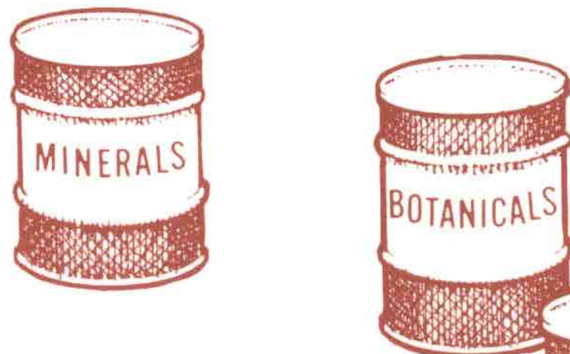
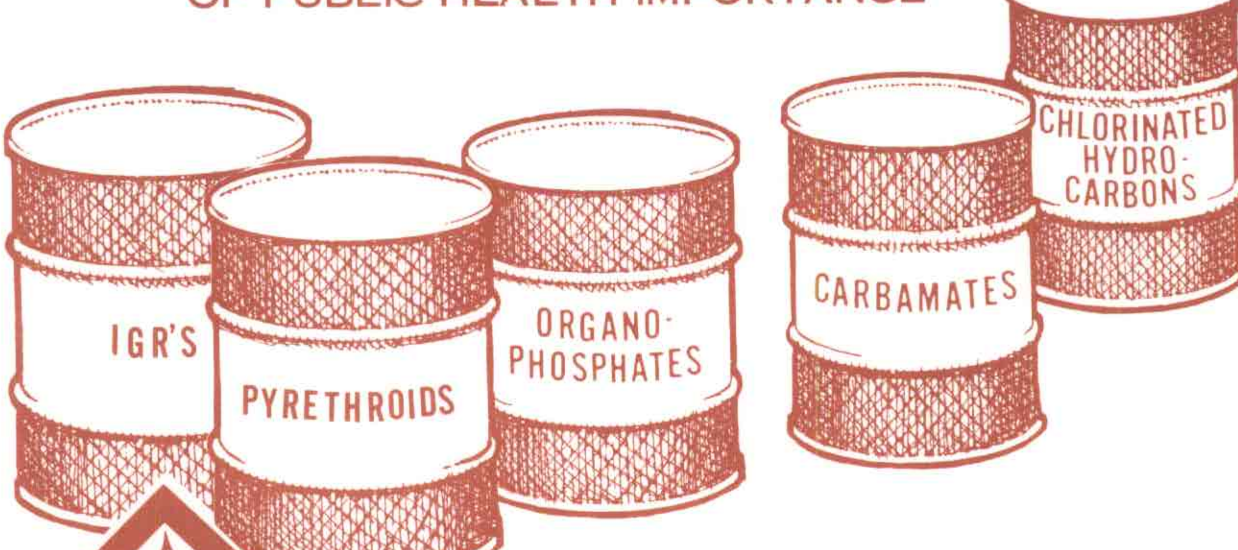
CDC
MANUAL 2

SELF-STUDY COURSE 3013-G
Vector-Borne Disease Control



INSECTICIDES
FOR THE CONTROL OF INSECTS OF PUBLIC HEALTH IMPORTANCE



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SELF-STUDY

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
Centers for Disease Control
Public Health Practice Program Office
Atlanta, Georgia 30333

INSECTICIDES OF PUBLIC HEALTH IMPORTANCE

CHLORINATED HYDROCARBONS

- DICOFOL (Kelthane)
- ENDRIN
- LINDANE
- METHOXYCHLOR

ORGANOPHOSPHATES

- ACEPHATE (Orthene)
- CHLORPYRIFOS (Dursban)
- DIAZINON
- DICHLORVOS (DDVP)
- DIMETHOATE (Cygon)
- FENITROTHION (Sumithion)
- FENTHION (Baytex)
- MALATHION
- METHYL PARATHION
- NALED (Dibrom)
- PARATHION
- PROPETAMPHOS (Safrotin)
- TEMEPHOS (Abate)
- TETRACHLORVINPHOS (Gardona)
- TRICHLORFON (Dipterex)

CARBAMATES

- BENDIOCARB (Ficam)
- CARBARYL (Sevin)
- METHOMYL (Lannate)
- PROPOXUR (Baygon)

SYNTHETIC PYRETHROIDS

- ALLETHRIN
- CYFLUTHRIN (Tempo)
- CYPERMETHRIN (Demon)
- DELTAMETHRIN (Decis)
- FENVALERATE (Pyrid)
- FLUVALINATE (Yardex)
- PERMETHRIN (Pounce)
- RESMETHRIN (SBP-1382)

BOTANICALS

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- PYRETHRUM
- ROTENONE

INSECT GROWTH REGULATORS-IGR'S

- DIFLUBENZURON (Dimilin)
- FENOXYCARB (Torus)
- HYDROPRENE (Gencor)
- METHOPRENE (Precor)
- TRIFLUMURON (Alsystin)

FUMIGANTS

SOLID-VOLATILE

- NAPHTHALENE
- PARADICHLOROBENZENE
- PHOSPHINE (Phostoxin)

LIQUID-GASES

- CHLOROPICRIN
- METHYL BROMIDE
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MISCELLANEOUS

- HYDRAMETHYLNON (Maxforce)
- Aerosurf
- Golden Bear Oils
- BACILLUS THURINGIENSIS (Teknar, Vectobac)
- SILICA AEROGEL (Drione)

INORGANICS

- BORAX (Boric acid)
- Sulfur

INSECTICIDES
FOR THE CONTROL OF INSECTS
OF PUBLIC HEALTH IMPORTANCE

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and
Kent S. Littig* Deceased

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INSECTICIDES FOR THE CONTROL OF INSECTS OF PUBLIC HEALTH IMPORTANCE

The common and trade names for the pesticides in this manual conform to sample pesticide labels and those in the "1990 Georgia Pest Control Handbook." (Reference 10)

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INTRODUCTION

During the past 90 years there have been tremendous changes in insecticides. These developments have led to vastly increased production in food and fiber, and the control of insectborne diseases such as malaria, yellow fever, dengue, encephalitis, plague, and typhus. In 1900, public health workers relied chiefly on the arsenicals, sulfur, petroleum oils, and pyrethrum as insecticides. Although pyrethrum continues to be widely used, today the emphasis is on the chlorinated hydrocarbons, organophosphates, carbamates, pyrethroids, and insect growth regulators developed since World War II. Some of these chlorinated hydrocarbons, as DDT and chlordane, remain in the environment for years and enter into nontarget organisms thus affecting the food chains of fishes, birds, and mammals. As a result, legislation restricting or abolishing the use of certain chlorinated hydrocarbon insecticides has been enacted (51).

Vector control today is giving much attention to <u>integrated</u> <u>pest</u> <u>management</u> programs. In general, the most effective vector control projects have resulted from a combination of biological, environmental, and chemical methods, rather than from the use of insecticides alone. For example, some of the best mosquito control projects have been based more on proper water management than on insecticide application. Similarly, flies have been controlled more by premises sanitation than by pesticides. Present day programs are concerned both with controlling the insect vectors and conservation of the environment, Chemical control supplements, but does not supplant, other insect control methods.

This manual includes information about insecticides currently available to public health workers, methods of formulation, toxic hazards, and precautions for safe use. The Federal Environmental Pesticide Control Act (FEPCA) of 1972, and later amendments, is discussed and the establishment of two categories of insecticides for <u>general</u> <u>use</u> and <u>restricted</u> <u>use</u>. There is a discussion of the certification program for people who apply pesticides. A list of references is included for the student who wants additional information.

INSECTICIDES WHICH CAN BE USED LEGALLY

The first Federal bill concerning the manufacture, labeling and interstate shipment of pesticides was introduced into Congress in 1908. This bill called the Insecticide Act, became law in 1910 and regulated the interstate movement of insecticides and fungicides. In 1947 the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) was passed. The legislation primarily regulated only the registration and labeling of pesticide products that were being shipped from one state to another state.

In October 1972 Congress passed the Federal Environmental Pesticide Control Act (FEPCA, often called the AMENDED FIFRA) which regulated the registration, labeling, manufacture, transportation and use of pesticides as well as the disposal of excess pesticides and pesticide containers. Since 1972, this act has been amended in 1975, 1978, and 1988 (10, 51).

Some important aspects of these regulations are:

- All pesticides must be classified for general use and restricted use.
- Most restricted use pesticides may be used only by persons working under direct supervision of a certified operator; some may be restricted to use only be the certified operator.
- It is illegal "to use any registered pesticide in a manner inconsistent with its labeling."
- Penalties (fines and jail terms) are provided for persons who do not obey the law.
- Both the toxicity of the pesticide and the use directions are considered in establishing its classification, with signal words DANGER, WARNING, and CAUTION.
- Control of a pest not mentioned on the pesticide label if the application is to a <u>site</u> mentioned on the label as long as no label statement restricts this application.

In the 1990's EPA will publish revised regulations on certification of applicators with particular reference to the level of supervision of applicators of restricted use pesticides.

<u>General use insecticides</u> are those that will not ordinarily cause unreasonable adverse effects on the user or the environment when used in accordance with their label instructions. Examples: pyrethrum and malathion.

<u>Restricted use insecticides</u> are those which may cause adverse effects on the applicator or the environment unless applied by, or under the supervision of, competent persons who have shown their ability to use these products safely and effectively. Such persons will be identified through applicator certification programs administered by state agencies, such as a State Department of Agriculture. Examples: parathion and methyl bromide (50).

CERTIFICATION OF APPLICATORS

The amended Federal Insecticide, Fungicide and Rodenticide Act (Amended FIFRA) provides for two types of certified applicators; private and commercial.

Private applicator is generally a farmer, rancher, orchardist or other applicator who uses or supervises the use of restricted use insecticides to produce an agricultural commodity on property owned or rented by him or his employer.

Commercial applicator is anyone who applies a restricted use pesticide other than as provided by the previous definition of a "private applicator." Such applicators include government employees, workers at mosquito control districts, health departments, and commercial pest control operators.

The Environmental Protection Agency has established 10 occupational categories for commercial applicators:

1. Agricultural Pest Control
2. Forest Pest Control
3. Ornamental and Pest Control
4. Seed Treatment
5. Aquatic Pest Control
6. Right-of-Way Pest Control
7. Industrial, Institutional, Structural and Health Related Pest Control
8. Public Health Pest Control
9. Regulatory Pest Control
10. Demonstration and Research Pest Control

Certification of private applicators may be oral or written examinations. Competence of commercial applicators will be determined by written examinations and, as appropriate, by performance testing. Such examinations shall include standards specifically identified for each category as well as general standards that apply to all categories. Tests on the general standards will include the following:

1. Label and labeling comprehension.
2. Safety.
3. Environmental factors and the consequence of use and misuse of the pesticide.

4. Knowledge of pests.

5. Knowledge of pesticides and types of formulations, including hazards associated with residues.

Penalties

It is a violation of the Act to use any pesticide in a manner inconsistent with its label. Penalties as provided for in FEPCA are also in effect and some commercial applicators have been fined or put in jail. The law specified civil penalties up to $5,000.00 and criminal penalties up to $25,000 and 1 year in jail for commercial applicators who violate the law.

The decision to apply any insecticide is the responsibility of the agency or the individual concerned. The information in this manual is brief. Anyone unfamiliar or inexperienced with a specific procedure must seek the advice of a person experienced in its use or obtain the necessary training from a recognized authority. **AT THE PRESENT TIME, THE BEST ADVICE TO ALL PESTICIDE APPLICATORS IS TO CONSULT AN APPROPRIATE AUTHORITY OR STATE REGULATORY AGENCY BEFORE APPLYING AN INSECTICIDE WHOSE USE MIGHT BE IN QUESTION.**

TYPES OF INSECTICIDES

An insecticide is a substance used for killing insects and their close relatives, the ticks, mites, and spiders. **A perfect insecticide**, if such were possible, would be:

1. Highly toxic to harmful insects and related arthropods.
2. Harmless to man and to beneficial animals, insects, and plants.
3. Attractive to insects and not unpleasant to humans.
4. Inexpensive, easy to produce, and readily available.
5. Chemically stable for residual applications.
6. Non-persistent for use in aerial applications that will not grossly contaminate the environment, killing insects rapidly, and breaking down subsequently into harmless compounds.
7. Nonflammable.
8. Noncorrosive.
9. Nonstaining.
10. Easily prepared into any desired formulation.

Several insecticides have some, but not all, of these desirable attributes in varying degrees.

Insecticides are classified traditionally according to the way that they kill insects, as:

1. **STOMACH POISONS** - must be swallowed to cause death. Vegetation is often treated with stomach poisons to control chewing insects. Poison baits are stomach poisons mixed with materials, such as sugar, to attract insects. Baits are placed where insects will find and eat them. Well-known examples include sugar-dichlorvos (DDVP) baits for flies, peanut butter-chlorpyrifos (Dursban) baits for cockroaches, and small plastic containers with hydramethylnon (Maxforce) for cockroach control.
2. **CONTACT POISONS** - penetrate the body wall or the tarsi of arthropods. They include <u>residual sprays</u> applied to walls and ceilings of buildings to kill insects that rest on the treated surfaces, <u>aerosols</u> and <u>space sprays</u> that adhere to and kill flying insects, and <u>larvicides</u> that penetrate the tracheae and body walls to kill insect larvae.
3. **FUMIGANTS** - are volatile chemicals whose vapors enter insects' bodies through the breathing pores (spiracles) and body surfaces. Methyl bromide, for example, is a nonflammable, deeply penetrating fumigant used to kill insects in fabrics, foods, and other stored products.
4. **DESICCANTS** - are sorptive dusts which scratch or abrade the body wall, or absorb its fatty, or waxy, protective outer coating, causing the insect to lose body fluids and die by dehydration. Silica gels are used as desiccants for the control of cockroaches and other insects.

Only one or two of these types of insecticides are used in controlling most insects. However, depending on circumstance, all four types may be used in cockroach control (Figure 1). Some insecticides as Dichlorvos kill insects as stomach poisons, contact poisons, and fumigants.

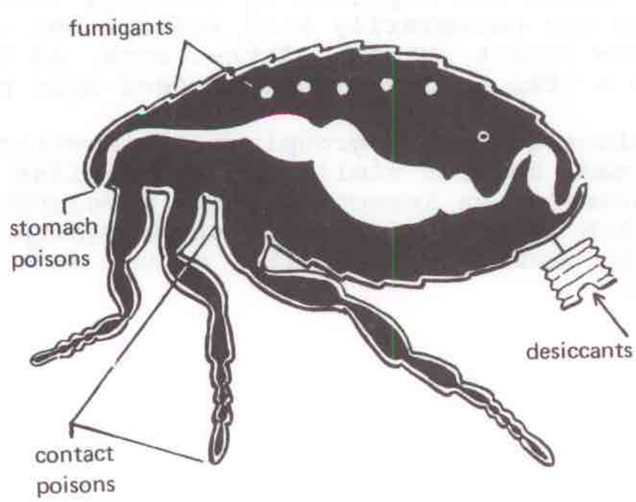


Figure 1. Types of Insecticides

Another system of classification is based on the insect stage upon which the insecticide acts, as adulticides, which kill adult insects; larvicides, which kill the immature stages of insects, whether larvae or nymphs; and ovicides which kill insect eggs. Many other terms are used, such as acaricides for killing ticks or mites, and pediculicides for killing lice.

Insecticides, in the field are applied as in Table 1.

TABLE 1. CLASSIFICATION OF INSECTICIDES ACCORDING TO USE

ADULTICIDES	LARVICIDES	OVICIDES
Space sprays	Solutions	Solutions
Aerosols	Emulsions	Emulsions
Fogs	Suspensions	Fumigants
Mists	Dusts	
Residual sprays	Fumigants	
Fumigants		
Dusts		
Fly cords		
Baits		
Sorptive dusts		
Insecticidal resins		

Repellents and attractants are materials which emit odors that repel or attract insects. Diethyl toluamide, a repellent, is applied to exposed skin surfaces and clothing to prevent attack by mosquitoes and other arthropods. Moths are repelled by clothing treated with naphthalene. Repellents do not necessarily kill insects but they do protect people and materials from insect attack. Attractants, as the name applies, lure insects into a trap or cause them to feed upon poison baits.

The frontispiece gives the groupings of insecticides, and shows choices that can be made between similar and dissimilar materials to suit the need. For example, an insect that has developed a resistance to malathion which is in the organophosphate group, would be expected to be susceptible to chemicals in another group, such as the carbamate insecticides.

The insecticides use to kill arthropods of public health importance may be divided conveniently into nine groups as shown on the frontispiece:

1. Chlorinated Hydrocarbons
2. Inorganics
3. Organophosphates
4. Carbamates
5. Synthetic Pyrethroids
6. Botanicals
7. Insect Growth Regulators-IGR's
8. Fumigants
9. Miscellaneous

Many insecticide labels contain three names. For example, the insecticide Dursban has the trade name Dursban, the common name chlorpyrifos, and the chemical name 0,0-diethyl-0-(3,5,6-trichloro-2-pyridyl) phosphorothioate. The trade name is used by the chemical company to promote sales of a specific product and is often the most recognizable name of the insecticide. The common name is a generic name. Only one common name exists for each insecticide. The chemical name describes the chemistry of the insecticide compound.

Often an insecticide is sold under different trade names: Dursban is a broad-spectrum residual insecticide; Killmaster is a shellac formulation with residual action for many months; Empire is a micro-encapsulated formulation; Lorsban is a formulation used in agriculture. There are formulations sold overseas under foreign names as Brodan and Detmor (48, 51).

Insecticides are developed and marketed by chemical companies. Prior to being used as an insecticide, the product undergoes thorough investigation by the chemical company, land grant Universities, and various State and federal agencies. The insecticide must be proven to kill insects, to be safe to non-target humans, animals, and plants, and to have no deleterious effects on the environment. Final approval for use as an insecticide is under the direct control of the United States Environmental Protection Agency (EPA). Each insecticide has an EPA registration number on the label, see Figure 10, number 4.

Chemical companies spend millions of dollars developing new insecticides and obtain a patent before releasing the product to the marketplace. A company retains exclusive or proprietary rights for that insecticide for 17 years after the patent has been issued. After the patent has expired, other chemical companies are free to market the insecticide. However, a different trade name must be used.

CHLORINATED HYDROCARBONS

The chlorinated hydrocarbons contain the elements chlorine, hydrogen, and carbon, hence their name. These compounds are often called the organochlorine insecticides. These insecticides act primarily as central nervous system poisons in which the symptoms appear in four successive stages; excitation, convulsions, paralysis, and death (51).

The introduction of the chlorinated hydrocarbon insecticides in the 1940's led to a revolution in control programs for insects of public health and agriculture importance throughout the world, sometimes referred to as "The Age of DDT." These insecticides were used successfully to control mosquitoes, flies, fleas, lice, ticks, and mites, and played key roles in reducing the incidence of malaria, yellow fever, dengue, encephalitis, plague, typhus, and other serious arthropodborne diseases. Some of these chlorinated hydrocarbon insecticides, as DDT, chlordane, heptachlor, aldrin, and dieldrin, were among the least expensive, most effective, widely used pesticides from the 1940's to the 1960's. However, they sometimes remained in the environment for years and entered into nontarget organisms thus affecting the food chains of fishes, birds, and mammals. Moreover, some of these chlorinated hydrocarbons are stored in the body of humans and other animals with possible deleterious effects, i.e., they were carcinogens in laboratory animals. In addition, some insects became resistant to some of these insecticides, as DDT and chlordane. Almost all uses of DDT in the United States were banned effective January 1, 1973 (43). However, in 1990 DDT residual sprays were still being used for malaria control in some Third World countries, primarily because of low insecticide cost and long residual action, up to six months in some areas. Use of aldrin, dieldrin, chlordane and heptachlor was gradually phased out in the United States in the 1970's and 1980's (51). As of 1990, only two chlorinated hydrocarbon insecticides, lindane and methoxychlor, both of which are biodegradable and are not stored in the human body, were widely used by public health workers in the United States. Two others, dicofol and endrin, have minor uses by public health workers, as discussed below.

DICOFOL (Kelthane) is a chlorinated hydrocarbon insecticide which is used to control mites which are resistant to the organophosphates. Usually it is used to control ornamental and turf mites. Spraying dicofol on the lower portion of buildings, and around doors and windows, has helped keep clover mites from entering buildings to hibernate in the fall.

ENDRIN is a highly toxic chlorinated hydrocarbon which has been used for years in elevated out-of-reach perches for the control of sparrows, starlings and pigeons in buildings. The birds are killed after resting on these perches and the absorption through their feet of endrin (or the highly toxic organophosphate insecticide, fenthion).

LINDANE (named for Von der Linden who published on the isomers of BHC in 1912) is the 99 percent pure gamma isomer of benzene hexachloride. Lindane is the insecticide in KWELL shampoos, lotion, or cream used to control head, body, and crab lice and scabies mites. In areas where body lice are resistant to DDT (as Korea in 1951 and 1952), or where the use of DDT is prohibited, these insects are readily killed with one percent lindane dust. Sprays or dusts containing 0.5% to one percent lindane give a quick control of hornets, wasps, and ticks (10). Lindane residual sprays are approved to kill woodboring beetles, particularly powder post beetles, on the underside of buildings with well-ventilated crawl spaces (10).

METHOXYCHLOR is a chlorinated hydrocarbon closely related to DDT, but it differs in being more readily biodegradable in a few weeks. It is used to spray ornamentals and shade trees, as a protective residual spray inside grain storage bins, and in some moth-proofing treatments for woolen carpets. It is also used as a thermal aerosol for adult mosquito control (48).

ORGANOPHOSPHATES

The organophosphate insecticides are derivatives of phosphoric acid (H_3PO_4). They act as nerve poisons by inhibiting the enzyme cholinesterase. Today the organophosphates play much the same role in controlling arthropods of public health importance as did the chlorinated hydrocarbons from the mid 1940's to the middle 1960's because they are: (a) effective against insects resistant to the chlorinated hydrocarbons, (b) biodegradable and do not contaminate the environment for a long time, and (c) have less long-lasting effects on nontarget organisms. In general, malathion may be considered as a low toxicity replacement for DDT, as a dust to control sucking lice, as a spray to control many crawling insects, and as an ultra-low-volume space application to control adult mosquitoes. Similarly, diazinon and chlorpyrifos, which are more toxic than malathion, replace chlordane to control cockroaches, termites, ants and many other arthropods.

ACEPHATE (Orthene) is labeled for indoor use against crawling insects such as cockroaches. It has a strong odor when being mixed and should be prepared outdoors. After mixing, this insecticide is said to have less odor and to be effective in controlling German cockroaches which may be resistant to diazinon or chlorpyrifos, particularly on tile or metal surfaces. It is also used to control fire ants outdoors.

CHLORPYRIFOS (Dursban) is one of the most widely used insecticides in buildings for cockroach and flea control, outdoors for ground inhabiting arthropods as scorpions, spiders, earwigs, centipedes and millipedes, and subsoil for the control of termites. It is available as emulsifiable concentrates, ready-to-use emulsions, microencapsulated formulations, lacquers, dusts, wettable powders, granules and baits. Dursban typically has a residual life of a several weeks for indoor cockroach and flea control, up to three months or more in baits in plastic containers for cockroach control, and five years or more for subsoil termite control. Dursban is labeled for low-volume, aerial application to control adult mosquitoes, and by ground or aerial application to control mosquito larvae.

DIAZINON is a broad spectrum organophosphate that is more toxic than malathion, but less toxic than chlorpyrifos, and therefore is used at lower concentrations for controlling many arthropods. It is used as 0.5% spray to control cockroaches, fleas, flies, spiders, ticks, millipedes, and centipedes and many other household arthropods. A microencapsulated form (Knox-Out) is widely used for cockroach and indoor flea control. Diazinon is also used outdoors to control many ground-inhabiting arthropods, as fire ants, but not on golf courses.

DICHLORVOS (DDVP or Vapona) differs from most other insecticides in that it can be incorporated into resin strips to give off toxic vapors for four months or longer and thus can be used as a residual fumigant. DDVP resin strips are sold commercially and used by the general public to control cockroaches, ants, spiders, clothes moths, silverfish, and other household pests. DDVP resin strips are not approved for use in kitchens, restaurants, or other areas where food is prepared and served, nor for use in nurseries, or rooms where infants, ill, or aged people are confined. Dichlorvos resin collars are used on some dogs and cats to control fleas, but care must be taken since some pets are sensitive to DDVP and develop definite allergy to this chemical.

DDVP is added to some residual sprays for household insects. It adds an irritating chemical vapor with a "flushing action" which drive insects from their hiding places and forces them to cross insecticide-treated surfaces. DDVP has been added to some aerosols registered for killing wasps and other stinging Hymenoptera. DDVP-sugar baits have been used for fly control. DDVP is incorporated in some space sprays used in warehouses to control exposed stored food pests.

DIMETHOATE (Cygon) is used as a residual spray to control flies, as on garbage can racks, or as a fly larvicide, as in manure piles in chicken houses where the birds are in cages.

FENITROTHION (Sumithion) has been used mostly in Third World countries as a residual spray to kill malaria mosquitoes (3).

FENTHION (Baytex or Entex) has a quick killing action and long residual activity. It is registered under two commercial names (a) Baytex, which is especially formulated for outdoor mosquito and fly control programs, and (b) Entex for use against household pests such as cockroaches. Baytex is one of the more effective larvicides for controlling culicine mosquito larvae in polluted water. Fenthion is also used as a poison in Rid-A-Bird perches to kill pigeons, starlings, and sparrows in buildings.

MALATHION (Cythion) is one of the least toxic organophosphates. Its acute oral LD_{50} toxicity is 1000 to 2800 mg/kg depending on the purity of the technical grade material. Residual application of malathion to surfaces at a rate of 100 to 200 milligrams per square foot (standard applications of one to two gallons of 2.5 to 5 percent sprays per 1000 square feet) have given effective control of mosquitoes for 3 to 5 months. Malathion is frequently used to control adult mosquitoes by thermal fogging or ultra-low-volume (ULV) application with ground equipment, or by aerial ULV application. Label directions must be followed carefully to avoid damage to vehicle paint by large undiluted spray droplets. Malathion sprays can also be used to control mosquito larvae.

Malathion dust is used to control human lice at 1 percent concentration, and fleas or ticks on pets at 4 to 5 percent concentration (10).

Malathion is highly toxic to honeybees and precautions must be taken to notify beekeepers before aerial applications are made, particularly ULV aerial applications.

METHYL PARATHION is a highly toxic contact organophosphate. It is used as a mosquito larvicide at the same application rate as parathion, namely 0.1 pound per acre.

NALED (Dibrom) is closely related to DDVP, two bromine atoms being added to the molecular structure. This chemical is used as space sprays for control of adult flies and mosquitoes at application rates of from 0.02 to 0.1 pound per acre. Naled application by air is reported to give better control of flies than malathion, a factor of some importance in vector control in disaster or flooded areas. Naled can cause corrosion of insecticidal equipment and requires special cleaning precautions or the use of special materials such as stainless steel, plastic, or fiberglass.

PARATHION (Ethyl Parathion) is dangerously toxic to mammals, including man, through inhalation, skin absorption, or ingestion. It is sometimes used to control mosquitoes that are resistant to the chlorinated hydrocarbon insecticides. Applications are made at a rate of 0.1 pound of technical grade parathion per acre by trained personnel using approved safety techniques, clothing, and respirators. There is a distinct hazard to spray operators as well as to cattle, fish, and wildlife. Parathion is used chiefly as an agricultural pesticide with strict warnings about people reentering sprayed areas (14, 51).

PROPETAMPHOS (Safrotin) is a moderately toxic organophosphate which is often used indoors to control cockroaches and fleas. In many areas a spray combining Safrotin and the insect growth regulator, Precor, has given control of fleas indoors for 75 days or longer.

TEMEPHOS (Abate) is very effective as a mosquito larvicide but not as an adulticide. Abate can be applied by ground or aerial equipment. Abate emulsions are recommended for spray application when breeding sites of mosquitoes are completely accessible. But when access is obstructed by heavy vegetation, granular formulations are more effective. The 1% granular form with a sand base works well with ground equipment, but the 2% and 5% clay-based granules are preferred for aerial application.

Because of its low toxicity to man, Abate has been used to control mosquito larvae in drinking or cooking water stored in drums or cisterns. In the eradication program of the World Health Organization and governments in Africa and Asia against the guinea worm (Dracunculus), Abate is used to kill the copepod intermediate host of the guinea worm in drinking water.

TETRACHLORVINPHOS (Gardona, Rabon) is an effective mosquito larvicide with low mammalian toxicity. It has been used to control mosquito larvae in containers. For fly control in chicken houses Rabon is used as a 1% residual spray applied to inside and outside surfaces of poultry buildings where flies congregate and feed to include floors, manure, and ceilings. Bait sprays are made by adding one cup of sugar or syrup to the 1% Rabon liquid (10).

TRICHLORFON (Dipterex) is a water-soluble stomach poison. It is sometimes used as a sugar bait to control flies and cockroaches in hospitals and nurseries where an insecticide with low human toxicity and no solvent odor is desired.

CARBAMATES

The carbamates are derivatives of carbamic acid (CO_2NH_3). Typical carbamates contain nitrogen, but differ from the chlorinated hydrocarbons and organophosphate insecticides in their lack of chlorine and phosphorus. Most carbamates are contact insecticides, lowering the level of the cholinesterase enzyme and acting as nerve poisons in much the same manner as the organophosphates. A number of carbamates, as carbaryl, produce a rapid knockdown of insects similar to the action of pyrethrum.

BENDIOCARB (Ficam) is a carbamate with low toxicity to humans, no odor, and good residual action when applied as a dust or wettable powder spray. It is used to control crawling arthropods such as cockroaches, earwigs, ants, fleas, spiders, ticks, centipedes, millipedes, and scorpions. Dusts of bendiocarb give a quick control when applied to bee, wasp, and hornet nests. In many areas the German cockroach has become resistant to Ficam, so the manufacturer has added pyrethrins and a synergist to the formulation (as Ficam Plus) which has given good control in areas, such as hospitals and nursing homes, where no odor is an important consideration (10).

CARBARYL (Sevin) is widely used in public health and agriculture programs to control a variety of insects. It has low toxicity to humans and high toxicity to honey bees, hence it can be used to eradicate honey bee colonies in walls of a building, or control wasps and hornets in their nests. Yellow jackets are often controlled by placing a cup full of 5 or 10 percent carbaryl dust over the entrance of the underground nest. Workers in the nest have to crawl through the dust to reach the nest below ground and may carry dust down with them to kill workers in the nest or even the queen, the mother of the colony. Carbaryl dusts are used at 2 to 5 percent concentration to kill fleas on dogs and cats (except puppies less than 4 weeks of age or kittens). Carbaryl dust or suspension is often used to control cat fleas in backyards or on lawns because these formulations do not "burn" vegetation. Carbaryl dust has given good control of oriental rat fleas in murine typhus control programs or wild rodent fleas in rural plague control programs. Carbaryl dusts and sprays have been used to control adult mosquitoes.

METHOMYL (Lannate) is a carbamate which is combined with sugar and fly pheromone (Muscamone) as a fly bait (Fly Tek), which has been used to control flies in barns, chicken houses, picnic areas, and parks.

PROPOXUR (Baygon) acts both as a stomach poison and residual contact poison. It differs from many other insecticides in having a "flushing action," or irritating quality that forces insects out of their hiding places to make greater contact with sprayed surfaces. In areas where cockroaches are suspected of being resistant to organophosphate insecticides, propoxur residual sprays have given good control for a month or longer. Residual sprays and dusts or propoxur are used to control cockroaches, ants, earwigs, ticks, and many other arthropods (14, 48).

PYRETHROIDS

The pyrethroids include synthetic insecticides similar to the natural pyrethrum. They include:

Non-residuals that break down in the presence of light:

ALLETHRIN is used like pyrethrum in aerosol preparations as a quick "knock-down agent" fortified by a synergist such as piperonyl butoxide.

RESMETHRIN (SBP-1382) is more effective against some insect species than the natural pyrethrins, is even less hazardous to mammals, and does not require synergists to enhance its insecticide action (48).

Residuals that are photostable and do not require synergists:

CYFLUTHRIN (Tempo) can be applied as a general, spot, or crack-and-crevice treatment for the control of cockroaches, pantry pests, ants, earwigs, spiders and many other household pests. It is labeled for use in food and non-food areas of food-handling establishments and often controls these arthropods for a month or longer.

CYPERMETHRIN (Demon) is used as a 0.1 to 0.2% spot or crack-and-crevice spray in non-food areas to control cockroaches, ants, bees and wasps and many other arthropods. It is not labeled for use in food areas.

DELTAMETHRIN (Decis) has been used as a residual spray to kill malaria mosquitoes in some Third World countries.

FENVALERATE (Pyrid) is a low-toxicity pyrethroid labeled for use as a general, spot, and crack-and-crevice treatment in food and non-food areas.

FLUVALINATE (Yardex) is labeled for outdoor pest control, particularly fleas, ticks, and ants. Yardex works more slowly than many conventional insecticides, but is reported to give control of outdoor pests in 3 or 4 days.

PERMETHRIN is sold under many tradenames. "Permanone" aerosol sprays are applied to clothing before it is worn to kill or repel mosquitoes, black flies, and ticks, including the deer tick that transmits Lyme disease. In Africa, where residual house sprays have not provided adequate malaria control, field trials are being conducted with bed nets treated with permethrin to kill infected malaria mosquitoes and prevent malaria transmission (42, 44). Elimite cream is a recently developed material containing permethrin for treating scabies.

BOTANICALS

Prior to the development of the modern organic insecticides, plant materials (Botanicals) were used widely in the United States because of their high toxicity to insects and their low degree of hazard to man and domestic animals. The botanicals, pyrethrum, rotenone, and limonene, have only three elements: Carbon, Hydrogen, Oxygen. They do not have chlorine or phosphorus as in the chlorinated hydrocarbons or organophosphates. Their formulae are very complex and are shown below:

PYRETHRUM is a mixture of:

Pyrethrin I -- $C_{21}H_{28}O_3$
Pyrethrin II -- $C_{22}H_{28}O_5$
Cinerin I -- $C_{20}H_{28}O_3$
Cinerin II -- $C_{21}H_{28}O_5$
Jasmolin I -- $C_{21}H_{30}O_3$
Jasmolin II -- $C_{21}H_{30}O_5$

These insecticides are extracted from the seeds of the Ox-eye or Shasta daisy, (Chrysanthemum cinerariaefolium), (Figure 2) grown chiefly in East Africa, particularly Tanzania, Kenya, and South America (13).

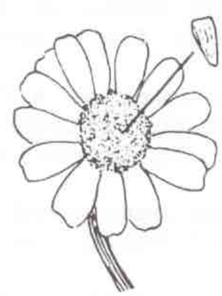


Figure 2. Flower of Chrysanthemum cinerariaefolium

Pyrethrum is the primary insecticide in many insect sprays and aerosols because of its quick knockdown of insects and its low toxic hazard to humans and domestic animals. Although pyrethrum frequently knocks down insects in few seconds, it does not always kill them. Therefore, many aerosol formulations include another insecticide, such as an organophosphate or a carbamate, to produce the final kill. A synergist, such as piperonyl butoxide, is generally mixed with pyrethrum compounds in order that low concentrations of the expensive pyrethrins may be used. Pyrethrum is one of the few insecticide sprays and aerosols that can be used safely in many indoor areas, such as kitchens and dining rooms before food is prepared or served, and in homes, barns, or airplanes. Pyrethrum dusts, sprays, or dips are some of the safest types of insecticides to use on cats and dogs, particularly puppies and kittens, for flea and other ectoparasite control.

There are many over-the-counter preparations containing pyrethrum and piperonyl butoxide sold for the control of head, body, and crab lice, particularly head lice. Most of these shampoos and other preparations kill nymph and adult lice, but not the eggs or nits, so a second application is recommended a week or two after the first treatment to kill lice that have hatched from eggs after the first application.

Pyrethrum sprays and mosquito capsules are often used to control mosquito larvae in fish and lily ponds where other insecticides might harm valuable fish or plants.

ROTENONE is a botanical insecticide derived from the roots of legumes such as Cube, Derris, Lonchocarpus, and Tembo. The technical grade materials is a white, crystalline solid that can be mixed with various carriers to make insecticidal sprays, dips, and dusts. The 0.75 to 1.0 percent dust is effective in killing flea and other ectoparasites on domestic pets, particularly kittens and puppies.

Rotenone has been used for many generations by natives in tropical countries to kill fish without rendering them toxic to humans. The roots of the legumes are pounded and thrown on the water surface. The fish become paralyzed and float to the surface where the best ones are collected for eating. In the United States rotenone is extremely useful for reclaiming ponds and lakes for game fishing. It kills all fish but breaks down quickly leaving no residues harmful to the desirable fish used for restocking. Rotenone sprays have been used in lily ponds where other insecticides might harm valuable plants.

LIMONENE is the newest addition to the group of botanical insecticides. It is derived from the peel of citrus fruits, such as oranges, to make pleasant-smelling dips to control fleas and other ectoparasites on domestic pets.

Other botanicals include nicotine derived from tobacco (as Nicotine Sulfate or Black Leaf 40), ryania, and sabadilla. These last two are generally not available and have not been widely used by public health workers.

INSECT GROWTH REGULATORS (IGR's)

Insect Growth Regulators are used to supplement, not supplant, conventional insecticides. They are designed to disrupt insect growth as juvenile hormone analogs, as hydroprene and methoprene, and as chitin synthesis inhibitors, as diflubenzuron. They are essentially non-toxic to humans (all with the signal word CAUTION, with oral toxicities ranging from 4640 mg/kg to 34,600 mg/kg, see Table 5). They are applied in very small amounts, as 1 ml. per gallon of conventional insecticides, as diazinon, for flea and cockroach control. They take time to work, as 14 days to 7 months on developing populations. Insect growth regulators show very little persistence in soil or water and leave no residue, stains, or odor when used in buildings (22, 45, 46, 48).

FENOXYCARB (Torus) is a juvenile hormone type of IGR that reduces the hatch of cockroach eggs, affects growth of nymphs, and inhibits adult cockroach reproduction. It prevents hatching of flea eggs and inhibits growth of flea larvae, preventing pupation and adult emergence. Following label directions a small amount of Torus can be added to conventional insecticide sprays used to control existing adult populations of cockroaches and fleas not affected by the IGR. The insect growth regulator works on the eggs and later stages to control developing populations of these insects, sometimes for as long as six months or more. Another form of fenoxycarb, Logic, is used to control fire ants. Granules of Logic are sprinkled on and around fire ant mounds and are carried below to the colony. Logic is slow acting, but 3 to 5 weeks later, there is considerable fire ant mortality and continual decline of the fire ant colony.

HYDROPRENE (Gencor) is a juvenile hormone type of IGR that affects cockroach nymphs during development and allows them to mature to adults. However, these adults have twisted wings and abnormal genitalia and cannot reproduce. Following label directions, a small amount of Gencor can be added to conventional cockroach sprays, as chlorpyrifos, to get immediate and short-term control of the existing adult cockroaches. The Gencor provides residual control of the developing nymphs for as long as 7 months.

METHOPRENE is registered as Precor, Altosid, and Pharorid. Precor is a juvenile hormone type of IGR used for indoor flea control. Following label directions, a small amount of Precor is added to conventional flea control insecticide sprays, as propetamphos, to give immediate and short-residual control of the existing flea population and the Precor to give 75 or more days in residual control (48).

Altosid is available in at least two formulations to control mosquitoes: liquid and briquets. Altosid liquid larvicide does not produce the rapid, directly toxic affects that are associated with traditional larvicides. The application has no affect on eggs, first stage larvae, pupae, or adult mosquitoes. Second, third, and fourth stage larvae continue to develop normally and will pupate. Eventually the pupae die and adult mosquitoes do not emerge. Altosid briquets, applied to floodwater mosquito breeding places before flooding, one to every 200 square feet, release the insect growth regulator for 30 days after flooding and prevent adults from emerging from the mosquito pupae. The World Health Organization has approved the use of methoprene to control mosquito larvae in drinking water in Third World countries.

DIFLUBENZURON (Dimilin) is a chitin inhibitor type of IGR. It is used in mosquito larval control. It interferes with the formation of the insect cuticle, causing inability to moult successfully.

TRIFLUMURON (Alsystin) is a chitin inhibitor type of IGR. It interferes with the molting process of mosquito larvae.

FUMIGANTS

Fumigants are gases which are discharged in very fine molecular form and penetrate into materials to kill pests. These volatile vapors kill by entering the insect's body through the body wall or breathing system. Fumigants are able to penetrate deeply into cracks and voids in materials infested with insects and kill all stages, as masses of clothing with eggs, nymphs, or adults of human lice, or sacks or bins of stored food infested with beetles, moths, their eggs and larvae. By contrast, insecticide aerosols, commonly referred to as smokes or fogs, are discharged as very fine particles of liquids or solids which remain suspended in the air long enough to distribute themselves throughout an area, acting primarily upon exposed insects. Aerosols are unable to penetrate deeply into materials because their particles are deposited on the outer surfaces.

Fumigants are produced in solid, liquid, and gas forms. Most of them are active as gases at temperatures above 5°C. (41°F), heavier than air, and usually contain one or more halogens: chlorine, bromine, or fluorine.

Monro (38), Torkelson, Hoyle, and Rowe (49), and Bond (6) have written excellent accounts of fumigants used by public health workers and pest control operators. They point out that the utilization of fumigants is limited by the following factors:

1. Flammability--some fumigants must be mixed with nonflammable materials to make them safe to use as insecticides.
2. Toxic hazards to operators.
3. High reactivity--including the problem of poisonous residues or residual odors in foods.
4. Tendency to corrode metals or damage dyes of fabrics.
5. Lack of chemical stability.
6. Cost.

All fumigants that produce effective control of pests are also toxic to humans, therefore every fumigator must receive thorough training, must be provided with proper equipment, and must understand the hazards associated with the fumigants he uses. Six fumigants are often used by public health workers. Three are produced as solid materials which give off volatile gases at temperatures above 41° F.: naphthalene, paradichlorobenzene, and phosphine. Three are produced as liquids that become gases at temperature above 41° F.: chloropicrin, methyl bromide, and sulfuryl fluoride.

SOLID-VOLATILE FUMIGANTS

NAPHTHALENE ($C_{10}H_8$) is a common household fumigant marketed as moth balls and flakes used to protect woolens, furs, silks, and feathers from attacks by clothes moths and carpet beetles. The white, crystalline solid gives off vapors slowly for weeks or months. For this reason it is sometimes used as a repellent for squirrels, bats, or mice in enclosed spaces such as attics. Naphthalene is less volatile than paradichlorobenzene and lasts longer as a repellent.

PARADICHLOROBENZENE ($C_6H_4Cl_2$), or PDB, is used chiefly to protect woolens, furs, and insect collections from insect attack, and as a masking deodorant in such places as public rest rooms. It is a white, crystalline solid which gives off vapors slowly for a long time that kill or repel insects. When the American or New Jersey light traps are used to sample insect, particularly mosquito, populations, a safe, long-lasting killing jar can be made with a layer of PDB in the bottom of the jar.

PHOSPHINE, or hydrogen phosphide (PH_3), is sold as Phostoxin, Gastoxin, or Detia to be used as a fumigant in stored grain and dry food processing places, or as a fumigant to kill Norway rats and their ectoparasites in burrows. It is applied as aluminum or magnesium phosphide tablets that are distributed throughout the grain, placed in trays in closed spaces to be fumigated, marketed as Phostoxin tablets on plastic sheets for railroad car and building fumigation, or dropped into rodent burrows as Gastoxin pellets. Within a few hours after exposure to the air, the aluminum or magnesium phosphide reacts with moisture in the air to begin liberating the deadly phosphine gas. The gas continues to be liberated for 2 to 3 days or longer depending on temperature and humidity. Phosphine gas has a garlic-like odor that serves as a warning agent. Phosphine gas is flammable and is corrosive to copper and other metals, as electric switches and equipment, which limits its use in building fumigation. Since calcium cyanide dust is no longer available to kill Norway rats in their burrows, EPA has given label permission to the placing in rodent burrows of 2-4 Gastoxin pellets which liberate phosphine gas to kill the rodents (4).

LIQUID OR GAS FUMIGANTS

CHLOROPICRIN, (Cl_3CNO_2) or tear gas, is sometimes used as a fumigant to kill rodents and insect pests in severely infested warehouses and other buildings. The liquid chloropicrin is poured over crumpled burlap sacks at a rate of one and one-half to two pounds of the liquid fumigant per 1000 square feet (19). Two percent chloropicrin (tear gas) is often added to odorless methyl bromide as a warning agent.

METHYL BROMIDE (Bromogas) (CH_3Br) is a colorless, odorless, very fast-acting, non-flammable gas that is heavier than air. Some formulations contain 2% chloropicrin (tear gas) as a warning agent, but preparations labeled for commodity fumigation are 100% methyl bromide. Methyl bromide is packaged as a liquid under pressure in one pound cans or in large steel cylinders. This liquid is released through tubing into the area to be fumigated and becomes a gas at temperatures above 38.5° F. (3.6° C). Methyl bromide is widely used to fumigate foods infested with pests, but reacts with many materials listed on the label to cause color or physical damage or foul odors. It reacts with so many objects containing sulfur, as rubber products, rug padding, and cinder blocks, producing long-lasting or permanent foul odors that building fumigations to control termites, powder post beetles, fleas, cockroaches, or rodents are usually done with sulfuryl fluoride (Vikane) (4).

SULFURYL FLUORIDE (Vikane) (SO_2F_2) is an odorless, non-flammable, fast-acting structural fumigant. It is used especially to control dry wood termites, powder post beetles, old house bores and other pests in building because it does not react with many objects to produce the foul odors often caused by methyl bromide. Fumigation with Vikane should be conducted when temperature is 55° F. or above (35). Vikane gas does not always kill insect eggs, particularly of dry wood termites.

MISCELLANEOUS

HYDRAMETHYLNON is sold under at least three trade names: Maxforce (or Combat) as a bait for cockroaches in tamper-resistant plastic containers that can be placed in kitchen drawers with silver and cutlery, or dish closets, without contaminating anything with harmful pesticides; Pharorid bait in tamper-resistant plastic containers for control of pharaoh ants; and Amdro bait for fire ant control (48).

BACILLUS THURINGIENSIS var. **ISRAELIENSIS** is sold under many trade names as Bactimos, Teknar, and Vectobac for control of mosquito and black fly larvae. After ingestion by the larvae, the bacteria cause paralysis of the midgut to occur within a few hours and usually death within 24 hours. These insecticides are used as granules, flowables, and briquets. The bacteria are harmless to plants and vertebrates including fish and humans (31, 48).

GOLDEN BEAR OILS are some of the few currently active, EPA-registered mosquito larvicide oils available in the United States. They replace kerosene and diesel oil which were used for many years as outdoor mosquito larvicides, but are not registered by EPA for mosquito control. The Golden Bear Oils (GB-1111 and GB-1356) are easy to apply, give control of mosquito larvae and pupae usually within 24 hours (as compared with the much longer time for insect growth regulators such as Dimilin), and develop no chemical resistance (which has occurred to many chlorinated hydrocarbon and organophosphate insecticides) since the killing action is by suffocation (2).

INORGANICS

The inorganics differ from most insecticides in that they lack the element carbon. Two with minor uses by public health workers are Borax and Sulfur.

BORAX (Boric acid) is used as a powder or dust formulation for controlling cockroaches, ants, and silverfish indoors. Boric acid is slow-acting, sometimes taking a week or more for control, but it is one of the longest-lasting insecticides and is useful in cracks and crevices, voids in walls, and attics as long as the material remains dry. It acts both as a stomach poison and as a desiccant, absorbing the wax on the exoskeleton of insects, and allowing body fluids to seep from the insect.

SULFUR dust is sometimes applied to clothing, particularly socks and trousers, to repel or kill chiggers.

DESICCANTS OR SORPTIVE DUSTS

Very finely powdered silica gels and silica aerogels have been used for the control of cockroaches, fleas, kissing bugs, dry wood termites, and ectoparasites of domestic animals as ticks, lice, and mites. Silica aerogels and diatomaceous earths are also used to protect stored grains from attacks by beetles and moths and their larvae. These compounds kill insects by damaging the outer, waterproof layer of the arthropod exoskeleton, the epicuticle, either by absorbing the fatty or waxy material or by abrasion. The insects lose liquid rapidly, and die by desiccation. These materials are reported to be nontoxic to humans and warm-blooded animals. Sorptive dusts are amorphous rather than crystalline compounds, so they do not cause silicosis. Since the action of the dusts is physical rather than chemical, it is possible that the insects will not become resistant to them. The real problem in using this type of control is to keep the fine powder in areas where the insects will come in contact with the dusts. Two desiccants, Drie-Die and Drione, are fortified with pyrethrum and synergists for better kill (51).

ATTRACTANTS

Attractants are materials used to lure insects into traps or to induce them to eat poisoned baits. Natural odors and scents play an important role in the life of insects, particularly in regard to seeking food, the opposite sex, and a place to lay their eggs.

Only a few attractants have been critically analyzed and synthesized commercially. Classic examples are the Japanese beetle attractants, Eugenol, Geraniol, and Japonilure; the gypsy moth sex attractant, Disparlure; Trimedlure used with malathion in a poison bait to eradicate the Mediterranean fruit fly in Florida and California; and Muscalure used as an attractant in some house fly baits.

In the field of public health, attractants have several practical applications as follows:

1. **To lure insects to poison baits or traps**. Poison baits include food type attractants such as sugar, peanut butter, and fish and selected organophosphorus insecticides (Dichlorvos, Trichlorfon) to kill flies, cockroaches, ants, and yellow jackets ( ). The sex hormone, Muscalure, is added as an attractant to lure house flies to poison baits and electocutor traps (Figure 3). Heptyl butyrate has been used successfully in the West to trap yellow jackets in campgrounds, roadside parks, and fruit orchards. This lure permits effective control of yellow jackets without the necessity of finding and treating each individual nest. Heptyl butyrate is effective only against the western yellow jacket and has not been found to control eastern yellow jackets (1).

2. **To sample local insect populations**. Mixed garbage, the natural food and oviposition medium of many species of flies, is a standard bait in fly traps (Figure 5). Sometimes beer-molasses mixtures are used to attract house flies, and decaying fish or meat is used to attract blow flies, to fly traps. Dry ice (or solid carbon dioxide) is often used in special lard can traps (Figure 4) to collect the encephalitis mosquito, *Culex tarsalis*, but does not work with many other mosquitoes. Dry ice is often used with CDC or conventional light traps to increase the number of mosquitoes attracted to these devices. Dry ice also increases the number of deer flies and horse flies collected in Malaise and Canopy traps (39).

Ticks are attracted to carbon dioxide released from dry ice wrapped in newspaper and set on white cloth on the ground. The ticks are easily collected from the white cloth for later study (21).

3. **To improve the attractiveness of residual sprays outdoors**. The addition of 2.5 times as much sugar as toxicant to residual sprays applied outdoors improves their attractiveness and prolongs the effectiveness of many organophosphate insecticides used in fly control, as residual sprays on garbage can racks (14).

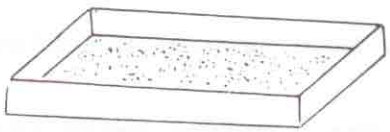


Figure 3. Tray for sugar baits for fly control.

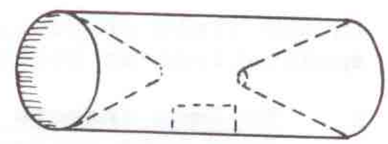


Figure 4. Lard can trap with dry ice to trap mosquitoes.

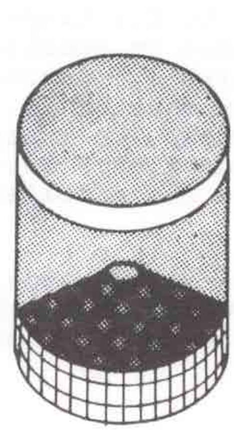


Figure 5. Fly trap

REPELLENTS

Repellents are those substances that produce avoidance reactions in animals. A satisfactory arthropod repellent should: (1) protect the user for several hours even under unfavorable conditions, (2) be nontoxic, nonirritating, and nonallergenic to the skin, (3) have no unpleasant odor, (4) be harmless to clothing and accessories such as plastic watch covers, (5) be effective against a wide variety of pestiferous arthropods, and (6) be stable in sunlight. The skin repellents should withstand sweating and resist loss by wiping; clothing repellents should resist leaching by rain and laundering (29).

Repellents are often the only practical means of protecting people from the bites of mosquitoes, black flies, Culicoides, chiggers, ticks, and many other biting arthropods in situations where residual and space spraying are not feasible. Their use adds greatly to the pleasure of golf, camping, hunting, fishing, and hiking in areas that are not ordinarily treated with insecticides. The military organizations have an even greater interest in repellents, since modern warfare and routine operations are carried out in vast areas in which arthropod control operations are impossible or not economically feasible.

Before World War II, there were five standard repellents for use against biting arthropods: sulfur, oil of citronella, dimethyl phthalate, Indalone, and Rutgers 612. During World War II, the last three compounds were combined into a mixture designated as 6-2-2, which was used as the standard all-purpose repellent in the military and widely used by the general public. It was composed of six parts dimethyl phthalate, two parts Indalone, and two parts of Rutgers 612.

During World War II and afterwards thousands of compounds were screened as repellents. This research lead to the development in 1957 of DEET (Diethyl Toluamide). DEET is available as a liquid, aerosol, lotion, and cream. When properly applied to the neck, face, arms, ankles, and other exposed body surfaces, a small amount of repellent will give protection for a period of from two hours to half a day depending on the person, and on the species and abundance of biting arthropods. Care should be taken not to apply this repellent to the eyes, lips, or other mucous membranes.

In most areas DEET has an excellent record in protecting people from biting arthropods without causing skin irritation. However, in Vietnam, particularly among military personnel crouching in cramped positions in foxholes under combat conditions, a number of cases of blistering skin eruptions in the inner elbow area were reported. Lamberg and Mulrennan (33a) suggested the "users should be cautioned not to apply the material to regions of skin flexion," i.e., the inner elbow and the area behind the knee.

DEET has been widely used as a tick repellent particularly in the Northeast where Lyme disease is prevalent. In 1989, CDC (15) reported that DEET "is used by 50-100 million persons each year. Since 1961, at least six cases of toxic systemic reactions from repeated cutaneous exposure to DEET have been reported." In 1989, there were anecdotal reports of seizures temporarily associated with the use of DEET. Prior to 1990, some brands of repellent contained a small amount of R-11 (since voluntarily eliminated by the manufacturer) which may have been involved in these adverse reactions.

Repellents containing 20%-30% DEET applied to clothing are approximately 90% effective in preventing tick attachment. To minimize the possibility of adverse reactions to DEET, the following precautions are suggested: (a) apply repellent sparingly only to exposed skin or clothing, and (b) avoid applying high-concentration products to the skin, particularly of children (15).

In some states, as Georgia, aerosol sprays of permethrin (Permanone) are registered to be applied to clothing before it is worn to repel or kill ticks, but not to exposed skin. The spray is applied with a slow sweeping motion, holding at a distance of 6 to 8 inches, with special attention to socks, trousers, and shirt cuffs. This may provide protection from ticks for a day or longer (10).

AUXILIARIES

Auxiliaries, in the context of this handbook, are materials which help the insecticides to work more efficiently and economically by acting as solvents, emulsifiers, spreading and wetting agents, adhesives or stickers, perfumes and masking agents, synergists, and carriers or diluents. It is generally not economical to apply pesticides as technical grade material or in concentrated form. A wide variety of chemicals have been found useful in formulating sprays and dusts.

SOLVENTS

A solvent dissolves an insecticide so that molecules of insecticide are evenly dispersed throughout the resultant solution. The solvent acts both as a carrier for the insecticide and as a diluent, reducing the concentration of the insecticide to the most economical percentage. Some solvents, such as petroleum fractions, also add to the insect-killing powers of the formulation. Many insecticides are dissolved in solvents such as fuel oil, kerosene, or xylene in the preparation of field spray solutions or emulsifiable concentrates. The selection of a solvent depends on its ability to hold the insecticide in solution, its toxicity to animal and plant life, its odor and staining characteristics and its fire hazard.

Three general types of solvents are commonly used: (a) water, which dissolves some insecticides as acephate and trichlorfon to form liquid baits, or evaporates to leave a toxic residual deposit after spraying, (b) volatile liquids, such as xylene, which evaporate after spraying and leave only a residual deposit of the insecticide, and (c) petroleum oil or its derivatives to make ultra low-volume or fogging concentrates.

EMULSIFIERS

An emulsifier is a surface active agent (detergent) that stabilizes a mixture of liquid within a liquid. Milk, for example, is an emulsion with tiny globules of butterfat and other ingredients suspended in water.

A technical grade insecticide is typically dissolved in an inert solvent, such as oil or xylene, and added to an emulsifier to produce an emulsifiable concentrate. Such a concentrate can be easily stored and shipped, thus preventing the expensive necessity of shipping large volumes of low concentrate insecticide and water. At the time of use, the emulsifiable concentrate is diluted with water, the most universal and economical carrier, to produce an inexpensive and effective emulsion. Emulsions typically appear milky. They are not transparent like water and many solutions.

The emulsifier forms a thin film around each minute droplet of insecticide in solution, resisting the tendency of the droplets to coalesce and separate into continuous layers of solvent and water. In the familiar oil-in-water insecticidal emulsions, the many finely divided solvent droplets form the dispersed phase and the water comprises the continuous phase (Figure 6).

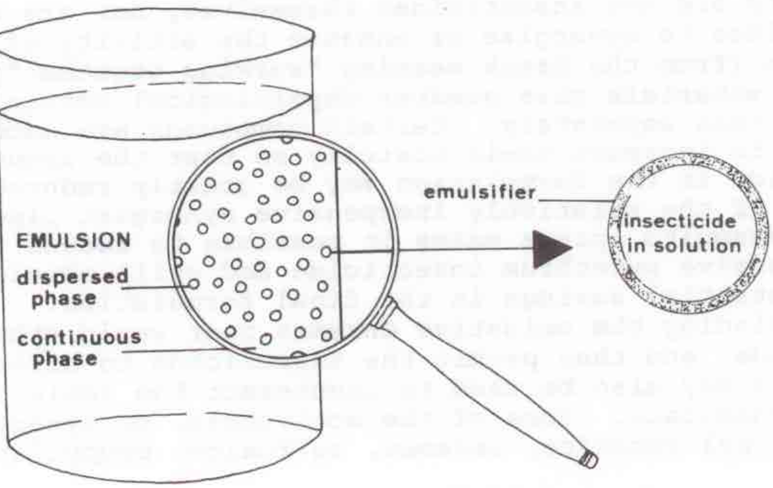


Figure 6. Physical structure of an emulsion

SPREADING AND WETTING AGENTS

Many of the synthetic emulsifiers and detergents are used also as wetting and spreading agents. These agents are rather difficult to define except according to the manner in which they are used. Detergents are developed primarily for their cleaning ability. Spreading agents, such as Triton B-1956, may be added to oil larvicides to decrease the surface tension and cause it to spread in a thinner film on the water surface in which the larvae live. Wetting agents promote the formation of a continuous film of insecticide on water-repellent surfaces or increase the rate with which the insecticide soaks into or wets other materials. Sulfonated oils, the higher sodium alkyl sulfates, and other surface-active dispersants may be added to insecticidal dusts to produce wettable insecticide powders (also known as water-dispersible powders) which form suspensions when added to water.

ADHESIVES OR STICKERS

Adhesives are substances added to liquid sprays to improve the adhesive quality of the insecticidal deposit, especially to avoid leaching by the rain. Protective materials such as gelatin, glue, rosin, and other gums are valuable adhesives.

PERFUMES AND MASKING AGENTS

Perfumes or masking agents are agreeable scents, like oil of wintergreen, that are added to household insecticides to mask unpleasant odors such as those of kerosene, pyrethrum or cyclohexanone. There are many proprietary perfumes and masking agents now available.

SYNERGISTS

Synergists are not insecticides themselves, but are materials used with insecticides to synergize or enhance the activity of the insecticide. Synergism (from the Greek meaning "working together") is said to occur when two materials give greater physiological action when applied together than separately. Certain compounds are added to insecticidal mixtures to increase their toxicity so that the amount of the basic insecticide in the formulation may be greatly reduced. For example, the addition of the relatively inexpensive synergist piperonyl butoxide to fly and mosquito sprays makes it possible to reduce the amount of the more expensive pyrethrum insecticide and still obtain effective control, with substantial savings in the final formulation. Synergists apparently work by binding the oxidative enzymes that would otherwise degrade the insecticide, and thus permit the insecticide to affect the insect. These synergists may also be used to counteract the resistance of insects to certain chemicals. Some of the activators, or synergists, currently used are piperonyl butoxide, sesamex, sulfoxide, propylisome, and MGK 264 (51).

CARRIERS AND DILUENTS FOR DUSTS

Most insecticidal dusts are purchased ready for use, but may be diluted for special purposes. Some of the generally available carriers include attapulgite, bentonite, calcite, diatomite, gypsum, hydrated lime, kaolin clay, pyrophyllite, and talc. Dust carriers should be relatively low in cost, and must have great absorptive capacity when they are used to absorb liquid insecticides such as malathion. These carriers must not produce any breakdown of the insecticidal chemical. Dusts are usually mixed in a ball-mill or other type of blending machine. They must be extremely fine particles and of low density in order that they may be airborne for a considerable distance when applied.

TYPES OF INSECTICIDAL FORMULATIONS

Insecticides are produced from natural or synthetic chemicals that kill insects readily, but will not cause undue hazard to man, animals, and plants when formulated and applied correctly. Precise formulation and application are essential in all insecticidal programs. Some toxicants are applied as technical grade insecticides, such as malathion or naled in ultra low-volume applications; most insecticides are diluted as granules, suspensions, solutions, or emulsions before application. Dusts are often diluted to lower concentrations with talc or pyrophyllite. Wettable powders are mixed with water to form suspensions of desired concentration. Liquid sprays are often purchased as concentrated solutions or emulsifiable concentrates. Concentrated solutions may be diluted with oils, and emulsifiable concentrates with water, to prepare field strength solutions or emulsions. The diagrams in (Figure 7) indicate the interrelationships between these various formulations.

Technical grade insecticide is the basic toxic agent in its purest commercial form. It is rarely chemically pure (C.P.). Some technical grade insecticides are liquids, others occur in solid form. Technical grade malathion is a clear amber liquid, whereas chlorpyrifos (Dursban) is a white, granular, crystalline material. Some undiluted technical grade insecticides are used in ultra-low-volume space applications. However, in most cases technical grade insecticides are mixed with a carrier before use, forming a dust, granule, suspension, solution, or emulsion.

Insecticidal dust in its simplest form is merely finely pulverized insecticide such as sulfur dust used to repel chiggers. Most insecticidal dusts, however, consist of the technical grade insecticide and an inert carrier, such as talc or pyrophyllite, with each minute particle of the carrier coated with the chemical toxic to insects. Most insecticide dusts are ready-to-use formulations with the amount of the active ingredient ranging from 1 to 10 percent. Dusts may be applied by hand, by simple dust guns, by large power dusters, or by airplanes. These materials are usually low in cost, easy to apply, nonstaining, and nontoxic to vegetation.

Insecticides in dust form are not generally absorbed through the skin, but may be dangerous if inhaled into the respiratory tract. Dusts do not adhere well to vertical surfaces and are easily removed by rain and wind. They are unsightly in the home and have been replaced, for the most part, by sprays and aerosols. Insecticide granules are larger dry formulations than dusts. They do not adhere to leaves and so will penetrate dense foliage, real advantages where it is desirable for the insecticide to reach the water surface for mosquito control in vegetated swamps, or to get to the ground surface through trees and shrubs for chigger or fire ant control.

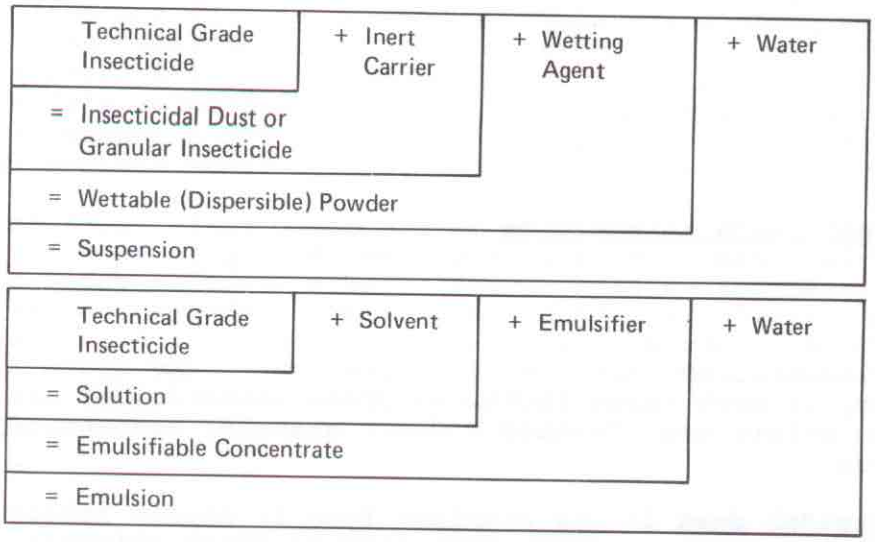


Figure 7. Insecticide formulations

A wettable (or water-dispersible) powder consists of the technical grade insecticide, and inert carrier, and a wetting agent (usually a synthetic detergent) which facilitates mixing it with water to form a suspension. Many wettable powders contain an anticaking agent, which prevents lumping while in storage, and a dispersant which helps keep the particles in suspension from settling out too quickly. Wettable powders may have a technical grade chemical content ranging from 15 to 90 percent. The insecticide is coated (absorbed) onto a fine inert dust, such as talc or pyrophyllite, which has thin plate-like particles that remain suspended in water for a reasonable time. During use, suspensions should be agitated continuously or frequently to prevent settling of the solid insecticide particles.

Wettable powders have advantages over other concentrates. They do not require the addition of solvents which can cause injury to plants, they lack a solvent odor, and they do not have a tendency to irritate the skin of the spraymen or to be absorbed through the skin. Another great advantage is the tendency of the insecticide to be deposited on the porous surface of the structure sprayed. When porous materials such as concrete, plaster, adobe, or unpainted wood are sprayed with a suspension, the water penetrates, leaving the carrier and the maximum amount of the insecticide on the surface, available to kill insects. By contrast, when solutions or emulsions are sprayed, they penetrate porous materials so that less of the insecticide remains on the surface.

Suspensions tend to clog the strainers and nozzles of sprayers, especially when the wettable powder is stored for long periods in humid areas, which causes a clumping of particles, or when it is applied in high concentration. Trouble is experienced when using some municipal water supplies. Some waters produce foaming while others require the addition of more wetting agent.

An insecticidal solution consists of the technical grade insecticide dissolved in a solvent such as water, kerosene, diesel oil, or xylene. Solutions are available as ready-to-use formulations, such as the ordinary household fly and mosquito sprays with a low percentage of insecticide, and as solution concentrates. Solution concentrates contain a high percentage of insecticide and must ordinarily be diluted with oil, water, or other suitable solvent and diluent, indicated on the label, before use. Some concentrates are used without dilution in ultra-low-volume (ULV) applications. In residual spraying the solvent evaporates from the treated surfaces, leaving a deposit of the insecticide. DDT and some other insecticides cause a "blooming" of fine crystals that are readily picked up by the feet and bodies of insects. Some other insecticides, such as malathion, do not crystallize but form a thin film of insecticide on treated surfaces.

Solution concentrates have the advantage of low volume, which reduces bulk, weight, and shipment costs. They are diluted at the destination, often in the field, making their portability a real advantage. The diluted mixture is termed field strength solution. Oil solutions are used extensively in fog applicators, but are unsatisfactory for most dilute spray applications because of their toxicity to plants.

Emulsifiable concentrates consist of the technical grade insecticide, a solvent, and an emulsifying agent, usually a synthetic detergent. When the emulsifiable concentrate is added to water and agitated, an emulsion is formed and the concentration of insecticide is reduced to the desired field strength. Insecticidal solutions and emulsifiable concentrates usually are clear, whereas emulsions have an appearance similar to milk, the commonest natural emulsion. Unlike solutions, most insecticidal emulsions require periodic agitation to prevent the concentrate from separating out of the water. Emulsions or solutions, diluted to field strength, are called finished sprays. Emulsifiable concentrates have the same advantages as the solution concentrates, plus the benefits of a low cost and readily available diluent water.

Emulsions are widely used for the residual treatment of solid surfaces. Insects that rest on these treated surfaces are killed by the residue of insecticide. Some emulsions remain effective for a longer time on masonite, bare or painted wood than on glazed tile or shiny metal. This is an important consideration in determining the time interval between residual applications. Emulsions with a high percentage of the insecticide (and solvent) may "burn" plants. Therefore, any emulsions sprayed on plants should have a low percentage of insecticide and solvent and a high percentage of water. Mosquito larvicidal treatments with emulsions are usually confined to shallow bodies of water and to treatment of water containers, where excessive dilution will not take place. Mosquito larvicidal treatments with emulsions are usually in a thin film that kills the larvae when they come to the sprayed surface to breathe atmospheric air. Emulsions may injure aluminum, varnish, and painted surfaces, due to the action of solvents such as xylene. Emulsions are often corrosive to metal sprayers and their fittings. Sprayers used to dispense emulsions should be made of stainless steel, aluminum, fiberglass or other noncorrosive materials. After use, the sprayers are easily cleaned by a water rinse.

Other formulations, such as insect baits, soluble powders, ultra-low-volume and fogging concentrates, and microencapsulated sprays, are well discussed by Ware (51) and Wamsley (50).

PREPARING INSECTICIDES FOR USE

Dusts are usually purchased ready to use, but may be diluted for special purposes with one of the inert carriers. Technical grade insecticides and their solvents do not usually have the same specific gravity or weight per gallon. They cannot, therefore, be mixed according to volume, but must be prepared on a weight-to-weight basis. They may then be further diluted by volume with sufficient accuracy, as the specific gravity of the ingredients has been compensated for in the preparation of the concentrate.

DILUTION FORMULAS

Liquid sprays are often purchased as solutions or emulsifiable concentrates. These must be diluted with oil or water to prepare the finished spray. Dusts are often diluted to lower concentrations with talc or pyrophyllite. This requires a mechanical mixer to ensure complete blending of the two ingredients.

The **PROPORTIONAL FORMULA** is a simple dilution formula for diluting a liquid with a liquid, or a solid with a solid. This formula is a ratio, such as 1:19, and does not give the amount of concentrate required to prepare a certain quantity such as 5 gallons of 50 percent malathion emulsifiable concentrate, Examples 1 and 2.

The **"SAC" FORMULA** is used when it is desired to produce a certain quantity of insecticide using materials of the same form, such as liquid with liquid, or solid with solid, Examples 3, 4, and 5.

The **"SAD SAC" FORMULA** is used when it is desired to produce a certain quantity of insecticide from ingredients whose form is different, such as mixing a solid wettable powder with water to produce a suspension, Examples 6, 7, and 8.

The **"SAD COW" FORMULA** is used when the liquid concentrate is prepared on the basis of pounds of insecticide per gallon of formulation, Example 9.

Figure 8 illustrates the principles for selecting the correct formula to use in diluting insecticidal concentrates. Table 2 provides ratios for diluting liquids with liquids or dusts with dusts. Table 3 lists quantities of water-wettable concentrates to use in preparing 100 gallons of field strength suspension.

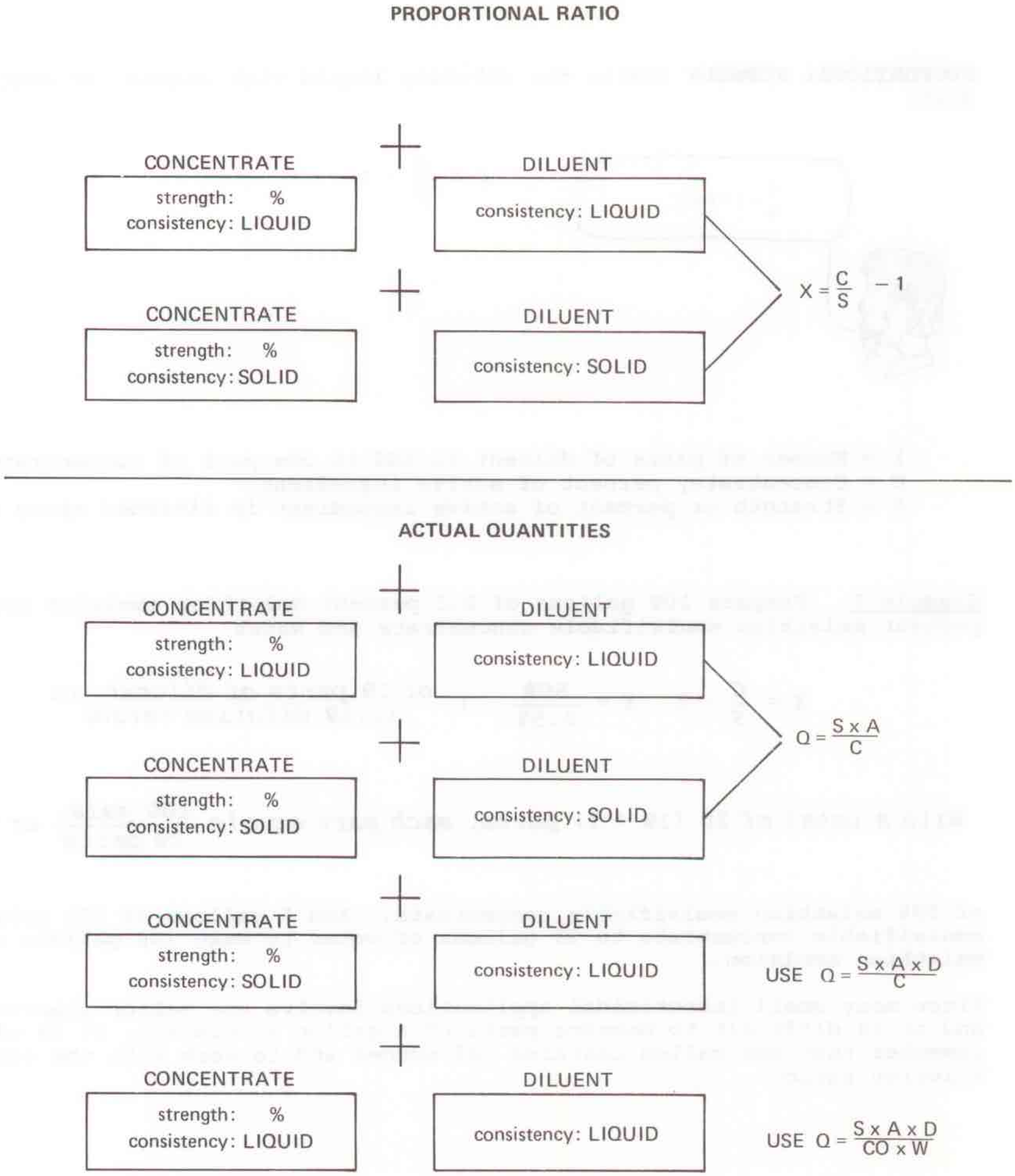
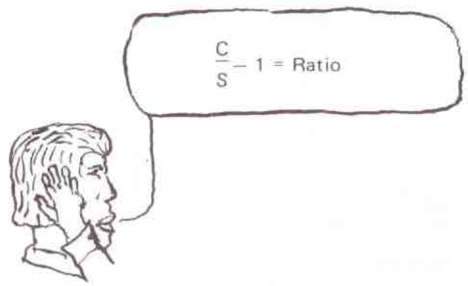


Figure 8. Principles for selecting correct dilution formula

PROPORTIONAL FORMULA (Ratio for diluting liquid with liquid, or dust with dust)



$$X = \frac{C}{S} - 1$$

X = Number of parts of diluent to add to one part of concentrate
C = Concentrate, percent of active ingredient
S = Strength or percent of active ingredient in finished spray or dust

Example 1. Prepare 100 gallons of 2.5 percent malathion emulsion from 50 percent malathion emulsifiable concentrate and water.

$$X = \frac{C}{S} - 1 \quad X = \frac{50\%}{2.5\%} - 1$$ *or* 19 *parts of diluent, or* (1:19 *dilution ratio*)

With a total of 20 (19 + 1) *parts, each part equals* $\frac{100 \text{ gals.}}{20 \text{ parts}}$ *or* 5 *gals.*

of 50% malathion emulsifiable concentrate. Add 5 gallons of 50% malathion emulsifiable concentrate to 95 gallons of water to make 100 gallons of 2.5% malathion emulsion.

Since many small insecticidal applications involve one gallon quantities, and it is difficult to measure parts of a gallon accurately, it is wise to remember that one gallon contains 128 ounces and to work with the ounce dilution ratio.

Example 2. Prepare 1 gallon (128 ounces) of 2.5 percent malathion from 50 percent malathion emulsifiable concentrate and water for use in a hand sprayer.

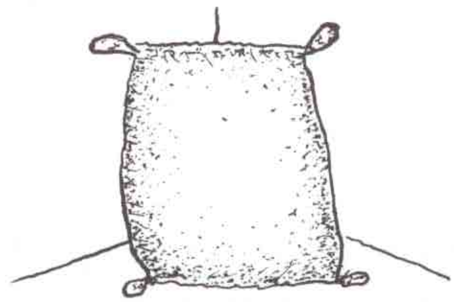
$$X = \frac{C}{S} - 1 \quad X = \frac{50\%}{2.5\%} - 1 \quad X = \frac{20}{1} - 1 \quad \textit{or 19 parts of diluent, or (1:19 dilution ratio)}$$

With a total of 20 (19 + 1) *parts, each part equals* $\frac{128\ oz.}{20\ parts}$ *or* 6.4 *ounces.*

Add 6.4 oz. of 50% malathion emulsifiable concentrate to the hand sprayer and fill to the one gallon fill mark on the tank. Use a plastic or metal measuring cup for accurate measurement.

"SAC FORMULA" (for preparing certain quantity)

$$Q = \frac{S x A}{C}$$



Q = Quantity of concentrate required in mixture (pounds, gallons, ounces)
S = Strength or percent of active ingredient in the finished dust or spray
A = Amount of finished spray or dust to be prepared (pounds, gallons, or ounces)
C = Concentrate, percent of active ingredient

Example 3. Prepare 100 pounds of 10 percent malathion dust using 75 percent malathion dust and talc:

$$Q = \frac{S x A}{C} \qquad Q = \frac{10\% \ x \ 100 \ lbs.}{75\%} = \frac{1000 \ lbs.}{75} = 13.3 \ lbs.$$

Add 13.3 lbs. of 75 percent malathion dust to 86.7 lbs. of talc to make 100 lbs. of 10 percent dust.

Example 4. Prepare 100 gallons of 0.5 percent diazinon emulsion using 20 percent diazinon emulsifiable concentrate and water.

$$Q = \frac{S \times A}{C} \quad Q = \frac{0.5\% \times 100 \; gals.}{20\%} = 2.5 \; gals.$$

Add 2.5 gallons of 20 percent diazinon emulsifiable concentrate to 97.5 gallons of water to make 100 gallons of 0.5 percent diazinon emulsion.

Example 5. Prepare one gallon (128 ounces) of 0.5 percent diazinon emulsion from 20 percent emulsifiable concentrate and water.

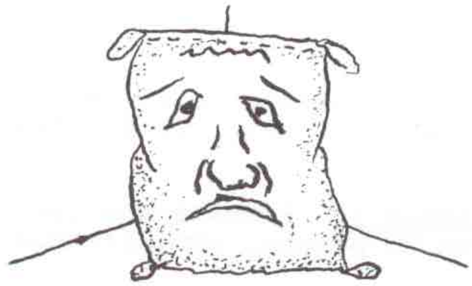
$$Q = \frac{S \times A}{C} \quad Q = \frac{0.5\% \times 128 \; oz.}{20\%} = \frac{64 \; oz.}{20} = 3.2 \; oz.$$

Place 3.2 fluid ounces of 20 percent diazinon emulsifiable concentrate in the sprayer and add enough water to make one gallon.

"Sad Sac" Formula (weight to weight formula)

The following formula may be used to prepare a suspension on a w/w (weight to weight) basis using either the technical grade insecticide or a concentrate.

$$Q = \frac{SxAxD}{C}$$



Q = Pounds of concentrate to use
S = Strength or percentage of active ingredients in the finished spray
A = Amount in gallons of finished spray
D = Density: Weight of one gallon of diluent (water is 8.34 lbs./gal.)
C = Concentrate: Percentage of active ingredient

Example 6. Prepare 100 gallons of 1.25 percent malathion suspension from 75 percent wettable powder and water.

$$Q = \frac{SxAxD}{C} \quad Q = \frac{1.25\% \times 100\ gals. \times 8.34\ lbs./gal.}{75\%} = \text{13.9 lbs. of 75\% water-dispersible powder.}$$

Fill the mixing tank with most of the 100 gallons of water. Add the 13.9 lbs. of 75 percent water-dispersible powder and mix. Fill to the 100 gallon level.

Example 7. Prepare one gallon of 2.5 percent malathion suspension from 75 percent water-wettable powder and water.

$$Q = \frac{SxAxD}{C} \quad Q = \frac{2.5\% \times 1\ gal. \times 8.34\ lbs./gal}{75\%} = \text{0.28 lb. (4.5 oz.) of 75\% water-dispersible powder}$$

Add 4.5 oz. of 75 percent wettable malathion powder to the hand sprayer. Add water slowly with constant mixing to the gallon mark.

Example 8. Prepare 7.5 liters (7500 ml or about two gallons) of 5 percent suspension from 75 percent malathion wettable powder.

$$Q = \frac{SxAxD}{C} \quad Q = \frac{5\% \; x \; 7500 \; ml \; x \; 1 \; gram/cc}{75\%} = 500 \; gm \; of \; 75\% \; water\text{-}wettable \; powder.$$

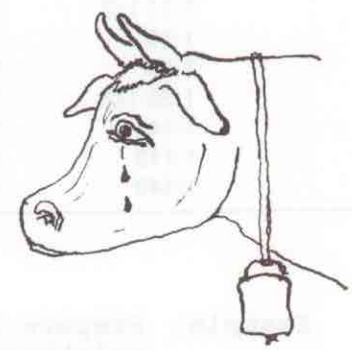
Place 500 grams of 75 percent wettable malathion powder in the 2 gallon sprayer. Add a small amount of water and stir to make a slurry. With constant stirring add water slowly to the 7500 ml mark.

This formula may be used to prepare solutions and suspensions on an accurate basis. After the amount of material to be used has been computed and weighed, place it in a container and make a permanent mark to be used when solutions or suspensions are being prepared by field men. The men will than be able to mix chemicals by volume without using scales to make measurements each time a tankful is to be mixed.

"Sad Cow" Formula

The following formula may be used to dilute liquid concentrates prepared on the basis of pounds of insecticide per gallon.

$$Q = \frac{S x A x D}{CO x W}$$



Q = Quantity of concentrate required in gallons
S = Strength or percentage of active ingredients in the finished spray
A = Amount of spray to be prepared in gallons
D = Density: weight of gallon of diluent, usually water (8.34 lbs.)
CO= Concentrate: 100 percent
W = Weight of the insecticide concentrate in pounds per gallon

Many insecticides are now sold with the label indicating pounds of insecticide per gallon rather than percentage of toxic materials; examples are chlordane - eight pounds per gallon, or four pounds per gallon. In this case, the weight to weight formula is modified so that the factor CO is considered as 100 percent, and a Factor W-pounds of insecticide per gallon is added.

Example 9. Prepare 100 gallons of 0.5 percent Dursban emulsion from an emulsifiable concentrate containing 4 pounds per gallon.

$$Q = \frac{S x A x D}{CO x W} \quad Q = \frac{0.5\% \times 100 \ gals. \times 8.34 \ lbs./gal.}{100\% \times 4 \ lbs./gal.} = \text{one gallon (approximately) of Dursban concentrate.}$$

Add 1 gallon of 4 pounds/gallons Dursban concentrate to sufficient water to make 100 gallons of finished spray.

TABLE 2 DILUTION TABLE FOR LIQUID CONCENTRATES OF DUSTS

Strength of Finished Spray or Dust	Strength of Concentrate					
	75%	50%	35%	30%	25%	20%
15%	1:4	1:2-1/3	1:1-1/3	1:1	1:2/3	1:1/3
10%	1:6-1/2	1:4	1:2-1/2	1:2	1:1-1/2	1:1
7.5%	1:9	1:5-2/3	1:3-2/3	1:3	1:2-1/3	1:1-2/3
6%	1:11-1/2	1:7-1/3	1:4-5/6	1:4	1:3-1/6	1:2-1/3
5%	1:14	1:9	1:6	1:5	1:4	1:3
2.5%	1:29	1:19	1:13	1:11	1:9	1:7
2%	1:36-1/2	1:24	1:16-1/2	1:14	1:11-1/2	1:9
1%	1:74	1:49	1:34	1:29	1:24	1:19
0.625%	1:119	1:79	1:55	1:47	1:39	1:31
0.5%	1:149	1:99	1:69	1:59	1:49	1:39

Example: Prepare 100 lbs. of 5 percent malathion dust from 50 percent malathion dust and talc. The Dilution Table 2 indicates a dilution rate of 1:9, so that there are a total of 10 parts in the desired 100 lbs. of finished dormulation. Therefore:

$$\frac{100 \ lbs.}{10 \ parts} \ \text{each part equals } 10 \ lbs.$$

With the 1:9 ratio mix 10 lbs. (1 part x 10 lbs.) of the 50 percent malathion dust with 90 lbs. (9 parts x 10 lbs.) of talc to obtain 100 lbs. (10 parts x 10 lbs.) of the 5 percent dust.

TABLE 3. DILUTION TABLE FOR PREPARING SUSPENSIONS FROM WETTABLE POWDERS

Percent Water Wettable	Pounds wettable powder required for 100 gallons of finished spray at percentage levels below				
	0.25	0.5	1.0	2.5	5
75	2.6	5.3	10.7	26.7	53.3
50	4	8	16	40	80
25	8	16	32	80	160

SELECTION OF AN EFFECTIVE INSECTICIDE

The classification table in the frontispiece can be used as an aid in selecting alternative insecticide once a resistance problem is known. The insecticides are classified into major groups, such as "organophosphates." Thus, if cockroaches are resistant to diazinon, a change would not be made to chlorphyrifos (Dursban) which is also an organophosphate, but to a chemical in another major group such as the carbamate propoxur (Baygon) or a pyrethroid as cypermethrin (Demon). Similarly, if mosquito larvae become resistant to temephos (Abate), an oil larvicide might be considered because it leaves an oil film on the water to suffocate the mosquito larvae.

Insecticides can be hazardous to humans, domestic animals, pollinating insects, valuable insect parasites and predators, and wildlife if they are not properly used. They can be used safely for their prescribed purposes when labeled instructions are followed and when they are used as directed by competent authorities.

TOXICITY OF INSECTICIDES

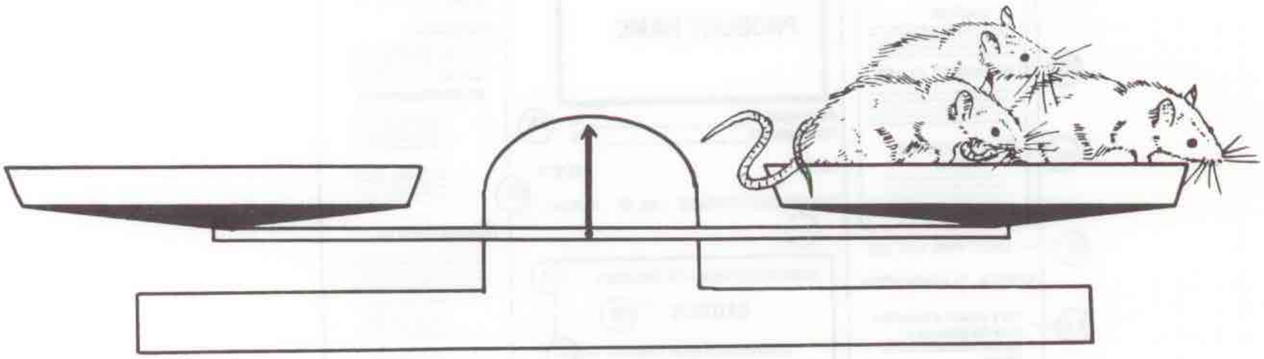
It is important to understand the difference between hazard and toxicity. Hazard refers to the risk or danger of poisoning when the substance is used or applied. Toxicity is the ability of a substance to produce injury. Some insecticides are acutely toxic, the toxic effects occurring within hours after a single exposure. Others have a chronic toxicity which results from repeated or multiple exposures over a period of time. A trained technician can use a highly toxic insecticide with little risk or hazard. Acute oral toxicity is usually determined with white rats by introducing the test material directly into the stomach by tube. Acute dermal toxicity tests are often made by applying the test material to the skin of shaved rats, rabbits, guinea pigs or other mammals.

Toxicity is ordinarily measured in milligrams of the insecticide per kilogram of body weight of the test animal that produces a 50 percent mortality (LD_{50}) in laboratory tests (Figure 9). Since a milligram is 1/1000 gram and a kilogram is 1,000 grams, the toxicity is actually expressed in mg/kg, or parts per million (ppm). The lower the LD_{50}, the greater the toxicity. The Environmental Protection Agency uses the results of acute toxicity studies in laboratory animals to place pesticides in categories (I-IV) which determine which signal word must appear on the label: "DANGER," "POISON," "WARNING," or "CAUTION." Although inhalation toxicity, eye corrosiveness, and skin corrosiveness studies are also used, results of acute oral and acute dermal toxicity studies are more publicized and usually more important. A pesticide that falls into category I only because of eye or skin corrosiveness must bear the signal word "DANGER" but not "POISON" nor the skull and crossbones symbol on its label (10). As the toxicity is based upon the amount of basic insecticide in a mixture, it follows that <u>the diluted, field strength insecticide creates a much smaller toxic hazard than the full strength concentrate</u>.

1000 milligrams = 1 gram
1000 grams = kilogram
1,000.000 milligrams = 1 kilogram

mg/kg.

Milligrams of insecticide | needed to kill | 1 kilogram of test animal

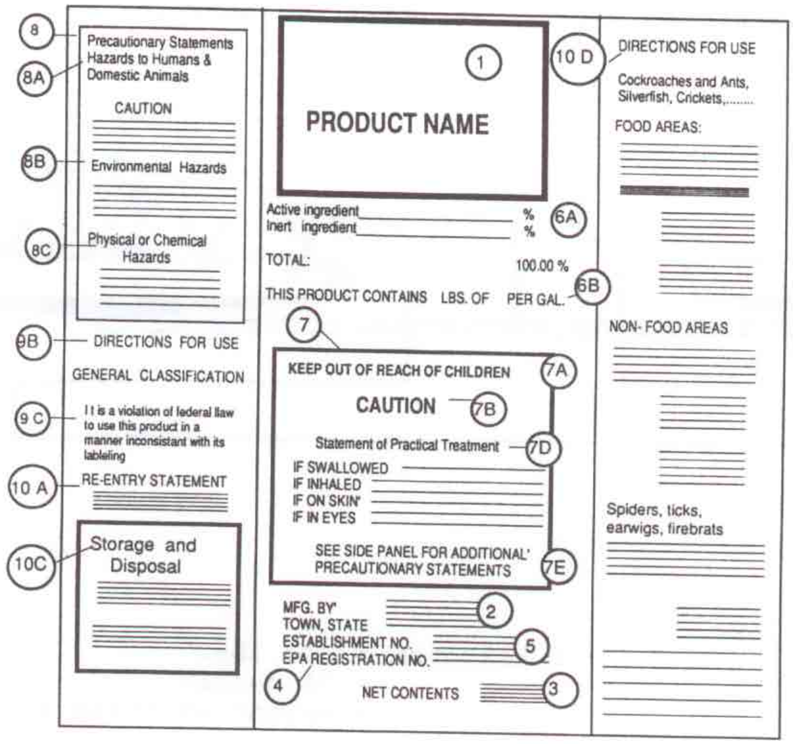


1 kilogram = 2.2 lbs.
= 36 ounces
= weight of three 12 ounce rats

Figure 9. Basis of mg./kg. ratings

The Environmental Protection Agency has established a standard format for pesticide labels as shown in Figure 10. These labels are keyed as follows:

From Reference 4, courtesy Edgell Communications.



restricted-use pesticides. The labels are keyed as follows:

1. Product name
2. Company name and address
3. Net Contents
4. EPA pesticide registration number
5. EPA formulator manufacturer establishment number

6A. Ingredients statement
6B. Pounds/gallon statement (if liquid)
7. Front-panel precautionary statements
7A. Child hazard warning, "Keep out of Reach of Children"
7B. Signal word - DANGER, WARNING, or CAUTION.
7C. Skull and crossbones and word Poison in red.
7D. Statement of practical treatment.
7E. Referral statement.
8. Side or back-panel precautionary statements.
8A. Hazards to humans and domestic animals.
8B. Environmental hazards.
8C. Physical or chemical hazards.
9A. "Restricted Use Pesticide" block.
9B. Statement of pesticide classification.
9C. Misuse statement.
10A. Reentry statement.
10B. Category of applicator.
10C. "Storage and Disposal" block.
10D. Directions for use.

Product Name (also called Brand or Trade Name)

Most manufacturers of technical pesticides

Figure 10. Generic label for a general-use pesticide

TABLE 4. CRITERIA FOR CATALOGING INSECTICIDES BY TOXICITY

TOXICITY CATEGORY	SIGNAL WORDS REQUIRED ON LABEL BY EPA	ORAL LD_{50} (MG/KG)	DERMAL LD_{50} (MG/KG)\ 24-HR. EXPOSURE	EQUIVALENT ORAL DOSE FOR 150 LB. MAN
I. Highly Toxic	DANGER, POISON, plus Skull & crossbones symbol	0 to 50	0-200	A few drops of 1 tsp.
II. Moderately Toxic	WARNING	50 to 500	200 to 2,000	1 tsp. to 2 tbsp.
III. Slightly Toxic	CAUTION	500 to 5,000	2,000 to 20,000	1 oz. to 1 pt. (1 lb.)
IV. Low Toxicity	CAUTION	5,000 and Up	20,000 and Up	1 pt. (1 lb.) or more

The data on acute oral toxicity have been used to divide insecticides into four groups as shown in Tables 4 and 5. These groups have considerable practical value because manufacturers must label each package of insecticide with key signal words such as "DANGER," "POISON," "WARNING," AND "CAUTION," and list antidotes where required or other necessary precautions.

The data on acute oral and dermal toxicities of the more important insecticides have been published by Hayes (26, 27), Gaines (20), Ware (51), and Brown (10). Table 5 lists the acute oral and dermal toxicities of a selected group of insecticides used by public health workers, using the same four groupings as in Table 4. It will be noted that, with some exceptions, there is a general correlation between toxicity and recommended strength of insecticides. None of Group I highly toxic insecticides are recommended for indoor household pest control. Ethyl and methyl parathion are used for outdoor mosquito control, usually with application by airplane, at 0.1 lb. per acre.

Group II moderately toxic insecticides such as chlorpyrifos (Dursban) and cypermethrin (Demon) are generally recommended for spot applications indoors and as broad residual sprays or dusts outdoors. Residual sprays of these insecticides, following label directions, are applied usually at 0.25% to 1.0%.

Group III slightly toxic insecticides such as carbaryl (Sevin) and malathion are recommended as residual sprays for both interior and exterior surfaces of buildings and for many other types of applications, including dusts of some of them for controlling ectoparasites on man and pets. Residual sprays of some of these insecticides generally contain 2% to 5% technical material and some dusts may contain as high as 10%.

Group IV low toxicity insecticides include temephos (Abate) which has been used for larval mosquito control even in cisterns with drinking water, and methoxychlor which may be used indoors as a residual 5% spray.

TABLE 5.
ORAL AND DERMAL TOXICITY OF SELECTED PUBLIC HEALTH INSECTICIDES

Insecticide	Class*	Acute Oral Toxicity to Rats LD_{50} (Mg/Kg)*	Acute Dermal Toxicity to Mammals LD_{50} (Mg/Kg)
SIGNAL WORD **DANGER** I HIGHLY TOXIC INSECTICIDES. Acute oral toxicity to rats: 1-50 mg/kg			
Ethyl parathion	OP	4-13	55
Endrin	CH	7-15	15
Methyl parathion	OP	9-25	300-400
Methomyl Lannate)	CARB	17-24	>5000
SIGNAL WORD **WARNING** II MODERATLEY TOXIC INSECTICIDES Acute oral toxicity to rats 50-500 mg/kg.			
Bendiocarb (Ficam)	CARB	40-156	>1000
Dichlorvos (DDVP, Vapona)	OP	56-80	107
Propoxur (Baygon)	CARB	70-200	>500
Lindane	CH	88-125	1000
Chlorpyrifos (Dursban)	OP	97-276	2000
Propetamphos (Safrotin)	OP	119	2300
Dimethoate (Cygon)	OP	215	400-610
Cypermethrin (Demon)	SYNPYR	251	>600
Fenthion (Baytex)	OP	255-298	1600-2830
Diazinon (Knoxout)	OP	300-400	3600
Naled (Dibrom)	OP	430	110
Trichlorfon (Dipterex)	OP	450	>2000
SIGNAL WORD **CAUTION** III SLIGHTLY TOXIC INSECTICIDES Acute oral toxicity to rats 500-5000 mg/kg.			
Carbaryl (Sevin)	CARB	500-850	>4000
Cyfluthrin (Tempo	SYNPYR	590	>5000
Dicofol (Kelthane)	CH	684-809	2100
Acephate (Orthene)	OP	866-945	>10250
Malathion (Cythion)	OP	1000-2800	>4444
Diethyl toluamide (Off)	REP	2000	
Fenvalerate (Pyrid)	SYNPYR	>3200	2500
Permethrin (8 Pounce)	SYNPYR	4000	>2000
Resmethrin (Synthrin)	SYNPYR	>4240	2500
Diflubenzuron (Dimilin)	IGR	4640	>2000

TABLE 5.
ORAL AND DERMAL TOXICITY OF SELECTED PUBLIC HEALTH INSECTICIDES
(CONTINUED)

Insecticide	Class*	Acute Oral Toxicity to Rats LD_{50} (Mg/Kg) *	Acute Dermal Toxicity to Mammals LD_{50} (Mg/Kg)
SIGNAL WORD **CAUTION** IV LOW TOXIC INSECTICIDES Acute oral toxicity to rats 5000+ mg/kg.			
Methoxychlor (Marlate)	CH	6000	>6000
Temephos (Abate)	OP	8600	4000
Fenoxycarb (Torus)	IGR	16800	>2000
Hydroprene (Gencor)	IGR	>34000	4550
Methoprene (Altosid, Precor)	IGR	>34600	>3000

Based largely on Evans in Brown (10) and Thomson (48).

* CARB, Carbamate; CH, chlorinated hydrocarbon; IGR, Insect Growth Regulator; OP, organophosphate; REP, repellent; SYNPYR, synthetic pyrethroid.

The phosphorus compounds are characterized by the similarity of their structure (derived from phosphoric acid) and by their similar mode of action. They are toxic to animals because of their ability to interfere with the normal mechanism of nerve impulse transmission.

When a nerve impulse is transmitted, acetylcholine is liberated and acts directly upon effector cells to produce their characteristic response such as the contraction of a muscle or the secretion of a gland. The enzyme cholinesterase is present in nerves and normally stops the response by hydrolyzing acetylcholine into the acetate ion and choline, essentially "clearing the deck" for the next nerve impulse. This reaction may occur in a tenth of a second or less. Part of the organophosphorus insecticides attach to cholinesterase in the nerve and prevent this enzyme from breaking down acetylcholine. If acetylcholine is allowed to accumulate, impulses continue to travel along the nerves and cause uncoordinated activity through the entire animal. This results in tremors, convulsions, muscular paralysis, and finally death from a variety of organic failures.

In cases of severe organophosphate poisoning of humans, initial symptoms usually appear less than six hours after exposure to the insecticides. These symptoms include headache, weakness, and fatigue. Patients feel dizzy and their pupils sometimes become contracted; the patient may have trouble focusing his eyes. Abdominal cramps set in, accompanied by vomiting and diarrhea, difficulty in breathing, profuse sweating, and excessive salivation, sometimes followed by convulsions, coma, and death (Figure 11).

Fortunately, although the initial compounds in this group were developed for chemical warfare in World War II, many of the present-day insecticides have low toxicity to man, domestic animals, and wildlife: as malathion, temephos, diazinon, and chlorpyrifos. These insecticides have great value because of their low toxicity to humans, their effectiveness in controlling many species of insects, and their biodegradability.

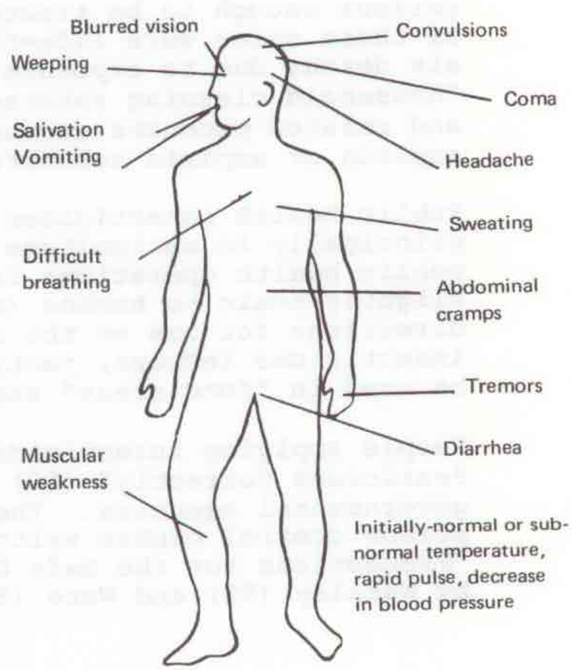


Figure 11. Symptoms of acute poisoning by organophosphate insecticide

PRECAUTIONS IN THE USE OF INSECTICIDES

Most cases of overt poisoning by insecticides occur in workers applying these toxicants. Therefore, the safe handling of insecticides must be a way of life for sprayman and persons applying insecticidal dusts, whether the materials used are highly toxic or only slightly toxic to humans. Respiratory exposure is most frequent among persons that handle dusts, which are not readily absorbed through the skin. Dermal exposure is usually associated with : (a) spilling insecticides on the skin while diluting concentrates to field strength insecticide (hence the need for rubber aprons, rubber gloves and respirators while mixing); and (b) splashing the insecticide on the skin or clothing while spraying. Poisoning by ingestion of insecticides is most critical in children under six years of age when insecticides are kept in accessible places such as the kitchen pantry or sink cabinet. Nevertheless, the hazard is not so great as that created by internal medications found in the home, such as aspirin or aspirin substitutes.

Ware (51) summarized the data on 1,166,940 exposures to all classes of poisoning of humans reported to the American Association of Poison Control Centers in the United States in 1987. These Poison Control Centers reported that there were 37,856 humans exposed to insecticides, with 8,534 cases serious enough to be treated in emergency room facilities. However, only 84 of these cases were life-threatening or resulted in disability. There were six deaths due to exposure to insecticides in 1987. By comparison, "household cleaning substances, including bleaches, ammonia, disinfectants, and related products accounted for 20,723 emergency room visits, while aspirin or aspirin substitutes accounted for 34,949 visits."

Public health insecticides are, in many cases, chemicals that are used principally in agriculture. A basic principle in choosing an insecticide for public health operations is to select a product that is moderately or slightly toxic to humans (see Table 5) and to follow completely the directions for use on the label of the insecticide container. In applying insecticides indoors, particular attention should be paid to those that can be used in "food areas" and "non-food areas."

People applying insecticides should have available a copy of "Applying Pesticides Correctly" (50) or similar publications available from governmental agencies. They should have the telephone number of the nearest poison control center written down near their telephone. Table 6 "Precautions for the Safe Use of Pesticides" is based on similar guidelines by Wamsley (50) and Ware (51).

TABLE 6. PRECAUTIONS FOR THE SAFE USE OF PESTICIDES

1. READ THE CONTAINER LABEL AND UNDERSTAND THE DIRECTIONS FOR PREPARING AND APPLYING THE INSECTICIDE; THEN FOLLOW THE DIRECTIONS AND PRECAUTIONS EXACTLY.

2. STORE INSECTICIDES IN CONTAINERS WITH THE ORIGINAL LABELS. KEEP THE INSECTICIDE OUT OF REACH OF CHILDREN AND ANIMALS, preferably in a locked cabinet or box in a locked room with signs posted such as "DANGEROUS-CHEMICALS-KEEP AWAY."

3. Mix insecticides in a well-ventilated area, preferably out-of-doors, to avoid inhalation of dusts and fumes.

4. When mixing and applying flammable chemicals, avoid the fire hazard associated with tobacco smoking, defective wiring, open flames, and hot plates.

5. Do not eat or smoke when working with insecticides. This practice will reduce opportunities for accidental ingestion of toxic materials.

6. WEAR PROTECTIVE CLOTHING AND HEADGEAR and avoid prolonged exposure to the insecticide. Special care should be taken to prevent contamination of the skin when concentrates are being handled. Use impermeable gloves and aprons and wear approved respirators when necessary.

7. AVOID CONTAMINATION OF FOODS AND DRINKING WATER OF MAN AND ANIMALS.

8. Avoid inhaling sprays and dusts when insecticides are being mixed or applied and avoid spilling on the skin. If any material reaches the skin, wash the affected area thoroughly with soap and water. Wash routinely after each day's application. If any particles or drops of insecticide accidentally enter the eye, flush them out immediately with large volumes of clean water.

9. If clothing becomes contaminated, remove it immediately and wash the affected part of the body thoroughly with soap and water and put on clean clothing. Wear clean clothing every day.

10. Keep insecticidal equipment clean and in good condition. Flush out insecticidal equipment only where contamination will not affect man or wildlife.

TABLE 6. PRECAUTIONS FOR THE SAFE USE OF PESTICIDES (CONTINUED)

11. Mix only as much insecticide as is needed for each application, thus reducing the problems of storing and disposing of excess insecticide. Dispose of excess insecticide carefully so that contamination will not affect man and wildlife.

12. Dispose of empty containers safely (e.g., bury them under at least two feet of soil). In some situations, burn empty insecticide bags and stay out of the smoke. For non-returnable liquid containers, wash inside and outside thoroughly, immediately after use. Puncture large metal containers so that they cannot be reused.

13. Know first aid measures and antidotes for insecticide, and the location and telephone number of the local poison control center.

14. Wash hands with soap and water after applying insecticides; take a bath at the end of each day after applying insecticides; wear clean clothing each day.

TABLE 7. FIRST AID FOR INTERNAL POISONING

1. Call a physician.

2. If unable to reach physician, call fire department rescue squad.

3. For special information, telephone nearest poison control center.

4. Provide supportive treatment for the patient. This may include:
   A. Artificial respiration.
   B. Maintenance of a free airway (suck out excess vomitus and secretion).
   C. Oxygen therapy for cyanosis (a blue or purplish coloration of the skin due to insufficient oxygen).

5. Decontaminate the patient as quickly as possible. Depending on the individual case this may involve:
   A. Removal of contaminated clothing.
   B. Washing skin and hair with soap and water, or rinsing eyes with water or saline solution.
   C. Evacuation to fresh air.

6. Eliminate the poison. Determine whether the insecticide is in water emulsion or petroleum solution, if possible.

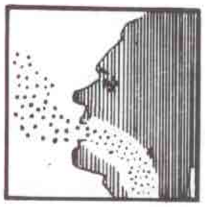
   A. If the insecticide is dissolved in a water emulsion, induce vomiting, by finger or spoon down the throat. If this fails, give one tablespoon of salt in glass of warm water until vomit is clear.
   B. If insecticide is dissolved in a petroleum product, as an insecticide in a kerosene solution, have doctor or nurse perform gastric lavage, sucking the insecticide out of the stomach with a tube, to prevent possibility of the petroleum product entering lungs and causing pneumonia.
   C. Administer a laxative such as Epsom Salts or Milk or Magnesia in water to eliminate insecticide from alimentary tract. Avoid oily laxatives, such as Castor Oil, which might increase absorption of additional insecticide.

7. Have insecticide container available for medical authority wherever possible. The label in most cases indicates if the insecticide is a chlorinated hydrocarbon, organophosphate, or carbamate. If the insecticide is an organophosphate, two antidotes are available: atropine chloride and 2-PAM chloride. The proper dose of atropine sulfate is 2 to 4 mg. intravenously as soon as cyanosis is overcome. The dose of 2-PAM chloride is 1 g. for an adult and 0.25 for an infant.

The diagram below from Project Safeguard (40) shows how accidental insecticide poisoning occurs.

HOW DO ACCIDENTAL PESTICIDE POISONINGS OCCUR?

BY MOUTH



DUSTS AND SPRAYS ENTERING MOUTH DURING AGRICULTURAL APPLICATIONS.

DRINKING PESTICIDES FROM UNLABELLED OR CONTAMINATED CONTAINER.

USING THE MOUTH TO START SIPHONAGE OF LIQUID CONCENTRATES.

EATING CONTAMINATED FOOD.

TRANSFER OF CHEMICAL TO MOUTH FROM CONTAMINATED CUFFS OR HANDS.

DRINKING FROM CONTAMINATED BEVERAGE CONTAINER.

THROUGH THE SKIN

ACCIDENTAL SPILLS ON CLOTHING OR SKIN.

DUSTS AND SPRAYS SETTLING ON SKIN DURING APPLICATION.

SPRAYING IN WIND.

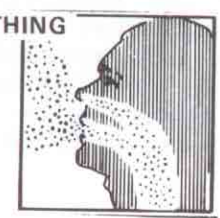
SPLASH OR SPRAY IN EYES AND ON SKIN DURING POURING AND MIXING.

CONTACT WITH TREATED SURFACES AS IN TOO EARLY RE-ENTRY OF TREATED FIELDS, HAND HARVESTING, THINNING CULTIVATING, IRRIGATING AND INSECT OR PEST SCOUTING.

CHILDREN PLAYING -
- IN DISCARDED CONTAINERS
- IN PESTICIDE MIXING OR SPILL AREAS

MAINTENANCE - REPAIR WORK ON CONTAMINATED EQUIPMENT.

BY BREATHING



DUST, MISTS, OR FUMES.

SMOKING DURING APPLICATION
OR
CONTAMINATED SMOKING SUPPLIES

RESISTANCE TO INSECTICIDES

Most normal populations of insects contain individuals that vary in their susceptibility to insecticides. Test with these chemicals will kill some individuals more readily than others. The individuals that are less susceptible than others are said to be more tolerant of the chemicals used. Continued insecticidal pressure to a population of insects will destroy the more susceptible individuals, permitting the more resistant individuals to survive and reproduce new generations of increasingly less susceptible insects. Thus, the species becomes increasingly more difficult to control because of genetic factors transmissible to subsequent generations.

Resistance of insects to insecticides is defined as the ability to withstand a poison which was generally lethal to earlier populations. In general, two types of resistance occur in insects:

Physiological resistance: the ability through physiological processes to withstand a toxicant by differences in: (a) the permeability of the insect exoskeleton to insecticides, (b) the detoxification of insecticides into less harmful compounds, (c) the storage of insecticides harmlessly in the body tissues such as fat, (d) the excretion of insecticides, or (e) insensitive sites of action.

Behavioristic resistance: the ability to avoid lethal contact with the insecticide through protective habits or behavior, such as mosquitoes resting outdoors rather than on treated wall surfaces, flies avoiding baits with organophosphates, or cockroaches avoiding insecticide residues in their normal hiding places in cracks and crevices.

Resistance to insecticides has been reported in many species of insects. Among arthropods of public health importance, this phenomenon was first noted in Italy in 1946 and 1947 in house flies, *Musca domestica*, and house mosquitoes, *Culex*. By 1971, Brown and Pal (9) reported that there were 104 species of arthropods of public health importance resistant to organic insecticides. With some of these insects, such as the house fly, initial resistance of a population to DDT soon lead to resistance to other chlorinated hydrocarbons such as benzene hexachloride and dieldrin, and later to organophosphorus compounds such as malathion. This resistance of insects to one insecticide bringing about resistance to other chemicals is known as cross resistance.

Insecticide resistance continues to spread to new species and to new geographical areas. By 1986 the World Health Organization (55) reported resistance to one or more insecticides in 137 species of arthropods of public health importance including 50 species of malaria mosquitoes (Anopheles), other important mosquitoes, house flies and black flies, bed bugs, cat and oriental rat fleas, head and body lice, and the German cockroach.

Public health workers, therefore, should run periodic tests on the susceptibility of important species to the insecticides used on control programs. It is particularly important to have a baseline level of susceptibility of a species to a new insecticide before changing chemicals. In many parts of the world, the widespread use of a particular insecticide in agriculture has lead to resistance in insects of public health importance. Thus, in Central America the widespread use of DDT to control insects on farmlands has exposed malaria mosquitoes in and near these fields to this insecticide, killed off the susceptible individuals, and gradually developed a strain of Anopheles resistant to this chemical. This situation led to the failure of malaria control programs in western Central America based on killing adult Anopheles by residual spraying of homes (8).

Kits for determining resistance to insecticides in mosquito adults and larvae, flies, fleas, lice, bed bugs, and other arthropods of public health importance have been developed by the World Health Organization (55). These kits should be purchased from the World Health Organization and used to determine susceptibility levels to an insecticide before changing to a new compound.

Although much has been learned through the use of the WHO Bioassay kits, it has inherent limitations: Tests usually are conducted in a laboratory; only one insecticide can be tested per insect; large numbers of insects are needed to generate probit lines; false positives may occur because of deteriorating filter-papers or procedural variables such as temperature and humidity; and considerable expense and difficulty in obtaining the WHO kits.

Therefore, Brogdon and co-workers (3, 7, 8, 11) proposed the development of Nonspecific Esterase (NSE) Microplate Assay tests which permit: tests conducted in the field; analysis of single insects; up to 30 assays from a single insect; fast and accurate methods which can be read with the naked eye, at considerably lower costs than the WHO Bioassay kits. With mosquitoes, Beach et al. (3) reported that the results could be read with the naked eye in the field, the colors produced ranged from pink to purple, organophorus-susceptible mosquitoes (pink) and organophosphorus-resistant mosquitoes with elevated Esterase levels (purple). Studies on the NSE Microassay types of testing are continuing with many species of insects.

APPENDIX

WEIGHTS AND MEASURES

Weights and measurements for insecticidal concentrations and dosages are expressed in both the metric and the United States system. Most scientific workers use the Metric system almost exclusively, or a combination of the two systems, such as "200 milligrams per square foot." It would be more consistent to say "two grams per square meter." Temperature may be given in either the Fahrenheit or Centigrade scales. Therefore, the following tables are provided to assist the field worker in converting the recommendations from one system to another. The units for each system are not given as they are defined in the dictionary.

WEIGHTS

AVOIRDUPOIS TO METRIC		METRIC TO AVOIRDUPOIS	
1 grain	64.8 milligrams	1 milligram	0.01543 grains
1 ounce	28.35 grams	1 gram	0.03527 ounces
1 pound	453.59 grams	1 kilogram	2.205 pounds
1 short ton	0.91 metric ton	1 metric ton	2205 pounds

LIQUID MEASURE

U.S. UNITS OF METRIC		METRIC TO U.S. UNITS	
1 fluid oz.	29.57 milliliters	1 milliliter	0.0338 ounces
1 pint	0.47 liter	1 liter	2.113 pints
1 quart	0.95 liter	1 liter	1.057 quarts
1 gallon	3.78 liters	1 liter	0.2642 gallons

LINEAR MEASURE

U.S. UNITS TO METRIC		METRIC TO U.S. UNITS	
1 inch	25,400 microns	1 millimeter	0.03937 inches
1 inch	2.54 centimeters	1 centimeter	0.3937 inches
1 foot	30.48 centimeters	1 meter	39.37 inches
1 yard	0.91 meter	1 meter	3.281 feet
1 rod	5.03 meters	1 kilometer	3281 feet
1 mile	1.61 kilometers	1 kilometer	0.6214 mile

CONVERSIONS TABLES AND EQUIVALENTS TEMPERATURE

The Centigrade thermometer is so calibrated that the boiling point of water is 100°C and the freezing point is 0°. The interval between freezing and boiling is divided into 100 parts or degrees. The Fahrenheit thermometer has the boiling point of water at 212°F. The 0° point represents the temperature resulting from mixing equal quantities, by weight, of snow and common salt. The freezing point of water is 32°F above the zero point on the scale. Temperatures may be converted from one scale to the other by using the following formulas:

Temperature Conversion Formulas

$$°F = (°C \times 9/5) + 32$$
$$°C = (°F - 32) \times 5/9$$

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