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Studies on a Peculiar Oscillatory Movement of the Larva of the Ramie Moth, *Arcte coerulea* GUENÉE

By

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With Plates I-V and 13 Text-figures

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Obituary

Mr. Tanesaburo YAMADA was born on the first of May, 1895 at his father's residence at Shichome, Shimmachidori in Nishiku, Osaka as the second son of Mr. Ichisaburo Yamada, a well-to-do business man. He became interested in natural history quite early in his boyhood and kept up his interest ever since until his last days. The collecting instinct of the boyhood manifested itself strongly even prior to his attendance at the middle school and he was actively engaged in the exchange of pictorial post cards with his over-sea correspondents and in the building up of a large collection of match labels while he was still in the public school. His love of nature and of living things in general took on a scientific trend when he entered the middle school at Sakai, his old home town. He became then absorbed in collecting insect and plant specimens and this finally led him to the decision to take up biology as his life work. With this determination, he went through the necessary preparatory courses at the Third National College at Kyoto after being graduated from the Sakai Middle School in 1913 and entered the College of Science at the Tokyo Imperial University in 1917. Before his first year at Tokyo was half over, however, he was forced to suspend his studies on account of ill health and went back to his home at Sakai. In 1919 the plan for the establishment of the Department of Zoology at the Kyoto Imperial University received the government sanction and Mr. Yamada was appointed assistant in biology. On the completion of the organization of the department, he became enrolled as a regular student and when he was graduated in 1924 with the title of Rigakushi, he was one of the first group of young zoologists to win this distinction at Kyoto. He was then registered in the Graduate School at his alma mater and specialized in animal physiology. He was strongly attracted to the fascinating field of research in insect behaviors and spent most of his time in the analytical study of the reflex movements of certain insects. His contribution along this line is embodied in the manuscript which he left and is now to be published in the following pages.

Although his life interest was in biology, he loved music also and derived much pleasure in his leisure hours in playing the cello.

By a tragic stroke of fate, he passed away most unexpectedly on March 19th, 1927 in Kyoto. In the premature death of Mr. Yamada, we lost not only a young investigator, but a friend as well.

Tamiji Kawamura.

Contents

Introduction

In the larval stage "Karamushi-ga" or Ramie Moth, *Arcte coerulea* GUENÉE exhibits a very peculiar kind of behavior which has long attracted the attention of field entomologists in this country. The larva, when disturbed by some means, shakes the anterior third of the body to right and left so violently that it is very hard to follow this movement with human eye.

Although I was told in private communication about this instinctive behavior of the insect by many naturalists, yet only two records seem to have been left in literature: SASAKI (24) stated that "when an enemy approaches, the larva vibrates its body so quickly that one can not perceive the insect's body. We may, therefore, suppose that the animal performs this action in order to dazzle the enemy's eye and to escape from being devoured." MUKAIKAWA (16) also expressed a similar opinion, though he does not report on any detailed study on this interesting behavior.

There are, however, several records concerning the occurrence of such a rhythmic movement among other insects. To begin with lepidopterous larvae, NARASAKA (19) reports that the second instar or older stages of *Brahmaea japonica* BUTL. shakes its head vigorously when stimulated by touch on any of its seven dorsal horns. Y. YAMADA and NAGANO (30) have reported on a similar behavior in a noctuid larva, *Seudyra subflava* MOORE comparing its movement with that of the species under consideration.

Among European authors, DEEGENER (4) observed that the social tent-caterpillar, *Phalera bucephala* (L.) struck neighbouring substances with its anterior end when it happened to touch its companion with its sensory hairs and for sometime repeated a twitching movement of the same portion of the body. This movement of the creature may swing the branch of the food plant and may thus be answered with the same reaction by another individual at a fair distance. The same phenomenon was noticed by myself in the caterpillars of *Euproctis conspersa* BUTL.

and *Crissiocampa neustria* (L.). MINNICH (12) in his research on the reaction of the larva of *Vanessa antiopa* (L.) found that in this species the initial dorsal jerk of the head is followed by some weaker dorsal or lateral jerks, and if the animals are bound in a colony, these movements may continue for several seconds after the cessation of the stimulus, the whole colony acting more or less in union.

In Hymenoptera, TAKEUCHI (27, 28) pointed out that *Cimbex tankushi* MARLATT and *Eriocampa mitsukurii* ROHWER exhibit in their larval stages the same behavior as the Arcte-larva.

Pupae of some Nymphalidae, *Pyrameis indica* HB. for instance, begin to dance in their dangling position on external stimulation. STOCKARD (26) observed a swinging motion in *Aplopus mayeri*. The adult of this animal exhibits a slow lateral swinging motion, more or less resembling the swinging of a branch in a light breeze. The young also is said to swing its body from side to side in a similar manner.

GRIMPE (6) called our attention to the "Pendelnde Bewegung" of an Indian leaf-insect, *Phyllium binoculatum* G. R. GRAY, which is manifested by the insect while in search of food or at rest. This oscillatory movement was explained by PLATE (22) as "Wind Mimikry", because GRIMPE described, "in der Luftzug gestellte Phyllien viel stärker pendeln als im *Zugdicht* geschlossenen Insektenhaus. Die Ausschläge wachsen, wie deutlich wahr zu nehmen ist, mit der Stärke des Luftzuges. Zunächst sind sie stets erheblich grösser als die Bewegungen, welche die Blätter der Futterpflanze im Winde zeigen. Erst allmälich passen sich die Pendelbewegungen in der Schnelligkeit denen des Laubes an; sie werden mit der Zeit offenbar passiv. Das Pendeln wird schliesslich aber noch langsamer, und es macht den Eindruck, als ob das Tier Bremse wirkende Bewegung verfiele". It is not very rare to see the mantis displays this sort of movement. We expect to find many other records of similar nature, if we search more carefully in literature, and all of them must be taken into consideration in discussing their nature as well as their teleology.

Since no detailed description of such phenomena in *Arcte* has been published, I shall report here the facts which I observed and also the results of my experiments on the behavior of this insect.

This work was carried out in the Zoological Laboratory of Kyoto Imperial University under the direction of Prof. T. KAWAMURA to whom my hearty thanks are due for his kind guidance. My sincere thanks are also due to Mr. T. YAMANOUCHI, Assistant in Zoology, and to both

Prof. H. YUASA and Assist. Prof. N. YAGI of the Entomological Laboratory for their encouragements and interest in my work; and I am indebted also to Mr. Y. YAMADA of the Entomological Laboratory for his kind help in the identification of the insect.

General Observations on the Insect

a) *Occurrence.* MATSUMURA (11) and SASAKI (24) both consider that the larvae of this insect appear once in a year. According to their observations in Hokkaido and in Tokyo respectively, the larvae hatch out in the middle of July and become full grown in the middle of August when they come down to the ground to spin their loose cocoons among fallen leaves or in sandy ground not deeper than four centimeters. The moths emerge in the fall and pass the winter in hibernation. They deposit eggs during the next spring. According to my own experience, however, the larvae appear twice a year in Kyoto district; the first brood may be already seen in the middle of May, which pupates in late June; and the imago is found to emerge in the first half of July. The second brood appears later in August and ends its larval existence at the end of October. The imago of this brood comes out in November and hibernates in some places until the next spring. I assume, therefore, that there are two distinct broods in a year in Kyoto district. Such a difference in the number of broods of an identical species in different localities may be related to the climatological conditions of the country.

b) *Egg.* Eggs are deposited on the underside of the leaf of the ramie plant. They are arranged on the leaf-blade, avoiding thicker veins and not traversing the mid-rib of the leaf (Pl. I, Fig. 5). The eggs were laid on an elliptic area in one case, but in the other they were deposited on a nearly circular area. In the former figure most of the eggs have already hatched while in the latter all remain intact.

The egg is hemi-spheroid with its flat surface on the substratum. The spherical surface is richly ornamented with radiate ridges and concentric sculpture. There is a small flat circular area at its apex. The radiate ridges consist of about 13 complete lines arising from the circular ring of the apical flat area and some half-way ridges located in the interstices of complete ridges. The interstitial ridges may be two in number, in which case one is longer than the other as it is shown in the schematic drawing (Pl. II, Fig. 12). The apical area has also a beautiful ornament in its center surrounding the micropyle.

c) *Larva.* The first instar larva is about 0.7 mm. in length. The body is almost transparent, of emerald green and with black spots which are rather large in comparison with the size of the body and which possess a seta each. The head is yellow with brown mouthparts. The first and second pairs of the abdominal legs are wanting; the manner of locomotion is, therefore, similar to that of the geometrid larvae.

The second instar larva, about 1.2 mm. in body length, has a body translucent and milky bluish white, with longitudinal white streaks along the subdorsal, suprastigmal and substigmal lines; the substigmal lines are only slightly perceivable in the abdominal region. Black spots as in the first instar are scattered on the body surface, each with a white seta. The thoracic legs are black and the first and second pairs of the abdominal legs are developed for half their mature length, the second pair being longer than the first. Spiracles are distinctly visible. The manner of walking is still geometrid-like.

The third instar larva attains the coloration as well as the form of the more advanced larvae (for whose description refer to the systematic work by HAMPSON (7)), and all 4 pairs of the abdominal legs are complete. The larva is very beautiful with its black striations on the greenish yellow back ground, and has very conspicuous carmine markings around the spiracles. In the end of the fifth instar the body length attains about 71 mm. The accompanying pictures (Pl. II, Figs. 10, 11) will give the exact idea of the larva in this stadium.

The larvae of the last three stadia show the same mode of locomotion and it is not any more peculiar than the ordinary lepidopterous larvae. Just before the oldest caterpillar transforms into the prepupal form, the ground color of the body turns to a beautiful green, which in the later stage becomes pale chocolate brown.

d) *Pupa.* The full mature larva quits the food plant by creeping or by merely dropping from the stem of the plant, and spins a very loose cocoon on the ground (Pl. I, Fig. 7) gathering small clusters of earth. Such a cocoon is found not far below the earth's surface, at depth of from 0 to 40 cm. When the larvae are prevented from reaching the ground, as is the case when they are kept in an insect cage, they make their cocoons with the leaves and the leaf-stalks of the food plant (Pl. I, Figs. 8, 9). The pupa is shown in Pl. I, Fig. 9. It has at its posterior end a cremaster which fastens the pupal body to the inner wall of the cocoon and assists the emergence of the imago. The color of the pupa, immediately after casting its last larval skin, is brownish yellow; after about 3 hours it changes into brown; and after 5 or 6 hours it becomes lustrous blackish brown. The duration of the pupal stage is about 10 to 15 days. As to the imago, the readers are referred to the work of HAMPSON (7).

e) *Food Habit of Larvae.* I have been able to ascertain that this insect feeds upon the following plants:

Boehmeria nivea, HK. et ARN.
Boehmeria spicata, THUNB.
Broussonetia Kashinoki, SIEB.

NAGANO (18) reports that this insect feeds on *Urtica Thunbergiana* S. et Z. which fact I have never been able to confirm. The caterpillar has a stronger preference for *Boehmeria* than for *Broussonetia*. The younger larvae bore small holes through the leaf-blade (Pl. I, Fig. 5, lower and Fig. 6). Fig. 6 shows the appearance of the branch of ramie plant attacked by the youngest larva. The older larvae devour the leaves from their margin so avariciously that the plant attacked exhibits a miserable appearance (Pl. II, Figs. 10, 11). The position and posture of the larva on the plant can be understood from Pl. I, Fig. 1 & Pl. II, Figs. 10, 11. The larva is always found on the underside of the leaves.

f) *Manner of Locomotion and Some Other Behaviors.* As has already been stated, there is nothing peculiar in the manner of locomotion of this larva after the second moult as in that of any Bombycine. caterpillars. The walking peristalsis proceeds from the posterior end of the body to the anterior. It is not reversely directed as is commonly observed in some tortricid larvae. While the tortricid larvae avoid obstacles by going straight backwards, without deviating from their course of progression, the present species turns its head to one side and proceeds in a new direction when it encounters an obstacle and retrogression has not been observed.

The larva shows many forms of reflex movements. It clings to its substratum when it is suddenly alarmed by the vibration of the substratum (clinging reflex); it emits green viscid liquid from its mouth with a jerk of its head directed toward the stimulated part of the body (squirting reflex); it also displays the reflex of changing direction just mentioned without spitting (avoiding reflex). The most conspicuous and interesting trait, however, is the one which I have mentioned in the previous chapter. I propose to designate this movement the '*oscillatory movement*' and the reflex the '*oscillatory reflex*', the detail of which will be elucidated in the following pages.

Description of the Oscillatory Reflex Movement

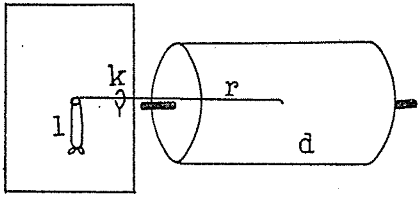
Method of Registering the Movement

In order to determine the amplitude and the period of the movement, it is necessary to have accurate record of it. To fulfill this requirement I chose both mechanical and optical methods. For the reason of giving the animal the least possible restraint, the latter method is preferable.

(A) Mechanical Methods

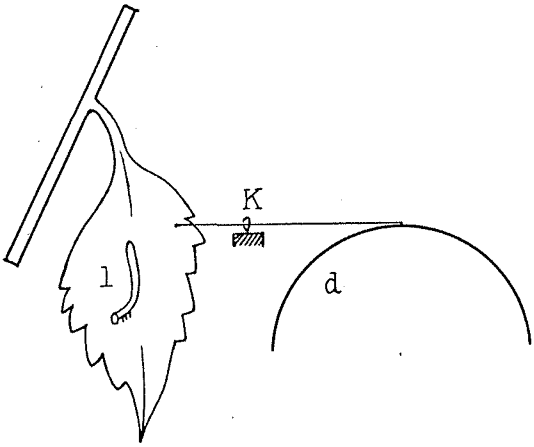
i) *Direct Method.* This is a method in which we transfer body motion on the recording drum by means of something attached to one part of the body of the insect. I drew out a fine glass capillary (Fig. 1, r), which I used as a writing lever or rod, and fastened one of its ends with sealing wax onto the vertex of the larva (l) and the other end, with its tip turned downwards serving as a recording pencil, rested on the surface of a smoked drum (d). A metal loop (k) restricted the movement of the lever. This method is not to be recommended, for it gives the animal too much load and the caterpillar usually ceases the movement after a short while. I did not, therefore, employ this means any further.

Fig. 1



ii) *Indirect Method.* When the insect exhibits this movement on a leaf of the ramie plant, the leaf vibrates in union. So I fastened one end of the rod above mentioned to the leaf at the middle point along the margin instead of the insect's head (Fig. 2). In this case the only duration of the movement can be studied and at the same time the inertia of the torsion of the leafstalk must be taken into consideration.

Fig. 2

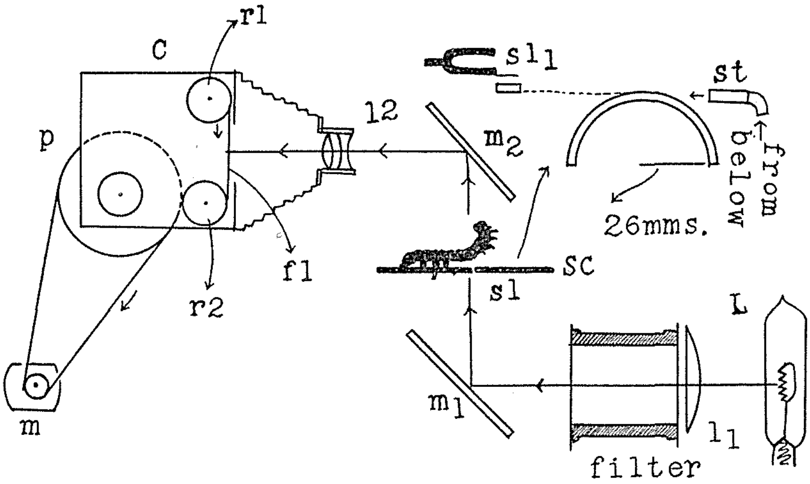


iii) *Drawing Method.* The insect with a drop of ink on its thoracic legs was laid on a sheet of coarse white paper. The insect will draw on the substratum the traces of its thoracic legs when forced to make its oscillation. With a pencil in each hand the observer noted the maximal points reached by the anterior end on both sides. From this tracing I made calculation of the maximal amplitude (Fig. 7).

(B) Optical Methods

i) I used an arrangement shown in Fig. 3. L is a 600 watt stereopticon lamp, whose rays are made parallel by a lens (l_1) and pass through a filter where the heat rays are absorbed. m_1 and m_2 are two plain mirrors placed parallel to each other. The animal is placed on a screen (sc) over a semi-circular slit (sl). The images of the slit and the anterior end of the worm, once reflected by the mirror m_2, are focussed by a photographic lens l_2 on a sheet of standard cinematographic film (fl). The film is firmly and uniformly tacked onto the roller r_2, which is rotated at desired speed by a system consisting of a pulley (p) and a mortar (m). C is a camera specially constructed for this purpose. The slit is shown in the right upper corner of Fig. 3. It is cut in semi-circular form to obtain the tracings of the head. The radius of the arc is 26 mm. Another short linear slit sl_1 for the time recorder is made tangent to the arc. Time is recorded by an electromagnetic tuning fork. A stimulator (st) is placed on the opposite side.

Fig. 3



Schematic sketch of the arrangement in the optical method.

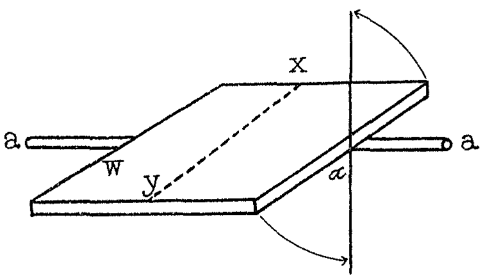
This optical method proved to be the most satisfactory.

ii) Another optical method is that by means of cinematograph. As the period of the movement is very short, we must rely upon the high speed cinematograph for a perfect result. I was, however, not able to try this method in Kyoto, for the machine was inaccessible. I tried a cinematograph of ordinary speed, but was not able to get distinct impressions. The calculation of the results was, moreover, so troublesome that I gave up this method.

Position and Posture of Larvae at the Time of the Oscillatory Movement

In nature, as has already been mentioned, the animal lies on the under side of a leaf of the food plant. In this position the animal is in a dangling attitude with its head pointing downwards. In this position the reflex is manifested readily. On the stalk of the plant, when the creature is resting with its head either up- or downwards, the movement is easily elicited. The animal will respond to a stimulus with the characteristic movement, even if it has been taken from the food plant and laid upon a flat surface, provided that this can be clung to with the abdominal legs. In any position and by any means the reflex movement may be aroused, if the animal is in proper condition to assume the normal posture which will be described presently. To ascertain this fact experimentally I used the following arrangement.

Fig. 4

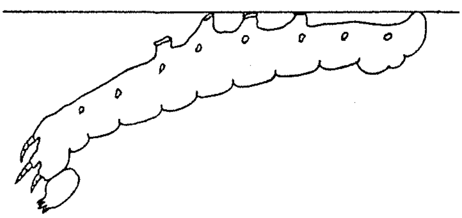


The apparatus consisted simply of a rotating axis (aa′) and a wooden plate (w) fixed upon it in a manner shown in Fig. 4. The plate was rotated around the axis. The insect was laid upon the plate and made to take all kinds of directions upon it. In my first experiment the larva was placed on the line (xy) with its head towards x, i. e., on the line perpendicular to the rotating axis (aa′), and the plane was turned around this axis commencing at the horizontal position. In various inclinations (i. e., in any magnitude of the angle) thus obtained, the animal was stimulated, and observed as to whether it would react to the stimulus or not. From my experiment with more than five specimens, it was learned that any inclination of the plane from the horizontal position will not change the responsiveness of the larva.

Next the direction of the body axis was changed, i. e., the body axis intercrossing with xy line at a random angle, and the plate was turned round as before and the behavior of the animal was observed. The results verified my conclusion based on my field observations under natural conditions.

i) *Normal Posture.* The most typical posture of the animal in which this interesting reaction is to be noticed, is as shown in Pl. II, Figs. 10, 11. When the reaction starts, the animal takes hold of the leaf vein with the posterior three pairs of the abdominal legs, while it keeps the first pair free and throws its head a little more backwards. The anterior portion of the body, including the second abdominal segment, is raised a little more dorsally. A schematic representation is given in Fig. 5.

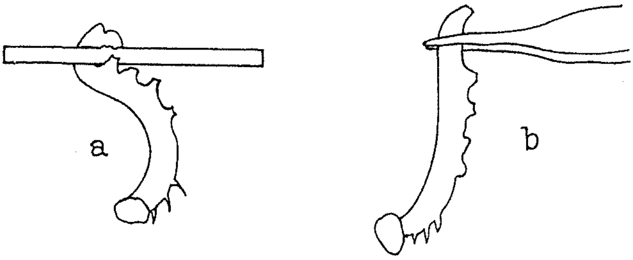
Fig. 5



ii) *Abnormal Posture.* Although in the normal posture the first pair of the abdominal legs is held free from the substratum, it is often seen also taking hold of the substratum. Even the thoracic legs are frequently seen touching upon the substratum, as when the animal is tired or in a condition unable to sustain its heightened tonic posture. In such cases, nevertheless, the larva will respond readily, unless it is physiologically disturbed.

The writer tried to place the caterpillar in many unnatural postures. In most cases it exhibited the expected reaction. The larva was laid on a table and a puff of air was sent over its body. It soon responded to this stimulus, without being affected on account of the unnatural position.

Fig. 6



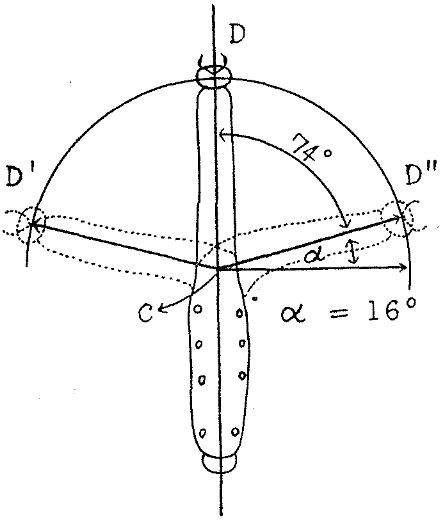
In the posture shown in Fig. 6, a, viz. when it was holding itself by means of the fourth pair of legs and the clasper, a positive result was obtained. I picked up a caterpillar with a pair of forceps in the manner shown in Fig. 6, b and observed that the animal, in such a helpless attitude, having no hold with its own legs, still shook its anterior end from side to side.

The responses are best produced when the stimuli are given to the animal at rest, and if it should happen while the larva is walking, it will stop at once, takes the normal posture as promptly as possible and then starts the response.

Typical Form of the Oscillatory Movement

When a larva, which is in a tonic condition as has been described in the preceding paragraph or is at rest, is suddenly stimulated, it begins at once the oscillatory movement. The anterior third of the body CD (Fig. 7, dotted line) is thrown to one side and then to the other with about the same amplitude, and thus the rapid succession of swinging motion from side to side follows. The anterior extremity describes in the oscillating motion an arc D′D″ with a radius CD.

Fig. 7



i) *Amplitude*. By the drawing method above mentioned I got tracings of the thoracic legs and from these and some other additional drawings (Fig. 7) I calculated the maximal amplitude. In one example (Individium No. 48) of a full grown larva, I found 24.2 mm. as the maximal amplitude and the angle $\angle \mathrm{DCD}'' = 74^\circ$. There exists a wide range of individual differences in the maximal amplitude. There is a difference even in the same individual, from time to time. If the stimulation is repeated many times after short intervals, the amplitude diminishes one time after the other, finally reaching zero.

ii) *Period*. By the indirect method I obtained the following records.

Table A

Indiv. No. 27

Record	Number of oscillation per minute
A	395.4
B	401.8
C	410.0
D	403.0
E	428.6
F	406.2
G	400.0
H	400.0
I	438.8
average	409.6

Some optical records are reproduced in Pl. III, IV. It was possible to determine from such records that the frequency is fairly constant throughout a series of movements. Some records from my reading are as following:

Table B

Frequency (number of oscillation per second) at a five second interval

Interval (sec.) / Indiv. No.	0 | 5	5 | 10	10 | 15	15 | 20	20 | 25	25 | 30	30 | 35	35 | 40	40 | 45	45 | 50	50 | 55	55 | 60	60 | 65
68a	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—	—	—	—	—
b	4.0	4.5	4.5	4.5	5.8	5.0	5.0	4.5	5.0	5.0	5.0	4.5	—
c	3.8	4.5	4.5	4.5	4.5	4.5	4.5	—	—	—	—	—	—
86a	4.3	4.6	5.0	5.0	5.5	5.3	—	—	—	—	—	—	—
b	5.0	5.0	5.5	5.5	—	—	—	—	—	—	—	—	—
92	5.0	5.5	5.5	—	—	—	—	—	—	—	—	—	—
94	4.0	4.5	4.0	—	—	—	—	—	—	—	—	—	—
95	4.5	4.5	4.5	4.7	4.6	—	—	—	—	—	—	—	—
105	4.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	—	—	—	—
106	4.5	4.5	4.5	4.8	4.5	4.5	4.0	—	—	—	—	—	—
108a	4.3	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	—	—	—	—
b	4.0	4.0	4.0	3.6	3.6	4.0	3.8	3.9	3.9	3.6	4.0	4.0	3.6
109a	5.5	5.8	5.8	5.8	—	—	—	—	—	—	—	—	—
b	5.0	5.0	5.3	5.3	5.4	5.5	5.5	—	—	—	—	—	—
c	4.0	4.5	4.5	4.5	4.5	—	—	—	—	—	—	—	—
d	4.8	5.0	4.5	4.5	4.5	5.0	—	—	—	—	—	—	—

Reading these records one may notice that the frequency is almost constant during the movement. Hence the period is constant. The mean value of the period is about 0.22″ in Table B, and in general 0.143″. It is a very interesting fact that there is a gradual decrease in the amplitude (see p. 12), while the period remains fairly constant throughout a series of movements.

iii) *Duration*. The duration of the oscillatory movement is variable. In some individuals it lasted about 59″ while in some others only 2″ or 3″. Irregularity was noticed not only in the different individuals but also in the same specimen. The average duration was about 29.5″. A detailed description of duration will come in a later chapter.

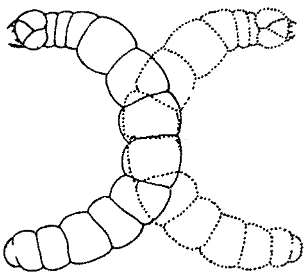
Table C

Indiv. No.	Duration in secs.			
68	28	59	40	
86	33	16		
92	12	9	10	
94	15			
95	29			
97	49	23	23	
105	42			
106	37			
108	41	58		
109	23	28	21	15

Condition of the Substratum

The oscillatory movement is easily performed on a coarse substratum, for this affords the larva a good holding. For example, the leaves, the stalks or other parts of the food plant, a wooden plate, cloth, human skin, blotting paper and other things with rough surfaces furnish a good stage. If a piece of cloth be used, it must be fairly well stretched. Anything cylindrical, thick enough and not too smooth to prevent clinging with the abdominal legs is also suitable. On the contrary, varnished or lacquered plates and tin or glass plates will render conditions unfavorable, i.e., the animal moves about totteringly and some specimens will loop about as aquatic dipterous larvae do with a flipping or snapping motion (Fig. 8) or with a writhing and wriggling motion. We will call this snapping motion an '*x-shaped movement*'.

Fig. 8



Life History and the Movement

The oscillatory movement can not be observed for 1 or 2 days before or immediately after the ecdysis. See Table D. The younger specimens whose body length does not exceed 18 mm., i. e., the first and second instar larvae do not react in this way. They will wriggle about when stimulated.

The larvae as well as the pupae wag their abdomen from side to side if a puff of air is applied to the head end.

Table D

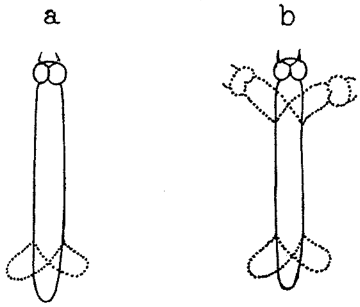
Indiv.	Date	3/VI	4	5	6	7	8	9	10	11	12	13	14	15	16
2	b.l.	15.4		21.8		26.5			33	35		36			
	resp.	—	— N	—	—	—	—	— H	—	+	—	+	+	+	+
3	b.l.	32.3							49			50			54
	resp.	+	+	—	— H	—	+	+	+	+		+	+	+	+
5	b.l.	32	40	45		47.5			50						
	resp.	+	+	—	—	H	+	+	+	+		+	+	+	+

b.l., body length; resp., response; H, ecdysis; N, wriggling motion;
+, oscillating movement present; —, oscillating movement absent.

Explanation of Forms of the Motion

Thus the oscillatory movement is not manifested by the younger larvae of the first and second stadia which bear only three pairs of abdominal legs. Their posture as well as their manner of locomotion is like that of a geometrid larva. When these larvae are irritated suddenly by a puff of air, they wriggle and writhe about. The older forms exhibit the oscillatory movement in the normal manner so long as they are healthy. Even these larvae, however, are unable to do so when the surface of the substratum is unsuitable, and the abnormal motions are commonly observed, as has been stated. In some unusual cases, the insect rolls about in a semicircular voltex ring, and in some cases it snaps about in the form

Fig. 9



already represented in Fig. 8. This form is also seen in a full grown larva immediately before spinning.

On some occasions, which are of course unique cases, I noticed that some specimens oscillated their posterior end, from the seventh abdominal segment on, in the same manner as in their anterior end. There were two types of movements: in the first type the posterior end only reacted in 'J-shape' (Fig. 9, a), with the seventh and remaining abdominal segments held up in the air just as we see in some notodontid larvae, and in the second type both the anterior and the posterior ends oscillated synchronously (Fig. 9, b), both ends being turned to the same side as in the snapping movement.

Comparing these forms, one can detect the interrelation between them. The most primitive and usual form is the x-shape, which will be manifested by all larvae which do not have any means of holding. So the youngest larvae wriggle about with a rapid succession of this form of movement. The oldest caterpillars and the pupae also, with their weakened holding ability, exhibit this kind of movement. After the second ecdysis, when the animal is provided with perfect abdominal legs the x-shaped movement receives some restrictions along the segments with abdominal legs. If the claspers are liberated and the anterior end is affixed to the substratum with the thoracic legs, then the J-shaped movement occurs. If the claspers do not loosen their hold, the form will be the one which we treat as normal in our oscillatory movement.

Ecological Significance of the Oscillatory Movement

Natural Enemies

SASAKI (24) was of the opinion that the oscillatory movement in question is manifested so quickly as to dazzle its enemy's eyes and let the performer escape from attacks. MUKAIKAWA (16) observed a larva of *Proctoparce convolvuli* and a pupa of *Argynnis hyperbius* J. which actually escaped in this way from their hymenopterous parasite which attacked them to lay eggs, and inferred a similar relationship in regard to the oscillatory motion of *Arcte*, although he had not been able to ascertain any natural enemy against this species.

As for the natural enemies to this larva, I found several organisms during my observations, namely, a spider, a nematoda and a hymenopterous insect.

i) *Spider*. I found once in the field an *Arcte*-caterpillar of about the third instar hanging almost lifeless from the ramie plant. On closer investigation, I found a small green spider biting firmly on the eighth tergite and getting the best of the unlucky victim. It appears to be a species belonging to the Genus *Thomisus*, though not yet thoroughly studied. Then I tried repeatedly to see how a *Thomisus* will behave in captivity, keeping the larva and the spider together in a Petri-dish for many days, but in vain. I also placed some other kinds of spiders with the larva and observed them for several days, but none of them attacked the caterpillar in this situation. I observed carefully the manner of the caterpillar when approached by the spider. As soon as the spider touched it at any part of the body, the hairs naturally coming in contact first, there ensued immediately an avoiding reflex but never the oscillatory movement. Spiders usually fled from the larva, being disturbed by the locomotion of its big body. In some cases, spiders apparently assumed an attitude of attack, but the caterpillar marched on paying no attention to them.

ii) *Nematoda*. One day, in 1925, I perceived the caterpillar individual No. 90 of my stock hanging from the wall of the insect cage with its third and fourth abdominal segments turned brown and the rest of the abdominal segments remarkably blackened. When I searched about in the box to find the reason, I found a worm yellowish brown in color, coiled up on the bottom. This was a kind of parasitic nematoda that had just escaped from its host. It was later identified by Mr. MORISHITA, to whom I am very much obliged, to be a premature young of *Mermis* sp. The body lengths of the parasites are given in the following table.

Table E

Host		Parasite
Indiv. No.	Body length	Body length
87	——	125mm.
113	33mm.	200
89	47	200

The parasite seems to quit its host in its fourth stadium.

In the caterpillar No. 83, the hole through which the worm crept out was found on the tergite of the tenth abdominal segment, immediately below the right subdorsal line, a little to the right of the anal aperture. The host was found dead clinging with its four anterior abdominal legs and with its ninth and the superjacent segments uplifted. These uplifted portions were covered with a greasy substance and turned black in color.

The nematoda is of a milky white color. It lies coiled up several times in the abdominal cavity as well as in the thoracic cavity of the host. In one example, the parasitic worm might have been just infecting the internal cavity of the last portion of the alimentary tract. A host is affected by a single worm so far as I know. This immature worm leaves the host, boring through the dorsal region of posterior segments, and reaching the adjacent water, it continues, if I infer correctly, its growth and mates in free life. *Boehmeria nivea* is a plant growing along the edge of ditches, so that it is convenient for such a semiparasitic worm as *Mermis* to seek the *Arcte* larva as a host. More careful study of this parasite, however, must be entrusted to the parasitologist.

Mermis, in spite of its interesting occurrence, has little relation to the peculiar behavior we are now considering, since the infected caterpillars react with the oscillatory motion readily, when they are stimulated, just as good as the unaffected.

iii) *Hymenoptera*. Again in my field work, I found a very small black pupa (pupa libera) encircling a dead caterpillar on the under side of a leaf of *Boehmeria*. This pupa is about 3 mm. in length and 1.5 mm. in width. Later I caught the grubs of the same when they had just crept out from the host. But unfortunately they all metamorphosed into pupae while I was keeping them in a collecting case. An imago emerged from this pupa was identified to be a species of *Metocharis* (Fam. Chalcididae) according to SCHMIEDEKNECHT's synopsis (25). I was not able, however, to learn whether *Arcte* will try to drive this chalcid parasite away or not, nor do I know whether this parasite lays its eggs on the larva or not. As I shall explain later, the caterpillar reacts to pizzicato sounds of ♯G, G, ♭G of the cello with dorsal jerks of the anterior third of its body, as MINNICH (13) has shown with *Pyrameis atalanta*. This fact suggests that our caterpillar may react to the wing tone of a pitch near to the above mentioned, and if the wing tone of *Metocharis* has such a pitch the caterpillar may naturally respond with the oscillatory movement. The question still remains, however, whether the movement is effective enough to prevent the attack of the parasite or not.

NAGANO (18) reports that the larva of *Spirarctia imparillis*, a tent caterpillar of the mulberry, wards off its hymenopterous parasite by shaking the anterior end of its body. But it is doubtful whether such a small fly as this will produce a sound strong enough to call forth the reaction in this larva.

Protrusible Organ or Osmeterium

The writer discovered a protrusible organ on the mid-ventral line of the sternite of the first thoracic segment (Pl. II, Figs. 14–16). This organ when protruded by eversion of its wall inside out, has a cylindrical form truncated at its apex and slightly curved dorsally near its tip and may reach as far as the mouth parts. Consulting literature, I was convinced that PACKARD (20) already pointed out the universal prevalence of such a protrusible organ in some insects. He listed many species, larval, pupal as well as imaginal forms. In his list we find 12 larval noctuids, among which there is one which he designated as *Catocala* sp. So the presence of this organ in our species is by no means a very special case. As for the function of these eversible organs PACKARD took it to be repugnatorial. Usually each stimulation is responded separately. The duration of the protruded state is also variable, in one case lasting as long as the stimulation lasts and in another being very short, generally of a few seconds. The response does not occur during the performance of the oscillatory movement. It may be that the protrusion will begin at the moment when the stimulation is given, but this point is not clear. This is very hard to judge, for in one side the velocity of the oscillation is very high, while on the other side the protrusion may be carried out only momentarily. The occurrence of this organ in our *Arcte* seems to cast light on the decision of the significance of the oscillatory movement. Judging from WEGENER'S conclusion (29) in regard to the osmeterium of Papillio, it may not be too much to say that the oscillating movement is performed in order to distribute widely some malodorous substance prepared by the protrusible organ.

The insect also emits a green viscid substance from the mouth which has a somewhat faint unpleasant odour, though not so strong as that produced by the osmeterium. It is somewhat similar to the odour of a crushed leaf of *Boehmeria nivea*.

From the preceeding fact, I might conclude that the ecological significance of this oscillatory movement is to distribute the repellent odorous substance produced in the protrusible gland by the air currents produced rather than to prevent assault by some parasitic intruders or any other enemies.

Physiological Studies on the Oscillatory Movement

a) *Adequate Stimulus.* In order to determine the effective sort of stimulation several methods were utilized involving the electrical, optical, thermal, chemical and mechanical stimulations, but out of these the mechanical stimulation only succeeded in provoking the reaction. The electrical stimulation when given externally, i. e., on the skin by putting electrodes at various parts of the body, gave no positive result, but when applied internally, i. e., with electric current passing through the body, caused normal oscillatory response. This matter will be dealt with in detail in a later chapter.

To stimulate optically, a beam of light from a 500 watt stereopticon lamp was used at a distance of 1 to 2 meters, screened by a board with a small slit in its center. The insect was placed on a table in the dark room and the light was so adjusted that it fell upon the insect's head. Another sheet of black paper was moved behind the screen so that a flickering light was thrown on the other side of the head. The experiment was repeated by sudden throw of fairly intense light on the animal but this produced no positive reaction.

Thermal stimulus was given by means of bringing a red hot needle near to different parts of the animal. No response was visible, even when the needle was brought so near that it burned the body hairs. When I placed the needle so as to touch the skin directly, only a twitch in the affected part was the result. In some other instances the insect escaped from the hot object, crawling or rolling away with a wriggling motion.

As for the chemical stimuli, both gaseous and liquid reagents were tried. Thinking that the animal may exhibit its oscillatory performance as it feels an odorous stimulation emitted from the enemies or from the human hand approaching it, I tried with several kinds of strong odorous vapors, such as glacial acetic acid, hydrochloric acid and ammonia. When 3 c. c. of the water solution of 1 : 1, 1 : 2, 1 : 4 up to 1 : 2048 respectively of these reagents was poured in a watch glass, and was brought gradually nearer and nearer to the insect, commencing at a distance of 30 centimeters, none of these reagents was able to evoke the slightest movement in the caterpillar except absolute or 1 : 2 solution both of glacial acetic acid and ammonia. To dilute solutions the animal responded with a chewing motion of the mouth part, while to stronger solutions it reacted by ejecting green fluid from the mouth, and then by lowering the head and rubbing the mouth parts with its first thoracic legs. This is nothing other than the so-called ' Putzreflex '. This reflex, however, was evoked only when these irritable substances were brought within 3 centimeters of the mouth parts. When the concentrated solution of any reagent other than glacial acetic acid or ammonia was used, the animal remained motionless, with its head bent down and pressed tightly against its thoracic segments.

If any of these substances is applied directly with a brush or a pipette to the skin of the caterpillar it became uneasy and in some rare cases performed the oscillatory reflex. Such positive results, however, can not be deemed really positive, for some mechanical stimulation may accompany this experiment. I am, therefore, inclined to discard the results of chemical stimulations just mentioned as abnormal.

The mechanical stimuli may be classed in four divisions, viz. the contact, the stroking, the pressure and the vibrating stimuli.

i) Contact. A needle was used as a stimulating agent. This must be applied very gently, so that there may not be any air disturbance caused by bringing it near to the animal.

A gentle touch with a needle on one of the body hairs, however, did not arouse the desired response, although I tried with several specimens at various spots of the body. Next I explored the skin all over with the tip or with the side of the needle. While 'Abwischreflex' was evoked in such examinations, the oscillatory reflex was not observed.

ii) Stroking.*

1) *With Solid Substances.* Striking the body hairs with solid substances such as a pencil, a needle, etc., no positive result was observed. To the contrary, the insect shook the anterior third of its body heavily as soon as the body surface was stroked. There was no restriction as to the spot stroked, i. e., it might be either on the dorsal or on the lateral side. I explored segment after segment beginning from the posterior end or in the reverse direction ; I found that the result was the same and positive for any segment. Another trial was done by hitting the skin with falling shot-balls,—No. 1. (each weighing on average 0.3 gr.) and No. 6. (each weighing on average 0.1 gr.). By letting these small lead balls fall upon the insect body from various heights mere "*Abwischreflex*" was evoked and not the wind reflex. Positive results were obtained when the stimulus was applied to any of the 5th, 6th, 7th and 8th abdominal segments. The result was irregular. For example, the same sized ball falling the same distance did not always induce the same reaction, and sometimes the larva responded to a height of 45 mm., while it did not give any positive response to either that of 48 mm. or 40 mm.; the fact is very hard to explain. Another unfavourable point in this experiment was that

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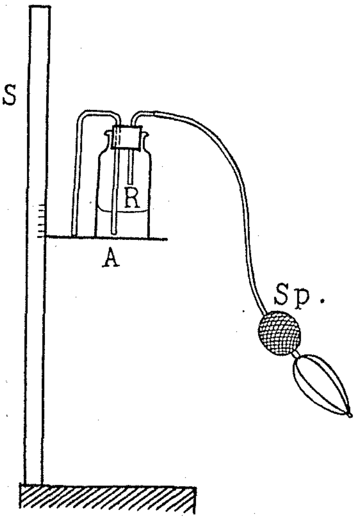
*This is to stroke the insect's body either with solid or fluid substances.

the ball rolled about on the wooden block on which the larva rested and some response might have been caused by the vibration of the substratum. Any heavier substances when dropped upon the animal would often cause a wriggling motion. In short, falling solid substances may call forth the response, but not regularly.

2) *With Fluid Substances.* I used water as a fluid agent not being in itself a chemical stimulus. In principle differed nothing in this case from the foregoing experiment, but a drop of water was used instead of a lead ball. The arrangement is shown in Fig. 10. *S* is a scale along which a plate *A* slides. On *A* a siphon is fastened so that the tip of its perpendicular arm is situated in the same horizontal plane as the lower edge of *A*. *R* is a reservoir in which two glass tubes are inserted, one forming another arm of the siphon, and the other tubing connected with a spray *Sp*.

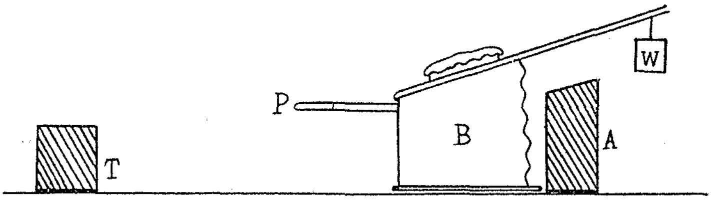
Fig. 10



The experimenter pressed the spray not abruptly but gently and just strong enough to push out a drop of water from the external tip of the siphon. A single drop weighed ca. 0.0037 gr. (1 gr. = 263.5 drops). When the animal thus stimulated irregular results were obtained, being similar to those when solid substances were used.

3) *With Air.* The animal responded with the typical motion when a puff of air was blown on it. When stimulated on the lateral side of the mouth, the animal clung tightly to the substratum. But when fanned with a sheet of paper which was held vertically 30 cm. apart from the insect, it gave a positive response. This experiment can be repeated with a good result.

Fig. 11



A glass tube *P* (Fig. 11), the internal diameter of which is 1cm., was drawn into the form of a pipette. This was connected on its wider end with a bellows *B*. The puff of air produced by this apparatus was able to evoke the normal reaction. Either an instantaneous or a continuous air stream applied with this apparatus always brought about the positive response.

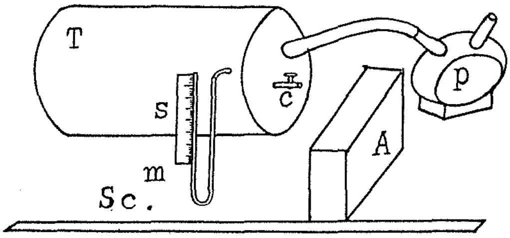
In some cases, the insect commenced to oscillate normally at the beginning of the successive stimulations and then began to exhibit the clinging reflex abandonning the oscillating movement.

In the field the insect does not seem to react either to breeze or to wind. Waving of the plant leaves caused by the breeze seems to have no relation to the oscillatory movement, while a gentle stroke on the stem evokes it. During a continuous swaying of the plant by breeze or a stronger bending by wind, the insect merely clings tight to the leaf. From such field observations as well as the laboratory experiments, it seems to me that a long lasting stimulation is of no use for evoking the oscillatory reflex and only a sudden instantaneous stimulation is effective for it.

As I have stated in the previous chapter, the insect responded to musical sounds, G, ♯G, ♭G of the cello and its first higher octave with a jerk of the anterior end of the body. But it must be remembered that such a reaction is rather conditioned. The positive result was obtained more readily when the insect was subjected to a blow of breath and then stimulated musically at the very moment when the response evoked by the first stimulation had just come to an end. The sounds produced with the instrument in pizzicato only was effective, while those in arco, staccato or spiccato were all ineffective.

In order to determine the intensity of the stimulation by air stream, I was able to carry out the following experiment by the courtesy and kindness of my friend, Assistant Professor Dr. Nakamura of the Physical Laboratory of this University.

Fig. 12



The apparatus for this experiment is shown in Fig. 12. *T* is a compressed air chamber or a cylindrical metal tank, to which a manometer *m* with a scale *S* is attached so that one can read the pressure within the tank. Air is compressed in the tank by a pump *P*. A cock *C* to let the compressed air escape is attached to one of the flat surfaces of the tank. This cock is directed towards the insect lying on a wooden block *A*, so that the air blow will stimulate the animal sidewise. On the scale *S*, the mark '30' denotes one atmospheric pressure and '40' indicates two atmospheric pressures. The distance between the mouth of the cock and the insect is read by another horizontal scale *Sc*.

Table F

Indiv. No. Dist. in cms.	No. 1 6	No. 1 7	No. 25 6	No. 24 7.0	No. 24 7.5	No. 5 12	No. 21 15
Pressure							
39.0		−			−		
38.5		−		−	−		
38.3		−					
38.0				−		−	
37.5		−					
37.3				−			
37.0					−	−	
36.8						+	
36.5		−		−	−		
36.0		−					
35.8							
35.5						+	
35.0				−		+	
34.9					−		
34.6	+						
34.5					−		+
34.0		−		−		+	
33.8				−			
33.5				−	−	+	
33.0	−	−			−	−	+
32.5	−	−		+	−	+	
32.3				+			
32.2		−					
32.0	−		+		−	+	+
31.8			−			+	−
31.6					−		
31.5	−	+	−	−		+	+
31.2	−			−	−		
31.0		+		−		+	
30.8	−	+			−	+	−
30.5	−	+	−	−	+	+	−
30.3	−	+	−	−	−	+	+
30.2	−	+		−			
30.1		+		−	+		
30.0	−	+	−	+	+	+	+

The individuals No. 5, 24 and 25 were of the fourth instar and No. 1 and No. 21 were of the fifth. From the above table we see that a stimulation by a weaker intensity was more effective than that by a stronger one. For example, in No. 24, reactions were observed in rather low pressures and at a greater distance. The same matter will be understood more clearly in No. 1. Throughout the data given on the table we see that effective pressure is rather *a low one*, not much exceeding one atomospheric pressure.

iii) Pressure. If a solid substance is laid upon the insect's body to press it, after the animal has bent its body in the 'avoiding reflex', the oscillatory response can be finally aroused. This method of stimulation is somewhat allied to a contact stimulation and also to a stroking by solid substances, but differs from the first in pressing so much that it will cause the distortion of the body of the insect and from the second in that acceleration has very little influence. With this stimulation, positive results were always obtained as far as it was given upon the abdominal segments. If the stimulation was applied to the lateral side of the abdomen, the reaction often ended in 'Abwischreflex'. Pinching the side with a pair of forceps also produced a positive result.

The positive reaction was obtained by dragging a pencil along the dorsal line of the abdominal segments commencing at the third abdominal and ending in the anal segment, and also by doing so in the reverse direction. The stimulation in this experiment is a combination of contact and pressure. The 'Abwischreflex' appears first, which is repeated several times, and then the true oscillatory movement occurs. Pinching or pressing on the abdominal legs evoked positive responses. Experiments with the remaining portions of the body were tried in vain.

iv) Vibration of the Substratum. By stroking the stems or leaves of the food plant the oscillatory movement is soon evoked. If the insect is resting on a flat surface, the reaction may be aroused either by giving a gentle stroke on the substratum or dropping something upon the same. I have often seen the insect on a table making this movement as I walked on the floor. This was of course due to the transmission of vibration of the floor to the table.

A ZIMMERMANN's electromagnetic tuning fork (I used two kinds: number of vibration 100/sec. and 50/sec.) sounded on a table for one minute failed to initiate the oscillatory movement of the insect. Of course I changed the distance between the animal and the fork.

To conclude from the above mentioned evidences, the most adequate stimulus for the oscillatory reflex is the mechanical one, and among mechanical stimuli, the stimulation by means of air current seems to be most effective. Another effective one is stroking with solid substances such as a stick or a needle. The pressing of the skin is also effective, provided that the 'Abwischreflex' does not persist long. Another conspicuous fact concerning the efficiency is that the instantaneous stimulation is the best.

b) *Inhibitory Factors.* A chemical stimulant such as glacial acetic acid will work as an inhibiting reagent. When a vessel containing concentrated glacial acetic acid is brought near to the oscillating animal, it stops the movement at once, and takes the attitude mentioned in this chapter a. In this case, however, the manifestation of the 'Putzreflex' is more pronounced than the ordinary response.

An individual manifesting the normal movement will cease this when some solid substance is applied heavily to its body surface. I noticed that the animal ceased the swinging motion when I wanted to count the number of strokes produced by the animal hitting a sheet of paper with its head. Perhaps the paper was placed too near to the animal and the continuous contact between the paper and the hairs on the posterior portion of the body inhibited the oscillatory movement.

When the animal is either sensorily stupefied or adapted to repeated stimulations or weakened by the loss of the body fluid owing to an operation, any kind of stimulations will be ineffective. The fact that the insect during the dormant period prior to ecdysis will never respond with the normal movement has already been mentioned (Chapter III., p. 15).

I was unable to find any other inhibitory factors.

c) *Receptor.* As the receptive organ for the reflex in question, the dermal hair may first be thought of. This organ, however, did not prove itself to be of any importance in my experiment as already been described. Having obtained no real response by means of mechanical stimulation, I tried electrical and chemical stimuli. In the former, an electrode was applied to the hair and in the latter, concentrated acid or alkali was used. These were both ineffective. I then cut all the hairs as far as possible with a pair of scissors. A puff of air thrown on to this larva evoked a good response. I then burned all the remaining hairs which were visible to the naked eye by passing the larva through a flame and after having laid the larva aside for about 1–2 hours (after which, I suppose, the shock-effect must have passed off) I tested the insect with a puff of air and obtained a very distinct positive result.

Next I took the following method to determine the localization of the receptors on the body surface. A fine glass tube (3 mm. in diamter), one end of which was connected with an air pump or a rubber spray, was placed behind a screen with a fine vertical slit 1.5 cm. × 2 mm. The larva was placed on the other side, 2 cm. away from the screen, with its body axis parallel to the latter. This distance was fixed, because in a shorter distance the insect might strike the screen with its head and the successive stimulations might inhibit the further movement. Shifting the body of the animal to and fro in front of the screen I could blow through the slit to any portion of the animal.

With such an arrangement I explored every part of the body from one side of the body, beginning at the anterior end and turning to the other portion, and found that the result was quite irregular. In the anterior portion, which was usually held free from the substratum, the response was always positive and in the abdominal region the reaction was not constant. To infer, from this, that more numerous receptive organs are distributed in the anterior portion than in the posterior, may be too hasty.

The local narcotising of the integument with such anaesthetics as chloroform, ether etc. was impossible, because of an ill effect of the reagents on the respiratory system. I was not able to ascertain the localization of the receptors by this method.

I applied to the integument M/8 $Mg\ Cl_2$, but disappearance of the cutaneous sense was not observed. This experiment was suggested by the work of MOORE (14), who succeeded in his experiment in abolishing the cutaneous sense in the earthworm. These different results in the two classes of animals may be due to the difference in the condition of the skin, which is dry in my insect, while it is always wet and can easily be affected by chemicals in the earthworm.

Thus I am not able at present to detect the receptive organs responsible for the oscillatory movement.

d) *Center.* An adequate stimulus was given to an animal which had been decapitated, with the idea that it might be found that the behavior is a reflex whose center is located in an abdominal cord. The operation caused the depression of the body tonus of the animal, and as a matter of fact, the oscillatory movement was impossible. The influence of the cerebral ganglion upon the body tonus was pointed out long ago by POLIMANTI (23) in his "Observation on the body tonus and the locomotion of the silk worm (*Bombyx mori*)."

If the head was cut off after a ligature was tied at the head-thorax articulation, the animal did not respond with the rhythmic movement. This experiment was repeated several times with the same results.

The central nervous system of *Arcte* consists of 1 cerebral, 1 suboesophageal, 3 thoracic and 7 abdominal ganglia. I sectioned the connectives in several places. A larva was etherized, a short longitudinal slit was cut along the ventral line with a pair of scissors, and a fine needle was used to draw out the connectives, which were severed by a fine knife. The animal recovered from the anaesthetics in about a quarter of an hour. The results obtained by the amputation of the connectives are represented in the following table.

Table G

Exper. No.	Indiv. No.	Connectives amputated	Result of amputation	Oscillatory movement	Effectors of the movement
1	9	5ab—6ab	+	+	2ab=3ab
2	20	cerebral	+	—	
3	12	2ab—3ab	—	+	1ab=2ab
4	11	1ab—2ab	+	+	2ab=3ab
5	31	suboes—1th	+	—	2ab=3ab
6	61	2ab—3ab	+	+	1ab=2ab

5ab—6ab, connective between 5th and 6th abdominal ganglia;
2ab=3ab, articulation between 2nd and 3rd abdominal segments.

I then made the following experiment in which ligatures were tied with a fine thread at the segmental articulations, and all the segments posterior to the ligature were cut off. This was done segment after segment, commencing with the last abdominal segment. Stimulation was given by means of a puff of air.

Table H

Indiv. No.	Ligature given	Movement
60 (a)	7ab=8ab	+
	5ab=6ab	+
	4ab=5ab	+
	3ab=4ab	+
	2ab=3ab	—
81 (b)	8ab=9ab	+
	6ab=7ab	+
	5ab=6ab	+
	4ab=5ab	+
	3ab=4ab	—

Comparing (a) and (b) in Table H, we find that the oscillatory movement will surely be present, if the segments down to the third abdominal remain intact posterior to including the fourth abdominal segment, be severed. Individual No. 60 shows a response with the 3ab=4ab ligature. So we may conclude that the negative result in No. 81 with the same ligature may be due to the failure of the operation or to some other causes. Through these observations I infer that the effective center for the oscillatory movement is apparently located in the segments anterior to the third abdominal segment. The experiment No. 4 in Table G suggests that any of the supraoesophageal, the suboesophageal, the thoracic and the first abdominal ganglia is not concerned with the movement, provided that the effector in this case is located in the 2ab=3ab. I noted also in the experiment Nos. 3 and 6 in the same table that the effector was in the 1ab=2ab articulation. The muscles of the first abdominal segment may be regarded, therefore, as an effector and the first abdominal ganglion at least as one of the seats of the effective center.

We may infer, therefore, that the center is apparently located in the first three abdominal ganglia, and the other ganglia have no relation to the movement.

In the amputation at the ligature 2ab=3ab, the insect loses all its abdominal legs, and hence its hold on the substratum; and the oscillatory movement, therefore, is impossible to occur.

e) *Effector.* The above statement suggests at once that the effectors are the muscles of the first three abdominal segments. We may ascertain this to be a fact by an observation on a healthy specimen.

f) *Duration.* An individual which is too weak to show muscular activities through hunger, fatigue or from other causes, oscillates only for a short time. In short, there is a pretty wide range of individual difference in the duration of oscillation; I will give some measurements of the first oscillation, i. e., the oscillation manifested for the first time by a fresh individual which has been kept quiet for a quarter of an hour (Table I).

Table I

Indiv. No.	Duration	Indiv. No.	Duration
13	42 secs.	74	30 secs.
20	45	75	19
50	13	76	33
59	42	87	36
71	73	112	13
72	12	117	35
73	13	Average	26.61 secs.

I tried next by means of the bellows method (Fig. 11) to determine whether the duration of oscillation in one individual subjected to a constant mode of stimulation is constant or not. The aperture of the pipette tube was 7 mm. in diameter. A 900 gr. weight w was affixed to the handle of the bellows which, when released, would press down the bellows and send forth sudden current of air. The distance in which the upper plate of the bellows moves downwards was adjusted to 2.5 cm. by means of a wooden block A. This distance was kept constant throughout the experiment. The intensity of the stimulus applied to the insect was changed at will by altering the distance which is noted in Table J as 'distance'. Five trials at each distance were made and the interval

Table J

(a) Indiv. No. 25

Distance in cms.	6	7	8	10	11	12	13
Trials							
1	20″	3	—	7	8	5	3
2	18	3	20	5	6	—	—
3	21	2	4	—	5	2	—
4	8	1	3	7	2.5	—	3
5	6	1	6	1	—	—	—

'—' means no response.

(b) Indiv. No. 1

Distance in cms.	13	14	15	16	17	18
Trials						
1	3″	2	2	4	2	2
2	3.3	—	3	3.5	2.8	2
3	3	1.3	3	4	2	2.5
4	3	3	2.5	3.5	3	2
5	3.1	3	2.5	2	3	3

(c) Indiv. No. 3

Distance in cms.	17.5	20	23	26	28	30	34	37	38	40
Trials										
1	16″	18	6	9	8	16	15	12	—	—
2	23	21	9	9	7	15	12	2		
3	21	21	17	10	7	21	18	—	2	2
4	21	22	9	5	16	15	5	—	—	—
5	25	17	13	7	6	15	6	—	—	—

between the two successive trials was 10″. The results of this experiment show that the duration is not always constant even with a constant mode of stimulation (Table J).

g) *Successive Stimulations.* The successive stimulations were given in two ways:

1) Immediately after the completion of the first movement caused by the first stimulus, the second stimulus was given, and so on. As the index to the completion of the reaction the 'chewing movements' of the mouth parts, which is shown by every individual on entering the resting period, were taken.

2) The succesive stimuli were given at definite intervals and continued till the insect could no more react to the stimulus.

The stimulus in both cases was a puff of air and the oscillating interval was measured as accurately as possible with a stop watch.

By the first method, as will be seen in the Tables K and L, there are fluctuations in the duration. This fact was confirmed also by many other specimens. The Individual A was stimulated repeatedly until it ceased entirely to react to the air stimulus, i. e., in the end the animal did not show any sign of the reflex to repeated stimulations as shown in the Table K and Fig. 13. The experiment was commenced at 7.35 p.m. and ended at 8.17 p. m. I noted that the oscillatory movement was repeated 84 times successively by this individual. At the 85th stimulation the animal was laid on its right side and seemed almost worn out. The fluctuation in the number of oscillations is represented graphically in Fig. 13. In this graph the 4th, 21st, 44th, 66th, 75th, and 79th reactions are maximal. The decrement in the duration of the movement is not linear.

To apply periodic or repeated stimuli in every few minutes the following arrangement was used. A glass tube with an aperture of 7 mm. in diameter was placed 8 cm. away from the insect, and a sidewise airblow was sent to the anterior third of the body. The duration of the movement of one of the individuals (No. 122) prior to this experiment had been 15″, 15″ or 10″.

Each experiment was made after allowing the insect to take a rest for nearly 5 minutes. So the insect was stimulated every other five seconds. When one minute elapsed without any reaction after the application of the stimulus we considered that the object was nearly tired out, and from this time the interval between two successive stimulations was reduced to one second and the observation was continued. At the end of 3′ 23″ from the initial stimulation the animal

Table K

Indiv. A

Trial No.	Duration	Trial No.	Duration	Trial No.	Duration
1	43″	30	27″	58	17″
2	45	31	26	59	20
3	53	32	23	60	18
4	62	33	23	61	17
5	54	34	17	62	18
6	55	35	28	63	18
7	40	36	30	64	15
8	50	37	27	65	17
9	52	38	30	66	26
10	46	39	28	67	20
11	34	40	45	68	15
12	28	41	28	69	15
13	33	42	23	70	15
14	42	43	19	71	14
15	42	44	36	72	12
16	42	45	27	73	11
17	34	46	28	74	11
18	28	47	26	75	23
19	38	48	29	76	14
20	43	49	27	77	15
21	34	50	27	78	13
22	50	51	23	79	16
23	33	52	24	80	11
24	33	53	18	81	12
25	26	54	22	82	12
26	25	55	19	83	8
27	28	56	20	84	4
28	32	57	16	85	—
29	28	58	17	86	—

Table L

(a) Indiv. A

Trial No.	Time	Duration	Trial No.	Time	Duration
1	6.35 p.m.	53″	11	6.59 p.m.	53″
2	38	50	12	7.02	38
3	40	48	13	06	43
4	43	48	14	09	35
5	44	46	15	16	23
6	47	30	16	20	18
7	49	28	17	22	32
8	51	27	18	29	35
9	54	38	19	34	35
10	56	43			

Table I. *Continued*

(b) Indiv. B

Trial No.	Time	Duration	Trial No.	Time	Duration
1	6·39 p.m.	16″	9	7.00 p.m.	10″
2	41	18	10	04	9
3	44	7	11	07	6
4	46	13	12	10	7
5	50	6	13	14	4
6	53	6	14	19	8
7	55	5	15	28	8
8	57	10	16	30	9

(c) Indiv. C

Trial No.	Time	Duration	Trial No.	Time	Duration
1	6·45 p.m.	60″	7	7.05 p.m.	18″
2	48	50	8	08	31
3	52	48	9	15	15
4	56	32	10	20	12
5	58	13	11	31	48
6	7·01	11	12	32	42

Fig. 13

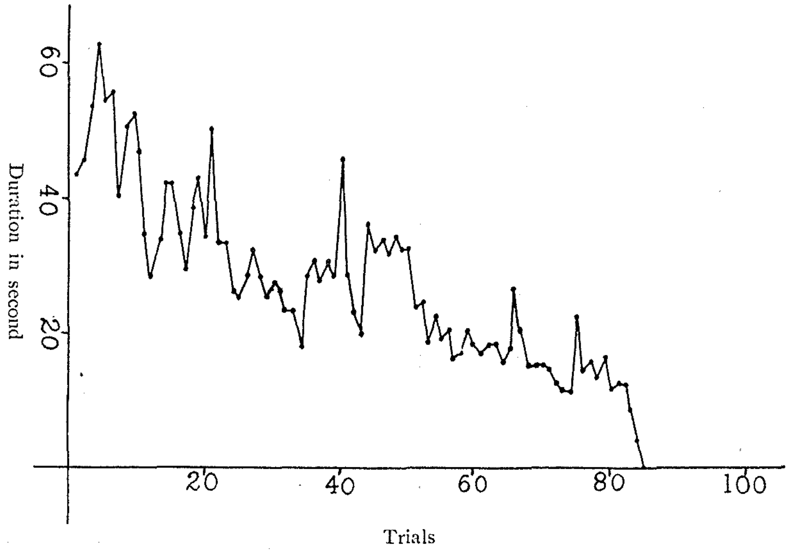


Table M

Exper. No.	Indiv. No.	Interval between each two successive stimulations	Duration of oscillation
1	119	3″	56″
2	119	3	40
3	120	3	23
4	120	2	30
5	121	3	66
6	122	3	43

ceased to react. From the above-mentioned experiments we see that successive stimulations produce a summation effect, increasing the duration of the movement.

h) *Recovery of Response.* A specimen, which has been exhausted by successive stimulations as in the former experiments (the first case), can be restored again to a state capable of response to the same stimulant. The method of doing this is to apply a different kind of stimulation, such as contact. This fact deserves a special notice, as it suggests to us that the movement belongs to a reflex type that can be inhibited by the irritation of some other reflex arcs.

Table N

(a) Indiv. No. A

Trial No.	Duration	Trial No.	Duration
1	30″	14	3″
2	26	15	6
3	23	16	7
4	18	17	3
5	18	18	3
6	13	19	2
7	13	20	—
8	10	21	—
9	7	22	—
10	3	23	—
11	—	24*	3
12	—	25	3
13	—	26	30

* Began to walk; then pricked with a needle.

Table N *Continued*

(b) Indiv. No. B

Trial No.	Duration	Trial No.	Duration
1	40″	14	13″
2	42	15	10
3	33	16	5
4	20	17	3
5	32	18	5
6	23	19	5
7	14	20	1
8	17	21	3
9	20	22	3
10	15	23	1
11	11	24*	45
12	13	25	30
13	13		

* Pricked with a needle, on the 8th abdominal segment (tergite).

As is shown in the accompanying tables, if a new kind of stimulus is given to an exhausted, non-responding animal (by pricking it with a needle for example) a very remarkable recovery is seen. This is indicated by the increased length of the duration.

Physiological Analysis of the Oscillatory Movement

In some optical records of the oscillatory movement I noticed a very distinct form of oscillation in the beginning of the movement. This is represented in the figures in Plates IV and V. It is of a very conspicuous type with a longer period and larger amplitudes. The whole series, therefore, consists of a single aperiodic portion and many other successive periodic movements. This heterogeneous constitution of the oscillatory movement can be explained in the following way. The aperiodic movement is usually performed by the insect by turning the anterior portion of its body to the stimulated side. This fact indicates that the stimulus is first received by the animal as contact stimulation and this in turn evokes the movement of an '*Abwischreflex*' type. The periodic portion is a real oscillatory movement. A series may be destitute of the aperiodic portion, if the reflex movement is aroused by the vibration of the substratum. Such a case is shown in Plate V. In this example, however, I am not able to show a typical one, for this individual entered into a new series of periodic movements since the last stage of the foregoing series (Plate III. Left column).

The following experiments were done in order to study the relation between the oscillatory reflex and the '*Abwischreflex*', and to detect how far either of the two reflexes will be affected by internal or bodily changes. Several sorts of reagents were injected into the animal; such as camphor, strychnine, nicotine, atropine, caffeine, veratrine, phenol, alcohol and adrenalin.

i) Camphor, saturated in normal saline water

Indiv. No.	67	68	45	112	88	72	73
Dosis c.c.	2/20	2/20	3/20	4/20	5/20	5/20	7/20
Injected in	3th	8ab	3ab	3th	3th	3th	6ab
Before Osc. inject. Abw.	+ +	+ +	+ +	+ +	+ +	+ +	+ +
After Osc. inject. Abw.	− +	+ +	− −	− −	− +	− +	− +

Osc., Oscillatory movement. Abw., Abwischreflex;
th., thoracic segment. ab., abdominal segment.

The universal reactions to camphor injection are a severe convulsive movement and a peculiar x-shaped movement described in page 14. These phenomena must be due to the exciting action of camphor, which has been well established in vertebrates. The x-shaped movement appears in the insect either spontaneously or on stimulation by contact or airblow. It is said that in higher animals camphor affects the central nervous system and makes the animal suffer from convulsion (Morishima (15)). The periodic occurrence of the x-shaped movement is due to an excitation of the central nervous system. The position of the effectors, the duration and the number of oscillations per second of the latter movement are as follows:

Indiv. No.	Effector	No. osc.	Duration
45	4ab—5ab	100	35″, 52″
88		81.8	
72	2ab—3ab	48	18″
67	3ab—4ab		

The 'Abwischreflex' seems to be more persistent than the oscillatory movement.

ii) Strychnine, 1 : 100 in Ringer's solution

By strychnization above mentioned two reflexes disappeared simultaneously while the convulsive movement occured. When the dosis does not exceed 1/10 c. c., the reflex movements could be restored after a certain length of time. The recovery of the oscillatory movement ensued almost at the same time and was marked as distinctly as in the case of camphor injection (Dosis, 2/20–3/20 c.c.).

iii) Nicotine, 1 : 1000 in Ringer's solution

Indiv. No. 68 died very soon after the injection, while Indiv. No. 71 recovered. In the latter animal the injection was made at 9.55 a.m. and the 'Abwischreflex' recovered at 10.20 a.m., but the oscillating reflex was not detected until 1.32 p. m. The duration of the movement before injection was 13″, 15″ and after it 15″, 17″ (Dosis, 1/20—2/20c.c.).

iv) Atropine, 1 : 100 in Ringer's solution

In this instance the oscillatory movement entirely disappeared; while the 'Abwischreflex' remained unaffected. The oscillatory reflex recovered later in two individuals (Dosis, 3/20–5/20 c.c.).

v) Caffeine, 1 : 200 in Ringer's solution

Both reflexes remained unchanged. The injected animal did not respond with the oscillatory movement unless it was stimulated by contact stimulus (Dosis, 5/20–8/20 c.c.).

vi) Veratrine, saturated in normal saline water

Both reflexes disappeared after the injection. In No. 86 only after 28 hours the 'Abwischreflex' recovered; in No. 116 the x-shaped movement was observed (Dosis, 3/20 c.c.).

vii) Phenol, in 1 : 100 water solution

In No. 80, 2/20 c.c. was injected in the third thoracic segment. The 'Abwischreflex' was persistent.

viii) Alcohol, in 12.5% water solution

Both reflexes remained unchanged. In No. 85 the x-shaped movement appeared; in No. 67 the duration of the oscillatory movement was 20″ and 35″, but 30 minutes after injection it was prolonged to 45″ and 50″.

ix) Adrenaline, 1 : 1000 water solution

Adrenaline abolished both reflexes. The x-shaped movement was observed (Dosis, 2/20–4/20 c.c.).

Summarizing all these experiments, the following table is obtained in which + or — represents presence or absence of the reflex respectively before and after the injection.

Table O

Reagent	Oscill. reflex		Abwischreflex		x-shaped movement
	before	after	before	after	after
Camphor	+	—	+	+	+
Strychnine	+	—	+	—	
Nicotine	+	—	+	—	
Atropine	+	—	+	+	
Caffeine	+	+	+	+	
Veratrine	+	—	+	—	+
Phenol	+	+*	+	+	
Alcohol	+	+	+	+	+
Adrenalin	+	—	+	—	+

* In this case the frequency became much less.

As a whole, the 'Abwischreflex' is more tenaceous than the oscillatory reflex when various sorts of chemicals are injected.

Discussion

A. The Neuromuscular Mechanism of the Oscillatory Movement

The fact that the rhythmical oscillatory movement has a wide prevalence in insects has been referred to in the introductory part of this article. There are, however, two types of oscillatory movements allied to those in *Arcte* which we have dealt upon in this report; i. e., one which can be caused by any external stimuli and the other which can only be elicited by autonomous factors existing within the insect. To the first category belong those occurring in *Arcte*, in *Bralmaea*, in some lepidopterous pupae, and in sawfly larvae. To the second category belong those types manifested by *Euproctis conspersa*, *Crissiocampa neustria*, and by some orthopteorous insects. I was not able to find any means to make Lepidoptera enter into the rhythmic movement. They displayed their feats, however, while they were marching in a train upon their tents. DEEGENER (4) supposed that the contact stimulation with a neighbour evoked the movement; or that the vibration of the food plant, caused by their marching, made in individual respond at a fair distance.

I have already shown that the movement of the *Arcte* larva analysed by cinematographic records convinced me that the peculiar oscillatory motion of this insect is composed of two reflex movements, 'Abwischreflex' and the oscillatory movement in its strict sense. This oscillatory reflex *s. str.* is purely manifested when the stimulus is nothing more than the vibration of the substratum, which may be caused by a small shot ball rolling about on the substratum (Plate III). From these facts we see that the oscillatory movement in *Arcte* in a wider sense is of the first type ('Abwischreflex' + oscillatory reflex) of the two categories. An abrupt motion such as the 'Abwischreflex' will provoke the succeeding rhythmic motion. In the second type ('Abwischreflex') the similar abrupt motion goes on by itself, without releasing the oscillatory reflex.

The effectors in the case under consideration, as has been stated, are the muscles in the I. to III. abdominal segments. Since the muscles in the insect larva are arranged symmetrically, it is obvious that the muscles in a symmetrical position in regard to the mid-dorsoventral plane, will work in correlation with each other. When the muscles on one side contract, the muscles on the other side are naturally put into a state of extension. Then these extended muscles in turn will contract. It is probable that such a mechanical process is carried on during the oscillatory movement. But to explain the long duration of the movement we must introduce an idea of the neuromuscular mechanism. The muscles must be in a high tonic condition, and it is necessary that some rhythmical centrifugal discharges of nervous impulse should be sent to the effector muscles, in order to put them into such activities.

Although I was not able to ascertain whether the impulse for the oscillatory movement comes from the cerebral ganglion or not, it is true that the central ganglia of the effectors in the I.–III. abdominal segments take part in the instigation of the movement. The abolishment of the muscle tonus by decapitation has been pointed out by POLIMANTI (22). In my pharmacological experiment, the longer persistence of 'Abwischreflex' than the oscillatory movement was clearly brought out, and in the decapitated specimens the former reflex alone was sustained. These data suggest that *the so-called oscillatory reflex is not a true reflex, but is one which requires the innervation from the higher cerebral center. It is a reflex which is performed only while maintained under the control of the cerebral ganglia.* It is a known fact that the homostrophic response is remarkably weakened after decapitation in the earthworm and *Tenebrio* larva (c. f. CROZIER (2), CROZIER and MOORE (3) etc.) and this fact supports that in such reflexes, responses originated by the peripheral impulse are conducted through the ventral nerve cord towards the higher center. The differentiated cerebral control is of primary importance in this case. Provided that the muscle tonus is maintained as in the normal case, the oscillatory movement will probably be evoked in full state in the decapitated animal too.

Next, the fact that the vibration of the substratum may act as an effective stimulus suggests that the pressure may be received by the abdominal legs as a contact stimulus, or, otherwise, some very minute distortion will occur in the body musculature, and this displacement or a slight change in the tension of the muscles will work upon the insect as a stimulus. That the extension of the muscles will act on an animal as a stimulus is a common fact, and in such cases the stimulus is said to be received by the proprioceptors.

I would, therefore, explain the mechanism of the oscillatory movement *s. str.* by assuming that the " under-threshold stimuli ", which have been received by the receptors in the epidermis or the proprioceptors in some part of the body, are accumulated gradually until they are abruptly discharged by the nervous center as an efferent impulse towards the effector muscles to start the oscillatory reflex.

The presence of nerve cell endings in the muscles in the body wall of insect larvae has been demonstrated by ALEXANDROWICZ (1). Contraction and expansion will thus go on in either side of the body in alternate phases, and the rhythmical movement continues so long as the effective centers are in excitation.

The first movement is effected on the side nearer to the source of the stimulation. From the proprioceptors in the muscles of the extended side will be sent a sensory impulse to the center of the effectors and from this center in turn an efferent impulse is sent to the extended musculatures. Thus, the idea of the reciprocal inhibition of the two antagonistic muscles solve the question of the oscillation observed in the *Arcte* larva. That this oscillatory reflex has a segmentary origin and also that the coordinated oscillation requires the bodily tonus to be highly maintained can easily be understood. Abolishment of the movement when decapitated is a result expected *a priori.*

B. Sensory Refractory State of the Oscillatory Movement

I have already pointed out that the interval of oscillation diminishes gradually (stair-case type), recurring at certain intervals, and finally the animal reaches a state of insensibility. Similar phenomena have been demonstrated by several authors. HOLMES (9) tabulated the durations of death-feigning in *Ranatra.* His figures show a striking similarity in the mode of decrease of the duration between the death-feigning and the oscillatory movement. MINNICH (13) showed, though insufficiently, that there is a fluctuation in the sensibility to sound in the *Vanessa* larva.

Both *Ranatra* and *Vanessa* finally reach a state of adaptation to stimuli. Previous authors took such an insensible state as that of fatigue. In my experiments this state was found to be overcomable and the responsiveness to a similar and more vigorous stimulus can be restored when some different kind of stimulus is given beforehand and then the former stimulation is resumed. So I am inclined to consider that this insensible state is a refractory period of the sensibility rather than a state of fatigue.

MAYER and SOULE (12) have described the final drop of response to repeated stimulation in the larva of *Daniis plexippus.* The larva, although it contracted quickly and remained motionless when a current of air was turned upon it, became indifferent to air currents after several successive stimulations. However, even such an insect might have shown the restoration of responsiveness to the stimulus, as in the case of the *Arcte* larva, had these authors continued their experiments still further.

DEMBOWSKA (5) who carried out an experiment with *Dromia,* observed a reflex of antennule started by an optical stimulus. "Beim Beginn zeigt der Krebse volle Reaktion.........welche zulezt aufhört. Bis zu einem gewissen Grade hat die Grösse des Quadrate (Stimulator) keinen auf die Geschwindigkeit der Gewöhnung; doch zeigt der Krebse ein merkliches Anwachsen der Reaktion, wenn die Grösse des Quadrates plötzlich wächst. Der Rhythmus der Reizes hat keinen Einfluss, da das Resultat eher durch eine gewisse absolute Zahl von wiederholten Reizen verursacht wird. Wenn an rhythmische optische Reize gewöhnt, zeigt *Dromia* volle Reaktion, wenn sie in etwas verschiedener Weise gereizt wird, besonders wenn auf mechanische Art. Wie durch verschiedene Tatsachen bewiesen wird, kann das Aufhören der Reaktionen auf optische Reize, nicht durch Ermühdung erklärt werden...........".

The result of my experiments agrees essentially with that of DEMBOWSKA, i. e., the effective stimulus is an instantaneous one and the reaction diminishes after repeated stimulation and the state of apparent insensibility can be overcome by treating the animal with a different kind of stimulus anew. Hence DEMBOWSKA denied that this state was due to fatigue and took it for a state of being 'gewöhnt'. I join DEMBOWSKA in this idea and consider the animal is not in a state of fatigue, but is sensorily adapted.

C. Period of the Oscillatory Movement

It is very interesting that the same period is maintained throughout a whole series of the oscillatory movements. The number of oscillations is about 7 per second. PELNÁŘ (21) found that the period of the physiological tremor in a healthy human being is about 8 per second. Although I do not know whether this coincidence is merely by chance or not, I consider it of some interest that such a coincidence in these rhythmical reflex-movements occurs among so widely separated classes of animals.

Summary

1. In the larva of *Arcte coerulea* GUENÉE there occurs a reflex-movement which I propose here to call the 'oscillatory movement' or 'the oscillatory reflex', in which the larva swings the anterior one third of the body from side to side in a short but definite period for a fairly long time.
2. The movement is manifested by the larvae older than the third instar, and is absent during the resting period one or two days prior to an ecdysis. The younger larvae, in which only 3 hind pairs of the abdominal legs are developed, respond merely with wriggling and writhing motions.
3. The conditions of the substratum may influence the type of movement even in an older specimen, while similar movements may be displayed by younger larvae.
4. The most primitive type is x-shaped. Upon the full development of the abdominal legs, i. e., in the third instar, the normal movement is observed. In older forms a J-shaped movement is observed as an abnormal case. Therefore, the morphological explanation of the oscillatory movement must be started from the x-shaped one; the completely developed abdominal suctorial legs inhibit the movement of the remaining two thirds of the body. The interrelation between the x-shaped and the oscillatory movement is confirmed by the presence of another J-shaped type.
5. The larva is able to exhibit the oscillatory reflex in any position

on the food plant. This was confirmed experimentally. The oscillatory movement can also be evoked in many postures other than normal one.

6. The number of oscillations is about 7 per second. The same length of the period is maintained from the initial swing throughout the series of movements. The maximum amplitude measured was 24.2 mm. But, as shown in the photographic records, there is a gradual decrease in the magnitude of amplitude during one series of rhythmic movements.

7. The adequate stimulus for the oscillatory movement is of the mechanical sort. A gentle stroke with a solid substance, a puff of air, or the vibration of the substratum are most effective. Pressing the larval body locally, also, is sometimes effective in provoking the reaction.

8. Judging from the photographic records, the oscillatory movement, when evoked by stimuli other than the vibration of the substratum, consists of two types: a single preliminary aperiodic portion and a subsequent periodic portion. The former was confirmed to be nothing but the so-called 'Abwischreflex' and the latter to be the oscillatory reflex *s. str.*. The oscillatory movement evoked by the vibration of the substratum is the oscillatory movement in the strict sense, being destitute of the first aperiodic portion of swinging.

9. A long continuous contact with the dermal hairs or the skin surface inhibits the movement. A chemical stimulation with conc. acetic acid or with conc. ammonia water also produces an inhibitory effect.

10. The response to any stimulus decreases in strength with repetition of stimulations and finally reaches a state of sensory adaptation. This adapted condition can be broken by applying a new kind of stimulus different from the one to which the animal has been adapted, and the specimen thus treated may recover its responsiveness to the original stimulus.

11. The writer was not able to detect any receptors considered to be concerned with the reflex.

12. The nervous center of the reflex is probably located in any of the ganglia anterior to the third abdominal ganglion. My experiments suggest the probability that the 1st to the 3rd abdominal ganglia being the seats of the effective centers.

13. The effectors of the reflex are the muscles in the 1st to the 3rd abdominal segments.

14. The so-called 'Abwischreflex' is more persistent than the oscillatory reflex, *s. str.*

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Explanation of Plates

Pl. I, Fig. 1. Larva of *Arcte coerulea* in a normal posture. ×2/3.
Fig. 2. The larva of *Arcte coerulea* creeping on a desk. ×1/3.
Fig. 3. Dorsal view of the same. ×2/3.
Fig. 4. Eggs deposited on a leaf of *Boehmeria*. ×8.
Fig. 5. Two leaves of *Boehmeria*: upper one with clustered eggs, lower one attacked by very young larvae. ×1/2.
Fig. 6. Branch of *Boehmeria*, the leaves were devoured by young larvae. ×1/2.
Fig. 7. Normal cocoon of *Arcte coerulea* found in the field. ×2/3.
Fig. 8. Cocoon prepared by *Arcte coerulea* in the laboratory. ×2/3.
Fig. 9. Same with fig. 8, partly opened to show the pupa lying inside. ×2/3.

Pl. II, Figs. 10, 11. Fullgrown larvae of *Arcte coerulea* in various postures. ×2/3; a, stalk of the leaf devoured by the larva.
Figs. 12, 13. Apical views of the eggs of *Arcte coerulea* before and after the larva is hatched. ×60.

Figs. 14, 16. Ventral and lateral views of the larva of *Arcte coerulea*, the protrusible organ (g. l. o.) completely protruded. ×5.

Fig. 15. Same organ in retroceded state. ×5.

Pl. III, One of the photographic records of the oscillatory movement.

Stimulation by a vibration of the substratum.

Left column: earlier portion. S denotes the moment of stimulation.

Median column: middle portion.

Right column: the last portion.

Pl. IV, Photographic records of the oscillatory movement.

Left column: a complete series of the oscillatory movement.

Median column: the irregular movement elicited by a resting larva.

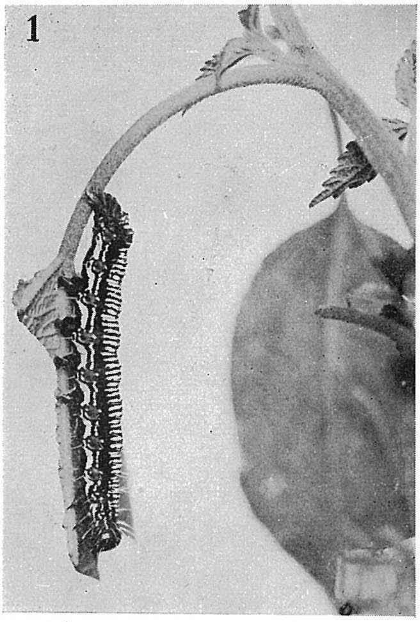
Right column: the last portion of the irregular movement.

Pl. V, Two Photographic records of the 'Abwischreflex' of the larva of *Arcte coerulea*.

A, moment of stimulation.

Upper row: stimulated while the larva is at rest.

Second, third and fourth rows: stimulated at the end of the proceeding series of the movement.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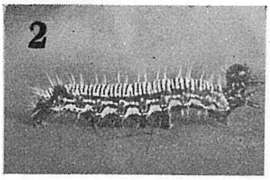
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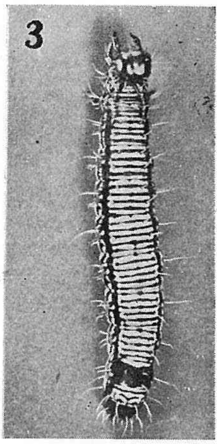
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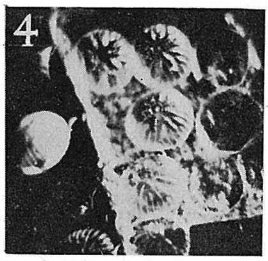
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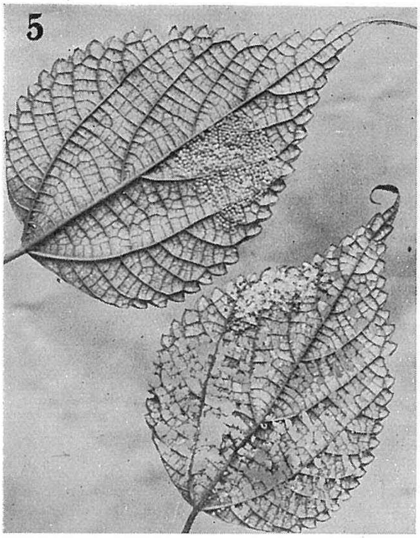
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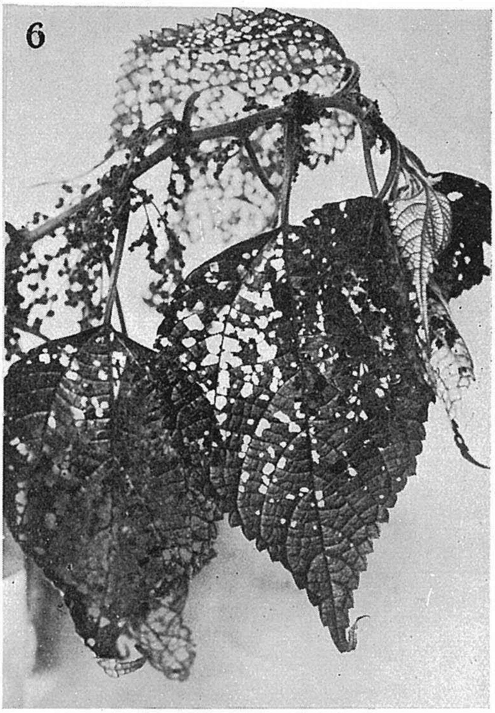
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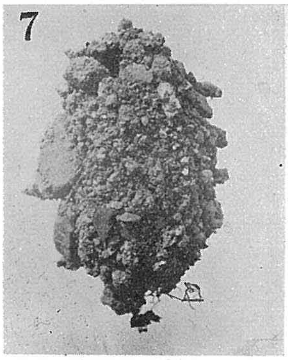
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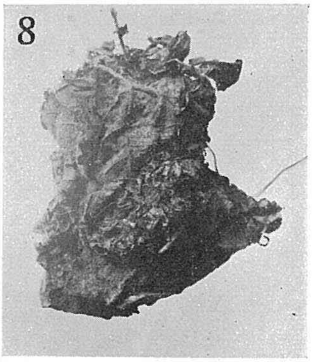
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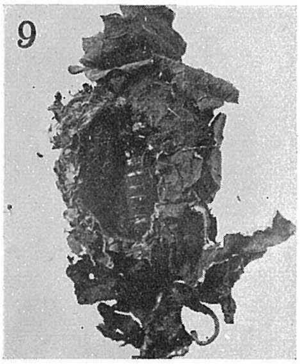
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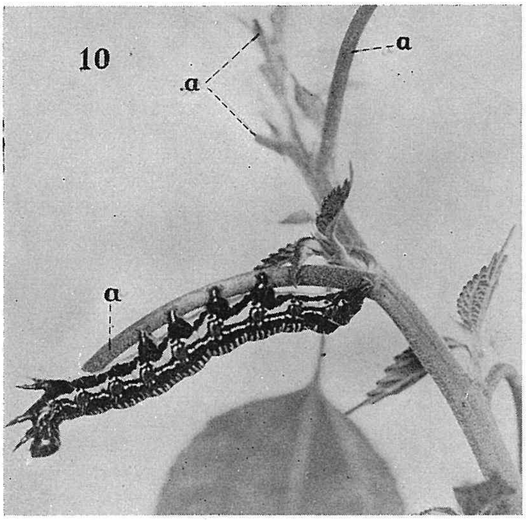

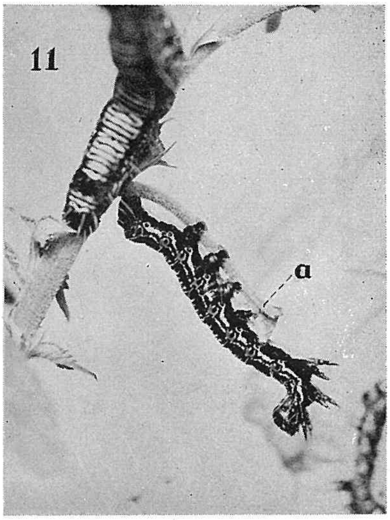

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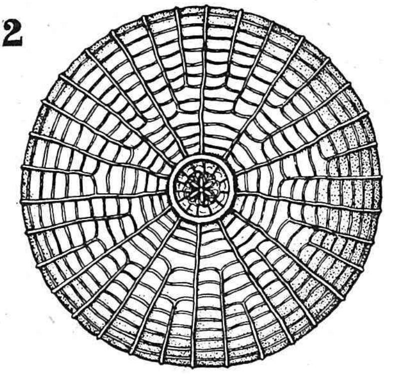

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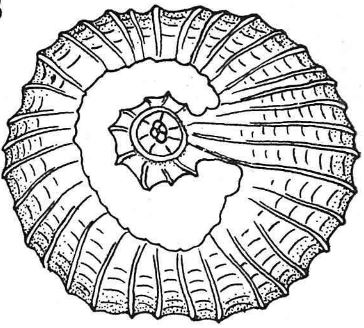

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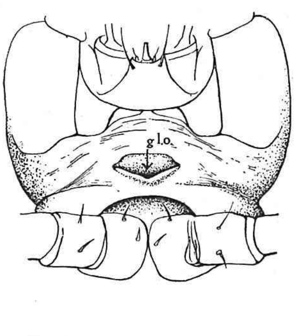

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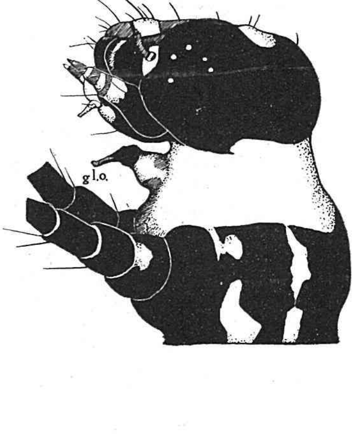

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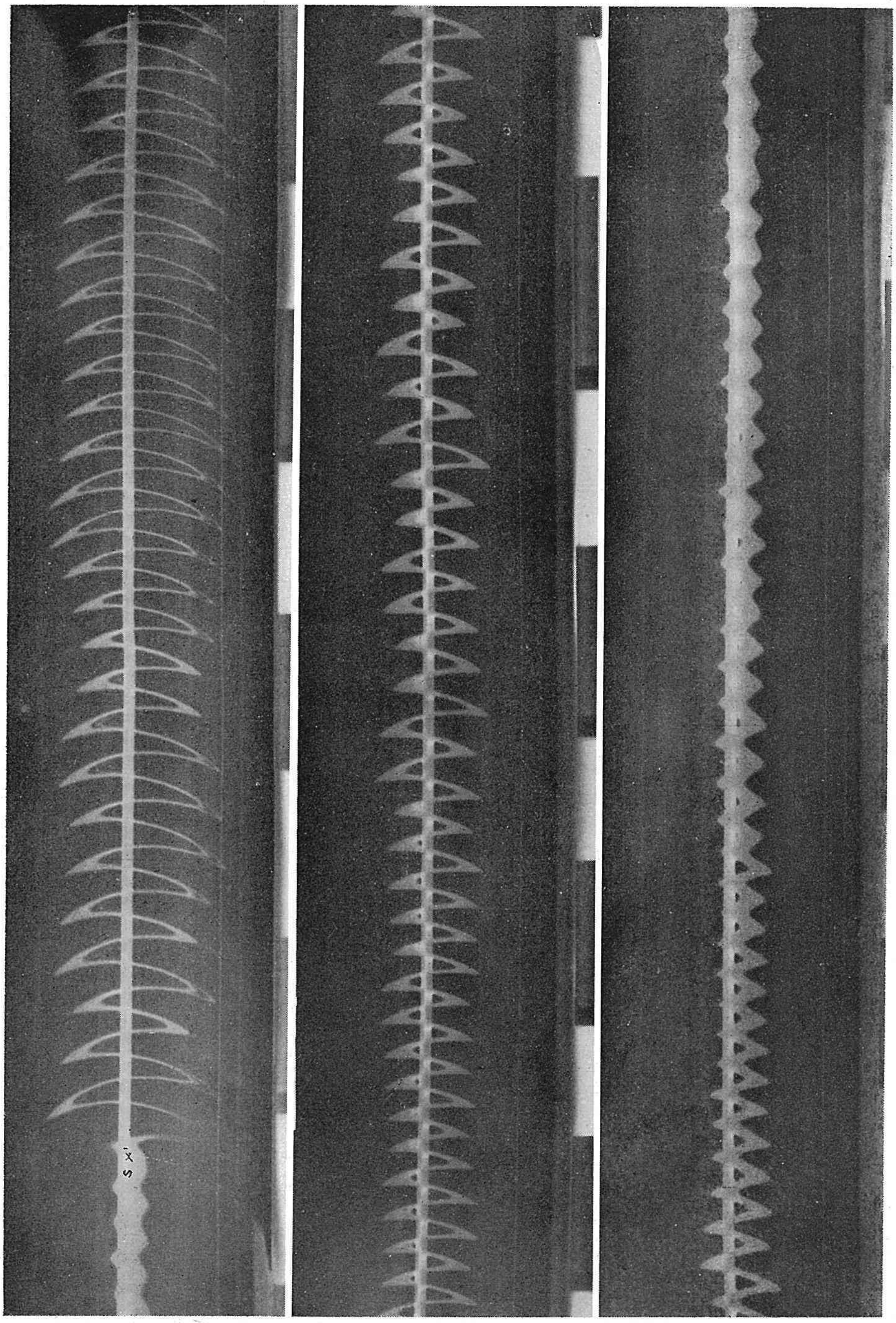

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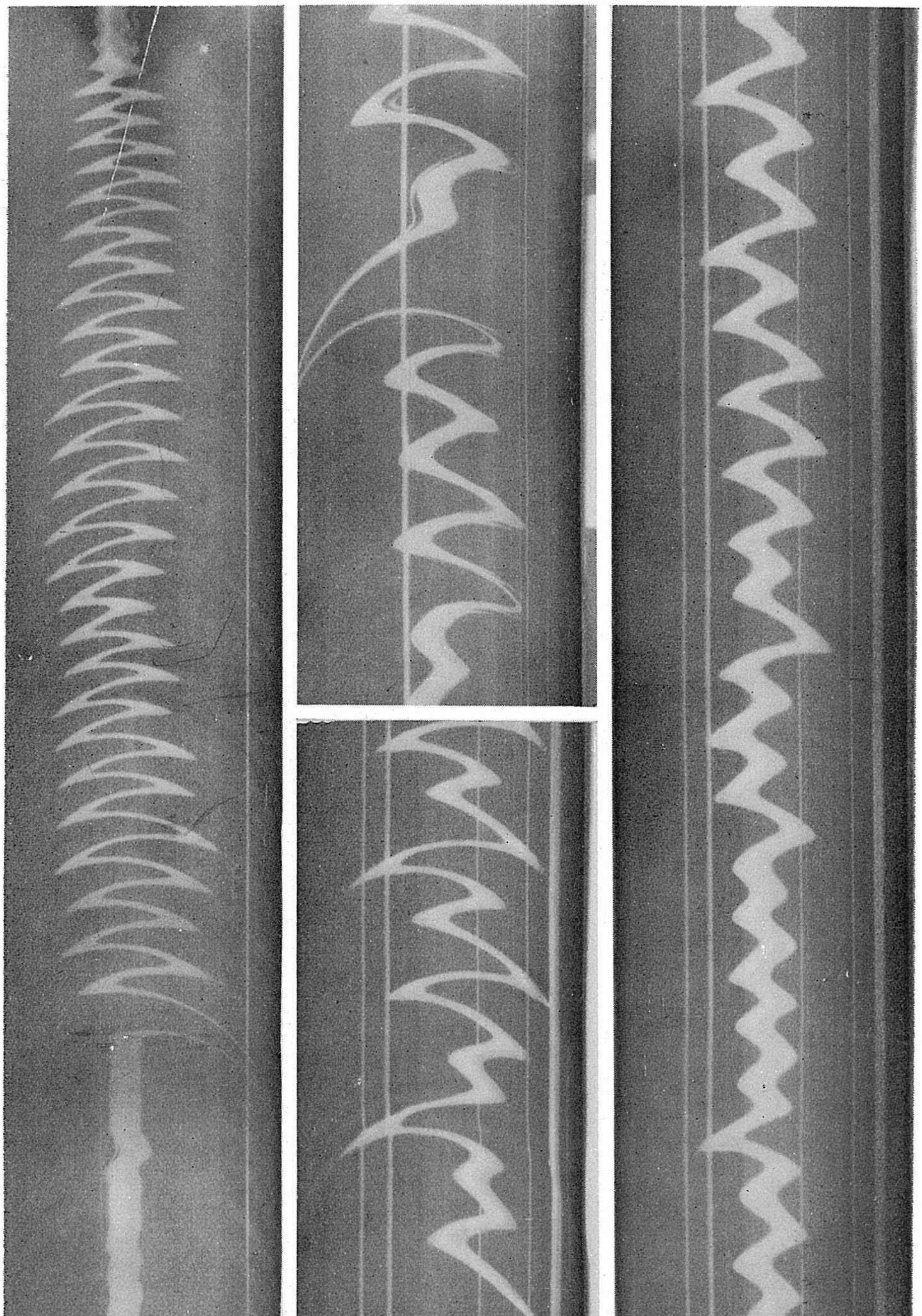

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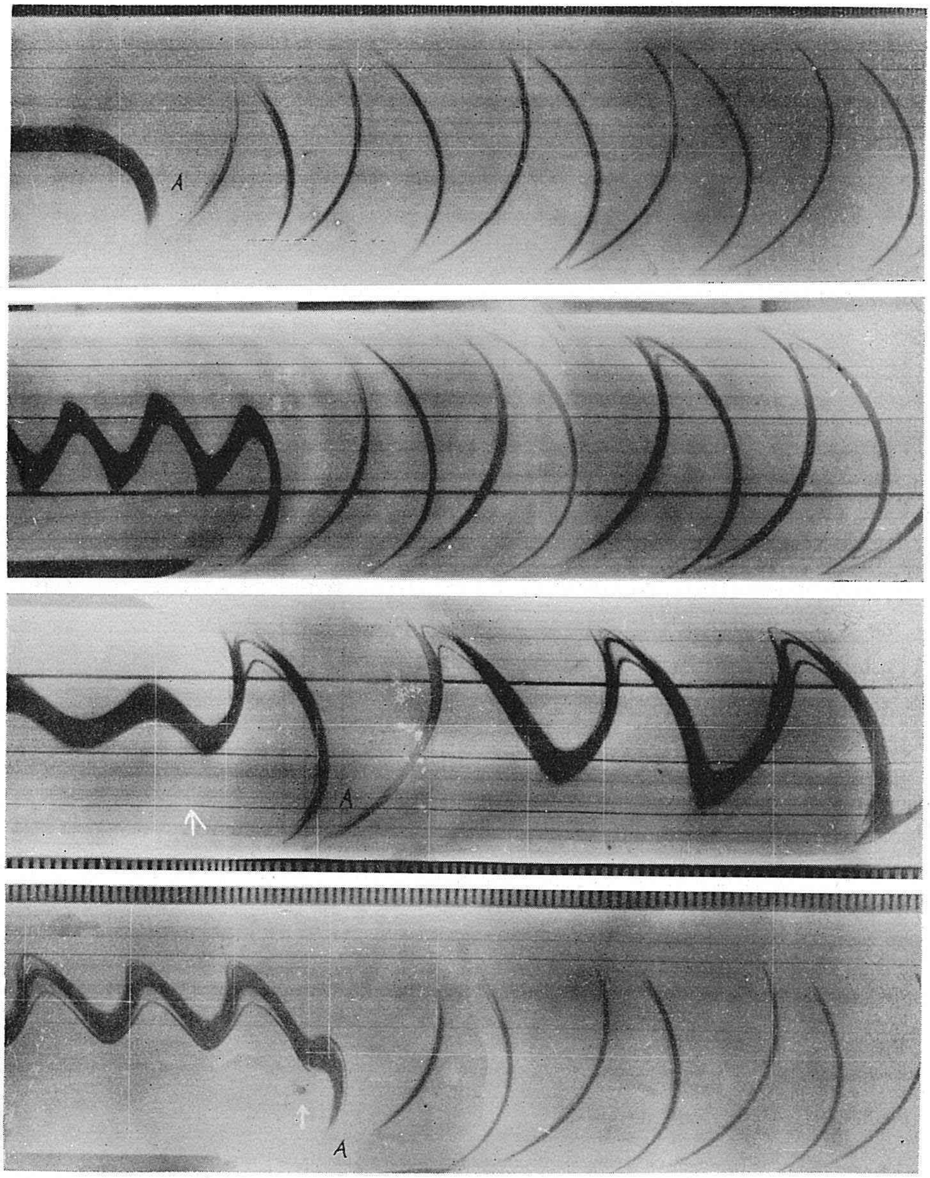

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