

the electrode voltage applied. (Maximum estimated field intensities in the insects used in these experiments are on the order of 1 kv/in.). Therefore, much shorter exposures are required for comparable mortality as the electrode voltage is increased. Data in Table 1 bear out this relationship, for a 2-sec exposure at 3.6 kv is equivalent in resulting mortality to an 8-sec exposure at 1.8 kv. For longer exposures, the ratio of exposure for equivalent mortalities at 1.8 and 3.6 kv becomes somewhat less than 4. This deviation is likely attributable to increased damage resulting from the longer time at elevated temperatures during the lengthy exposures at the low electrode voltage.

When *T. molitor* larvae were exposed for 5 sec to 39-MHz electric fields in the holder described with 3.6-kv rf potential across the holder, mortality of 50% or greater always resulted within 24 hr, and within 1 week the mortality increased to 90% or more. When the larvae were exposed under the same conditions for 3.5 sec, 50% mortality occurred only after 2 weeks. Exhaustion of the food reserves may be a factor in delayed mortality, for injured larvae did not feed after treatment.

Temperature measurements in different regions of the larval body showed that temperatures in the thorax and last abdominal segment approached levels which would be lethal if the insects were maintained at those temperatures for several minutes. At least 80% of the insects receiving exposures expected to produce thoracic temperatures greater than 130°F died within 1 day after treatment, and about 95% were dead within 1 week. Internal heating thus appears to be a likely explanation for the resulting mortality.

The high temperatures produced in the thorax and last abdominal segment may be explained by the presence of legs on the thorax, the 2 sharp, pointed urogomphi which project dorsally from the last abdominal segment, and the 2 fleshy, fingerlike projections under the anus. These appendages reduce the air gap between the insects and the electrode, thus providing higher field intensities in those body regions. Differences in the dielectric properties of

Table 2.—Thoracic temperatures (°F) of sixth-instar *T. molitor* larvae following radiofrequency electrical treatment at 39 MHz with 3.6 kv across holder. Pretreatment larval temperature 75°F.

Exposure (sec)	Temperature*		
	Exp. 1	Exp. 2	Avg
1.1	94	93	94 f
2.1	107	104	106 e
3.0	113	115	114 d
4.0	125	122	123 c
5.0	125	132	128 b
6.0	134	131	132 ab
7.1	134	136	135 a

* Figures for each experiment are means for 5 insects. Therefore, averages are for 10 insects. Means followed by the same letter are not significantly different at the 5% probability level.

Table 3.—Temperature distribution in sixth-instar *T. molitor* larvae following radiofrequency electrical treatment for 7 sec at 39 MHz with 3.6 kv across holder. Pretreatment larvae temperature 75°F.

Body region	Temperature* (°F)			
	Exp. 1	Exp. 2	Exp. 3	Average
Cervical	124	129	133	129 c
Prothorax-mesothorax	137	138	137	137 a
Mesothorax-metathorax	128	132	132	130 bc
First abdominal segment	127	129	124	127 cd
Fourth abdominal segment	123	122	124	123 d
Last abdominal segment	134	129	139	134 ab

* Figures are means for 5 insects in Exp. 1 and for 6 insects each in Exp. 2 and 3. Therefore, averages are for 17 insects. Means followed by the same letter are not significantly different at the 5% probability level.

tissues in the various regions of the insect could also cause temperature differentials.

Morphological changes were noted in adults developing from rf-treated larvae, and physiological differences between rf-treated and untreated insects have also been studied, but these will be subjects of subsequent papers.

CONCLUSIONS

Mortality of *T. molitor* larvae exposed to 39-MHz radiofrequency (rf) electric fields in confining polystyrene holders increased as expected with increasing length of exposure and increasing rf electrode voltage across the holder. Mortality continued to increase over a 2-week period following rf treatment. An exposure for 7 sec at a high electrode voltage resulted in complete mortality after 1 week. Exposures of this level produced thoracic temperatures of about 135°F, and shorter exposures resulted in correspondingly lower temperatures. Temperatures produced in the last abdominal segment were nearly as high as those in the thorax, but temperatures in the cervical region and in first and fourth abdominal segments were significantly lower.

While some evidence is cited for nonthermal biological effects of rf electric fields on insects, temperatures measured in the larvae after rf treatment would indicate that mortality can be accounted for by internal heating to lethal levels.

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Morphological Abnormalities Resulting from Radiofrequency Treatment of Larvae of *Tenebrio molitor*¹

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ABSTRACT

Adults developing from larvae of the yellow mealworm, *Tenebrio molitor* L., exposed at sublethal levels to radio-frequency electric fields, exhibited malformed and missing legs. The number of imaginal legs was reduced as exposure time increased. The degree of leg malformation increased when treatment was administered later during

the last (sixth) instar. Similar treatments of fifth-instar larvae did not interfere with normal imaginal leg development. Deformities most likely result from heat damage to the histoblasts which project into the legs of the last-instar larvae.

Studies concerning mortality and thermal effects of radiofrequency (rf) electric fields on larvae of the yellow mealworm, *Tenebrio molitor* L., were reported by Kadoum et al. (1967). Observation of adults developing from larvae exposed to rf fields during the last instar revealed morphological abnormalities which included malformed and missing legs.

Histoblasts found in the thoracic region of last-instar larvae are the anlagen for the legs of adult insects. Goin (1894), Kellogg (1901, 1904), and Verson (1904) determined that the legs of insects having complete metamorphosis are derived from histoblasts which develop from an invagination of the larval hypodermis and exist within the body wall of the larvae at the bases of the larval legs. In this location, the histoblasts lie in the pathway formed by the legs and thorax, and would be subject to heating caused by exposure to rf electric fields. The purpose of the work presented here was to study the effects of

rf energy on histoblast development in last-instar *T. molitor* larvae.

MATERIALS AND METHODS

T. molitor larvae were reared, handled, and exposed to the rf electric fields in special polystyrene holders as described by Kadoum et al. (1967).

Two different field intensities were employed at a frequency of 39 MHz (megahertz = megacycles/sec). With the electrodes in contact with the top and bottom of the polystyrene holder, an electrode voltage of 3.6 kilovolts (kv) was used for 1 experiment, and 0.9 kv was used for another. The larvae were also separated before treatment into last-instar and penultimate-instar groups. Following treatment, the larvae were placed in individual containers for observation. Bran and pieces of potato provided food and moisture in each container.

RESULTS

Sublethal rf exposures of sixth (last)-instar larvae resulted in malformation or complete absence of legs in adults developing from such larvae. Exposure in the fifth instar caused no apparent injury to the imaginal legs. The nature of the abnormalities resulting from exposure in the last instar is illustrated in Fig. 1-6.

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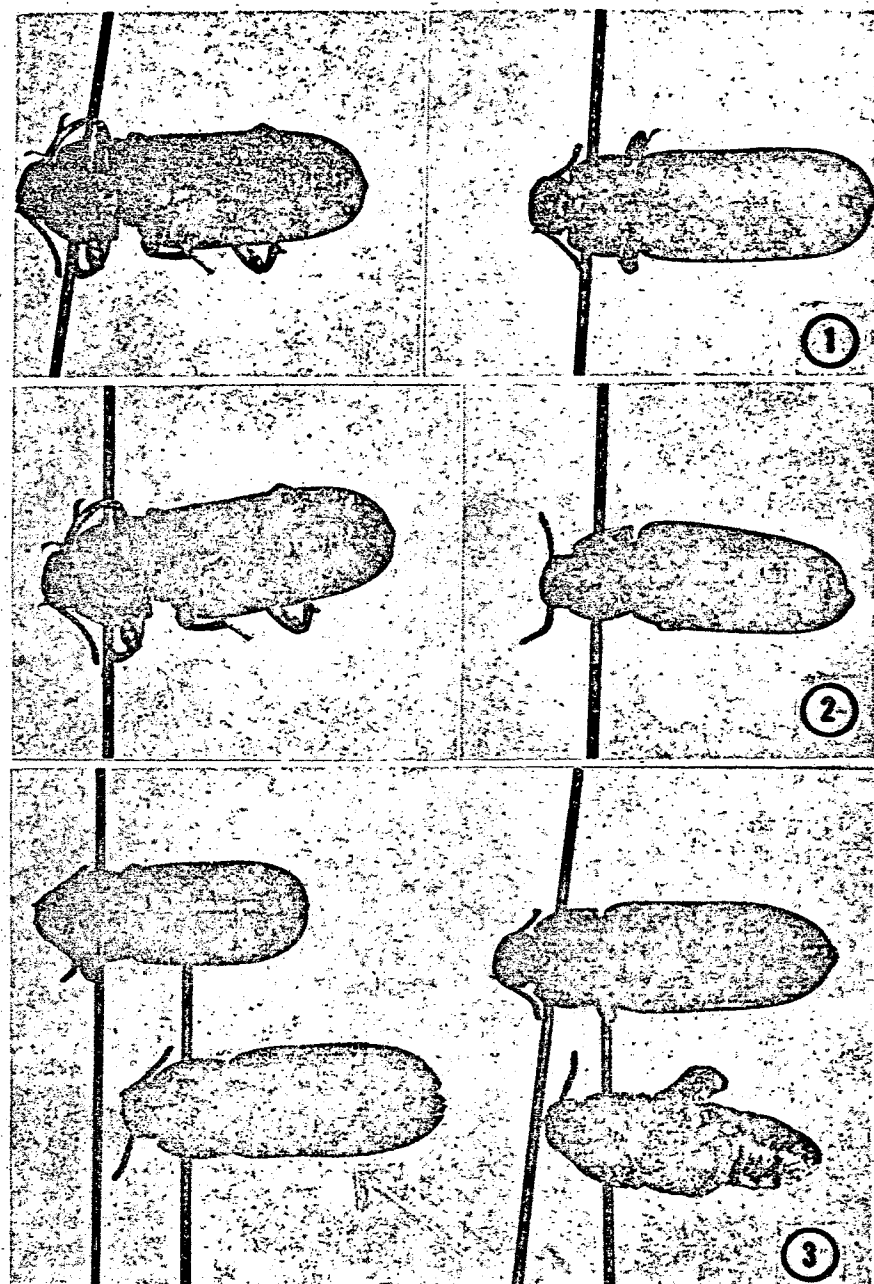


FIG. 1.—Typical adults which developed from larvae treated in fifth instar (left) and sixth instar (right) for 0.5 sec with 3.6-kv rf electrode voltage across polystyrene holder. FIG. 2.—Typical adults which developed from larvae treated in fifth instar (left) and sixth instar (right) for 2.0 sec with 3.6-kv rf electrode voltage across polystyrene holder. FIG. 3.—Typical adults which developed from larvae treated with 3.6-kv rf electrode voltage across polystyrene holder for 0.5 sec (upper left), 1 sec (upper right), 2.5 sec (lower left), and 4 sec (lower right).

Typical adults which developed from fifth- and sixth-instar larvae receiving a 0.5-sec exposure to the rf electric field are compared in Fig. 1. Only the prothoracic legs developed following the 0.5-sec treatment of the last-instar larvae. A similar comparison for a 2-sec exposure shows that legs did not develop when larvae were treated in the sixth instar, but legs developed normally following exposure during the fifth instar (Fig. 2).

The influence of exposure time on imaginal leg

development is further illustrated in Fig. 3 and 4. Imaginal leg development was completely inhibited by 2.5- and 4-sec exposures, while partial leg development was observed for 0.5- and 1-sec exposures. In addition, the 4-sec exposure resulted in adults with deformed wings and empty coxal cavities. On increasing exposure, injury resulted first to the meta-thoracic legs and progressed forward through the meso- and prothoracic legs. When exposure times were 2 sec or less, the imaginal legs were injured

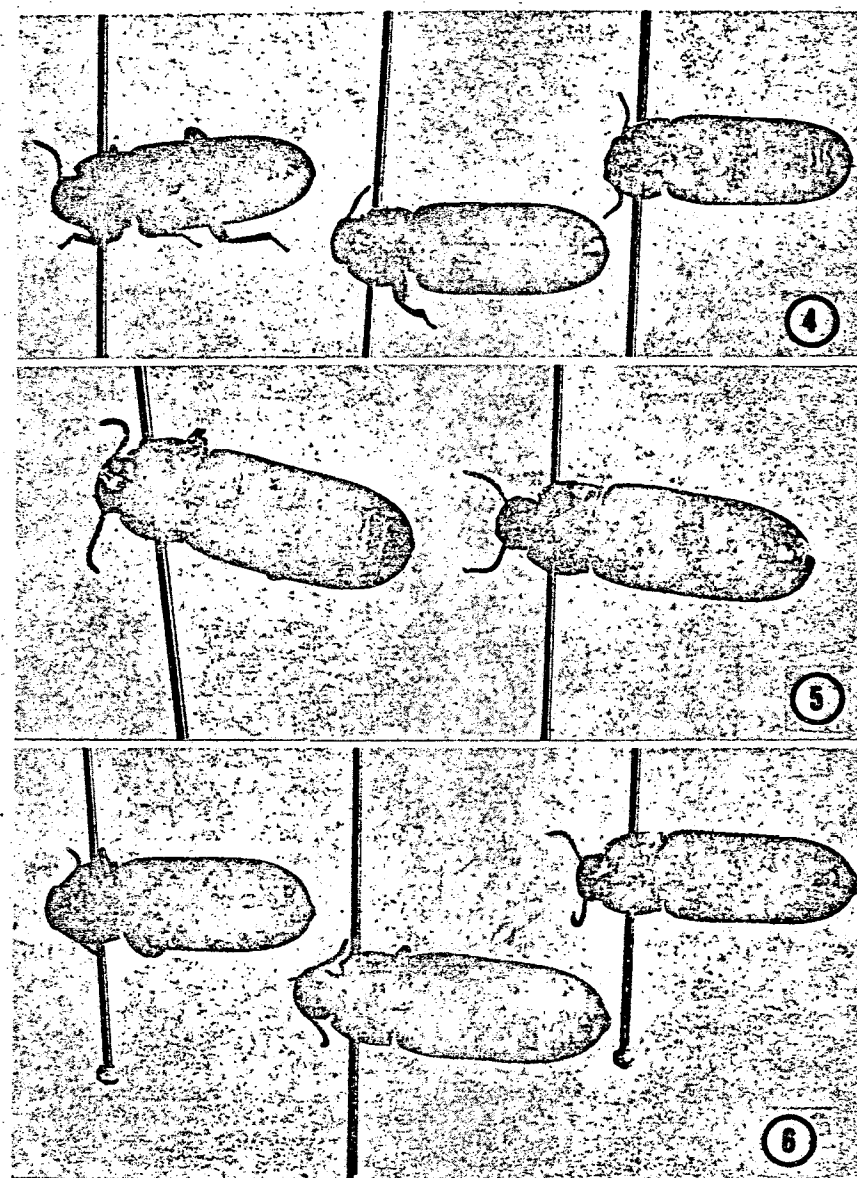


FIG. 4.—Typical adults which developed from larvae treated with 0.9-kv rf electrode voltage across polystyrene holder for 14 sec (left), 28 sec (center), and 56 sec (right). FIG. 5.—Typical adults which developed from larvae treated with 0.9-kv rf electrode voltage across polystyrene holder for 42 sec during early (left) and late (right) periods of the last instar. FIG. 6.—Typical adults which developed from larvae treated with 3.6-kv rf electrode voltage across polystyrene holder for 1.5 sec during early (left), middle (center), and late (right) periods of the last instar.

only distal to the trochanter. In most cases, when exposure exceeded 2 sec, the entire appendage was missing.

Similar gradations in damage to imaginal leg development resulted when exposure time to lower intensity rf electric fields was varied (Fig. 4). Longer exposures were required at low field intensities than were needed at high field intensities to produce comparable damage.

Larval age within the last instar was also critical in determining the degree of damage to imaginal leg development. Exposures to 0.9-kv rf electric fields early in the last instar were not so damaging as exposures later in the instar period (Fig. 5). Similarly, treatments at 3.6 kv late in the last instar were more damaging than those given earlier in the last instar (Fig. 6). The influence of larval age at the time of treatment during the last instar and the effect of length of exposure on imaginal leg development are further defined by data in Tables 1 and 2. The number of imaginal legs developing subsequent to rf treatment of larvae during the final instar is inversely related to both exposure time and age of the larvae.

DISCUSSION

Malformation and absence of imaginal legs undoubtedly result from injury to the histoblasts when the larvae are exposed to rf electric fields during the last instar. Since the histoblasts project into the legs of the last-instar larvae, they are more susceptible to damage than are those of earlier instars. The injury most likely results from heating, which occurs during

Table 1.—Average number of imaginal legs developing after rf treatment of last-instar *T. molitor* larvae. Twenty larvae of each age group were treated at 39 MHz with 3.6 kv across holder at indicated times before pupation.

Exposure time (sec)	Days before pupation		
	10 to 11	8 to 9	5 to 7
0.5	6.0	5.0	2.0
1.0	3.0	2.0	1.0
1.5	2.0	1.0	0
2.0	1.8	1.3	0

A Revision of the Subfamily Stolidosominae (Diptera: Dolichopodidae)¹

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ABSTRACT

Three genera are recognized in the subfamily Stolidosominae, *Stolidosoma* with 17 species, *Sympycnidelphus* with 3 species, and *Pseudosympycnus*, a new genus with 5 species. *Stolidosoma flavidum*, *S. varipes*, *S. inornatum*, *S. abdominale*, *S. acutum*, *S. hexachaeta*; *Sympycnidelphus tibialis*, *S. coxalis*; *Pseudosympycnus bicolor*, and

P. perornatus are described as new. *Argyra violacea* Van Duzee and many species described in *Sympycnus* are transferred to the subfamily and 2 species named in *Stolidosoma*, *S. tarsale* Van Duzee and *S. obscurum* Parent, are tentatively excluded.

Table 2.—Average number of imaginal legs developing after rf treatment of last-instar *T. molitor* larvae. Twenty larvae of each age group were treated at 39 MHz with 0.9 kv across holder at indicated times before pupation.

Exposure time (sec)	Days before pupation	
	9 to 11	6 to 8
14	6.0	6.0
21	5.5	3.8
28	4.8	2.5
35	3.7	1.4
42	1.5	0
49	1.0	0
56	0	0

exposure to the rf electric fields. Higher temperatures were observed in the thorax than in most other regions of the larval body following exposure to rf electric fields, and the presence of legs in this region was believed to be a contributing factor (Kadoum et al. 1967). Frings (1952) observed damage to legs of adult insects exposed to rf electric fields and attributed this damage to rapid heating in the legs which serve as conducting paths for the high-frequency current. The likelihood of higher field intensities being developed in the thoracic region appears to support the idea that imaginal leg malformation results from heat injury to the histoblasts.

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in the American tropics and contains some of the largest and most distinctive members of the family. Still, since Becker's (1921) original efforts, based on

relatively little material, no careful analysis of the subfamily has been attempted. The following treatment provides a review of the diagnostic characters of the subfamily, and keys are furnished for the 3 genera and 25 species presently known.

Becker described the Stolidosominae as a group in 1921 with the single genus *Stolidosoma*. He compared the group with both the Neurigoninae and Diaphorinae. The Stolidosominae were said to resemble the Neurigoninae in the long slender abdomen, slender legs, and the form of the head, but to lack the depression on the mesoscutum and the larger hypopygium. In the latter characters the Stolidosominae agreed with the Diaphorinae, and Becker particularly emphasized the resemblance to the diaphorine genus *Symbolia*.

Although Becker placed his new group adjacent to the Sympycninae (Campsicneminae), he made no comparison and provided no reliable distinguishing characters. Nevertheless, it is the Sympycninae to which the Stolidosominae seems most closely related and with which it is most easily confused. Both Parent (1930) and Van Duzee (1931) described members of the Stolidosominae as species of *Sympycnus*. As presently recognized, the Sympycninae is a diverse group within which *Stolidosoma* and its relatives could be easily accommodated. However, it seems best to maintain the subfamily Stolidosominae and to anticipate other future subdivisions of the Sympycninae.

When the Stolidosominae are compared with the genera *Sympycnus* and *Calyxochaetus*, 3 characters are apparent which indicate that the former is a distinct and natural group. The Stolidosominae have 5 large pairs of dorsocentral bristles; a sixth anterior pair is very reduced in size except in 1 species. In *Sympycnus* and related genera there are usually 6 well-developed pairs of dorsocentrals, of which the fifth pair is subject to reduction or displacement (in at least 1 case being completely absent and leaving a rather obvious gap). Secondly, in the Stolidosominae the second joint of the male fore tarsus is modified in every presently known species. This feature is sometimes very pronounced as obvious deformation or shortening but sometimes is represented only by a brush of fine pale hairs borne on 1 side. In many cases, other joints of the fore tarsus are not modified. In *Sympycnus* and its relatives the first joint or the apical joints of the fore tarsus may be modified, but rarely the second joint. The male Stolidosominae are also distinct by a notch that occurs dorsally or anterodorsally in the tip of the hind tibia. This feature is very obvious in *Sympycnidelphus* with its distorted hind tibia, but it is usually very small in *Stolidosoma*. In *Sympycnus*, in contrast, there is no notch whatsoever, the apical margin being completely straight.

The Stolidosominae as delimited here show unusual uniformity in the structure of the male genitalia. In all species the hypopygium is relatively short, borne on the tip of the preabdomen, the lower anterior end consists of a pair of short broad armatures below which are borne a pair of lanceolate, densely

pubescent lamellae. No gross differences between species or genera have been observed except in *Sympycnidelphus coxalis* where the hypopygium is longer and projects prominently downward from the end of the preabdomen.

The subfamily is basically divided into 2 groups. One group has a normal ocellar triangle, has numerous setae on the anterior slope of the mesonotum, and has 2 distinct rows of acrostichal setae. This group includes *Sympycnidelphus* and *Pseudosympycnus*. The second group, containing the genus *Stolidosoma*, shows a very prominent ocellar tubercle in all but 1 species, the setae are less prominent on the anterior slope of the mesonotum, and the acrostichals vary from partly biseriata to uniseriate or lacking.

The following key distinguishes the 3 genera of the Stolidosominae recognized here. These are restricted to the Western Hemisphere and, with 1 exception, to the Neotropical region. Although possibly not related, certain described features of the Indomalayan genus *Chaetogonopteron* are reminiscent of this subfamily.

- Hairs present on posterior surface of hind coxa; last part of fifth wing vein about half as long as the crossvein..... *Stolidosoma* I
Posterior surface of hind coxa bare; last part of fifth vein as long as the crossvein or longer.... 2
- Acrostichal setae uniseriate or lacking; mesonotum with shining metallic blue or violet coloration..... *Stolidosoma* II, III
Acrostichal setae distinctly biseriata; mesonotum metallic green dulled or obscured by pollen..... 3
- Wing with crossvein half as long as last part of fifth vein; dorsocentral bristles in nearly straight line; male with face and palpus plain, fore and hind tarsi not highly ornamented. *Sympycnidelphus*
Wing with last part of fifth vein about as long as crossvein; fifth pair of dorsocentral bristles displaced toward mid line; the enlarged palpus and the face of the male covered with silvery white pollen, fore and hind tarsi highly ornamented.... *Pseudosympycnus*

Genus *Stolidosoma* Becker

Becker, 1921: 213; Type-species, *permutans* Becker, 1921: 217; present designation.

Medium size to large, partly yellow, sometimes rather bluish or black, with setae mostly dark. Face narrow and sometimes obliterated in the middle, wider above and below, in the male sometimes projecting well below lower margin of eyes; front broad, broader above, usually blue or violet; ocellar bristles mounted on a pair of prominent tubercles behind anterior ocellus. Antennal segment 1 with or without setae above; segment 2 truncate apically; arista dorsal near base of segment 3. Hind surface of head rather flat in male, lower postocular setae pale. Thorax without noticeable prescutellar depression, usually shining bluish along middle of dorsum; acrostichals weak, biseriata, uniseriate or lacking; 5 pairs of strong dorsocentrals, a sixth anterior pair usually very small; scutellum with a pair of large bristles, otherwise bare; proepisternum with clustered pale hairs, sometimes nearly bare above. Legs long and slender, fore and middle coxae usually with numerous

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