Excitation and Initiation of Impulse

Part III. Accommodation

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As stated in Parts I and II, distinction of excitation from initiation of impulse is very useful for understanding several phenomena of excitation, particularly some phenomena of "accommodation", without introducing the very concept. This does never mean, however, that accommodation does not occur. As a matter of fact, some rise of I_r has been the case near¹⁾⁻³⁾ β_r . The point is whether the observed rise of I_r was due to rise of i_r or of m , because $I_r = m\eta i_r$ and $\eta = 1 + \frac{m-1}{m} \frac{1}{\frac{D}{e^a} - 1}$ (eq. (5), Part I). We will examine the matter in various cases, below.

I. Normal β_r and $\frac{I_\infty}{I_r}$ - γ -line

1. In relation to i_r -rise, supposed

1) On β_r . If i_r really rises near β_r , then it will be reasonable to suppose that it will do so in larger β , too, even if little in magnitude. Let us consider therefore $i_r(\beta)$, the rheobase as a function of β , and put

$$i_r(\beta) = i_r f(\beta),$$

i_r : the value of $i_r(\beta)$ for $\beta = \infty$ (rectangular pulse),

$f(\beta)$: a function of β , which is practically unity in large β , then grows gradually with decrease of β .

Now, the gradient is β at $x=0$ and $\frac{\beta}{m}$ at $x=L$, hence $i_r(\beta)$ should

be $i_r f(\beta)$ and $i_r f(\frac{\beta}{m})$ respectively. However, m is very near unity in normal conditions, so we may disregard this difference and consider just the difference due to variation of β itself.

Assuming m , D and η constant, and neglecting ϵ (see Part I) as before, we have for the limiting case

$$\Delta t = t_2 - t_1 = \frac{m i_r f(\beta_r)}{\beta_r} - \frac{i_r f(\beta_r)}{\beta_r} = \frac{i_r f(\beta_r)}{\beta_r} (m - 1) = D$$

$$\text{Hence, } \beta_r = \frac{i_r f(\beta_r)(m-1)}{D} = \frac{I_r}{\eta D} \frac{m-1}{m} f(\beta_r) = \text{eq. (1) (Part II)} \times f(\beta_r) \quad (1)$$

In other words, β_r gets $f(\beta_r)$ -times larger than when the rheobase is invariable.

Now, eq. (1) has a meaning only when $f(\beta_r)$ is finite. Actually, I_r at β_r was found finite (1.2–1.3 times normal) as stated in Part II. This means that $f(\beta_r) = 1.2–1.3$, accordingly, that β_r expressed by eq. (1) can be about as large as the standard value (see eq. (2), Part II). However, the finiteness of I_r at β_r , as a fact as well as a theoretical claim, contradicts strongly to the classical idea, which predicts ∞ . Another serious point that a slight reduction of β makes the current suddenly ineffective, was described in Part II. A discontinuous change of the rheobase, from 1.2–1.3 normal to ∞ , might not be impossible, but more probably there is something else still undiscovered there. This is nothing but the condition $\Delta t \leq D$, if viewed from the present theory.

2) On $\frac{I_\infty}{I_r}$ - γ -line. We take here the rheobase as a function of the rate of increase of the current. The rate is determined by I_∞ and γ , and also by time. For convenience, we will take the initial slope $\delta (= \frac{I_\infty}{\gamma})$ and put $i_r(\delta) = i_r F(\delta)$,

i_r : the value of $i_r(\delta)$ for $\delta = \infty$ (rectangular pulse),

$F(\delta) = F(\frac{I_\infty}{\gamma})$: a function similar to $f(\beta)$.

For the points $x=0$ and $x=L$, we should put, strictly,

$$\begin{aligned} I_\infty(1 - e^{-\frac{t_1}{\gamma}}) &= i_r F(\delta), \\ \text{and } \frac{I_\infty}{m}(1 - e^{-\frac{t_2}{\gamma}}) &= i_r F(\frac{\delta}{m}). \end{aligned}$$

But if taken $F(\delta) \doteq F(\frac{\delta}{m})$ as in the case of linearly rising current, then

$$t_1 = \gamma \ln \frac{I_\infty}{I_\infty - i_r F(\delta)} \quad \text{and} \quad t_2 = \gamma \ln \frac{I_\infty}{I_\infty - m i_r F(\delta)}$$

In the limiting case

$$\Delta t = t_2 - t_1 = \gamma \ln \frac{I_\infty - i_r F(\delta)}{I_\infty - m i_r F(\delta)} = D$$

The solution is

$$\frac{I_\infty}{i_r} (= \frac{I_\infty \gamma m}{I_r}) = F(\delta) \frac{m e^{\frac{D}{\gamma}} - 1}{\frac{D}{\gamma} - 1} = F(\delta) (m + \frac{m-1}{\frac{D}{\gamma} - 1})$$

$$\begin{aligned} & \doteq F(\delta) \{m + (m-1) \frac{\gamma}{D}\} \left(\frac{1}{e^{\frac{\gamma}{D}} - 1} \doteq \frac{\gamma}{D} \text{ introduced} \right) \\ \therefore \frac{I_\infty}{I_r} &= \frac{F(\delta)}{\eta} \left(1 + \frac{m-1}{m} \frac{\gamma}{D} \right) \end{aligned} \quad (2)$$

By assumption, $F(\delta)$ is a function which, growing from unity, gets larger with decrease of δ . We cannot foretell precisely how δ will change with γ , because we do not know how I_∞ will change with γ , this being the very thing which we wish to clarify. But it is certain that δ starts with a very large value, and, decreasing with increase of γ , reaches a certain value, δ_r , which corresponds to β_r . $i_r(\delta)$ will then be $i_r F(\delta_r)$. If taken $F(\delta_r) = f(\beta_r) = 1.2 - 1.3$, then eq. (2) may be said to be practically linear, although never so strictly except in the range of large δ where $F(\delta) \doteq 1$.

2. In relation to m -rise, supposed

A slowly rising cathodic current will probably loosen the membrane and thus diminish the resistance r_m (see Suzuki⁴). This makes k smaller, which makes L larger in turn (see Fig. 1, Part I). A further enlargement of L is expected from reduction of f due to diminution of V amounting to 50% of the normal at β_r ¹). There are also factors which act to diminish L , namely, ¹) enlargement of f by decrease of r_m ⁵), and 2) some possible decrease of k' , although presumably very little. Even if L remains unchanged after all these changes, still m can augment as the result of k -decrease alone. The rise of m seems thus highly probable.

1) On β_r . Assume i_r , D , a and practically also η constant, and further

$$m(\beta) = mf(\beta),$$

m : the value of $m(\beta)$ for $\beta = \infty$ (rectangular pulse),

$f(\beta)$: the same function as before.

From $I_0 = \beta t_1 = i_r$ and $I_L = \frac{\beta}{mf(\beta)} t_2 = i_r$, and under neglect of ϵ as before, we have for the limiting case

$$\begin{aligned} \Delta t = t_2 - t_1 &= \frac{i_r}{\beta_r} \{mf(\beta_r) - 1\} = D; \\ \beta_r &= \frac{i_r}{D} \{mf(\beta_r) - 1\} = \frac{I_r}{\eta D} \frac{mf(\beta_r) - 1}{m} \\ \text{or} \quad &= \frac{I_r}{\eta D} \frac{m-1}{m} \frac{mf(\beta_r) - 1}{m-1} = \text{eq. (1) (Part II)} \times \frac{mf(\beta_r) - 1}{m-1} \end{aligned} \quad (3)$$

In a standard case, eq. (1) (Part II) turns into eq. (2) (Part II), which gives $\beta_{r,0} = 0.6$ mV/msec. Hence, if taken $f(\beta_r) = 1.2 - 1.3$ in eq. (3) above, then $\beta_r \doteq 0.6 \times (11 - 16) \doteq 7 - 10$ mV/msec, which is larger than the largest value obtained by Diecke¹). This suggests that rise of m in linearly

rising current is improbable, as long as $f(\beta_r)$ is so large as 1.2–1.3.

2) On $\frac{I_\infty}{I_r}$ - γ -line. Suppose that $m(\delta) = mF(\delta)$, and i_r , D and γ constant.

From $I_\infty(1 - e^{-\frac{t_1}{\tau}}) = i_r$ and $\frac{I_\infty}{mF(\delta)}(1 - e^{-\frac{t_2}{\tau}}) = i_r$, we have

$$t_1 = \gamma \ln \frac{I_\infty}{I_\infty - i_r} \quad \text{and} \quad t_2 = \gamma \ln \frac{I_\infty}{I_\infty - i_r m F(\delta)};$$

$$\Delta t = \gamma \ln \frac{I_\infty - i_r}{I_\infty - i_r m F(\delta)} = D;$$

$$\frac{I_\infty}{i_r} = \frac{mF(\delta)e^{\frac{D}{\gamma}} - 1}{e^{\frac{D}{\gamma}} - 1} = mF(\delta) + \frac{mF(\delta) - 1}{\frac{D}{\gamma} - 1}$$

Introducing $\gamma m i_r = I_r$ and $\frac{1}{\frac{D}{\gamma} - 1} = \frac{\gamma}{D}$,

$$\frac{I_\infty}{I_r} = \frac{F(\delta)}{\gamma} \left(1 + \frac{1}{m} \frac{F(\delta)}{D} \gamma \right) \quad (4)$$

Eq. (4), like (2), can be linear in the range of $F(\delta) \approx 1$ only. The final slope is larger than that of eq. (2), so the linearity is the worse as a whole.

3. Consideration

Two important conclusions are drawn from the above examinations:

1) A rise of I_r , whether due to rise of i_r or m , not only contradicts to the appearance of β_r of a reasonable value, but also disturbs the linearity of I_∞ - γ -curve, except when the rise is very small. At least, it never favours the appearance of these lines, as was foreseen already in Part I.

2) The rise of I_r near β_r appears to be due to rise of i_r , not of m . This is, however, because $f(\beta_r)$ is so large as 1.2–1.3. If it is smaller, then the matter turns out quite different. The possibility will be stated in Discussion below, but before that we will examine the matter in some other cases.

II. I_r and β_r in Electrotonus

It is known that I_r and β_r both rise in long-lasting C.E.T. (Tasaki⁶). A remarkable thing thereby is that the rise of I_r is just little while that of β_r enormous. In Tasaki's observation above quoted, "the rheobase was not appreciably changed" but β_r changed from $\frac{1}{62}$ to $\frac{1}{18}$ -msec⁻¹, that is, to about 3.5-times as large.

If wanted to understand this unproportionality from Hill's theory, we have to consider two events, a small rise of the rheobase and a large reduction of λ , taking place simultaneously. But if viewed from the present theory, it is comprehensive as a simple result of m -rise only:

$$\text{Eq. (5) (Part I) : } I_r = m\eta i_r$$

$$\text{Eq. (1) (Part III) : } \beta_r = \frac{i_r(m-1)}{D} f(\beta_r) \quad (i_r \text{ varying with } \beta)$$

$$\text{Eq. (3) (Part III) : } \beta_r = \frac{i_r}{D} \{mf(\beta_r) - 1\} \quad (m \text{ varying with } \beta).$$

If C.E.T. raises i_r , then both I_r and β_r should rise in the same proportion, but if it raises m , then I_r rises just proportionally as before, while β_r very much more. Quantitatively, eq. (1) (Part III) is satisfactory, because a rise of m by just 5% (from 1.02 to 1.07) suffices to explain Tasaki's result. Eq. (3) (Part III) is not available, again because $f(\beta_r)$ is so large as 1.2–1.3.

If the above consideration is correct, then in A.E.T. a little decrease of m (from 1.02 to 1.00 at most), accordingly of I_r , and a relatively large diminution of β_r are expected. In actuality, β_r decreased to $\frac{1}{900}$ msec⁻¹, but I_r increased from 25 to 100 mV in Tasaki's experiment above quoted. The reason of this discrepancy is not clear, but one might be that in Tasaki the stimulus was expressed in voltage, which could have acted only through the membrane resistance, which must have been increased in A.E.T.

III. I_r and β_r in Low Temperature

As quoted in Part II, I_r changes very little but β_r gets very small in low temperature (Tasaki⁷⁾). We have here another example of unproportional change of I_r and β_r . It must be due partly to prolongation of D as stated before, but very probably also to diminution of m , which, if occurred in a standard case, cannot be large only from 1.02 to 1.0 at most), but still can bring forth an enormous decrease of β_r .

IV. I_r and β_r in Relation to Na⁺-concentration

It may not be appropriate to discuss the complicated effects of ions upon excitability, on the same line with that of electric current. Here just one example which is very interesting in connexion with the present theory, will be quoted.

According to Diecke¹⁾, both I_r and β_r decrease with increase of Na⁺-concentration of the bathing fluid. Here again, the decrease of β_r is much more marked than that of I_r (Abb. 11). For example, at [Na⁺]=444 mM/l, β_r was already so small as 44%, while I_r remained at about 80%, of the

normal (see Tab. 1 and Abb. 11). This unproportional change of I_r and β_r seems to point to m -change taking place in this case, too. In Diecke's preparations, the value of m is seemingly near about 1.2 as stated in Part II. If m ran down to 1.1 in the above example, I_r must have decreased by about 10%, while β_r by just 50% (eq. (1), Part II), which is about in accordance with the actual observation. Why m decreases in higher Na-concentrations, is not clear, but decrease of L due to increase of V , accordingly of f , the safety factor, must be a powerful agent.

V. Repetitive Responses

1. To constant current

The limiting condition for initiation of impulse is

$$\text{Eq. (4) (Part I): } \Delta t = \alpha \ln \frac{I_0 - i_r}{I_0 - m i_r} = D$$

In Part I, the characteristics of the repetitive responses were interpreted as due to gradual rise of α with time. However, I_0 being long-lasting, there are two other possibilities, namely, rise of i_r and m . If they increase, they exert just similar effects as α -increase upon t_2 and Δt , so that the known features of repetitive responses can be explained similarly. Here, just some consideration will be carried out on the time-length, during which the response is repeated.

1) Rise of i_r with time and I_0 , supposed, under m , D , α constant. Replacing i_r with $i_r(I_0, t)$ in eq. (4) (Part I), we have

$$I_0 - i_r(I_0, t) = e^{\frac{D}{\alpha}} (I_0 - m i_r(I_0, t)),$$

from which $i_r(I_0, t) = I_0 \frac{e^{\frac{D}{\alpha}} - 1}{m e^{\frac{D}{\alpha}} - 1} = I_0 \frac{1}{\gamma m}$ (see eq. (5), Part I) This is the relation between i_r (raised) and I_0 (applied) when the response is just stopping.

Put now $i_r(I_0, t) = i_r f(I_0, t)$, where i_r is the value of $i_r(I_0, t)$ at $t=0$ and $f(I_0, t)$ a function growing from unity, and introduce it into the above equation. Then

$$f(I_0, t) = \frac{I_0}{i_r \gamma m} = \frac{I_0}{I_r} \quad (5)$$

2) Rise of m with time and I_0 , supposed, under other variables unchanged

Replacing m in eq. (4) (Part I) with $m(I_0, t)$, we have

$$m(I_0, t) i_r e^{\frac{D}{\alpha}} = I_0 e^{\frac{D}{\alpha}} - I_0 + i_r$$

$$m(I_0, t) = \frac{I_0}{i_r} (1 - e^{-\frac{D}{\alpha}}) + e^{-\frac{D}{\alpha}} = \frac{I_0}{I_r} \gamma (1 - e^{-\frac{D}{\alpha}}) + e^{-\frac{D}{\alpha}}$$

Putting $m(I_0, t) = mf(I_0, t)$, m being the value of $m(I_0, t)$ at $t=0$,

$$f(I_0, t) = \frac{I_0 \eta}{I_r} (1 - e^{-\frac{D}{\alpha}}) + \frac{1}{m} e^{-\frac{D}{\alpha}} \quad (6)$$

The values of t which satisfy eq. (5) or (6) respectively determine the "total adaptation time, T " in Granit and Skoglund's terminology⁸⁾. Presumably, eq. (6) will fit the observations better, because the case under examination is a special case of C.E.T., where the rise of m seems certain, as stated before. Unfortunately, the form of $f(I_0, t)$ is unknown, so we cannot formulate T as a function of I_0 , but it is interesting to make a simple assumption that $f(I_0, t) = f(t)$, that is, that i_r or m is a function of t only, and to consider two special cases, 1) $f(t) = e^{\frac{t}{p}}$, p constant, and 2) $f(t) = \ln(e + \frac{t}{q}) \doteq \ln \frac{t}{q}$ in large $\frac{t}{q}$. The former, combined with eq. (5), leads to $t = p \ln \frac{I_0}{I_r}$. If p is replaced by λ , then we have just the equation derived by Katz⁹⁾ on the basis of Hill's theory. Katz's equation represents therefore a special case where $f(t) = e^{\frac{t}{\lambda}}$ is introduced, which, in view of the present theory, has no proper reason. It is not strange that it does not fit the observations well⁸⁾. On the other hand, the latter combined with eq. (6) leads to

$$\ln t = \frac{I_0}{I_r} \eta (1 - e^{-\frac{D}{\alpha}}) + \frac{1}{m} e^{-\frac{D}{\alpha}} + \ln q = c_1 \frac{I_0}{I_r} + c_2$$

$$(c_1 = \eta (1 - e^{-\frac{D}{\alpha}}); c_2 = \frac{1}{m} e^{-\frac{D}{\alpha}} + \ln q),$$

a linear relationship between $\ln t$ and $\frac{I_0}{I_r}$ as long as $\frac{D}{\alpha}$ remains unchanged. This supports Granit and Skoglund⁸⁾ who demonstrated a practical linearity of the $\ln T - \frac{I_0}{I_r}$ -curve, and suggests, conversely, a logarithmic rise of m with t strongly.

2. To linearly rising current

Eq. (3) (Part II) was derived from eq. (4) (Part I), regarding i_r and m constant. Here we assume them to be a function of β and T .

1) $i_r(\beta, T) = i_r f(\beta) F(T)$, supposed

i_r : the value of $i_r(\beta, T)$ at $\beta = \infty$ and $T = 0$,

$f(\beta)$: the same function as before,

$F(T)$: a function of T growing from unity; the end of t_0 taken as origin of T (Fig. 2, Part II)

Assume $m = \text{constant}$, and consider the case of $\beta = \beta_r$. Then, in the same way as in Part II,

$$\begin{aligned} \Delta t_n &= \alpha \ln \frac{i_r + \beta_r T_{n-1} - i_r f(\beta_r) F(T_n)}{i_r + \beta_r T_{n-1} - i_r m f(\beta_r) F(T_n)} \\ &= \alpha \ln \frac{1 - \frac{i_r f(\beta_r) F(T_n)}{\beta_r T_{n-1}}}{1 - \frac{i_r m f(\beta_r) F(T_n)}{\beta_r T_{n-1}}} \quad (i_r \text{ neglected against } i_r f(\beta_r) F(T_n)) \\ &= \alpha \ln \frac{1 - \frac{D}{m-1} \frac{F(T_n)}{T_{n-1}}}{1 - \frac{mD}{m-1} \frac{F(T_n)}{T_{n-1}}} \quad (\text{eq. (1), Part III, introduced}) \\ &\doteq \alpha \ln \frac{1 - DM \frac{F(T_n)}{T_n}}{1 - DMm \frac{F(T_n)}{T_n}} \quad (M = \frac{1}{m-1}; T_{n-1} \doteq T_n, \text{ assumed}) \end{aligned}$$

2) $m(\beta, T) = m f(\beta_r) F(T)$, supposed

$$\begin{aligned} \Delta t_n &= \alpha \ln \frac{i_r + \beta_r T_{n-1} - i_r}{i_r + \beta_r T_{n-1} - i_r m f(\beta_r) F(T_n)} \\ &= \alpha \ln \frac{\beta_r T_{n-1}}{\beta_r T_{n-1} - i_r m f(\beta_r) F(T_n)} \quad (i_r \text{ neglected against } i_r m f(\beta_r) F(T_n)) \\ &\doteq \alpha \ln \frac{1}{1 - D \frac{m f(\beta_r)}{m f(\beta_r) - 1} \frac{F(T_n)}{T_n}} \quad (\text{eq. (3), Part III, introduced, and } T_{n-1} \doteq T_n, \text{ assumed}) \\ &\doteq \alpha \ln \frac{1}{1 - DN \frac{F(T_n)}{T_n}} \quad (N = \frac{m f(\beta_r)}{m f(\beta_r) - 1}) \end{aligned}$$

The quantity $\frac{F(T_n)}{T_n}$ represents the mean rate of i_r - or m -rise. If this gets larger with T , then Δt doing so too, the repetitive response will cease after a certain while. But if it decreases sufficiently rapidly or if, in addition, a larger β is chosen, then the response will continue on without cessation. The practical necessary condition for this is that the rate of rise of i_r or m gets smaller with time. The logarithmic nature of m -rise suggested above, will probably satisfy this condition, to establish Hoffmann's observation¹⁰⁾, provided that α -rise is relatively little.

DISCUSSION

1. β_r and I_∞ - γ -line, and their probable independence of I_r -rise.

In Part II, it was shown that β_r and I_∞ - γ -line can be the case without threshold rise; in Part III that threshold-rise, if it occurs, disturbs the appearance of β_r of a reasonable value, and of the linear relationship between I_∞ and γ . These results, together with the fact that I_r is certainly finite at β_r in contradiction to the theory of accommodation, point to independence

of the threshold from β_r and I_∞ - γ -line.

2. I_r -variation and its probable dependence on m -rise.

It is sure that I_r varies according to conditions. But as far as examined above, it seems to be m that changes in electrotonus, temperature varied, in varied Na⁺-concentration of the bathing fluid, and also in repetitive responses to constant and linearly rising currents. The only exception encountered is the I_r -rise observed near β_r , where the rise of i_r appeared responsible. One possibility might be that i_r changes in short-lasting while m changes in long-lasting exposure to new conditions. There are, however, also reasons to believe that the actual rise of I_r near β_r might have been much smaller than observed: 1) the time of ascent (up to the I_r -level) is only several ten msec in most cases, which seems to be too short to exhibit any appreciable depressive action, 2) in Sugi's experiment⁽¹¹⁾ with linearly rising current, the range of constant threshold was so wide that even β_r could hardly be confirmed, and 3) in stimulation with exponentially increasing current, the excitation always took place at an almost constant level of potential^(1), 3). All these facts point to threshold constancy in stimulation with slowly rising currents. I dare suppose: was the I_r -rise near β_r not an artifact, at least in part, due to polarization still remaining on isolated fibres? Was the actual rise not much smaller and this small rise not due to rise of m ? This might be a wilful supposition, but if it is correct, and if we can put $f(\beta_r) \doteq 1$, then eq. (1) and (3) in Part III are both reduced to eq. (1) or (2) in Part II which provide a reasonable value of β_r ; and eq. (2) and (4) in Part III to eq. (5) in Part II, which expresses a strict linearity of $\frac{I_\infty}{I_r}$ - γ -curve. A unific explanation can thus be presented by rise of m . Further, the rise of m , thus supposed, needs be just small. If it is large, it makes β_r too large, $\frac{I_\infty}{I_r}$ - γ -curve not linear, the total adaptation time for constant current too short, and the ever-lasting repetitive responses to linearly rising current with $\beta > \beta_r$ impossible. It is quite interesting in this connexion that just a 5% increase of m was found enough for explaining the facts in C.E.T., as stated above.

3. "Accommodation" in terms of I_r - or m -rise

"Accommodation" is certain as long as a rise of I_r is meant by it. In view of the present theory, however, I_r is different from i_r , and the rise of I_r is highly probably due to rise of m . The so-called accommodation becomes then a matter of initiation of impulse having nothing to do with i_r , the rheobase for excitation. I dare propose therefore to define accommodation practically by rise in I_r , or theoretically by rise in m , and to call m the "constant of propagation" for convenience.

The point is whether the distinction of excitation from initiation of impulse is correct or not. However, the identification of these two has no basis, either. If the distinction has any reason, and the accommodation is really a matter concerning initiation of impulse, then all the explanations for the mechanism of accommodation on the basis of i_r -rise, including the modern one of Hodgkin¹²⁾, though to be questioned or reconsidered.

SUMMARY AND CONCLUSIONS

1. β_r of the observed value and the linear relationship between $\frac{I_\infty}{I_r}$ and γ cannot be expected from the present theory, unless the rise of I_r is very small.

2. β_r and $\frac{I_\infty}{I_r}$ - γ -line are very probably independent of I_r -rise.

3. Variation of m supposed to occur to a small extent, was shown to be very useful for explaining various experimental facts. The rise of I_r near β_r was supposed to be due partly to artifact, and partly to rise of m .

4. It was proposed to define accommodation by rise in I_r or m , and to call m the constant of propagation.

5. Discussions were made on 1) probable independence of β_r and $\frac{I_\infty}{I_r}$ - γ -line from I_r -rise, 2) probable dependence of I_r on m , and 3) accommodation.

6. General conclusions from Part I, II and III.

1) Distinction between excitation and initiation of impulse is very useful for explaining experienced facts.

2) The rise of m , not of i_r , to a small extent seems to be a general basic event that happens in normal nerves in various conditions.

3) Of the well-known three factors of stimulating currents, a) intensity ($>i_r$), b) duration ($>$ utilization time) and c) slope ($>\beta_r$), the third one appears to be an additional requisite for initiation of impulse.

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