect.

Nevertheless, also with this effect as index, it is clear that for slowly rising stimuli the nerves may cease to accommodate, that is, that breakdown of accommodation takes place.

In order to obtain a better defined index, microelectrodes were inserted in the muscle and isolated spikes, elicited by stimulation of the motor nerve with slowly rising currents, are used as the constant index necessary for measuring accommodation correctly.

Breakdown of accommodation is shown to take place also with this index and is redefined in terms of the properties of single spikes. It is shown that "grouped activity" in which several fibres fire synchronously is an alternative to breakdown or accommodation and that the accommodation curves are determined by the degree of interaction of the stimulated fibres.

In the region above the accommodation curves the nerves fire repetitively.

Not only anodal but also cathodal polarization caused by the slowly rising stimuli is capable of inhibiting a spontaneous discharge in the nerve.

The significance of these results is discussed from the point of view of nerve as model sense-organ on the assumption that a slow "generator potential" is the mechanism which in sensory end-organs fires the axon repetitively.

Application of the model to the retina and optic ganglion of *Dytiscus* shows that both excitation and inhibition may be obtained by anodal and cathodal polarization of the ganglion and that no impulses but only a slow potential is generated within the isolated retina of this animal. A silent isolated optic ganglion is excited, and a spontaneously firing one, inhibited by the polarizing current.

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