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Chemical Insect Attractants

Insects promote their own destruction in responding to traps baited with specific lures.

Martin Jacobson and Morton Beroza

Insects have managed to persist in hostile surroundings because they have developed extraordinary adaptations or abilities, one of which is a highly specialized sense of smell. Some insects can follow unerringly an odor trail to a source of food, to host plants and animals, to the opposite sex, or to the right place to lay eggs. Because many insects depend for their survival on these odors, frequently they can be attracted by means of a chemical to a trap for detection purposes, or to a toxicant that destroys the insect, or to a substance which makes them incapable of fertile mating.

The naturally occurring sex attractants, emitted by the insect in fantastically minute amounts, are among the most potent, physiologically active substances known today. For example, only 10^{-7} microgram of sex attractant released by a virgin female gypsy moth will lure to her numerous males flying upwind from a distance of ¼ mile or more. Traps baited with infinitesimal amounts of such attractants are being used to delineate areas of infestation, making it unnecessary to spray with pesticides large areas that are uninfested. These lures are usually highly specific, attracting only one or a few closely related species, and then only males. To our knowledge there are no powerful general attractants.

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Attractants may be classified as sex, food, or oviposition lures. The type of lure is inferred or deduced from insect behavior, and the assignment is frequently uncertain. If exposure to a chemical causes a male insect to assume a mating position, the chemical is probably a sex attractant.

Sex Attractants

The key to the survival of insects is their high reproductive potential, which depends on the ability of opposite sexes to find each other and mate. An important, if not essential link of this process is the sex attractant, usually released by the female to lure the male. These chemical messengers have been called "female assembling scents" (*1*) and "sex pheromones," from the Greek "pherein" (to carry) and "horman" (to excite, stimulate) (*2*).

The extent to which sex attractants occur in the insect world is unknown. The more obvious examples of insects attracting mates, as the gypsy moth does, were discovered when males responded to caged or immobilized females. Although such observations are comparatively few, the interesting possibility remains that sex lures may be prevalent among insect species. Uncertainty here arises from our lack of knowledge of insect mating habits. In the case of the European corn borer, *Pyrausta nubilalis* (Hübner), one of our most destructive insect pests, not until observations were made with infrared light was the existence of a sex attractant disclosed (*3*). The honey bee (*Apis mellifera L.*) has a sex attractant which may be extracted with ethyl ether from the mandibular glands of queens (*4*). The drone (males) did not respond to these extracts until materials impregnated with the extracts were suspended from a pole at least 15 feet above ground level. In this manner, the olfactory nature of this lure was demonstrated.

Chemical fractionation of the lipids from the honey bee gland yields "queen substance" (*trans*-9-oxo-2-decenoic acid) (I), which is attractive to drones at 0.1 mg per assay tube, and at least two other substances with some attractiveness. Since sex lures are usually much more potent, the queen substance may not be the true honey-bee sex lure. Indeed, extirpation of the mandibular glands does not necessarily render a virgin queen incapable of mating (*5*), and reconstitution of the lipid complex results in considerably more attractiveness than is shown by individual fractions.

$$CH_3\underset{\underset{O}{\|}}{C}(CH_2)_5CH{=}CH\underset{\underset{O}{\|}}{C}{-}OH$$

(I)

The sex attractants of some species of bumble bee are released by the female abdomen (*6*). Although the odorous substance was not isolated, dummies, rubbed mechanically with freshly caught females, attracted males that attempted copulation with these dummies.

The virgin female of the introduced pine sawfly, *Diprion similis* (Hartig), is capable of attracting exceptionally large numbers of males; one caged female placed in a field attracted well over 11,000 males. Column chromatography of extracts of females yielded a substance which, though impure, in amounts as small as 0.004 microgram, attracted 500 to 1000 males over a distance of 100 to 200 feet within 5 minutes. Activity of an attractant in some types of extracts is often masked, but a potent extract may be recovered by chromatography (*7*).

The elucidation of the chemical structure of sex attractants has been hampered by the infinitesimal amounts of lure emitted by the insect. Thus far the true sex lures of only three insect species have been identified—those from the gypsy moth, *Porthetria dispar* (L.); the silkworm moth, *Bombyx mori* (L.); and the American cockroach, *Periplaneta americana* (L.). These insects have been studied because of their tremendous economic importance. In *P. dispar* and *B. mori* the attractant is formed in the lateral glands of the abdomen of the virgin female. The female is able to protrude and retract these glands, and thus regulate the release of the attractant.

The moth *B. mori*, a native of Europe, is not considered to be a pest, since it is extremely valuable to the silk industry. But *P. dispar* is very destructive to forest and shade trees in New England, causing millions of dollars worth of damage. The female gypsy moth is unable to fly, but the male is a strong flier and is lured upwind by the female scent from a distance of approximately ¼ mile. Although it had long been known that a benzene extract of the virgin female abdominal tips would lure males in the field, it took a great deal of painstaking chemical study over a period of about 30 years to isolate and identify the pure sex attractant (*8, 9*). It was possible to isolate, from an extract of 500,000 virgin female gypsy moths, 20 mg of the pure attractant. A colorless oily liquid showing blue fluorescence in ultraviolet light, it has been identified as *d*-10-acetoxy-*cis*-7-hexadecen-1-ol (IIa) and synthesized (*8, 10*).

$$CH_3(CH_2)_5\underset{\underset{\underset{O}{\|}}{OCCH_3}}{\overset{|}{C}}HCH_2CH=CH(CH_2)_nCH_2OH$$

(II, a, b, and c)

(In IIa, IIb, and IIc, n is equal to 5, 7, and 9, respectively.) Fractions were bio-assayed in field traps (*8, 9*) or in the laboratory (*11*). In the latter method, male gypsy moths, clipped by their wings to a rack and exposed to the scent on a rod or filter paper, exhibited curving of the abdomen and copulatory attempts. The *dl*-form (synthetic) of IIa was successfully resolved by treating the acid succinate with *l*-brucine, separating the brucine salts by fractional crystallization from acetone, decomposing the salts, and saponifying the acid succinates with ethanolic alkali (*12*). Characterization of the natural attractant of the gypsy moth led to the synthesis of a homolog, *d*-12-acetoxy-*cis*-9-octadecen-1-ol (IIb), which has been designated "gyplure" and is almost as attractive to males as the natural lure (*13*); a higher homolog (*d*-14-acetoxy-*cis*-11-eicosen-1-ol) (IIc) was much less attractive to males (*14*). Conversion at the double bond of gyplure to the *trans* form causes a tremendous decrease in activity. Comparisons of the activities of these gypsy-moth attractants are shown in Table 1. The preparation and use of gyplure as a gypsy-moth attractant have recently been patented (*15*).

Table 1. Comparative attractancy of gyplure and its homologs to male gypsy moths.

Compound	Attractancy (μg) Laboratory	Field
d-IIa	10^{-12}	10^{-7}
l-IIa	10^{-12}	10^{-6}
d-IIb (*cis*-gyplure)	10^{-12}	10^{-5}
d-IIb (*trans*-gyplure)	10^{4}	2.5×10^{5}
d-IIc	10^{-2}	10

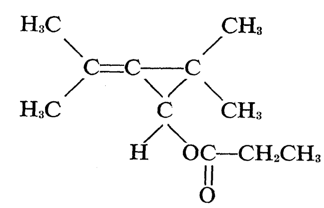
"Bombykol," the sex attractant of the female silkworm moth, has been isolated from an ethanol-ethyl ether extract (3:1) of the abdominal tips; 12 mg of pure attractant was obtained from 500,000 virgin females (*16*), and identified as 10,12-hexadecadien-1-ol (III) (*17, 18*). Although the configuration

$$CH_3(CH_2)_2CH=CHCH=CH(CH_2)_8CH_2OH$$

(III)

in bombykol was at first thought to be *cis*-10, *trans*-12 (*17*), subsequent synthesis of the four possible geometric isomers of III showed that *trans*-10, *cis*-12 was the correct structure (*19*). The four geometric isomers showed the following attractiveness to male silkworm moths (in micrograms per milliliter) in laboratory tests (*20*): *cis*-10, *cis*-12, 1; *cis*-10, *trans*-12, 10^{-3}; *trans*-10, *cis*-12 (bombykol), 10^{-12}; *trans*-10, *trans*-12, 10. The laboratory bioassay was based on the behavior of the male moth when confronted close to the antennae with the attractant placed on a glass rod. A whirring vibration of the wings and typical circling dance ("schwirrtanz") are elicited by exposure to the odor of an active compound (*16*). The similarity in structure of the sex attractants of the gypsy moth and silkworm moth is remarkable. The synthesis of straight-chain, primary alcohols containing 14 to 18 carbon atoms with a pair of conjugated double bonds and their use as insect sex attractants have been patented in Germany (*21*).

The female American cockroach [*Periplaneta americana* (L.)] produces a specific sex attractant which has not been obtained by extraction from the insect but which has been obtained in extremely poor yield by extracts of filter papers over which virgin females had crawled (*22*). The attractant was collected in much larger amounts by drawing a stream of air through large milk cans containing thousands of virgin female roaches and collecting the volatile substances in a trap cooled with dry-ice (*23*). Fractionation by chromatography and steam distillation of the combined volatile fraction, that was collected continuously from approximately 10,000 female roaches for 9 months, yielded 12.2 mg of the pure, odorous attractant as a yellow liquid. Identified as 2,2-dimethyl-3-isopropylidenecyclopropyl propionate (IV) (*24*), it elicits typical intense excitement, wing-raising, and copulatory attempts in males at less than 10^{-14} microgram; this amount is equivalent to approximately 30 molecules! The attractant has not yet been synthesized, and the glands that produce this attractant have not been located.



(IV)

From the abdomen of the female pink bollworm moth, *Pectinophora gossypiella* (Saunders)—a pest of cotton—a sex attractant for males can be extracted with ether or methylene chloride (*25*), and the same solvents will remove an attractant from the abdomens of female tobacco hornworm moths, *Protoparce sexta* (Johannson) (*26*).

Although most of the insect sex attractants are species specific, there are some exceptions. For example, an extract of female gypsy moths (*Porthetria dispar*) attracts male gypsy moths and male European nun moths, *P. monacha* (L.), but an extract of female nun moths attracts only males of this species (*27*).

The release of sex scents is not constant throughout the day. A maximum is reported in the early morning hours for *Polychrosis botrana* (Schiffermüller) (*28*) and *Protoparce sexta* (*27*), but with the gypsy moth mating takes place only during daylight hours (*9*).

Males of the tropical water bug,

Lethocerus indicus (Lepetier and Serville), produce a scent that may possibly belong to the group of sex attractants. The extract, a clear fluid with a cinnamon-like odor, is used by the natives of Southeast Asia as a spice for greasy foods. The active compound, identified as *trans*-2-hexenyl acetate (V), is believed to make the female more receptive to the male (*29*).

$$CH_3(CH_2)_2CH{=}CHCH_2O{-}\underset{\underset{O}{\|}}{C}CH_3$$

(V)

Food and Oviposition Lures

Since insects live in almost every conceivable environment, their food requirements are extraordinarily diverse. With the exception of microorganisms, almost no form of life (including insects themselves) or organic matter of natural origin is immune to attack by this voracious group of animals. Because of the sheer numbers of species (well over 900,000), our knowledge of their food habits is limited to some of the disease-bearing, economically important, or pestiferous species. Very little is known about the stimuli that draw insects to their food supply. This area of research promises to be a fertile one in the future because the tools necessary for analysis of the infinitesimal quantities of chemicals associated with odors have already been devised. Basic knowledge gained here is bound to lead to more selective and efficient insect control.

There is still little information on the exact nature of insect attractants. However, entomologists have faithfully observed and reported the attraction of insects to certain foods, extracts of plants, animals, and chemicals. Although the chemist can derive little from references to attraction of foods, such as sliced cucumbers, crushed bananas, and fish meal, because of their complex composition, certain observations of attraction to chemicals fall into a pattern. For example, ammonia, amines, sulfides, and fatty acids have been reported to attract many species (*30*). These compounds are products of decomposing organic matter and apparently represent a source of food to the insect. Many insects, especially in the order Diptera, instinctively oviposit in the vicinity of these chemicals (*31, 32*), probably to provide food for their young on emergence; for example 91 percent of the house flies, *Musca domestica* L., attracted to ammonium carbonate were females, and nearby food traps captured equal numbers of both sexes (*32*).

That fruit flies respond to, and consume protein hydrolyzates (*33*), has led to the wide use of the latter in insecticide preparations for the control of pests. This combination obviates the need for complete coverage because the insect comes to the lure. Tests on the attraction of constituent individual amino acids have usually been disappointing, although lysine attracts the mosquito (*Aedes* and *Culex* spp.) (*34*); Mexican fruit fly, *Anastrepha ludens* (Loew); oriental fruit fly, *Dacus dorsalis* Hendel; Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), commonly known as "medfly"; and melon fly, *Dacus cucurbitae* Coquillett (*35*). Of the other amino acids tested, only glutamine attracted the medfly. One report states that certain mixtures of amino acids attract mosquitoes but the individual amino acids do not (*36*). One would not normally expect amino acids to be effective attractants because of their low vapor pressure, and, in general, they are not *strong* attractants.

Essential oils and various plant extracts are promising as sources of attractants, possibly because they may contain compounds which draw an insect to a favored food or ovipositional site. Methyleugenol, a constituent of citronella and of Huon pine oil, is a powerful lure for the oriental fruit fly (*37*). Some entomologists believe it to be a sex attractant because it attracts only the male. Only relatively small amounts are required for its action. This compound can also be considered a food lure because the male flies devour the chemical and some avidly gorge themselves to the bursting point (*38*). A mixture of eugenol and geraniol (9:1) is an effective lure for the Japanese beetle; it attracts equal numbers of each sex (*39*).

Finding a lure in nature and isolating the active substance is one approach to finding insect attractants. Another way is to screen a large number of chemicals to obtain a "lead," that is, a weak attractant; related compounds are then examined in an attempt to find a better lure. Initial screening may be hit or miss; but when a large number of chemicals of many different types are tested, some leads do turn up. To pursue a lead, a program of systematic chemical synthesis is needed since the desired compounds are seldom available. Scientists of Entomology Research Division of the U.S. Department of Agriculture were the first group to pursue a synthesis program in the search for insect lures. The synthesis of "siglure" (*sec*-butyl ester in Table 2), which in 1957 helped eradicate the medfly from Florida (*40*), was a result of their systematic search.

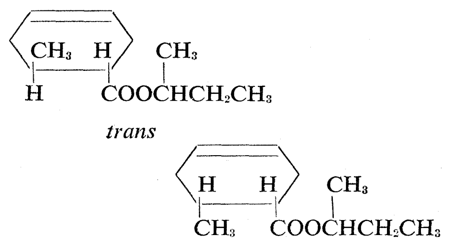
Table 2. Olfactometer and field ratings of siglure and related compounds. The esters of 6-methyl-3-cyclohexene-1-carboxylic acid are designated by *R*. The isopropyl ester is arbitrarily rated as 100.

R	Olfactometer	Field
CH_3	48	
CH_2CH_3	122	38
$CH_2CH_2CH_3$	96	58
$CH(CH_3)_2$	100	100
$CH_2CH_2CH_2CH_3$	71	98
$CH_2CH(CH_3)_2$	99	48
$CH(CH_3)CH_2CH_3$*	87	279
$CH(C_2H_5)CH_2CH_3$	83	231
$CH_2CH{=}CH_2$	107	53
$CH_2C{\equiv}CH$	83	40
CH_2CH_2Cl	86	29
$CH_2CH_2OCH_3$	0	
$CH_2C_6H_5$	0	

*Siglure.

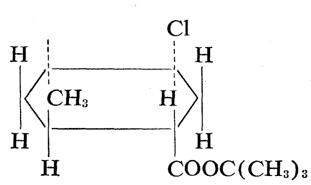
In seeking medfly lures the ethyl ester of 6-methyl-3-cyclohexene-1-carboxylic acid was one of the first synthetics to prove attractive in laboratory (olfactometer) tests. Thirty additional esters with the same acid moiety were synthesized and tested (*40*). The olfactometer ratings of 13 of these esters are given in Table 2. A striking feature of the data is that a small difference in *R* may give a large difference in attractiveness. Table 2 also gives the results of testing the most attractive compounds in field trials. Although agreement between olfactometer and field ratings is poor, the olfactometer permits rapid screening of chemicals and thus eliminates those compounds unlikely to be attractants so that they are not used for time-consuming field tests. Final evaluation of a lure must be made in field tests, preferably under actual conditions of use.

The commercial production of siglure brought new problems since field tests indicated that the commercial product was less appealing to the medfly than the original laboratory preparations. Further investigation disclosed that the laboratory chemical had a *trans* configuration (VI) and that the commercial product contained appreciable amounts of the *cis* isomer (*41*), which proved to be much less attractive. The commercial method of synthesis had to be changed, and an infrared method of analysis was written into the specification to insure the procurement of the more attractive *trans* isomer.



(VI)

It is thus clear that subtle stereochemical or minute structural alterations can cause great differences in the insects' response. In order to avoid the epimerization (change of *trans* to *cis*) of *trans*-siglure, conditions that induce this change were studied. In one of these experiments the hydrogen chloride adduct of siglure was produced. When the compound was found to exceed the attractiveness of siglure, 45 other esters of the hydrohalogenated acid were synthesized (*42*). Medlure and trimedlure, the secondary and tertiary butyl esters, were most effective. Trimedlure (VII), now in commercial production, is the lure that rapidly helped eradicate, in the summer of 1962, a reinfestation of the medfly in Florida.



(VII)

Preparations of trimedlure are mixtures of isomers—theoretically there are eight—depending on the position of the chlorine atom (one of the four dashed lines of VII), and whether the methyl and ester groups are *cis* or *trans*. Two solid substances of correct elemental composition and a liquid portion have been separated from the mixture. The liquid and one of the solids are attractive, but the other solid is not (*43*).

The best medfly attractants in both the siglure and trimedlure series contain alcohol moieties having three to five carbon atoms with methyl groups (branching) on the oxygen-linked carbon atom. Attempts to vary the structure of the acid portion have yielded only inferior products.

We do not know why the male medfly finds siglure, medlure, and trimedlure so attractive, and we know of no such chemicals in nature. Before the discovery of the synthetics, male medflies were found to be lured to angelica seed oil, which they consume. Presumably the insect may also associate the odor of the synthetic medfly lures with a source of food. However, most of the synthetics do not cause feeding, nor should it be supposed that food attractants necessarily induce feeding. Some substances, termed arrestants (*44*), trigger a feeding response, but do not attract; sucrose, of negligible vapor pressure, does not actually attract the house fly, but upon finding sucrose the fly remains to feed. The protein hydrolyzate is an example of a material that attracts the medfly and other tropical fruit flies (although weakly) and also induces a feeding response.

The discovery of the specific medfly attractants illustrates the success of the volume-screening approach, which depends heavily on the development of a rapid, reliable screening procedure. A potent lure for the melon fly, cue-lure, was found by this method (*45, 46*). Compounds containing the 4-phenyl-2-butanone structure were attractive to the melon fly; the best of these were para-substituted through an oxygen (*47*). Table 3 gives the results of testing cue-lure and related compounds in the field (*45*).

We tested about 2000 synthetics for attracting the gypsy moth before the structure of the natural sex lure of the female gypsy moth was determined. Even though virtually nothing was known about the chemical structure of this natural lure, several attractive compounds were found. Although they were far less potent than the insect product, they were, like the natural attractant, 16-carbon, straight-chain compounds with a primary alcohol group, or an epoxy group which could be hydrolyzed to an alcohol (*48*).

Biological Testing and Survey

The testing of materials for attraction to insects requires considerably more finesse than the testing of insecticides, and no general means suitable for testing against all insects has been devised and probably never will be. A suitable bioassay must be built around the natural habits and idiosyncrasies of each species. Few gypsy moths, for example, seek a mate on a cloudy day, and even very attractive preparations are ineffective on such days. The southern army-

Table 3. Melon flies attracted by cue-lure and related compounds in field tests. *R*, the para-substituent in phenyl butanone 2.

R	Flies caught
$CH_3C(=O)O$ —*	30,752
$CH_3CH_2C(=O)O$ —	22,985
HO —	14,574
$CH_3CH_2CH_2C(=O)O$ —	12,508
$(CH_3)_2CHCH_2C(=O)O$ —	6,894
CH_3O —	2,408

*Cue-lure.

worm, *Prodenia eridania* (Cramer), which responds to its sex attractant in the early morning hours (between 3:00 and 5:00 A.M.), is indifferent to the same stimulus at other times. An olfactometer for fruit flies is an 8-foot cubical screened enclosure containing about a dozen traps suspended from a slowly rotating wheel (*49*); as in nature, the flies respond to the lures while in free flight. Crawling insects have been offered a choice of two air streams of identical composition except that one contains a chemical vapor (*50*).

Testing is further complicated by the effect of vapor concentration on attraction. Too low a concentration will not be detected, and too high a concentration may repel. Thus several concentrations of a chemical should be tested in order to avoid missing a good attractant. Of course, the most desirable lures attract at both high and low concentrations.

Laboratory testing of lures, which is possible with certain species, has some advantages. Conditions, such as light, temperature, and humidity, may be standardized; insects may be reared in a controlled environment; tests may be carried out throughout the year; tests may be rapid and well replicated. However, an important prerequisite for efficient laboratory testing is a method of rearing large numbers of insects. Such rearing is often stymied by the vulnerability of some species to disease or parasites. Daily and seasonal variations are other obstacles. Some species respond to an attractant only at a definite stage of maturity.

The method of exposing the chemical may be important. It may be spotted on paper, dispersed in solution or emul-

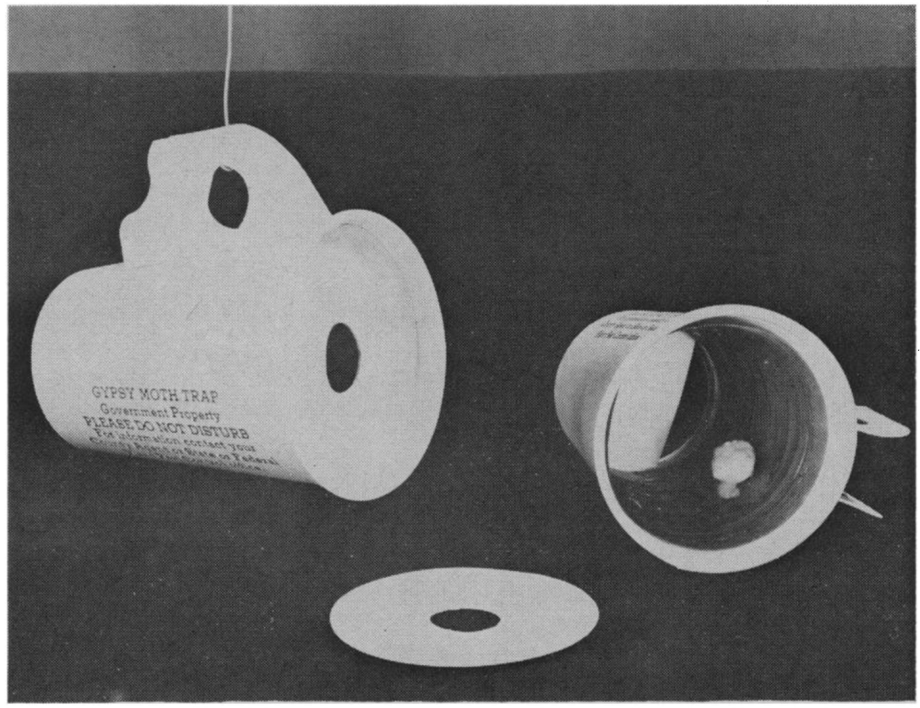


Fig. 1. Recent design of gypsy moth trap.

sion, or impregnated on a wick. The latter (a dental roll) has been used to measure a lure's persistence by determining, under standard conditions, the number of days a given amount of chemical will attract.

A new and unique means of testing attractants in the laboratory may soon be practicable. The sex attractants of the silkworm moth and gypsy moth and probably those of most Lepidoptera (moths and butterflies), as well as insects of other orders, are perceived by olfactory receptors located in the male antennae (*51*). On this basis, an electrophysiological method for the bioassay of the sex lures has been developed which is as much as 1000 times more sensitive than any available behavioral method. By means of tiny silver electrodes inserted into the sensory hairs of the male antenna, it was found that a local electrical potential is set up by exposure to the female sex scent; the released nerve impulses are amplified and recorded from an oscilloscope to give characteristic patterns, called "electroantennograms" (*52*). The shape of the patterns, which depend on the stimulus, is reproducible.

The organs of olfaction are not always on the antennae; in the blow fly their location could not be found (*53*). Presumably, in the foregoing electrophysiological method, the electrodes would have to be inserted into the appropriate sensory sites. Location of the sites may be determined by causing loss of response to an odor on extirpating or covering the olfactory receptor.

Ultimately the best attractants must be tested in the field since laboratory and field data all too often do not agree. In the field, attractants must prove themselves in the presence of a multitude of natural odors, colors, light conditions, and weather. For insects that cannot be reared in the laboratory, direct field testing of chemicals, although entailing considerable labor, is a valid recourse. Such tests, limited to the season when the insects abound, are subject to such variables as light, temperature, humidity, weather conditions, insect density, age of population, predators, and natural competing attractants. It is desirable to include in these tests, as well as in laboratory trials, a standard lure, if one is available. Comparison with the standard helps minimize the many variables.

In traps the attractants assure early detection of an infestation before it can enlarge or spread. By delineating an infestation, the attractants also make control and eradication measures very efficient, help locate those last few hard-to-find insects, and show when insecticide applications may be terminated in a given area. Since the high volume of fast international trade and traffic has made the introduction of foreign injurious species much more likely, if not inevitable, chemically baited traps have become an important means of preventing an accidentally introduced species from becoming established and assaulting the products of our agricultural community.

The number of insects caught in the field depends to a large extent on the design of traps and their placement. In an attempt to improve the efficiency of the gypsy-moth trapping program, trap design, trap color, bait dispensers, duration of bait effectiveness, bait strength requirements, trap height, trap placement, and related parameters were studied (*9*). The latest gypsy moth trap, shown in Fig. 1, depends on a sticky adhesive to ensnare moths responding to the sex lure. Another type of trap, extensively used for detecting fruit fly infestations, is shown in Fig. 2 (*54*). The chemically baited wick attracts insects inside the trap, where they are overcome by a fast-acting volatile insecticide, such as DDVP (2,2-dichloro-

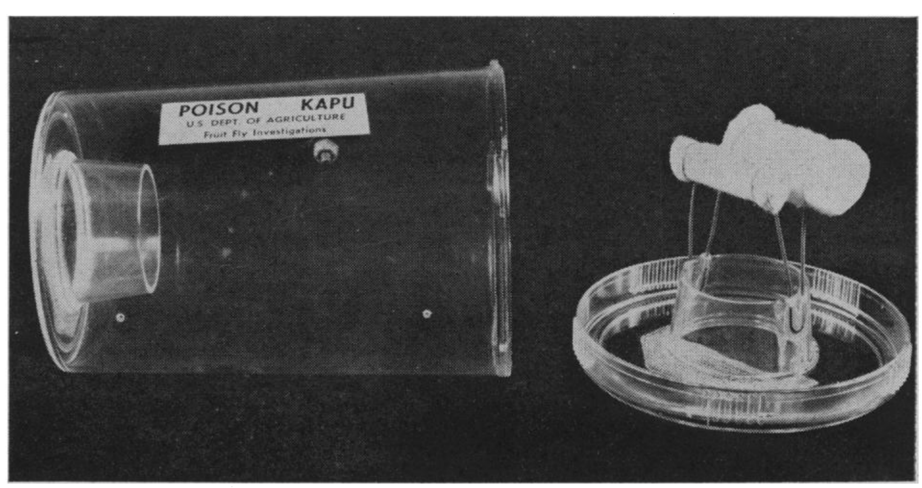


Fig. 2. Plastic trap for fruit flies.

vinyl dimethyl phosphate), lindane, or naled (Dibrom). Birds and ants sometimes consume trapped insects, and means of discouraging these raids have been devised; for example, chlordane keeps ants out of traps. The McPhail trap (Fig. 3) traps the Mexican fruit fly when baited with a fermenting mixture or a protein hydrolyzate. Oddly enough, the same lures in the trap of Fig. 2 catch no Mexican fruit flies.

Air movement is probably the most important parameter to consider in trap placement (*9*). Traps situated upwind from an infestation are more likely to catch insects than those down or across wind. Traps in hollows or surrounded by dense growth do not catch well because of restricted air movement. Odors of chemicals tend to sink to the ground because they are almost always much heavier than air. The male gypsy moth apparently has adapted its behavior to this property since it flies long distances close to the ground. Catches of this moth in traps placed between ground level and 6 feet above showed little difference but fell off at the 12-foot level.

The gypsy moth is an excellent example of an insect whose sex attractant may be used for survey and possibly for control. Males fly into the wind and pick up the scent as they approach the nonflying females. Early experiments with marked males showed that they may be attracted by the female scent from distances of up to ¼ mile. For many years entomologists of the USDA made use of hydrogenated benzene extract of the abdominal tips of virgin females (*55*) in metal field traps to locate infested areas and to determine the size of the infestation by the numbers of males caught in the traps. Synthetic gyplure has now replaced the natural sex lure; and the disposable, inexpensive cup-type paper trap shown in Fig. 1 has completely supplanted the costly, unwieldy metal traps previously used. The gyplure is impregnated on small wicks of dental roll at a concentration of 25 micrograms per trap, and an adhesive substance ("Tanglefoot") is used to line the inside walls of the cup. Baited traps are hung on the limbs of trees and attracted males enter through an opening in each end of the cup. Each year, immediately before the male flight season (July and August), approximately 50,000 traps are placed in the infested New England area. Gyplure has such potency that a single pound of this attractant, which may be made quite inexpensively, is sufficient to last for more than 300 years if used for survey alone.

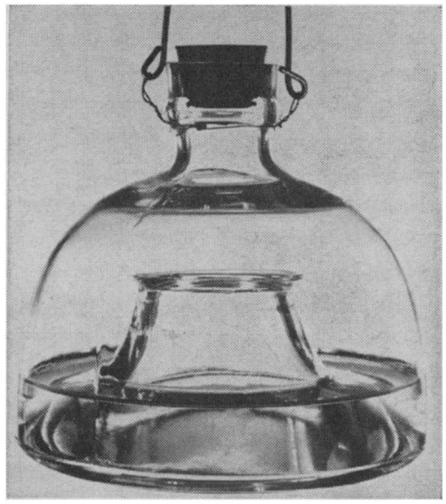


Fig. 3. McPhail trap.

The results of field trapping completed very recently in cotton-growing areas of the United States and Mexico have shown that a crude extract of the abdomens of the virgin female pink bollworm moth may be used satisfactorily as a survey tool and possibly for control purposes. The sex attractants of other insect species, especially those that fly, have the potential for equally valuable use.

One of the largest insect-detection programs is aimed at keeping out three destructive species of fruit fly not present on the U.S. mainland—the oriental fruit fly, Mediterranean fruit fly, and melon fly. A unique feature of the program is a trap (Fig. 2) baited with three different attractants to lure the three species.

The utility of gyplure-adhesive combinations coated on fiber boards is being explored for control. In limited field trials, boards coated with Tanglefoot containing 5 percent gyplure resulted in large catches of moths and appeared to be effective. Consideration is also being given to limited and large-scale field tests aimed at annihilating male moths through the use of the lure combined with toxicants. The lure may suffice to confuse males seeking mates, making a toxicant unnecessary. Since the males are multiple maters, chemosterilants are worth trying (*56*).

Summary

Many insects depend on odors to lead them to sources that supply their basic needs. Knowledge of these behavioral patterns helps to combat insects of economic importance. For example, attractants in traps offer a remarkably simple means of detecting insects and may even be useful in direct control. They are increasing the efficiency of insecticide applications because treatments need be applied only where insects are caught and only as long as they are caught.

The sex attractants are the most sophisticated of the lures and the most desirable for survey or control because of their great potency and specificity. The sex lures of the gypsy moth and silkworm moth have been identified and synthesized; the lure of the American cockroach has just been identified. Sex lures have recently been demonstrated in the European corn borer, honey bee, pink bollworm, southern armyworm, tobacco hornworm, and introduced pine sawfly. Additional study of insect mating habits is needed to ascertain the prevalence of sex lures in the insect world.

Food and oviposition lures have been found among foodstuffs and essential oils, and by screening chemicals. Chemical screening, accompanied by programs of synthesis, has produced excellent lures: trimedlure for the Mediterranean fruit fly and cue-lure for the melon fly. In this effort a means of rapidly evaluating the attractiveness of many chemicals is most important. The bioassay must be tailored to the idiosyncrasies of each species and should preferably be a laboratory procedure. However, the final judgment on lures must be based on performance under field conditions.

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Carbamyl Phosphate

Many forms of life use this molecule to synthesize arginine, uracil, and adenosine triphosphate.

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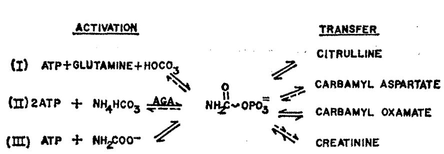
Carbamyl phosphate is a low molecular weight, high energy intermediate in several important biosynthetic enzyme reactions. The formula for carbamyl phosphate, $NH_2CO{\sim}OPO_3^{=}$, indicates that it is a dianion at physiological *p*H and the squiggle sign ($\sim$) denotes the high-energy phosphate bond. This interesting compound, discovered only in 1955 (*1*) combines, as it were, ammonia, carbonate, and phosphate in a single molecule.

The enzyme reactions in which carbamyl phosphate participates are



The enzymes catalyzing the activation reactions are: (i) carbamyl phosphate synthetase from Basidiomyces, (ii) carbamyl phosphate synthetase from ureotelic vertebrate liver, and (iii) carbamyl phosphokinase. The enzymes catalyzing carbamyl transfer reactions are for citrulline, ornithine transcarbamylase; for carbamyl aspartate, aspartate transcarbamylase; for carbamyl oxamate, oxamate transcarbamylase; for creatinine, the enzymes have not been purified to define the exact substrate and are therefore not named. *N*-Acetyl glutamic acid (AGA) is a required cofactor for carbamyl phosphate synthetase.

Carbamyl phosphate may be formed biologically from ATP (*2*) by means of the activity of one of the three enzymes, in reactions which are essentially a fixation of ammonia and carbon dioxide or bicarbonate (left hand side of diagram). Therefore, carbamyl phosphate can be synthesized with the consumption of the energy resident in ATP, and then it can utilize this energy for the subsequent synthesis of carbamyl compounds; or it can be produced by the phosphorolytic degradation of certain carbamyl compounds and then be used for the production of ATP.

Chemically, at neutral *p*H in aqueous solution, carbamyl phosphate is in equilibrium with phosphate and cyanate (*3*, *4*) and biologically it serves as a cyanate to "carbamylate" amino compounds by introducing the NH_2CO- group as cyanate does chemically.

Biologically, carbamyl phosphate appears to be the universal donor of the carbamyl moiety in the biosynthesis of citrulline and carbamyl aspartate. These two amino acids are essential for the synthesis of arginine and uridylic acid, and therefore for the biosynthesis of protein and nucleic acid.

Carbamyl-Transfer Reactions for Energy Production

When carbamyl phosphate was discovered (*1*) it was already known to be the high-energy, intermediate compound occurring in the enzymatic synthesis of citrulline. The enzymatic reaction is catalyzed by ornithine transcarbamylase

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