CONTENTS

Senses of the Cotton Boll Weevil—An Attempt to Explain How Plants Attract Insects by Smell 1095
N. E. McIndoo

Efforts to Determine the Means by Which the Cotton-Wilt Fungus, Fusarium vasinfectum, Induces Wilting 1143
H. R. Rosen

Correlated Inheritance in Wheat 1163
George Stewart

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE
WITH THE COOPERATION OF THE ASSOCIATION
OF LAND-GRANT COLLEGES
JOINT COMMITTEE ON POLICY AND MANUSCRIPTS

FOR THE UNITED STATES DEPARTMENT OF AGRICULTURE

E. W. ALLEN, CHAIRMAN
Chief, Office of Experiment Stations

C. L. MARLATT
Chairman, Federal Horticultural Board, and Associate Chief, Bureau of Entomology

C. L. SHEAR
Senior Pathologist in Charge, Plant Disease Survey and Pathological Collections

FOR THE ASSOCIATION OF LAND-GRANT COLLEGES

R. W. THATCHER
Director, New York Experiment Station

H. W. MUMFORD
Dean, Illinois College of Agriculture, and Director of Experiment Station

S. B. HASKELL
Director, Massachusetts Experiment Station

EDITORIAL SUPERVISION

M. C. MERRILL
Editorial Chief of Publications, United States Department of Agriculture

All correspondence regarding articles from State experiment stations should be addressed to R. W. Thatcher, Agricultural Experiment Station, Geneva, N. Y.

Published on the first and fifteenth of each month. This volume will consist of twelve numbers and the Contents and Index.

Subscription price: Domestic, $4.00 a year (two volumes)
Single numbers, 20 cents
Foreign, $5.25 a year (two volumes)
Single numbers, 25 cents

If separates are desired in quantity, they should be ordered at the time the manuscript is sent to the printer; single copies may be purchased until the supply is exhausted; in either case they will be supplied at cost.

Address all correspondence regarding subscriptions and purchase of numbers and separates to the Superintendent of Documents, Government Printing Office, Washington, D. C.
SENSES OF THE COTTON BOLL WEEVIL—AN ATTEMPT TO EXPLAIN HOW PLANTS ATTRACT INSECTS BY SMELL

By N. E. McIndoo
Entomologist, Deciduous-Fruit Insect Investigations, Bureau of Entomology, United States Department of Agriculture

INTRODUCTION

A thorough and comprehensive investigation of the senses and sense organs of the cotton boll weevil (Anthonomus grandis Boh.) will undoubtedly throw light on the means by which the cotton plant attracts this insect. Entomologists have considerable faith in the theory that there is some definite or indefinite relation, or possibly attraction, between insects and their host plants. In regard to some of the insect-pollinated plants it has been proved that the relation is a definite and mutual one, the insects and plants both being benefited; the insects receiving nectar or pollen in exchange for the unintentional labor of cross-pollination. In this case the insects are attracted either by sight or smell, but more probably by both. In other cases, however, the attraction is certainly not mutual, because only the insects profit by the relation. In such cases, how are the insects attracted—by sight or smell, or by some unknown sense? For short distances we believe that either sight or smell would suffice, but boll weevils are apparently able to locate cotton plants from long distances and do not seem to make mistakes in doing so. If smell is the chief or only factor to be considered, the most reasonable theory is to suppose that plants, like animals, emit odors, and that insects in searching for food, either for themselves or their progeny, are guided by them. It may also be assumed that the volatile chemical constituents of plants emit particular odors, and that the odor emitted from a plant is a combination of all the odors from these constituents, or possibly one odor may be so strong that it masks all the others. Upon this hypothesis, the odors from plants would vary according to the number, combination, and quantitative percentages of the various volatile constituents. Reasoning along this line, we may be able to explain why a few insects have only one host plant; why many have a preferred host plant, but will eat allied plants; and why others feed upon a large number of plants. If we had positive information on this subject, we might be able to devise practical methods for the control of the boll weevil and certain other insect pests by using attractive poisoned baits, or by placing the “attractant” in traps.

1 Received for publication July 3, 1926; issued January, 1927.
The foregoing is only a brief theoretical statement of how plants attract insects by odors. At once the reader may rightly ask, "Is there any definite information to support this theory, and are insects really attracted by odors from a distance?" A mass of literature dealing indirectly with this subject has been published, but very little of it is actually applicable to this particular problem, chiefly because nearly all of the investigators have used certain chemicals, or other compounds, not necessarily plant constituents, and for that reason it is difficult to correlate the results. For lack of space only a few references will be cited. Verschaffelt's (57)² results are the most important along this particular line. He observed that cabbage butterflies seem to be attracted to various members of the Cruciferae, and found by tests that their larvae ate the leaves of 15 species, representing 14 genera of this family. Chemists had previously determined that all of these contain mustard oils; thereupon Verschaffelt devised experiments and proved that the larvae actually seek out various mustard oils.

There is no definite or reliable information to show that insects are attracted from long distances by plant odors, but members of the Biological Survey of this department have had success in attracting mountain lions, wildcats, and lynxes from a distance to traps baited with oil from the catnip plant, although this particular subject may have little or no bearing on that discussed in this paper. Nevertheless, we do have definite information about the attraction of insects from long distances by insect odors. Riley (50, p. 38-39) reports that a caged female of the Ailanthus silkworm moth of Japan was apparently scented from a long distance by a marked male of the same species, which had been carried one and a half miles one evening and then released; the next morning the two moths were together. Fabre (5, p. 189-216), Forel (9, p. 76), and Mayer (40) conducted many experiments to prove that male moths apparently by smell alone can easily locate their females from long distances.

No direct evidence has been presented to support the theory that cotton plants really attract boll weevils by means of odors or emanations, but Power and Chesnut (44, 45) have shown experimentally that living cotton plants do give off emanations containing two odorous substances, one of which has an extremely strong and persistent odor, and the present writer (38) in 1925 experimentally convinced himself that the Colorado potato beetle (Leptinotarsa decemlineata Say) is attracted partially, if not wholly, by the emanations from its host plants.

While conducting experiments at Tallulah, La., in July and August, 1922, to determine whether or not the practice of dusting cotton plants with calcium arsenate is injurious to honeybees, the writer was asked by B. R. Coad, in charge of the Delta Laboratory at Tallulah, to study the behavior of the cotton boll weevil in the field and laboratory. During the latter half of June, 1924, the writer was again at Tallulah, collecting more material and conducting further experiments on the boll weevil. The results obtained are herein recorded. Although only of a preliminary nature, they add considerable weight to the remainder of this report, which is of a morphological character.

² Reference is made by number (italic) to "Literature cited," p. 1139.
The writer has made a thorough study of the anatomy of the sense organs of the boll weevil, and has brought together the available information along this line in the hope that new light may be thrown on the entire subject.

**ATTRACTIVENESS OF COTTON PLANTS TO BOLL WEEVILS**

The boll weevil, compared with many other insects, is a weak flyer, but during the dispersal period in autumn it has been known to migrate more than 40 miles in a short time by successive short flights. At other periods it is comparatively quiet and seldom travels far, although in spring, when it emerges from hibernation, it may be a mile or more from the nearest cotton. It is, however, usually much nearer. Regardless of its distance from cotton plants, Hunter and Pierce (18, p. 41) inform us that it apparently makes no mistakes in finding its favorite food.

The cotton boll weevil is known to eat normally several species of plants; but when forced to feed upon others to which it is not accustomed, it will partake of them only to a limited extent; however, practically all the plants which it will eat belong to one family, the Malvaceae. Coad (4, p. 3) and Smith (53, p. 5) state that the boll weevil normally feeds on the various species of the cultivated and wild cottons (Gossypium hirsutum, G. herbaceum, G. barbadense, G. brasiliense, G. davidsoni, etc.) and also on the so-called wild cotton (Thurberia theesperioides). Coad succeeded in rearing weevils on the buds of the shrubby althaea (Hibiscus syriacus), but had only partial success in rearing them on the buds of Callirhoe involucrata, C. pedata, and Sphaeralcea lindheimeri.

**CHEMOTROPIC EXPERIMENTS**

Hunter and Hinds (17, p. 70–71) report that owing to the belief that it might be possible to destroy the weevil by attracting it to sweetened poisons, a number of experiments were performed in the laboratory and field. Various grades of sugar, molasses, and honey were used in comparison with the attractive influence of cotton leaves. None of the sweets seemed to exert any noticeable attraction, except the honey, and that only slightly; but the cotton leaves always attracted many weevils. Hunter and Pierce (18, p. 43) corroborate these findings.

Recently this theory has been revived and many tests conducted to determine whether it has any practical application. McGehee (26, p. 7, 15) does not believe that the molasses in the sweetened poison attracts the weevils, although this method compared favorably in its results with the dust method. Leiby and Harris (24, p. 9, 12, 18), who tested a proprietary sweetened poison, and home-mixed ones containing blackstrap molasses, state that their findings are inconclusive as far as results are concerned. Isely and Baerg (19, p. 16, 17, 23) used proprietary sweetened poisons and found that they appeared less effective than the dust method and involved much more labor.

**EXPERIMENTS IN WHICH SWEET SUBSTANCES, WATER, COTTON LEAVES, AND COTTON SQUARES WERE USED**

In order to find a substance, preferably a sweet one, which would attract boll weevils equally as well as do cotton squares, the experiments described below were performed at Tallulah, La., during July.
and August, 1922. If such a substance were found, it could be mixed with poisons and applied in cotton fields to control the weevils; or traps baited with it might be installed in the fields for the purpose of catching the weevils. The writer was ably assisted by G. L. Smith, who performed the field tests and aided with those at the laboratory.

PRELIMINARY EXPERIMENTS

The first few preliminary experiments showed that weevils pay little or no attention to three brands of molasses (blackstrap, kookoo, and karo), honey, saccharine (strong solution), and sugar sirup (saturated solution). Fifty weevils, collected the day before being tested, were put in each of eight wire-screen cages (12 inches square by 1.5 inches deep) which were placed side by side on supports in the shade of a large cottonwood tree. Experience quickly showed that most of the weevils went to one corner or to one side of the cage and usually remained there, regardless of the substance placed in the cage; therefore, in order to force them to change their position, it was necessary before testing them to reverse the cages end for end. The seven liquids used were put on small pieces of absorbent cotton of equal size, and the pieces of cotton were then laid on small pieces of paper of equal size, one of which was placed at the center of each of seven cages. A cotton square, lying on a piece of paper of the same size, was also placed in the center of the eighth cage. Counts were made every minute up to 10 minutes, when the liquids and cotton squares were shifted from cage to cage, so that at the conclusion of the experiments each of the eight cages had contained each of the eight substances. A summary of these eight series of tests at the end of the 10 minutes showed the total number of weevils which had eaten of the substances to be as follows: Cotton square, 27; water, 8; honey, karo, and koo-koo, 7 each; sugar sirup and saccharine, 5 each; and blackstrap, 3.

The following morning about half of the weevils were dead. The foregoing experiments were repeated by using 25 of the remaining weevils, now hungry, in each cage. A summary of these tests at the end of 10 minutes showed the number of weevils which had eaten of the various substances to be as follows: Cotton square, 21; water, 11; honey and karo, 6 each; sugar sirup and koo-koo, 3 each; blackstrap, 1; and saccharine, 0.

The preceding experiments were repeated three times, 50 fresh weevils being used in each cage each time, although in these tests the liquids were dropped upon fresh cotton leaves which were placed at the centers of the cages. A summary of all three sets gives the following results: Cotton square, 172; water and sugar sirup, 58 each; karo, 53; honey, 44; koo-koo, 35; blackstrap, 21; and saccharine, 15.

Tests in which 30-minute periods were used instead of 10-minute ones did not materially change the above proportions.

TESTS IN FIELD CAGES

Experiments somewhat similar to the preceding, but performed on a larger scale, were carried on by releasing 100 fresh weevils in each of 7 field cages, 4 feet square by 4 feet deep. The cages were turned upside down and heavy muslin used as tops, which made more or less shade for the weevils. The various liquids to be tested
were dropped upon fresh cotton leaves, one of which was then placed at the center of each side and bottom of the cage. Cotton squares and leaves not bearing any liquid were similarly placed. The weevils were released at 10.30 a.m., and counts were made every half hour up to 5 p.m. A summary of two sets of experiments, showing the maximum number of weevils at one time on all the leaves or squares in a cage, is as follows: Cotton square, 28; koo-koo, 7; honey, 6; blackstrap, 5; karo, 4; leaves (control), 4; and sugar sirup, 1.

The field cages used in the preceding experiments were moved to a cotton field and each was placed over a cotton plant in the usual manner when such cages are employed. At 8.30 a.m., about 12 leaves at the top of a plant were treated with drops of either sugar sirup, honey, karo, koo-koo, blackstrap, or with ice-cream powder in a liquid form. The control plant was left untreated. At 9 o’clock, 100 fresh weevils were released in each cage, and thereafter up to 5 o’clock the number of weevils found on the treated plants and control were counted hourly. This set of weevils was used two days, the liquids being applied to the leaves again on the second day.

These experiments were repeated twice, fresh weevils being used each time. The second set of insects was used three days and the third set two days. In these five tests a sweetened proprietary calcium arsenate mixed with water was also applied to the leaves in addition to the substances enumerated above.

Table 1.—Maximum number of boll weevils found at one time on untreated plant and on other cotton plants variously treated

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Number of weevils on untreated plant</th>
<th>Number of weevils on plants treated with—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sugar sirup</td>
<td>Honey</td>
</tr>
<tr>
<td></td>
<td>Entire plant</td>
<td>Treated leaves</td>
</tr>
<tr>
<td>1</td>
<td>89</td>
<td>91</td>
</tr>
<tr>
<td>2</td>
<td>84</td>
<td>83</td>
</tr>
<tr>
<td>3</td>
<td>85</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>96</td>
<td>94</td>
</tr>
<tr>
<td>5</td>
<td>83</td>
<td>73</td>
</tr>
<tr>
<td>6</td>
<td>91</td>
<td>86</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
<td>84</td>
</tr>
<tr>
<td>Average</td>
<td>85</td>
<td>86</td>
</tr>
</tbody>
</table>

Tables 1 and 2 show the detailed results of these seven tests. It is seen that the plants treated with karo and ice-cream powder bore a few more weevils than did the control; those treated with koo-koo, blackstrap, and sweetened calcium arsenate bore a few less; and those treated with sugar sirup and honey bore practically the same number as did the control (Table 1). Since these differences are
so small, they may be attributed to probable errors. The maximum number of weevils found at one time on the treated leaves shows that the liquids used had little or no attractiveness, but the blackstrap and sweetened calcium arsenate seem to have been slightly repellent (Table 1). Relative to the total number of weevils found on the treated leaves during the full period of the experiments, Table 2 shows that honey and ice-cream powder might have had a slight attractiveness, although so slight that they could have been of no practical importance.

**Table 2.**—Number of boll weevils found on treated leaves of cotton plants during the full period of experiments

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Sugar sirup</th>
<th>Honey</th>
<th>Karo</th>
<th>Koo-koo</th>
<th>Blackstrap</th>
<th>Ice-cream powder</th>
<th>Sweetened proprietary calcium arsenate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>15</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>15</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>18</td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>12</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>10</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>6</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>9</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

**Conclusions**

The results obtained in this investigation indicate that the various substances used attract boll weevils very little or not at all, and none of them is of any practical value as a means of controlling these insects.

**Olfactory Experiments**

The following observations were made by the writer in 1922 while trying to find a sweet substance that would attract boll weevils. As already stated, nearly all of the weevils tested in the cages (12 inches square) for some unknown reason went to the west side, and there remained regardless of the substances in the cages. Just as soon as the cages were reversed end for end, the weevils immediately walked from the east to the west side, and in so doing many of them passed within one-quarter, one-half, or three-quarters of an inch of the sweet substance on the absorbent cotton or on the cotton leaves, yet in hardly an instance did they turn from their straight course to go to it. They behaved differently, however, toward the cotton squares. Many of them went directly to the squares from a distance of 4 or 5 inches; and often a weevil turned at right angles while passing a square in order to reach it. If the honey and five brands of sirup used had acted as attractants, the weevils certainly would have behaved similarly toward them; although in regard to all of these responses, sight instead of smell might have been the sense used.

In collaboration with this bureau, F. B. Power and V. K. Chesnut, of the Bureau of Chemistry, undertook to determine the volatile constituents of the cotton plant in order that these substances might be used to attract boll weevils. This work was begun at Tallulah,
La., in the summer of 1923 by distilling large quantities of cotton plants, and owing to the complex nature of the investigation, it lasted for some time. All of the results are now published, including two papers (44, 45) concerning the volatile substances. These writers believe that the alkalinity of the dew of the cotton plant is to be attributed, at least in part, to the presence of ammonia and trimethylamine, because these substances were found to be emanations from living cotton plants and were also identified in the dew collected from the foliage. Among the 12 individual substances found by them in the concentrated distillate, which included all the odorous and volatile constituents in the cotton plant, were 3 of particular interest for chemotropic tests. The so-called "essential" oil was about 0.003 per cent of the material employed. It had a strong, rather agreeable, and persistent odor. The ammonia and trimethylamine were present in appreciable quantities, but the ammonia largely predominated. So small an amount of trimethylamine as 0.0000005 gm. can be detected by its odor. In regard to the essential oil, ammonia, and trimethylamine, Power and Chesnut believe that only the trimethylamine serves as an attractant to allure boll weevils to cotton plants.

During the latter half of June, 1924, the writer used for the first time a sample of the concentrated and strongly odoriferous trimethylamine (33 per cent in water), which was isolated from cotton plants by Power and Chesnut. Several simple tests were made similar to those in which the sweet substances mentioned above were employed, but in no instance was any perceptible attraction observed. The next step was to develop a special apparatus to test this chemical further. A crude device, now greatly improved, and called by the writer an insect "olfactometer," was made. A brief summary of the results obtained in 1925 by the use of this instrument with other insects is given on pages 1135-1136. During June of 1924 only a comparatively few old weevils, which had come to the cotton fields from their hibernating places, could be collected daily, and it was therefore necessary to use the same weevils repeatedly until they failed to respond. Being thus handicapped by lack of material and with only a crude apparatus, the writer could not obtain accurate and positive results, but the preliminary laboratory experiments showed that when the trimethylamine was sufficiently diluted with water the weevils seemed to be slightly attracted.

Some of the old weevils mentioned above were put singly in small wire-screen cages with glass tops, the inside measurements of the cages being 5 inches long, 2 inches wide, and 1½-inch deep. All the chemicals tested in these olfactory experiments were held in vials of equal dimensions and capacity. When a weevil was ready for testing, the stopper of one of the vials was removed and the vial was placed just beneath the weevil on the bottom of the cage. In each instance the source of the odor was about three-fourths inch from the weevil. In nearly all cases only the reaction times of the first responses observed have been recorded, the time being registered with a stop watch the seconds of which were divided into fifths.

Trimethylamine (1 to 100): 3 turned to one side quickly; 2 turned around over vial and flew away; 2 turned around over vial and walked away; 1 moved quickly and then flew; 1 moved slightly, then tried to get through wire screen over vial; 1 moved quickly, then tried to put snout through wire screen, and rubbed hind legs together; reaction time 2 to 10 seconds, average 3.9 seconds.
Trimethylamine (1 to 1,000): 4 moved away slowly; 2 turned around and rubbed legs together; 1 raised wings; 1 moved an inch toward vial and turned around over it; 1 moving weevil stopped 5 seconds after vial had been held under it, then tried to put its snout through wire screen over vial; 1 turned around over vial and tried to put snout through wire screen; reaction time 3 to 7 seconds, average 4.9 seconds.

Benzy1 acetate: 5 moved away quickly; 2 turned around quickly; 2 jumped quickly; 1 moved away and worked legs. Reaction time 1 to 4.4 seconds, average 2.6 seconds.

n-Butyl acetate: 7 moved away quickly; 2 moved away slowly; 1 jumped quickly. Reaction time 0.6 to 5 seconds, average 1.9 seconds.

Methyl acetate: 4 moved away slowly; 4 moved away quickly; 1 worked legs; 1 moving weevil stopped, then walked away. Reaction time 2 to 6.4 seconds, average 3.5 seconds.

Allyl alcohol: 5 weevils tested; reaction time 4 to 10 seconds, average 6.2 seconds.

Capryl alcohol: 5 weevils tested; reaction time 4 to 7 seconds, average 4.3 seconds.

One weevil was tested with each of the following: Anisole, n-butyl alcohol, caproic acid, caprylic acid, carvacrol, citral, p-cymene, iso-amyl alcohol, iso-amyl benzoate, iso-amyl formate, iso-butyl acetate, iso-butyl alcohol, iso-propyl acetate, iso-propyl alcohol, methyl ethyl ketone, n-propyl acetate, n-propyl alcohol, and tertiary amyl alcohol, but no reaction was shown which indicated that the weevil was really attracted by the odor emitted.

**Conclusion**

Not one in the list of 24 chemicals tested, except the trimethylamine, seemed to have any attractive properties. The trimethylamine appeared to attract weevils slightly at times, but there was never any pronounced attraction. During these tests the vial was placed beneath a few moving weevils to determine what effect the odor would have on their movements. In most cases the insect stopped, very often rubbed its legs together, then feigned death, but several seconds after the vial had been taken away, it “awoke” and moved on.

Lutz (25, p. 275) tested a large number of chemicals found either in flowers or employed in the manufacture of perfumes. He says:

These were used with lard as a base in various concentrations and combinations. They were exposed in small dishes placed where flower-visiting insects were abundant, but no such visitors came to the dishes, although other insects (chiefly various flies) did so either by accident or otherwise. Possibly the right odors or combinations of odors were not used; possibly flower-visitors were not to be fooled by odors coming from such unflowerlike contraptions as glass dishes; and possibly insects do not find flowers by the sense of smell. Certainly, although the experiments consumed considerable time, they proved nothing.

**Sense Organs of Adult Boll Weevils**

Before entering into a discussion of the morphology of the sense organs of the boll weevil, it seems expedient to describe the material, methods, and histological technique employed in the study.

**Material and Methods of Preparing Whole Mounts**

The writer is often asked about his methods of preparing whole mounts of insects and about his histological technique, and since he has not published any details on these subjects in the past 10 years, he considers it worth while to give his most recent and best methods on these subjects, particularly since some of them have never been published.
Some of the material on the boll weevil was collected by the writer at Tallulah, La., in July and August, 1922; some in June, 1924; and other material was collected and preserved by various assistants of B. R. Coad, particularly by A. J. Chapman.

To obtain material for whole mounts of adult boll weevils, both dried and alcoholic specimens were used; but for whole mounts of larvae, only alcoholic specimens were employed. The specimens were treated with saturated caustic potash in the usual way by heating in a test tube over a Bunsen burner, or were allowed to stand in the unheated liquid for a day or longer, depending on their size and hardness. They were then removed and thoroughly washed with water, and the adult specimens were decolorized or bleached with chlorine gas in the following manner: A small quantity of potassium chlorate or chloride was put in a small wide-mouthed bottle (bleaching bottle). The specimens were then wrapped loosely in a small piece of cheesecloth which was suspended from a hook in the middle of the stopper. A pipeteful of hydrochloric acid was next dropped upon the potassium salt in the bottom of the bottle. At once chlorine gas was liberated, which in a few minutes bleached the dark-colored specimens. The specimens were again thoroughly washed in water and finally preserved in 50 per cent alcohol.

To study the external parts of the sense organs, 10 individuals of each sex and several larvae were dismembered by having all the appendages, head, thorax, and abdomen carefully severed. These parts were then put in vials in such a way that their identity was preserved. Some of these parts were temporarily mounted in 50 per cent alcohol, and others were mounted in Canada balsam or in a 15 per cent solution of potassium acetate. This solution, as well as the 50 per cent alcohol, gave a good refractive index, so that the minutest pores or slits could be easily discerned, but the balsam was less satisfactory in this respect. All parts were mounted between cover glasses in order that both sides of the specimen could be carefully studied under a high-power lens. In the case of the potassium-acetate mounts one cover glass was considerably smaller than the other in order that it might be securely sealed with asphaltum.

MATERIAL AND HISTOLOGICAL TECHNIQUE

To obtain material for the study of the internal anatomy of the sense organs, full-grown larvae and adult weevils (just ready to emerge) were taken from the flower buds, called "squares." To insure a good supply of material, a large number of squares bearing larvae and pupae were collected in the fields, and these were kept in the laboratory and examined daily. Some of the material was put at once in alcohol to be used for whole mounts, but most of it was preserved in the Bouin and the modified Carnoy fixing fluids. The latter, consisting of equal parts of absolute alcohol, chloroform, and glacial acetic acid, with corrosive sublimate to excess, was kept in a glass-stoppered bottle so that it might not lose its fixing ability by absorbing moisture from the air, although it does deteriorate within a few weeks in spite of all precautions taken. When material was dropped into vials containing this fluid, the stoppers were left off no longer than was absolutely necessary. To assure good fixation of the internal tissues, the snout or beak, antennae, head, legs, wings, and thorax were severed, and immediately dropped into the fixing
fluids, the Carnoy fluid being mostly used. The material preserved in the Bouin fluid was left in it overnight, and then washed several times in 95 per cent alcohol, but the material preserved in the Carnoy fluid was removed when it sank to the bottom of the vial, and then thoroughly washed in 95 per cent alcohol. All material was kept in 85 per cent alcohol until sectioned.

From this stage on, the procedure is considerably different from the double or paraffin-celloidin method described by the writer in 1915 (30). The successive steps in its use are as follows: Remove excess mercury in tissues fixed in Carnoy fluid by leaving pieces of material overnight in 85 per cent alcohol containing tincture of iodine (wine color); put small pieces of material containing sense organs in clear 85 per cent alcohol to wash out the iodine; put material in 95 per cent alcohol containing eosin; place pink tissue in absolute alcohol and ether (half and half) containing eosin, for only a few minutes; put material in tiny vials containing thin celloidin and leave overnight; next morning put vials in melted paraffin in small beaker on hot plate, and allow ether to boil gently for a few minutes; remove vials from paraffin, take out pieces of material, one at a time, and be sure that each has considerable celloidin surrounding it; drop each piece in chloroform and leave it until celloidin has become firm; remove these pieces from chloroform, dry on blotting paper, trim celloidin, and put them in paraffin in Petri dish on hot plate for a few minutes; when all bubbles have left them, transfer to tiny paper cups in another Petri dish containing the best and hardest paraffin (58° or 60° C., M. P.), and leave them there for a few minutes. (Note.—Never allow paraffin to become more than a degree or two higher than its melting point, for excess heat makes the tissue brittle.) With a very sharp knife cut the ribbons 5 microns in thickness, and if paraffin fails to ribbon properly, warm the knife; mount ribbons, using a thick film of fresh Mayer's albumen and flatten them by pressing on them with fingers, but use no water or heat, for heat blisters celloidin; let slides dry on top of paraffin oven 48 hours; after that put them in 50 per cent alcohol and then in Ehrlich's or Delafield's haematoxylin stain (well ripened) for three or four minutes; leave them in water one hour or longer, then run them up through the alcohols (50, 70, 85, and 95 per cent plus eosin), leaving them in each five minutes; then put them in clear 95 per cent alcohol to wash out the excess eosin; next in Gage's carbol-xylene (1 part carabolic acid to 3 parts of xylene) for only a few seconds, for this liquid slowly dissolves paraffin; lay them flat on match sticks upon the table, then drop xylene upon the slides gently with a pipette; after paraffin has dissolved, gently incline slides to allow xylene to run off them, then add Canada balsam and cover glasses.

Amateurs who try to follow these directions will doubtless have trouble, chiefly because experience and an understanding of the principles involved mean much more to a successful microscopic technician than the mere ability to follow directions closely. For this reason the writer hesitates to give such a complicated method, knowing that someone will pronounce it of no value.

**OLFATORY ORGANS**

Since the sense organs of the adult or imago weevils are the more numerous and diversified, they will be described first, and a discussion of the sense organs of the larvae will follow.
Owing to the belief that the sense of smell in boll weevils is the primary one which aids them in locating cotton plants, the writer has paid more attention to the olfactory organs than to the other sense organs.

**Disposition of Olfactory Pores**

Hicks in 1857 (13) first described the sense organs herein referred to as “olfactory pores,” and suggested that they might serve as olfactory organs. Nagel (42) saw some of them on the mouth parts of *Dytiscus marginalis*, and called them “Gruben ohne Kegel.” Hochreuther (15) found them on the same species, and called them “Kuppelförmige Organe.” He saw a few on the epicranium; 11 on the scape and pedicel; a few on the labrum; very few on the mandibles; 6 to 8 on the maxilla; 14 to 16 on the labium; and 10 to 20 on the coxa, trochanter, femur, and tibia. Lehr, in 1914 (22), described them on the wings and elytra of the same beetle. Before this date they had been seen in other insects, and were called “organes sensitifs à ombelle” by Janet (20), and “sensilli campaniformi” by Berlese (1). Years ago the writer (28, 29, 30) studied them thoroughly in Hemiptera and Coleoptera, called them olfactory pores, and determined to his own satisfaction that they serve as olfactory organs.

Several years ago J. A. Nelson, of this bureau, began a thorough study of the morphology of the boll weevil, but resigned before he had accomplished much. However, he prepared a 3-page manuscript on the sense organs, which still remains unpublished. Most of his time he spent in studying the disposition of the olfactory pores, but he also noted the tactile hairs and hypodermal gland pores. He found the olfactory pores located in about the same positions as recorded by the present writer in the following pages, and he saw a few very minute pores, presumably olfactory ones, on the tibial spines. In this insect the present writer did not note these, but has described them in the tibial spines of many other beetles. Nelson says, in part:

> These pores are excessively minute, measuring 5-7 micra in diameter. Largely for this reason a study of their histological structure was found to be impossible.

* * * The most satisfactory sections were those of the pores at the bases of the antennae (of pupae). As far as could be determined, these correspond in structure to the so-called olfactory pores described by McIndoo, but the nature of the material makes it decidedly unfavorable for a study of the minute structures of these organs. It should be noted finally that in general the distribution and appearance of all of the sensory pores mentioned accord closely with the account given by McIndoo (1915). * * * Since McIndoo has brought sound experimental evidence to show that the pores described by him are actually olfactory in function in a wide range of insects, including several representatives of the Coleoptera, it would seem reasonable to extend this view to cover *Anthonomus*.

The elytra, wings, maxillae, and labium have dorsal and ventral surfaces; the submentum, only a ventral side; and for descriptive purposes, the antennae, legs, and mandibles may be divided into outer and inner surfaces. Since female No. 3 was studied most critically and all the drawings were made from this specimen, the disposition of its olfactory pores will be described in detail, and then will follow a discussion of the individual and sexual variations found in these organs in five females and five males.

Group 1, consisting of 53 pores (fig. 1, A, B), lies on the dorsal surface of the elytron, being found on the radial plate (RP) between the muscle disk (MD) and the subcostal head (ScH), with its distal
or broader end against the basal margin (BM) of the elytron. Groups 2 to 6 (C) lie on the wing, Nos. 2 to 5 being on the dorsal surface and No. 6 on the ventral surface; No. 2, of 25 pores, No. 3, of 30 pores, and No. 4, of 104 pores, lie on the radius (R); No. 5, of 4 pores, on the first cubitus (ICu); and No. 6, of 26 pores, on the media (M).

Groups 7 and 8 and isolated pores a, b, and c are found on the legs (fig. 2); single pore a lies on either surface at the proximal end of the femur; b and c at the proximal end of the tibia, b, consisting of two widely separated pores, lies on the outer surface, and c, of a single pore, on the inner surface. Nos. 7 and 8 lie, respectively, on the outer and inner surfaces of the trochanter; No. 7 on the front legs consists of 5 pores, but of 6 pores on the middle and hind legs; No. 8 on the front and middle legs consists of 2 pores, but of 4 pores on the hind legs.

Groups 9 to 11 and isolated pores d to n are found on the mouth parts (fig. 3); d, e, and f (each of 1 pore), g (2 pores), No. 9 (4 pores), and No. 10 (5 slits) lie on the ventral surface of the maxilla, d being found on the stipes, e on the palpifer, No. 9 on the first segment of the maxillary palpus, f on the second segment, and g and No. 10 on the third or distal segment of the same palpus (fig. 3, A and B). On the dorsal (partly lateral) surface of the maxilla are found the isolated pores h, i, and j; h (1 pore) lies on the palpifer, i (1 pore) on the third segment of the same palpus (2 pores) on the third segment of the same palpus (C). On the submentum lies j of 5 pores, and on the ventral surface of the labial palpus lie l and m, each of 1 pore, l being found on the first segment and m on the third segment (D). The dorsal surface of the labium is devoid of pores (E). No. 11 of 4 pores and n of 2 pores lie on the outer surface of the mandible; the inner surface of the mandibles of this specimen bore neither pores nor hairs (F and G).

On the head capsule lie 10 pairs of pores (fig. 4, A and B); 2 pairs (o) are found just behind the compound eye on the epicranium; 3 other pairs (p) on the epicranium; 4 pairs (q) on the occiput; and 1 pair (r) on the genae (B).

At the base of one antenna lie 4 pores (C); 2 (s) being found on the outer surface and 2 (t) on the inner surface of the scape; but the other antenna of this specimen bears only 3 pores (A and B).

In regard to the individual variations only a few remarks need be made because most of the minor differences observed may have been due to the writer's inability to find the pores, particularly where the chitin was dark. As a rule, most of the groups of pores were fairly
constant in position, and varied only in the number of pores they contained. Some of the minor groups were often absent, or sometimes were united so that two were counted as one. No. 1 on the peduncle of the elytron was always present, and never had less than 45 pores. The 5 groups on the wings were sometimes reduced to 4, but the total number of pores was thereby seldom decreased; No. 5 ranged from 0 to 6 pores; No. 6 from 26 to 67; and in one instance No. 6 extended entirely to the fold in the wing. The disposition of

![Diagram of boll weevil legs and mouth parts](image)

Fig. 2.—Portions of legs of female boll weevil No. 3, showing location of Groups 7 and 8, and isolated olfactory pores a, b, and c; tactile hairs (THn); A, front leg; B, middle leg; and C, hind leg. The drawings at the right represent the inner surface and those at the left, the outer surface. All × 24

the pores on the legs, mouth parts, and antennae was similar to that already described, and the only striking difference found was in the total number of pores. Group 10 (fig. 3, B) on the third or distal segment of the maxillary palpus was always present and in each case seemed to consist of 5 slits. Only one male and one female were examined for pores on the head capsule (fig. 4, A and B), and no variations were noted; therefore probably all the head capsules bear these organs.
Relative to these pores, no sexual variations were found other than what might be regarded as individual differences, except that the females always had a greater number of pores than the males. Table 3 shows the individual and sexual variations in the total number of pores found. The pores varied in part as follows: Legs: Females, 22 to 28; males, 19 to 25. Elytra: Females, 90 to 106; males, 90 to 96. Wings: Females, 376 to 413; males, 322 to 376. Total number: Females, 604 to 641; males, 527 to 576. Average: Females, 624; males, 549. Thus the females have 13.7 per cent more pores than have the males. It will also be noted that about two-thirds of the pores are borne by the wings, and nearly five-sixths by the wings and elytra combined.

Fig. 3.—Portions of mouth parts of female boll weevil No. 3, showing location of Groups 9 to 11 and isolated olfactory pores 4 to 11; tactile hairs (THr); and gland pores (PorGl). A, B, and C, maxilla; A, ventral surface; C, dorsal-lateral surface; and B, dorsal surface of distal or third segment of maxillary palpus. D and E, ventral and dorsal surfaces, respectively, of labium. F and G, outer and inner surfaces, respectively, of mandible. Ca, cardo; L, lacinia; Mt, mentum; Pa, palpifer; S, subgalea; SMt, submentum; and St, stipes

Circles and slits represent the olfactory pores, while black dots represent the gland pores, the lines through the latter showing the direction in which their efferent tubes extend. Ca, cardo; L, lacinia; Mt, mentum; Pa, palpifer; S, subgalea; SMt, submentum; and St, stipes
EXTERNAL STRUCTURES OF OLFACTORY PORES

When examined under a low-power lens, the large olfactory pores may be easily mistaken for hair sockets from which the hairs have been removed; and the smaller ones may be mistaken for the pores of hypodermal glands, or vice versa. When they were more care-

fully observed under a high-power lens, it was usually not difficult to distinguish them from the hair sockets and gland pores. Both types of pores and hair sockets usually appear as small, round, bright spots when a strong transmitted light is used, but after a more careful study all three structures were found to differ widely. The hair
sockets generally appear the least bright; their walls are usually heavier and darker; and their pore apertures are usually bounded by rough or torn chitin, thus showing the mutilation caused by removing the hairs. The gland pores (fig. 5, A and B) as a rule are much smaller than the olfactory pores (fig. 5, C to L); they are many times smaller than those on the legs; usually much smaller than those on the wings and antennae; but almost the same size as those on the elytra and mouth parts. It is often difficult to distinguish a hair socket from an olfactory pore, but a gland pore is always easily recognized by its aperture (A, PorApGl) which, when one focuses downward on it, is observed to run \( V \) shaped from the pore wall (PorWGl) to the center or entirely across the pore.

### Table 3.—Disposition of olfactory pores on adult cotton boll weevils

<table>
<thead>
<tr>
<th>Appendages examined</th>
<th>Females</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Males</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. 1</td>
<td>No. 2</td>
<td>No. 3</td>
<td>No. 4</td>
<td>No. 5</td>
<td>No. 1</td>
<td>No. 2</td>
<td>No. 3</td>
<td>No. 4</td>
<td>No. 5</td>
</tr>
<tr>
<td>Front legs</td>
<td>22</td>
<td>25</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td>22</td>
<td>20</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Middle legs</td>
<td>24</td>
<td>26</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>22</td>
<td>19</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Hind legs</td>
<td>27</td>
<td>27</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Elytra</td>
<td>106</td>
<td>97</td>
<td>106</td>
<td>90</td>
<td>94</td>
<td>90</td>
<td>96</td>
<td>90</td>
<td>94</td>
<td>91</td>
</tr>
<tr>
<td>Wings</td>
<td>376</td>
<td>413</td>
<td>376</td>
<td>411</td>
<td>400</td>
<td>322</td>
<td>345</td>
<td>376</td>
<td>328</td>
<td>340</td>
</tr>
<tr>
<td>Mandibles</td>
<td>12</td>
<td>8</td>
<td>12</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>10</td>
<td>4</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Antennae</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Maxillae</td>
<td>23</td>
<td>36</td>
<td>36</td>
<td>29</td>
<td>36</td>
<td>27</td>
<td>23</td>
<td>25</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>Labium</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Submentum</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>604</td>
<td>641</td>
<td>622</td>
<td>636</td>
<td>628</td>
<td>527</td>
<td>555</td>
<td>576</td>
<td>538</td>
<td>548</td>
</tr>
</tbody>
</table>

*These numbers should be increased to 644 and 569 to include the 20 pores found on the head capsule each of a female and male.

The external structure of an olfactory pore consists of the aperture, wall, and border. The aperture (fig. 5, G, PorAp) may be round, oblong, or slit shaped (H). The wall (C, PorW) may be round, oblong (E), eye shaped (G), or slit shaped (fig. 3, B, and fig. 5, H). The border (fig. 5, G, PorB) may be round or oblong, but it was not discernible in most cases; on the wings it was usually present and surrounded each pore wall, although on the elytra it surrounded the entire group (fig. 5, E).

Most of the olfactory pores are round or oblong (fig. 5, C to E), but a few are eye shaped (fig. 5, F and G), and a few others are slit shaped (fig. 3, B, and fig. 5, H). The round or oblong ones are found on the femora, tibiae, elytra, wings, mouth parts, head, and antennae; the eye-shaped ones, on the wings; and the slit-shaped ones, on the trochanters and third segments of the maxillary palpi. In external structure the slit-shaped ones resemble the slits in the lyriform organs described in spiders by the writer (27) and others. Not all of those on the trochanters are as slender as the one shown (fig. 5, H), but they vary from this shape to the extremely elongated type.

### Internal Structure of Olfactory Pores

In sections the olfactory pores are never mistaken for the gland pores (fig. 5, M to O) because they are usually much larger, and, besides, the reservoirs (Re) of the gland pores stand out quite con-
spicuously in the chitin. From the reservoir the efferent tube (Ef) leading to the exterior is also plainly seen, but the large gland cell (G1C) is not always easily distinguished from the hypodermal cells (HypC), although whenever it is discernible a portion of it runs into the pore canal (PorC) leading to the reservoir, and a clear area or ampulla (Am) in the gland cell lies just beneath the pore canal. These glands are almost like the young stages of those described in the squash beetle (Epilachna borealis Fab.) by the writer (31).

The olfactory pores (fig. 5, P to D') are more or less flask-shaped structures, and all really belong to one type, for as a rule their apertures open to the exterior on the same level as the surrounding chitin, and not into pits or at the tops of small domes as described by the writer (30) for some other beetles. However, the one represented in Figure 5, P, approaches the pit-shaped type, and the one in Figure 5, V, the dome-shaped type. The chitinous cones (Con) were usually visible, but the sense cells (SC) were not always found. Owing to the difficulty of obtaining good sections and to the minuteness of these organs, it was impossible to find one in which all the parts were present. Figure 5, P, shows the sense fiber (SF) piercing the cone, while Figure 5, R and S, and others show the pore aperture (PorAp).

The third or distal segments of the maxillary palpi were repeatedly sectioned in order to arrive at an understanding of the internal structure of their five slit-shaped organs, but after all of these attempts it was not definitely learned how the sense fibers unite with the apertures. The difficulties encountered will be appreciated when it is understood that the diameter of this segment was the same
as that of a hair from the writer’s wrist, and it was impossible to secure good fixation of its tissues. The best cross section made is represented by Figure 5, D', which shows that the knife passed through four of the five slits and that the aperture of one of these connects with the interior of the segment. It will be noted that one of the dark-staining bodies, the sense fibers (SF), unites with this aperture. Most of the sense cells present in the maxillary palpus lie in the first segment (fig. 6, A), while the remainder were seen in the second, but none was ever noticed in the third or distal segment. In the labial palpus (fig. 6, B) the sense cells are similarly located.

Figure 6, C, shows the large nerve (N) passing through the wing to group 4 on the dorsal surface. Attention is called to the sense cells (SC), trachea (Tr), thick and rigid chitin on the dorsal surface, but thin and flexible chitin on the ventral side. Figure 6, D, shows group 2 and other internal structures in a cross section of the wing.

ANTENNAL ORGANS

It will be noted that the above heading falls under “Olfactory organs.” The antennal structures are described in connection with the olfactory organs because it is commonly believed that the antennae bear the organs of smell. The present writer, however, shows that the antennae do not bear organs suitable for this purpose, except the few olfactory pores at the base of each antenna. The antenna of the boll weevil is made up of three parts. The scape or scapus (fig. 4, C) consists of the first segment; the funicle or funiculus (F), of the second to eighth segments, but the second segment is also called the pedicel or pedicellus (P); and the club (Cl) consists of the ninth to twelfth segments.

The external anatomy of all the structures on the antennae of five males and five females was critically studied. Only three types of organs were found: (1) The 3 or 4 olfactory pores (Table 3) on the base of each scape (fig. 4, C), already described; (2) the gland pores, represented by dots widely distributed over the antenna; and (3) numerous hairs of various sizes. For descriptive purposes, the hairs are numbered from 1 to 6; but for comparative purposes, Nos.
1 to 4 are called sense hairs and sense bristles (Table 4). They are only approximately represented in Figure 4, C, and Figure 8, and in Table 4. The smallest ones, Nos. 1 and 2 (THr₁ and THr₂, fig. 7, A and B), were found almost entirely on the scape and club; the next in size, Nos. 3 and 4 (THr₃ THr₄, fig. 7, B and C), on all the segments, but mostly on the club; and the largest ones, Nos. 5 and 6 (Hr₅ and Hr₆, fig. 7, B and D), on the funicle and club.

The internal anatomy (fig. 8; fig. 9, A–G) of these hairs shows that all are innervated, except the largest ones, Nos. 5 and 6 (fig. 9, E and F). Numbers 2, 3, and 4 are most numerous, and those in the club seem to have a thread or extra fiber (fig. 9, C and D) running lengthwise in their sense cells from the base of the hair to the nucleus, or even beyond the nucleus. Figure 8 shows that the antenna is well supplied with nerves (N) and tracheae (Tr), but none of the innervated structures seems adapted to receive odor stimuli.

No experiments were conducted to determine whether the antennae of boll weevils carry the olfactory organs, but the writer in the past 10 years has tested many other insects having these appendages either cut off or otherwise mutilated. Since he has been criticized for using strong-smelling substances, chiefly essential oils, in order to induce the mutilated insects to respond to odors, he decided to conduct some experiments in which only the natural food odors would be used. Accordingly, two sets of potato beetles, each set of 50 individuals as usual, were tested in the insect “olfactometer” (38) by subjecting them to the odors from water extract, distillate, and emanations from living potato plants. The antennae were then cut off, and a few days later, when the insects had largely recovered from the operation, they were again tested daily with the odors and emanations. In all, 10 experiments, including 40 individual tests, were conducted. In all of the experiments except one the beetles
responded attractively to the plant odors, although slightly less so than before they were mutilated. Judging from these results alone and not considering the fact that the beetles had not totally recovered from the operation, we should say that the antennae bear only a few

of the olfactory organs, which is contrary to the general opinion held about the location of these organs. Nevertheless, Minnich (41), who conducted many experiments with cabbage butterflies, partly

supports the view of the present writer. He found that the amputation of both antennae of these insects reduced the olfactory response 58 per cent, and, accordingly, claims that the antennae do not constitute the sole olfactory area.
<table>
<thead>
<tr>
<th>Head and its appendages</th>
<th>Sense hairs, Nos. 1 and 2 (Sinneshaare)</th>
<th>Sense bristles, Nos. 3 and 4 (Sinnesborsten)</th>
<th>Sense pegs (Sinneszapfen)</th>
<th>Pit pegs (Grubenkegel)</th>
<th>Olfactory pores (Kuppelförmige Organe)</th>
<th>Eyes</th>
<th>Johnston organ?</th>
<th>Chordotonal organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head capsule</td>
<td>Numerous on beak, especially near mouth parts and base of antenna.</td>
<td>Few on epicranium, vertex, front, occiput, genae.</td>
<td>Few near base of antenna.</td>
<td>None</td>
<td>10 on epicranium, 8 on occiput, 2 on genae.</td>
<td>2 compound eyes, 1 rudimentary ocellus.</td>
<td>In pedicel.</td>
<td>In pedicel.</td>
</tr>
<tr>
<td>Antenna</td>
<td>About 51 on scape, 2 on funiculus, 280 on club. 2 on outer surface</td>
<td>About 12 on scape, 20 on funiculus, 200 on club.</td>
<td>None</td>
<td>do</td>
<td>3 or 4 on base of scape.</td>
<td>4 to 12.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mandible</td>
<td>2 on second segment of palpus.</td>
<td>None</td>
<td>19 at tip of palpus.</td>
<td>2 near tip of palpus.</td>
<td>5 on submentum, 2 on palpus.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxilla</td>
<td>2 on mentum, 3 on palpus.</td>
<td>Probably many on palpi fer and lacinia.</td>
<td>9 at tip of palpus.</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 The labrum is absent in the boll weevil.
TACTILE ORGANS

Besides the tactile hairs (Nos. 1 to 4) already described on the antennae (fig. 9, A to G), innervated hairs were also found elsewhere; particularly on the mouth parts, other appendages, and even widely distributed over the body. The only safe way to determine a sense hair is to find its nerve in sections, but this is a difficult and slow task, and one can hardly be expected to do this for every individual hair; so after a careful study of the internal anatomy of certain groups had been made, the others were judged merely from their external structure. The internal anatomy of only a part of those recorded in Tables 4 to 6 were studied in sections, but since other investigators have found tactile hairs similarly located in other beetles, the writer feels that most of those which he calls sense hairs are really innervated, although perhaps he has overlooked certain other ones.

DISPOSITION OF TACTILE HAIRS

Hochreuther (15) made a thorough study of the sense hairs on a water beetle (Dytiscus marginalis L.). On the basis of external structure, he separated them into five divisions, one of which will be discussed under another heading, Since the writer knows of no similar work pertaining to a weevil, he has used Hochreuther's classification as a guide in the present investigation.

Table 5.—Disposition of sense organ on thorax of adult cotton boll weevil

<table>
<thead>
<tr>
<th>Divisions of thorax and its appendages</th>
<th>Sense hairs</th>
<th>Sense bristles</th>
<th>Sense pegs</th>
<th>Pit pegs</th>
<th>Olfactory pores</th>
<th>Chordotonal organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prothorax</td>
<td>None</td>
<td>Several on margins of pronotum and post sternum.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Mesothorax</td>
<td>Numerous on anterior margins of episternum and mesosternum; on prescutum and scutellum.</td>
<td>Same as for sense hairs.</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td></td>
</tr>
<tr>
<td>Metathorax</td>
<td>Several on anterior margin of metaergum.</td>
<td>Several on metaergum, metapleurum, and metasternum.</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td></td>
</tr>
<tr>
<td>First pair of legs</td>
<td>Several on coxa; 2 groups on trochanter; several at distal end of femur and on its teeth; few on tarsus.</td>
<td>Several on coxa; several widely distributed on femur, tibia, and tarsus.</td>
<td>do</td>
<td>do</td>
<td>6 to 8 on trochanter; 1 on femur; 3 on tarsus.</td>
<td></td>
</tr>
<tr>
<td>Second pair of legs</td>
<td>Several on coxa; 2 groups on trochanter; remainder, same as above, but hairs less numerous.</td>
<td>Distribution same as on first pair of legs, but less numerous.</td>
<td>do</td>
<td>do</td>
<td>6 to 9 on trochanter; 1 on femur; 3 on tarsus.</td>
<td></td>
</tr>
<tr>
<td>Third pair of legs</td>
<td>Same as above...</td>
<td>Same as on second pair of legs.</td>
<td>do</td>
<td>do</td>
<td>7 to 10 on trochanter; 1 on femur; 3 on tarsus.</td>
<td></td>
</tr>
<tr>
<td>Elytra</td>
<td>None?</td>
<td>None</td>
<td>do</td>
<td>do</td>
<td>45 to 53 on each peduncle.</td>
<td></td>
</tr>
<tr>
<td>Wings</td>
<td>Few</td>
<td>Few</td>
<td>do</td>
<td>do</td>
<td>322 to 413 on both wings.</td>
<td>In base?</td>
</tr>
</tbody>
</table>
Senses of the Cotton Boll Weevil

**SENSE HAIRS Nos. 1 AND 2 (SINNEshaare, or Sensilla tricho-dea).—** Hochreuther found these on the head capsule, antennae, all mouth parts, thorax, legs, abdomen, and sexual apparatus. The present writer found them on the head and all its appendages (Table 4), parts of thorax, legs, and wings (Table 5), and on certain parts of the abdomen (Table 6).

**SENSE BRISTLES, Nos. 3 AND 4 (Sinnesborsten, or Sensilla chaetica).—** Hochreuther found these on the epicranium, antennae, labrum, maxillae, labium, epipharynx, cervical sclerites, thorax, legs, and abdomen. The present writer found them on the head capsule, antennae, and probably on the following: Maxillae, labium, thorax, legs, wings, and abdomen (Tables 4 to 6).

**TABLE 6.—Disposition of sense organs on abdomen of adult cotton boll weevil**

<table>
<thead>
<tr>
<th>Divisions</th>
<th>Sense hairs</th>
<th>Sense bristles</th>
<th>Sense pegs</th>
<th>Pit pegs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tergites......</td>
<td>Few on each</td>
<td>Few on each</td>
<td>None........</td>
<td>None.....</td>
</tr>
<tr>
<td>Pygidium, or last ter-gite.</td>
<td>Few........</td>
<td>Few........</td>
<td>Few........</td>
<td>Do........</td>
</tr>
<tr>
<td>Female genitalia.</td>
<td>None........</td>
<td>Several on palpus of ovipositor.</td>
<td>None........</td>
<td>Do........</td>
</tr>
<tr>
<td>Male genitalia.</td>
<td>None........</td>
<td>None........</td>
<td>None........</td>
<td>Same as for sense hairs.</td>
</tr>
<tr>
<td>Sternites.......</td>
<td>Very numerous on last sternite; less numerous on other sternites.</td>
<td>Same as for sense hairs.</td>
<td>None........</td>
<td>do........</td>
</tr>
<tr>
<td>Epipleurites....</td>
<td>Few on each, near spiracle.</td>
<td>None........</td>
<td>do........</td>
<td>Do.</td>
</tr>
</tbody>
</table>

**SENSE PEGS (Sinneszapfen, or Sensilla basiconica).—** Hochreuther found these on the head and all its appendages, thorax, legs, abdomen, and sexual apparatus. The present writer found probably a few on the head, maxillae, labium, and female genitalia.

**PIT PEGS (Grubenkegel, or Sensilla coeloconica).—** Hochreuther found these on the antennae, all mouth parts, epipharynx, mesothorax, legs, and sexual apparatus. The present writer found two near the tip of the maxillary palpus, and many on the female and male genitalia.

**STRUCTURE OF TACTILE HAIRS**

Vom Rath (47, 48) found sense cells connected with all the small hairs on the maxillary palpi of Coccinella septempunctata, Melolontha vulgaris, and Tenebrio molitor, and also with all the small hairs on the labial palpi of the last species, in much the same manner as shown in Figure 6, A and B. Using Ehrlich’s “Methylenblaumethod” and Golgi’s “Chromsilberverfahren,” Vom Rath traced the sense fibers of insects, myriapods, spiders, and crustaceans. In all the innervated hairs, whether short or long, and even in those at the tips of the maxillary and labial palpi, he saw a fine thread running lengthwise through each sense fiber to the tip of the hair, as shown in Figure 9, C and D, although the present writer was able to trace the sense fibers only to the base of the hair and never far into its cavity. Relative to Vom Rath’s work, Hilton (14, p. 566), who has reviewed the literature on this particular subject, says:

Earlier workers with methylen blue who studied simply the surface views represent nerves coming from the tips of the hairs; but it seems probable that
such figures are in large part diagrammatic. Vom Rath found by the Golgi method cavities of sensory hairs filled with nerves; this result is regarded as an artifact by Duboscq, who shows clearly how appearances like nerves may be obtained in the cavity of hairs due to deposits of chromate of silver; and he shows quite clearly that when nothing but the nerve cell and fiber is impregnated the nerve fiber stops at the base of the hair, as was apparently the case in his methylene blue preparations.

Figure 9, A to N, illustrates internal structure of hairs as seen by the writer, using Ehrlich's haematoxylin stain with eosin.

THE SO-CALLED TASTE ORGANS

Several writers, particularly Nagel (42), have described certain tiny peglike hairs on the mouth parts of insects as taste organs, but no one has ever demonstrated that they perform such a function. Hochreuther (15) found many "Tast- und Geschmackszäpfchen" on the maxillary and labial palpi of Dytiscus marginalis. Comstock (5, p. 132) briefly summarized the description of such hairs, and said:

Many experiments have been made to determine the function of the various chemical sense-organs but the results are, as yet, far from conclusive.

The present writer wishes to emphasize the fact that so far as he is aware no recent observer has found gland cells connected with these sense hairs, as claimed by Berlese (1).

As shown for adult boll weevils in the preceding pages and for the larvae in the following pages, only two kinds of sense organs—olfactory pores and innervated hairs—were found on the mouth parts. Neither of these seems suitable to act as taste organs, and consequently the writer has come to the same conclusion concerning the boll weevil that he reached several years ago (32) in regard to the honeybee. In brief, he does not believe that insects have a true gustatory sense, but since in many cases they must first "taste" certain foods before they can discriminate between them, it seems that their responses may be similar to ours when we are "tasting" the flavors of particular foods. Long ago physiologists determined that flavors to us are only smells, brought about by placing food in the mouth and then exhaling through the nose.

Since it was impossible to demonstrate by experiment the function of the sense organs on the mouth parts, the writer argued that in view of the fact that bees do not have suitable gustatory organs they can not have a true gustatory sense. Snodgrass (54, p. 59–63) well summarizes the writer's results, and adds the following precautionary remarks:

Most entomologists, probably, will not be convinced by this form of reasoning that insects do not taste, since it places too much reliance on a personal interpretation of the functional possibilities of an observed anatomical structure. It shows, however, that the experimenter who claims a sense of taste for insects must demonstrate it with tests that will clearly avoid a confusion between taste and smell.

THE SO-CALLED AUDITORY ORGANS

Much has been written about the auditory sense of insects, but critics still contend that it has never been demonstrated beyond a doubt that any insect can really hear. Most students on insect behavior believe that insects can hear, yet very few have produced evidence supporting this belief. Rádl (46), after summarizing the results of several other investigators on this subject, says that certain
experiments have convinced him that insects have a crude auditory sense. He offers several reasons for this conviction, and concludes by saying that the auditory sense in insects is on a much lower plane of development than that of vertebrates. Its anatomical and physiological antecedents are to be found, not in the tactile organs and contact activities, but anatomically in sense organs which register muscle activities and physiologically in general sensation. That is, he believes that their sense of hearing is a highly refined muscular sense. Turner and Schwarz (56) and Turner (55) have produced good experimental evidence to show that certain moths really hear, although the present writer is unaware of results equally convincing that beetles can hear; nevertheless, it is common for them to have stridulating devices and chordotonal organs.

The common belief that insects can hear is based on the three following facts: (1) Many have special sound-producing organs; (2) some have so-called auditory organs; and (3) many of the experimental results obtained indicate that insects can hear, although certainly not as we do.

Since the writer could find no reference in literature to the "auditory" organs in a weevil, he has used the two investigations of Lehr (22, 23) as a guide for the work here reported. Lehr, who first studied the anatomy of the sense organs in the elytra and wings of Dytiscus marginalis, found a chordotonal organ at the base of the subcostal vein. It lies on the ventral side beneath a group of olfactory pores, is well developed, and has all the parts common to such an organ. In his second work (23), Lehr pointed out two other so-called auditory organs in the pedicel or second antennal segment. The Johnston's organ is situated near the distal end of the segment; while the chordotonal organ, lying by its side, arises nearer the proximal end. Both of these organs run lengthwise in the segment and connect with the articular membrane between the second and third segments, but Lehr failed to see all their parts distinctly. Judging from his drawings, the Johnston's organ is the better developed. At this place in the antenna the interior is nearly filled with sense cells.

Johnston in 1855 (21) first pointed out a supposed auditory organ in the second antennal segment of the Culex mosquito. This structure, later called after his name, was thoroughly investigated by Child (3), who saw it in all the insect orders examined, except the Orthoptera. He found it in Diptera, Hymenoptera, Coleoptera, Neuroptera, Pseudoneuroptera, and Homoptera. He also saw sense organs in the second antennal segments of Orthoptera, but decided that they were not Johnston's organs. These have since been described as olfactory pores by the present writer (36), who has also recently described the Johnston's organ in the honeybee (37). He did not, however, see a chordotonal organ in the same segment, as mentioned by Lehr and as here reported for the boll weevil.

Externally, there are no signs of an auditory organ in the pedicel or second antennal segment (fig. 4, C) of the adult boll weevil, but sections through the distal end of this segment always show large masses of sense cells. After these masses had been carefully studied under the highest magnification, they were divided into two groups, based on size and structure; but, owing to their minuteness and perhaps to poor fixation and staining, it was not possible to distinguish
all the details ordinarily described for the supposed auditory organs. Since these groups are similar in position and somewhat resemble those described by Lehr in Dytiscus, the writer has called one of them the Johnston’s organ (fig. 10, A, J) and the other the chordotonal organ (CO), although perhaps these names should be reversed, or possibly both groups belong to the same organ.

Both groups of sense cells run nearly the full length of the segment. Near the distal end (fig. 10, A) they expand and occupy most of the interior, but near the proximal end (fig. 10, B) they are much smaller and take up less space. One side of each group is always in contact with the hypodermis and seems firmly anchored. The distal ends of

![Diagram of auditory organs](image)

**Fig. 10.**—The so-called auditory organs of the cotton boll weevil. A and B, two-thirds diagrammatic from oblique longitudinal sections of pedicel (P of fig. 4, C), showing Johnston’s organ (J) and the chordotonal organ (CO). A, from distal end of segment and B, from proximal end. C and D, two of smallest cells from these organs, C being from Johnston’s organ and D, from the chordotonal organ. ×564

Abbreviations: Ax, axial tube; Chi, primary cuticula; Chs, secondary cuticula; N, nerve; Nuc, nucleus; and Tr, trachea

the sense cells are attached to the secondary cuticula (fig. 10, A, Chs) of the articular membrane between the second and third segments. A nerve is always near the groups, and branches of it (N) can be traced directly to the sense cells.

The sense cells in the Johnston’s organ are usually smaller than those in the chordotonal organ, and seem to be simple in structure (fig. 10, C), while each sense cell in the chordotonal organ apparently bears two additional structures—the axial tube (fig. 10, D, Ax) and secondary nucleus (Nuc). This would seem to indicate that the chordotonal organ consists of the various parts common to this type of sense organ.

As already stated, Lehr found a well-developed chordotonal organ in the base of the subcostal vein of Dytiscus. The present writer likewise found a chordlike structure (fig. 6, D, Co) in identically the same place in the boll weevil, but no details could be distinguished.
Since it appears nearly structureless in the few sections showing its presence, we may infer that it is either a rudimentary organ or had not had time to develop fully when the weevils emerged.

Graber (10), after finding chordotonal organs in many of the insect orders, was convinced that the integument of insects, like the tympanum of vertebrates, is well adapted to be set in vibration by sounds, and that the terminal nerve connections of these organs are the sound receptors.

During the past 75 years, the stridulating or sound-producing organs of insects have been much discussed, but still we do not know whether the noises made by them are intentional or unintentional. Darwin (7) calls these organs sexual characters, but he has much difficulty in finding examples to prove that they are so. If all our present information were carefully analyzed, however, with this object in view, we might be able to produce many good examples to support his belief.

In regard to beetles Darwin (7, p. 310, 311, 312) says:

Nevertheless, the power of stridulating is certainly a sexual character in some few Coleoptera. * * *. In the case of the Heliopathes and Oryctes there can hardly be a doubt that the males stridulate in order to call or to excite the females; but with most beetles the stridulation apparently serves both sexes as a mutual call. Beetles stridulate under various emotions, in the same manner as birds use their voices for many purposes besides singing to their mates. The great Chiasognathus stridulates in anger or defiance; many species do the same from distress or fear, if held so that they can not escape; by striking the hollow stems of trees in the Canary Islands, Messrs. Wollaston and Crotch were able to discover the presence of beetles belonging to the genus Acalles by their stridulation. Lastly, the male Ateuchus stridulates to encourage the female in her work, and from distress when she is removed. Some naturalists believe that beetles make this noise to frighten away their enemies; but I can not think that a quadruped or bird, able to devour a large beetle, would be frightened by so slight a sound * * *. Finally, it is probable that the two sexes of many kinds of beetles were at first enabled to find each other by the slight shuffling noise produced by the rubbing together of the adjoining hard parts of their bodies; and that as those males or females which made the greatest noise succeeded best in finding partners, rugosities on various parts of their bodies were gradually developed by means of sexual selection into true stridulating organs.

So far as known to the writer, no one has reported stridulating organs in boll weevils, nor has anyone heard noises made by these insects, yet stridulating organs may be present and the adults may make noises which have never attracted the attention of any observer. Darwin cites cases of other curculionids having stridulating organs with which they are able to make audible noises, and Westring (58) as early as 1847 reports finding these organs in certain curculionids. In these weevils the rasps are located on the inferior surface of the elytra, near the apices, or along their outer margins, and the edges of the abdominal segments serve as the scrapers. This arrangement is the reverse of what usually occurs in other beetles. These weevils make a loud noise by rapidly rubbing the tips of the abdomen on the ends of the elytra. As already quoted by Darwin, Wollaston (59) called Acalles argillosus in the Canary Islands a musical curculionid, and another observer reports five other species of Acalles, one of which is very minute, as being musical in the Madeira Islands. All of these species have stridulating organs.
EYES AND LIGHT EXPERIMENTS

The two compound eyes (fig. 4, A, E) of the adult boll weevil are present; but, as reported by other writers, the ocelli are apparently absent. The faceted eye is small, though moderately convex. The number of facets in the eyes of one male and one female were counted; they ranged from 400 to 448, with an average of 433 per eye; and there was practically no sexual difference. According to Müller's mosaic theory of sight in insects, which most entomologists have accepted, the larger and more convex the eyes the larger will be the visual field, and the smaller and more abundant the facets the sharper and more distinct will be the image. Using the preceding information as a basis for speculation, we may infer that the visual field of the boll weevil is small and its image of objects is neither sharp nor distinct. From this statement we may also infer that the boll weevil probably can not, merely by sight, distinguish from a distance cotton plants from certain other plants, and furthermore that it may not be able by sight alone to distinguish the various parts of a cotton plant.

Many sections of the eyes were made, but after a preliminary study of them no unusual structures were noted that would modify the generally accepted view of insect vision. If one may judge from the large amount of pigment present, the boll weevil has day eyes and not night eyes. The subject of day and night eyes is well summarized by Comstock (5, p. 142).

A median ocellus (fig. 4, A, Oc) was finally found in the boll weevil after a diligent search under a high magnification. It is very small, extremely oblong, and lies nearly buried in a slit between the compound eyes; but viewed from the inner side of caustic-potash preparations it appears much larger, and is nearly round.

The only light experiments conducted by the writer were a few preliminary ones to verify the statement that the boll weevil is positively phototropic to daylight. No artificial lights were tested; although it might be possible to attract weevils to lights closely imitating daylight. Ever since the advent of this insect to cultivated cotton fields, and even up to the present time, there has been a belief that it might be attracted to artificial lights and then killed. Hunter and Hinds (17, p. 160) and Hunter and Pierce (18, p. 154) assure us that there is no scientific foundation for this belief. Thousands of insects, including many weevils similar in appearance to the boll weevil, have been attracted to lights in cotton fields, but as yet no scientist has found a single cotton boll weevil among them.

Hunter and Pierce (18, p. 43) report the results of some preliminary experiments conducted in 1907 to ascertain the color sense of boll weevils. Of the 14 shades and colors used, the 3 most attractive were light blue, dark green, and light pink, the light blue being most preferred.

Lutz (25, p. 265), discussing the color sense of insects, says:

Hess may be right in believing that insects are totally color blind. Probably Frisch is more nearly correct in saying that they can distinguish all of the colors except red and certain greens as colors, those two of our colors appearing to them as darker or lighter grays; in other words, that their color vision is similar to that of some partially color-blind humans.

Lutz determined that the flowers and occasionally other parts of certain plants emit ultra-violet rays, and that flower-visiting insects respond to ultra-violet light, but he did not use the cotton plant
and the boll weevil; although it is possible that the cotton plant emits these rays and perhaps the boll weevil responds to them. Lutz (25, p. 271, 278, 280), further states:

It has been shown that, in addition to the colors which man can see, some flowers are ultra-violet, while others are not at all ultra-violet, and still others have an ultra-violet pattern. It has also been shown that flower-visiting insects can see ultra-violet as well as or even better than they can see the rays perceived as light by man. The effect of this work is to add one more color—and apparently an important one—to the list of those which plants use in facilitating the visits of insects, if plants do use colors for such a purpose.

All of the colors of the spectrum from red to ultra-violet, both included, are to be found in light reflected by one flower or another. Of these waves of light reflected by flowers, those of relatively great length, red to green, are more common than those of shorter length, blue to ultra-violet. Flower-visiting insects do not see red to green as well as they do blue to ultra-violet.

It is also shown that a wide range of flower-visiting insects are photopositive to ultra-violet. It appears as though they see ultra-violet better than they do colors that seem bright to us. Accordingly, ultra-violet becomes quite as important in discussions of the relation between floral colors and insects as any other color.

OTHER SENSES

Among the general sensations of insects might be mentioned those of temperature, humidity, direction, hunger, fear, pain, and statical conditions. Very little is known about these senses in insects in general, and practically nothing about them in the boll weevil.

The sense of temperature in the boll weevil, judging from its reactions to different degrees of heat and cold, is probably well developed, but, as in other insects and even in ourselves, there are probably no special sense organs to receive thermal stimuli. The subhypodermal nerve plexus, if it is present in the adult weevil, could easily perform this function. Humidity, which is closely related to temperature, also has much to do with the behavior of this insect.

In this connection might also be mentioned some of the ingenious but absurd mechanical devices which have been invented from time to time for the purpose of eradicating the boll weevil. Among these the most common are “light” traps, one even being pulled through the fields on wheels; another is planned to attract the weevils by sounds; and still another would kill the weevils with a beam of high pitched inaudible sound waves of great intensity.

One of the newest ideas about the means of communication among insects is wireless telegraphy. This suggestion seems to have been first made by Fabre (8, p. 194–199) to explain how male moths find their mates from long distances, but his experiments convinced him that moths do not communicate by this means; next he predicted that science would provide us with a radiography of odors, after the pattern of the Röntgen rays, although Forel (9) says that Fabre’s own results contradict this view. The next idea along this line was suggested by Riley (50, p. 38–41), who used the word telepathy to explain how insects communicate from long distances, but still he had no faith in this view.

Now, since we are able to communicate among ourselves so readily by radio, this means has been suggested as possible for insects. The writer can find no authentic data on this subject, but in some newspaper reports which recently appeared it is stated that one authority claims that man and most other animals constantly emit
N rays or electric rays which are used in communication. He says in part:

Look at the birds which fly at night, insects, blind fish at the bottom of the sea—all are irresistibly drawn toward their prey not so much by sight or odor, but by the action of the radiations which direct them and to which they submit automatically.

In regard to insects he imagines that these tiny “radio waves” are received by the antennae. Another report, this one given out by Science Service, of Washington, D. C., says in part:

Animals and plants while living give off rays similar to those emitted by the metal radium, according to reports made to the French Academy of Sciences by Albert Nodon.

Mast (59) experimented with fireflies and concluded that smell played no part in bringing the sexes together, but that the sexes communicate and are attracted to each other by means of their flashes of light. Singh and Maulik (52) determined that the so-called “phosphorescence” of the fireflies would affect the photographic plate through wood, dark brown leather, black paper, or flesh, and conclude:

The light emitted by the insect cannot therefore be taken as phosphorescent. It may be, perhaps, premature to conclude that some of the rays emitted by the insects are X-rays, but it may be safely asserted that these rays are, at least, similar to X-rays and ultra-violet light in so far as they render certain opaque media transparent and are intercepted by glass.

Harvey (11, p. 61, 62) says:

Although Muraoka (1896) and Singh and Maulik (1911) have described radiations coming from fireflies which would pass opaque objects and affect a photographic plate. * * * the existence of such radiation has been denied by Suchsland (1898), Schurig (1901), and Molisch (1904).

There is, then, no specific emission of X rays or similar penetrating radiation from luminous tissues which will affect the photographic plate through opaque screens.

A letter from E. N. Harvey to the writer, dated June 7, 1925, contains his latest ideas on this subject, including the possibility that boll weevils might give off rays which can be perceived by themselves but not by us. He states:

I do not think there is any evidence that animals give off X rays or any other kind of peculiar radiation. Short ultra-violet radiation is very destructive to living matter, so there is not much chance of wave length shorter than 3,000 Å being emitted, but I see no reason why ultra-violet between 4,000 Å and 3,000 Å should not be produced. We do not know definitely of a case, so that the matter is merely speculation.

RECOGNITION AMONG BOLL WEEVILS

Hunter and Hinds (17, p. 76) found that the male boll weevil was unable to recognize the female at a much greater distance than an inch, and that the attraction is apparently effected by smell. Field observations, as well as laboratory ones, seemed to show that the sexes are attracted only when they meet, as they are likely to do either on the stems or squares of the plant.

While watching female weevils both in the field and in confinement, the writer observed that they seemed to pay little attention to one another; but such is not usually the case where the opposite sex is concerned. The males in confinement usually do not lose an opportunity to mate, and should no female be handy, a male may often be
seen trying to copulate with another male. This behavior of either sex does not necessarily imply that the females do not know one another, or that the males can not distinguish the sexes, because we can cite many similar cases among other animals; for example, cows in heat or rut often try to copulate with one another.

If boll weevils do not communicate with one another by telephathy, radio, or by any other type of radiation, as mentioned above, then there are left perhaps only three other means—sight, touch, and smell. At short distances the weevils may be able to distinguish many other insects and perhaps inanimate objects by sight alone, and when in contact may partially recognize one another by sight and touch; but if they are similar to other insects and the higher animals, smell probably plays a more important rôle in recognition than do the other senses.

If boll weevils recognize one another by means of smell, then they must produce odors which can be smelled. Insects, as well as the higher animals, have glands connected with their sexual organs, and those in the boll weevil might serve for sexual recognition.

The unicellular glands found widely distributed over the entire body surface are, in point of abundance, as follows: On the elytra (fig. 16, E, po) and antennae (fig. 4, C; fig. 8, PorGl), very numerous; on the beak or snout (fig. 7, A), numerous; on the wings (fig. 16, D, po) and ventral side of the abdomen, fairly numerous; on the head capsule, mouth parts (fig. 3, A, C, D, and F), thorax, legs (fig. 16, C), and dorsal side of the abdomen, few.

The external appearance of these glands is shown in Figure 5, A and B, and the internal anatomy in Figure 5, M, N, O, and Figure 16, B and F. It will be noted that the gland cell (GlC) is much larger than the hypodermal cells (HypC) and that an ampulla (Am) is present. The secretion collects in the ampulla, passes through the cell wall into the pore canal (PorC), then into the reservoir (Re), and finally to the outside through the efferent tube (Ef). It was not possible to decide definitely whether this tube is open or closed at its inner end; theoretically, it should be closed, but in many cases it seemed to be open. The drawings show it both ways. It is shaped like a finger or a test tube, and its walls are so thin that it really does not matter whether it is closed or open, for in all probability the secretion can pass through its walls by osmosis.

Several years ago the writer (33) collected the literature pertaining to the scent glands or scent-producing organs in insects and classified them on the basis of their distribution. The simplest and commonest type found among beetles and a few other insects is composed of the unicellular glands widely distributed over the body surface. This type is well illustrated on pages 38 to 40 of the above paper, although it is not up to date.

Parts of the body surface of live weevils appear shiny, but not wet, as is often observed in certain other beetles. Several years ago the writer (31) made a careful study of this question in the squash beetle (Epilachna borealis). These beetles always appear wet, and the more they are irritated the wetter they become. The secretion, which comes from numerous hypodermal glands widely distributed over the integument, is easily seen on the body surface. It has a bitter taste and emits an odor repugnant to us.
What is the function of this secretion? When it is repellent or distasteful to the insect's enemies, we say that its primary function is for protection and its secondary function probably for recognition. Since the boll weevil does not have a wet body surface, its hypodermal glands certainly do not secrete as copiously as do those in certain other beetles, and in all probability this secretion is not for protection; in which case its primary function must be for recognition. A single boll weevil emits little or no odor noticeable to a person, but when several are confined in a small box or bottle, they emit a characteristic and rather pronounced odor.

Scent glands of this type do not have reservoirs on the body surface to hold the secretion and so prevent it from evaporating too rapidly, but such structures are common in other types. Wherever these glands occur the secretion runs to the exterior and spreads in a film over the chitin and then constantly and perhaps quickly evaporates, giving off its own characteristic odor. However, on the elytra of boll weevils there are peculiar structures called punctures, which might serve as reservoirs for this secretion, provided it spreads sufficiently to reach them. On all parts of the surface (fig. 16, C to F, po), except on the wings, where these gland pores occur, they are associated with the hairs, one usually lying at or near the base of each hair (C and E). On the dorsal surface of an elytron there are numerous club-shaped or protective hairs (g); numerous gland pores (po); and several longitudinal rows or striae of slit-shaped pits, the punctures (n). Each puncture consists of an oblong, heavily pigmented border (l), a lengthwise slit (E and F, n), and a tiny hair (m), which lies flatly over and nearly closes the opening of the slit or puncture. The punctures on the right elytron of a male were counted. They lie in 10 rows, ranging from 25 to 39 per row, making a total of 319 for the elytron. What can be the function of these punctures? The writer does not know, unless they serve as reservoirs for some secretion. The minute hair is always present in the same place, and could well serve as a door for these pits.

**SENSE ORGANS OF LARVAE OF BOLL WEEVILS**

The larvae of boll weevils are white, delicate, and legless grubs, being well protected by the covering of the bolls or squares. Since they spend all their lives inside a dark house, well surrounded by food, the question may properly be asked, "Do they need sense organs?" It is possible that they do not eat all parts of the food surrounding them, in which case they must distinguish the edible from the non-edible by touch, taste, or smell; on the other hand, if they do eat all of the food surrounding them and have sense organs suitable for this purpose, then we conclude that these organs are useless and have only a phylogenetic significance.

**OLFACTORY PORES**

The olfactory pores on five full-grown larvae were carefully studied. They were found practically constant in position and number, and since those on larva No. 4 were most critically examined and then drawn, they will be described in detail.

No groups of pores were found, but the isolated ones (fig. 11, A to F, a to z) were usually arranged in pairs; one pore being on the right
side and its mate on the left side of a median line. Ten pairs (a to j) lie on the head capsule, pore g of these being on the microscopic antennae; 3 or 4 pores (k) on each mandible; 5 pairs (l to o) on the labium; 1 pair (p) on the mentum; 1 pair (q) on the submentum; 1 pair (r) on the labrum; 1 pair (s) on the clypeus; 8 pores (t to y) on each maxilla; 2 pairs (z) on the second thoracic segment; and 4 pairs (fig. 12, B) on what appears to be the epipharynx.

The external structure (fig. 12, A and B) and internal structure (fig. 12, D to H) of the pores on the larvae are like those already described for the adult weevil. On the maxillary palpus (fig. 3, B) of the adult there are five slit-shaped pores, but on that of the larva there is only one (fig. 11, F, and fig. 12, A, x).

**Olfactory Pores of Other Larvae**

No one, except the writer, has apparently identified the olfactory pores as the Hicks' organs in any larva, although it is evident that they have been seen by various systematists, for Schiødtte (51, 1872–73)
figured them on the antennae and labial palpi of staphylinid larvae, on the legs of scarabaeid larvae (51, 1874), on the maxillae of lucanid larvae, and on other coleopterous larvae. Böving (2) figured a few of them near the spiracles of a coccinellid larva, and Cotton (6) showed a very few on the mouth parts of different curculionid larvae. Nagel (42) saw two of these pores on the maxillary palpus of a larva of a stonefly (Perla bicaudata Panzer); very few on the antennae and labrum of a lepidopterous larva (Antheraea pernyi Guér.), and a few widely distributed on the antennae, maxillae, and labium of a coleopterous larva (Dytiscus marginalis). Nagel called them “Gruben ohne Kegel” and made sections through them, but did not suggest a function for them, because he failed to understand their internal anatomy. The present writer (35) made a careful study of these pores in 30 species of lepidopterous larvae, and determined experimentally that these larvae respond to chemical stimuli, although no experiments were performed to determine the function of the pores.

The writer (34) carefully studied the morphology of the olfactory pores in the larvae of Cotinis nitida L. Two types of pores were found, single and compound. The compound were observed only on the terminal segments of the long antennae. Recently the same type has been seen similarly located in the larvae of a May beetle (Lachnosterna sp.) and the Japanese beetle (Popillia japonica Newm.), two other scarabaeids. The single organs (isolated pores) in Cotinis were found on the antennae, mouth parts, head, thorax, and legs. The average total number of pores counted in both types was 1,359. Many drawings of the two types were prepared and published, but photomicrographs, not previously published, are here presented (figs. 13–15) to convince the reader that the sense fibers of these organs actually enter minute pores, called pore apertures. Of course the writer is well aware that such a view is contrary to the accepted belief concerning the presence of pores in the integument of insects; nevertheless he is thoroughly convinced that the ends of these nerves.

---

**Fig. 12.—**A to C, external structure of olfactory pores and tactile hairs of larva of boll weevil. In A the olfactory pores are lettered a to z (with pores b, d, f, h, j, l, n, and r omitted), their position being indicated in Figure 11. A to F: c, e, z, and r, from head capsule; q, antenna with its pore; k, from mandible; m, from labial palpus; o, from ligula; p, from mentum; q, from submentum; r, from labrum; s, from clypeus; t, from stipes; u, from palpifer; v, from palp; w and x, from lacinia of maxilla; and y, from clypeus; and z, from second thoracic segment. B, olfactory pores (too near one another) from epipharynx. C, one of smallest tactile hairs (THn, fig. 11, A) on head. Internal anatomy of olfactory pores and innervated hairs of larva of boll weevil. D to H, olfactory pores; D, from labrum; E, from mandible; F, from antenna; G, from maxillary palpus; and H, from labial palpus. I, innervated sense pegs around base of antenna. J and K, from longitudinal sections of maxillary palpus and labial palpus, respectively (mostly diagrammatic), showing innervation of olfactory pores (Por) and sense pegs (Thr). × 492
come in contact with the external air. Just how they end in these pores can not be stated, because they are so small and indistinct that no definite details can be discerned. In the best sections there does not appear to be any membrane, however thin, between the end of the sense fiber and the outside air, although it must be granted that the tip of this fiber is covered by its own cell wall. A careful study of these photomicrographs will show how the two types of pores appear under a high magnification, but particular attention is directed to Figure 13. C shows the complete innervation of an olfactory pore. B is a section of an olfactory pore obtained by using an ordinary photographic plate. Attention is called to the sense fiber (c) which passes through the chitinous cone, and stops at A, a. A is a section of the same olfactory pore, obtained by using a photographic plate sensitive to yellow. Attention is here called to the pore aperture (p) or pit passing from the exterior to the point a, where the sense fiber (c) enters the pit.

OLFATORY ORGANS IN MAN AND THE HIGHER ANIMALS

Reference to recent textbooks such, for example, as Howell’s "Physiology" (16) and Piersol’s "Human Anatomy" (43) will quickly show the reader that the protoplasmic cilia of the olfactory cells in man and the higher animals also come in contact with the outside air. Except in this type of olfactory organ, the microscopic sense cilia are constantly covered with mucus, and in order to produce a sensation of smell the odoriferous particles are first dissolved in this mucus. It is generally believed by the layman that these cilia and their cells are covered by a thin and moist membrane through which the odoriferous air must pass; but the authorities on this subject tell us that wherever the olfactory cells occur in the nasal passages, the epithelium consists of two chief constituents—supporting cells and olfactory cells. The olfactory cells project slightly beyond the general level of the epithelium and each bears six to eight minute stiff cilia, often called olfactory hairs. Mucous glands, lying just beneath the outer or olfactory layer, are very numerous; their orifices are barely distinguishable by the unaided eye; and they keep the outer surface of the membrane well covered with mucus all the time.

The end of each sense fiber in the olfactory pores of insects might be compared to a cilium on an olfactory cell of man. Since the sense cells in insects are modified hypodermal cells, they may still retain a small part of their original secretory use, in which case they would be able to keep the tip ends of their sense fibers sufficiently moist so that the odoriferous particles touching them would be dissolved. If this condition exists, then the olfactory apparatus in insects and the higher animals is very similar in structure, and certainly must be so in function.

TACTILE HAIRS

Since the hairs on the larvae of the boll weevil are comparatively scarce and widely scattered, they were not easily found in sections; consequently many of those called sense hairs and sense bristles in Table 7 have been thus classified merely from their external structure; although the innervation of those at the tips of the maxillary and labial palpi (fig. 11, D, F, and fig. 12, J, THR, and K), and at the base of the antennae (fig. 12, I) has been thoroughly studied.
Fig. 13.—Photomicrographs showing olfactory pores in antenna of larva of Cotinis nitida. A, section of olfactory pore obtained by using a photographic plate sensitive to yellow. Attention is called to the pore aperture (p) or pit passing from the exterior to the point a, which is the end of the sense fiber. It is clear that no membrane separates the end of this fiber from the outside air. B, section of same olfactory pore obtained by using an ordinary photographic plate. Attention is called to the sense fiber (c) which passes through the chitinous cone and stops at A, a. C, portion of cross section, showing complete innervation of another olfactory pore (P); f, sense cell, and g, branches of nerve. d, wall of olfactory pore; e, hypodermis; h, primary cutícula; and i, secondary cutícula. × 1,450
FIG. 14.—Photomicrographs from sections through tips of antennae of Cotinis nitida, showing internal anatomy of compound olfactory organs, including $e$, hypodermis; $f$, groups of sense cells; $g$, branches of nerve; $j$, plate over sense cells; $p$, pore through plate; and $P$, a single olfactory pore. A, cross section, and B, portion of longitudinal section.
FIG. 15.—Photomicrographs showing disposition of olfactory organs on legs and antennae of *Cotinis nitida*. A, four single olfactory pores (two not in focus) and a hair (at upper left corner) on outer surface of trochanter; B, ventral view of distal end of antenna, showing three compound olfactory organs, and just beneath them four olfactory pores (only one shows plainly); C, a greater magnification of the above three compound olfactory organs. Attention is called to the pore apertures (small circles) in their plates.
Hilton (14), who used the section method for tracing nerves to hairs and also the method of injecting methylene blue just beneath the integument of live larvae, mostly Lepidoptera, summarizes his results as follows:

Lepidopterous larvae are clothed with hollow hairs, each of which is supplied by a bipolar nerve cell, a process of which penetrates a short distance into the hair and probably terminates before reaching the tip. In most species all body hairs are sensory; large hairs are supplied by large bipolar nerve cells, and small ones by smaller bipolar cells. Under the hypodermis of caterpillars there is a system of multipolar cells more or less intimately connected with nerve cells and fibers which stain lighter than the larger nerves and are closer to the hypodermis than the other cells and fibers. Nerves from bipolar sensory nerve cells go to the central nervous system, run to the ganglia, leaving at once to follow on the outside of the connectives cephalad, forming a well-marked sensory tract. Motor nerves—those that go to muscles—seem to come directly from the central cell areas of the ganglia. Almost the only sensory termination of nerves on the body of insects is by means of hairs.

Hilton furthermore states:

In the larvae of May beetles the hairs of the body surface are supplied with bipolar nerve cells.

In the mind of the present writer it is very questionable whether all the hairs on any larva are actually sensory.

Zawarzin (60) used a similar method of injecting methylene blue into live larvae of three species of Aeschna, and he also used the section method for studying the chitinous apparatus of the sense organs. Very often he had no success with the methylene-blue method, but after much experience he was able to trace nerves to the body hairs.

The present writer, using live larvae of the boll weevil, tried the injection method used by Zawarzin, but had no success in the few preliminary tests conducted, and did not make further attempts because of the lack of live larvae at the time.

### Table 7.—Disposition of sense organs on larva of cotton boll weevil

<table>
<thead>
<tr>
<th>Divisions</th>
<th>Sense hairs</th>
<th>Sense bristles</th>
<th>Sense pegs</th>
<th>Olfactory pores</th>
<th>Eyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head capsule</td>
<td>Several</td>
<td>Several ?</td>
<td>None</td>
<td>18</td>
<td>Vestigial ocelli.</td>
</tr>
<tr>
<td>Antenna</td>
<td>None</td>
<td>None</td>
<td>?</td>
<td>1 at base</td>
<td></td>
</tr>
<tr>
<td>Mandible</td>
<td>2</td>
<td>2</td>
<td>None</td>
<td>3 or 4</td>
<td></td>
</tr>
<tr>
<td>Labium</td>
<td>2</td>
<td>2</td>
<td>Several</td>
<td>3 on palp, 4 on ligula.</td>
<td></td>
</tr>
<tr>
<td>Mentum</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Submentum</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Labrum</td>
<td>2</td>
<td>4</td>
<td>10 ?</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Clypeus</td>
<td>2</td>
<td>2</td>
<td>None</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Maxilla</td>
<td>2</td>
<td>Several ?</td>
<td>Several</td>
<td>1 on stipes, 2 on palp, 1 on lab, 4 on palpus.</td>
<td></td>
</tr>
<tr>
<td>Thorax</td>
<td>Few on second segment, probably few on other segments.</td>
<td>Several on second segment, probably several on other segments.</td>
<td>None</td>
<td>4 on second segment.</td>
<td></td>
</tr>
<tr>
<td>Epipharynx ?</td>
<td>None</td>
<td>None</td>
<td>Few</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

### OTHER SENSE ORGANS

Besides the olfactory pores and tactile hairs (fig. 11) already described, we should hardly expect to find other sense organs in the larva of the cotton boll weevil; but vestigial ocelli, nevertheless, were found in sections through the head near the antennae. Sphere-
shaped masses of dark-brown granules, the rudiments of the internal anatomy of these eyes, were present, but no convex cornea was visible; however, the chitin above these granular masses was thin and unpigmented, and thus this rudimentary eye might be able to distinguish light from darkness.

Fig. 16.—Internal and external structure of body wall of boll weevil: All figures are mostly diagrammatic. A, section from tibia; B, section from trochanter; C, superficial view from trochanter of front leg, showing Group 7 of olfactory pores; D, superficial view from wing, showing portions of media (M), radius (R), and six pores of Group 6; E, superficial view from elytron; and F, section passing crosswise through elytral puncture (n) a, Primary, and b, secondary cuticula; c, hypodermis; d, chitinous cone; e, sense cell; f, tactile hair (No. 1); g, gland cell; h, noninnervated hair on leg; i, prickle or noninnervated pseudohair on wing; j, large club-shaped, noninnervated hair on elytron; k, hair socket or alveolus; l, border of puncture; m, noninnervated hair lying over opening (n) of elytral puncture; e, trichogen cell forming club-shaped hair (f); p, olfactory pore; and po, pore of gland. A and B, X 714; C to F, X 271

No attempt was made to find chordotonal organs in the larva. They may be present, for Comstock (5, p. 148) says:

Chordotonal organs have been observed in so many larvae that we may infer that they are commonly present in larvae. These organs are very simple compared with those of certain adult insects.

Credit is due Schiødte (51, 1869) for describing and figuring chordotonal organs for the first time. He found them on the thoracic segments of buprestid larvae. Graber (10) described chordotonal
organs in the larvae of Dytiscus, and Hess (12) has given us a good description of them in cerambycid larvae. In 1874 Schiodte (51, p. 88) gave an account of the stridulating organs in the larvae of certain Scarabaeidae and Lucanidae.

Larvae, like adult insects, certainly have general senses, but nothing definite is known about them. The subhypodermal nerve plexus, described by Hilton (14) and several earlier writers, may serve as receptors for temperature and humidity.

HOW PLANTS ATTRACT INSECTS BY SMELL

It was assumed in the introduction that cotton plants emit odors which attract boll weevils, but so far no proof in support of this assumption has been given. Although the writer has not been in a position to work extensively with boll weevils and cotton plants, he has nevertheless carried on the same line of work using other insects and their host plants. Only a very brief summary of the results of these experiments can be given here.

As flowers are generally more or less fragrant, so the foliage of most plants also emits odors. These odors are usually weak, judged by the human olfactory sense, but to the insect which feeds upon the foliage such may not be the case. Of course, it was impossible to test the response of the insect to the odor of its host plant in the field, because the interfering factors could not be controlled. Consequently it was necessary to develop a special apparatus to be used in the laboratory. A full description of this apparatus, called an insect “olfactometer” and already mentioned under “olfactory experiments,” is now in print (38).

The name “olfactometer” means an olfactory measuring apparatus. The one devised has been used to measure or record the responses of insects to attractants and repellents. Briefly stated, it consists of a specially constructed Y-tube, through which insects pass from a dark chamber, being attracted by a light suspended near the free ends of the forks of this tube. The dark chamber is attached to the base of the Y-tube, and a suction apparatus to draw odors through the forks is attached at the point where the base and forks unite. The insects are attracted equally toward the entrances of the forks by the light stimulus, but when ready to enter these forks they are influenced unequally by the odors drawn through the forks, one fork serving as an attractant or repellent side, and the other fork as the control side.

The whole apparatus is so constructed and manipulated that the interfering factors are practically controlled, leaving only the olfactory responses to be recorded.

Only the results obtained with the Colorado potato beetle (Leptinotarsa decemlineata Say) will be given here to show that plants attract insects by the odors which they emit. A small potted potato plant was placed in a special chamber of the olfactometer, and a gentle current of air was drawn over it into one fork of the Y-tube by means of the suction apparatus. This supposedly scented air could not be smelled by the writer, but the potato beetles responded to it readily. This experiment on various dates and under different conditions was repeated 24 times, 4 individual tests being considered as one experiment. Each of these 25 experiments plainly showed that the beetles had responded to the odors or emanations from the living potato plants. On an average, 62.7 per cent of them went toward these
odors, while the other 37.3 per cent went (perhaps accidentally) into the control fork. The highest percentage obtained was 76.7 toward the plant odors. Potato beetles, when potato plants are scarce or entirely wanting, feed on the horse nettle, jimson weed, and tomato plant. Experiments similar to the above were conducted in which these plants were used, but as a rule the beetles did not seem to like the odors from these three species. They often failed to respond, and not once did their response give a high percentage of attractiveness.

Eighty experiments were conducted, using the water extracts (diluted juices) and steam distillates of the potato tuber and foliage of the following plants: Potato, jimson weed, horse nettle, tomato, and henbane. In these experiments air was bubbled through the liquids and then drawn into one fork of the Y-tube. In the other or control fork air was bubbled through distilled water. To the odors from the water extracts of potato tubers and potato foliage the beetles always responded, except once, but not as strongly as to the odors from the living potato plants. To the odors from the extracts of the other plants mentioned the beetles usually responded, and more strongly than they had to the odors from the living plants of the same species. To the odors from the steam distillates the beetles generally responded, although many times repellently. The odors from the jimson weed distillate remained repellent throughout the tests; the odors from the other distillates were usually repellent for some time, but later became attractive. The odors from the distillates of the potato tuber, horse nettle, and tomato were only slightly attractive, but those from the potato foliage and henbane were usually strongly attractive. It seems that the steam removed something from these plants which was repellent to the beetles for a time, but later, when this apparently repellent substance had been either changed or volatilized by bubbling air through the liquids, the odors became attractive. When the odors from all these distillates, except from jimson weed, had become attractive to the insects, the liquids gave off a common odor, judged by the nose of the writer. This odor closely resembled that from boiling potatoes or from the juice of freshly cut potatoes, and might be called a potato odor. Since all of these plants belong to the potato family (Solanaceae), it would be interesting to know whether they possess a particular constituent or constituents which emit a common odor, as indicated by the above experiments.

Assuming that the cotton plant emits some volatile and odorous substance which attracts boll weevils from a considerable distance, Power and Chesnut (44, 45), of the Bureau of Chemistry, undertook to isolate this substance. Among the 12 individual substances found by them in the concentrated distillate, which included all the odorous and volatile constituents in the cotton plant, 3 are of particular interest for chemotropic tests. These are the so-called essential oil and 2 basic substances, ammonia and trimethylamine. The percentage of oil isolated is so very small that these writers believe it can not have any significance in attracting boll weevils, and, furthermore, despite the fact that more ammonia was found than trimethylamine, they conclude that if the cotton plant really possesses an attractive odorous constituent, it is in all probability the trimethylamine. If so, the difficult task for the entomologist is to use the substance properly. Of all substances having powerful and persistent odors, trimethylamine is certainly one of them, as illustrated by
the following. Before using a small bottleful of this material, prepared by Power and Chesnut, the writer kept it well stoppered for a few days in a drawer with a small dictionary and some stationery. Both became permeated with the odor, and for weeks afterwards smelled strongly of it. The dictionary still emits a faint odor after a period of two years.

The writer tested the sample of trimethylamine mentioned above in only a preliminary way, using a comparatively few old weevils which had come to the cotton plants from their hibernating places, and the most that he can say in its favor is that it seemed to attract the weevils slightly under certain conditions.

The writer entertains a serious doubt whether it is possible to reproduce accurately the odor or odors which emanate from a plant merely by using the constituents derived from the plant by chemical means. It seems that the most that may be hoped for is an imitation closely resembling the plant odor and even with this it may be difficult and sometimes impossible to deceive the insects. This whole subject is closely related and perhaps analogous to the making of perfumes for the use of the human species. Expert perfumers admit that, after all their long experience in trying to reproduce exactly the odors found in living flowers, the best they have been able to do so far is to imitate closely the natural odors. In many cases the layman can not tell these artificial odors from the natural ones, but the expert perfume tester can readily distinguish them. Insects, which evidently have a keener sense of smell than human beings, should be able to distinguish these differences even more readily.

To find a substance, preferably a sweet one, which would attract boll weevils equally as well as do cotton squares (flower buds), many experiments were conducted in the laboratory and cotton field, using saccharine, sugar, ice-cream powder, a sweetened proprietary calcium arsenate, honey, and three brands of molasses (karo, koo-koo, and blackstrap). The honey and ice-cream powder seemed to attract the weevils slightly, but there was no indication that any of these eight substances can be of practical importance in the control of these insects. Similar results have been obtained by other writers who have tried to attract boll weevils by the use of sweetened baits.

**SUMMARY OF SENSES OF COTTON BOLL WEEVIL**

Since the sense of smell in boll weevils is believed to be the primary one which aids them in locating cotton plants, the two kinds of so-called olfactory organs have been thoroughly studied and described. The organs, called olfactory pores by the writer, are common to both the adult and larva; but the other so-called olfactory organs, which are nothing more than ordinary innervated hairs, are common only to the antennae of the adult, although similar innervated hairs are also found on other parts of both adult and larva. In the adult the olfactory pores were found on the head capsules, legs, elytra, wings, mouth parts, and at the base of the antennae; in the larva, on the head capsule, base of antennae, mouth parts, clypeus, and second thoracic segment. The individual and sexual variations found in the pores of each of five males and five females were small, although the females have 13.7 per cent more pores than have the males. The anatomy of these pores is like that described for many other beetles by the writer (30), except that some
of them are slit shaped, closely resembling those in spiders. These are found on the maxillary palpi of both adult and larva and on the legs of the adult.

The antennae of boll weevils have four types of sense organs, as follows: Many innervated hairs, chiefly on the club; three or four olfactory pores at the base of each antenna; and two so-called auditory organs in the second segment. Not one of these organs, except the olfactory pores (fig. 13), is suited anatomically to receive olfactory stimuli. The hairs are all long, thick-walled throughout their full length, and consequently odors can not pass through them. The so-called auditory organs are totally internal, having no outside connections whatever, so that they certainly can not receive olfactory stimuli.

Innervated hairs were found widely distributed over the surface of the boll weevil, being present on the head capsule, antennae, mouth parts, thorax, legs, wings, abdomen, and genitalia. According to their structure they seem to be fitted only for tactile organs, and, judging from their number and distribution, the sense of touch must be highly developed. When the insect is once upon its proper food and ready to deposit eggs, the tactile sense may be more important than the olfactory sense. The numerous sensitive hairs on the antennae, mouth parts, ovipositor, penis, and elsewhere must certainly render great aid in the various activities of the boll weevil.

No organs were found which can really be called taste organs, although some of the smaller innervated hairs on the mouth parts of both adult and larva would be designated taste organs by certain writers. The present writer believes that the senses of smell and taste in insects are inseparable, but since insects in many cases must first "taste" certain foods before they can discriminate between them, this combined sense may be comparable to ours when we smell flavors.

Three so-called auditory organs were found—two in the pedicel or second antennal segment and one in the base of each wing. We know nothing about the function of these organs, and, indeed, it is difficult to imagine what their offices might be, unless they receive some kinds of waves which we can not detect, such as some of the inaudible sound waves, or even radio waves; but the writer has been informed that radio waves can not be considered in this connection.

Judging from the structure of the compound eyes, the visual field of the boll weevil is small and its image of objects is neither sharp nor distinct, indicating that it can not by sight alone distinguish from a distance cotton plants from certain other plants, or in all probability even the various parts of a cotton plant when it is near them.

As a corollary to the sense organs, the scent-producing organs, sometimes called scent glands or recognition glands, were also studied. These are minute, unicellular, hypodermal glands, and are widely distributed over the surface of the insect. Their secretion comes to the surface, spreads out over the integument, and, besides keeping the body moist, is also supposed to give off an odor which probably serves as a recognition odor among the beetles themselves.

The reader will have noted that the olfactory sense has been greatly emphasized, perhaps too much, but in the present state of our knowledge there seems to be no other tangible sense or senses which serve quite so well to explain how boll weevils find cotton plants from
a distance. When they have once found their food or a place to deposit eggs, we can easily think of two or more senses being employed, in their activities thereafter, touch, smell, and "taste" particularly being used during feeding and egg laying, as has recently been pointed out by Richardson (49), who reviewed the literature pertaining to the oviposition response of insects.

LITERATURE CITED

<table>
<thead>
<tr>
<th>Reference</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>(38)</td>
<td>———. 1926. AN INSECT OLFACTOMETER. Jour. Econ. Ent. 19: 545–571, illus.</td>
</tr>
</tbody>
</table>
(41) MINNICH, D. E.  

(42) NAGEL, W. A.  

(43) PIERSOL, G. A.  
[1923.] HUMAN ANATOMY. Ed. 8, 2104 p., illus. Philadelphia and London.

(44) POWER, F. B., and CHESNUT, V. K.  
1924. ALKALINE REACTION OF THE COTTON PLANT. Science (n. s.) 60: 405.

(45) and CHESNUT, V. K.  

(46) RÁDL, E.  

(47) RATH, O. VOM  


(49) RICHARDSON, C. H.  

(50) RILEY, C. V.  

(51) SCHIØDTE, J. C.  

(52) SINGH, P., and MAULIK, S.  
1911. NATURE OF LIGHT EMITTED BY FIREFLIES. Nature 88: 111.

(53) SMITH, G. D.  

(54) SNODGRASS, R. E.  

(55) TURNER, C. H.  

(56) and SCHWARZ, E.  

(57) VERSCHAFFELT, E.  

(58) WESTRING, N.  
1847. BIDRAG TILL HISTORIEN OM INSEKTERNES STRIDULATIONS-ORGANER. Naturhist. Tidsskr. (2) 2: 334-345.

(59) WOLLASTON, T. V.  

(60) ZAWARZIN, A.  