



# THE CHEMISTRY AND ACTION OF INSECTICIDES

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THE CHEMISTRY AND ACTION OF INSECTICIDES

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III

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## PREFACE

Insecticides are the materials utilized in chemical control of insects. It is with the properties of these insecticides, not with the details of insect control, that this book is primarily concerned, although specific pests may be named in connection with the chief uses of each material or mentioned as laboratory animals used to determine relative toxicity or mode of action.

It is the purpose of the author to present the more essential facts and theories relating to insecticides, including not only chemical, physical, and toxicological aspects but also historical and commercial information. Fungicides, rodenticides, and other economic poisons are frequently mentioned and described because of their chemical and toxicological relationship to insecticides and their reactions in mixtures with insecticides or when applied to the same objects. Original references have been cited freely as an aid to those who need to investigate further along particular lines.

Mention of a particular usage, especially under experimental conditions, should not be construed as an indication of practical value, much less as a recommendation of such use in insect control. Many uses, now outdated by more efficient materials, are cited for purposes of discussion.

This book is the outgrowth of a mimeographed edition published in 1939 under the title *The Chemistry and Toxicology of Insecticides*. The subject matter has been rearranged and almost entirely rewritten. The author acknowledges with gratitude the many kind words and criticisms received regarding the original work and the assistance given him in preparing the present volume. To name all who have so aided would risk omissions which he would regret. Particularly valuable have been the many suggestions and corrections made by L. B. Norton of Cornell University and by numerous associates of the author in the U.S. Department of Agriculture. Phyllis J. Ford spent long hours preparing the manuscript for publication, and much credit is due her for her careful work.

Although the author is now a member of the U.S. Department of Agriculture, the opinions expressed herein are his own and do not necessarily represent the views of the Department.

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## CONTENTS

PREFACE. . . . .	v
1. Introduction. . . . .	1
2. Arsenical Compounds. . . . .	10
3. Fluorine Compounds . . . . .	42
4. Sulfur and Its Compounds. . . . .	54
5. Copper Compounds. . . . .	72
6. Miscellaneous Inorganic and Metal-organic Substances . . . . .	92
7. Plant Products: Nicotine and Other Alkaloids . . . . .	115
8. Pyrethrins, Rotenone, and Miscellaneous Plant Extractives . . . . .	144
9. Petroleum, Animal and Vegetable Oils, Soaps, Creosotes. . . . .	191
10. Synthetic Organic Insecticides—I. . . . .	233
11. Synthetic Organic Insecticides—II . . . . .	269
12. The Chemical Control of Insects: General Aspects . . . . .	336
13. Relative Toxicity and Mode of Action of Insecticides . . . . .	413
14. Attractants and Repellents. . . . .	458
APPENDIX . . . . .	475
INDEX. . . . .	487

## CHAPTER 1

### INTRODUCTION

A demand for more and better insecticides has developed rapidly in recent years, resulting in widespread interest and vigorous research in this field. After many years of seeking for multipurpose materials, it is being realized that particular insecticides and formulations often must be developed for specific types of pests. Other reasons for this growing demand are the convenience of applying custom-made formulations prepared on a large scale, the swelling of profits because of foodstuffs saved from insect consumption, and the intensive publicity given to insecticides and repellents developed for use in the Second World War.

Consumption of insecticides is dependent upon the incidence of insect pests and the damage they cause (Table 1). Annual losses in the

TABLE 1. ANNUAL LOSSES CAUSED BY SOME INSECT PESTS IN THE UNITED STATES\*

Pest and crop	Year of damage	Loss
European corn borer.....	1947	\$ 97,000,000
Corn earworm.....	1945	140,000,000
Grasshoppers (21 states).....	1946	22,740,000
Hessian fly.....	1945	37,000,000
Boll weevil.....	1930-1946 (av.)	116,435,000
Cotton insects other than boll weevil.....	1946	51,415,000
Tobacco hornworm (southern states).....	1944	84,073,000
Aphids on potatoes (northern states).....	1944	66,476,000
Codling moth on apples.....	1940-1944 (av.)	50,000,000
Livestock pests.....	Average	500,000,000
Weevils and moths in stored grain.....	1947	600,000,000

\* Estimates by U.S. Dept. of Agriculture.

United States due to the work of insects are estimated to be as much as \$4,000,000,000. Similar losses from plant diseases are reported. Living plant crops suffer the heaviest losses from insects, so here is found the largest use of insecticides. Large quantities of chemicals are applied also in public sanitation, in the protection of stored materials, especially foods, and in the control of insect pests of domestic animals.

No horticulturist would attempt to grow apples as a commercial crop without a spray program involving considerable financial outlay. On the

other hand, the growing of potatoes and tomatoes may frequently be accomplished with little or no application of chemicals. It is important to emphasize, however, that through plant protection by chemical means the grower can increase his control over production and thus provide greater stability for his business. The potato crop no longer need fluctuate violently owing to blight, the fungus disease which was the direct cause of the Irish potato famine of the 1840's and the emigration of many Irish to the United States. Investment in insecticides and fungicides is now as much a form of crop insurance as the purchase of fertilizers.

The United States is in a leading position among the countries of the world in the production and consumption of insecticides. Use of sulfur and copper fungicides, however, is greater in countries such as France and Italy. Variation in different countries is due not alone to differences in farm practice but also to differences in ability to buy the chemicals and in advancement in agricultural technology. Some insecticides are competitive to a certain degree. Naturally occurring materials may be locally important but not sufficiently valuable for shipment to distant points, or the locality may be too remote for more effective insecticides to be available. Many commercial by-products have seen some use in the field of insecticides, and much research has been devoted to finding cheaper or more efficient synthetic substitutes for established materials.

To combat insects and plant diseases, large quantities of chemicals are applied as sprays, utilizing as diluents many million gallons of water or light oils. Additional large quantities are applied as dusts diluted with thousands of tons of lime, talc, clays, and other suitable materials. The total consumption of poisons in concentrated form probably exceeds 500 million lb. Diluents other than water and various additive materials such as adhesives and emulsifiers may amount to a further 750 million lb. Governmental agencies, such as the U.S. Department of Commerce, and various trade organizations collect valuable statistics relating to the production and consumption of insecticides and fungicides. Reliable consumption figures can be obtained for chemicals which are limited to insecticidal uses, but when a chemical is sold for many other purposes, the insecticidal consumption can usually be estimated only roughly. For instance, lead arsenate wherever produced or sold is with safety assumed to be an insecticide. Carbon tetrachloride is not only an insect fumigant, but it is a dry-cleaning agent, a fire extinguisher, and a raw material in the manufacture of other chemicals.

Although a few present-day insecticides have been so utilized for many centuries, most insecticides were not in common use until relatively recent years (Table 2). Early recommendations for using insecticides included many curious and ingenuous suggestions. Pliny the Elder (A.D. 23 to 79)

collected many of these in his *Natural History*, largely from the folklore and Greek literature of the previous three or four centuries. Included were superstitions regarding the time of the moon that certain cultural operations should be carried out to exempt plants from insect injury. Apples were said to be preserved from the attack of caterpillars as well as from rot by touching the top of the tree with the gall of a green lizard. Pliny also recorded many valuable observations, such as the fact that pitch, oil, and grease are highly detrimental to trees, especially young trees. Instructions in gardeners' handbooks of but two or three centuries ago were derived largely from Pliny's writings.

Early writers suggested a variety of materials as insecticidal agents: hot water, brine, lye, whitewash, soapsuds, vinegar, petroleum, turpentine, fish oil, sulfur, decoctions of aloes, pepper, soot, tobacco, and wormwood. In 1629 John Parkinson recommended vinegar to prevent canker on orchard trees. Even in as recent and authoritative a source as the *Report of the United States Commissioner of Agriculture* for 1865 it is stated, under remedies and preventives for the apple worm and the curculio: "Strong-smelling herbs, such as tansy and elder-leaves and blossoms, or other nauseous matters not agreeable to the olfactory nerves of the insect, are hung among the branches, in hopes the insect will give them a wide berth." The substances formerly employed as insecticides were often characterized by offensive (to human noses) or caustic, rather than poisonous, properties. An acrid or bitter taste and a pungent odor were evidently deemed necessary qualifications for insecticides, and the more unpleasant the greater merit they were supposed to possess.

According to Howard (1930), "The advertising of quack remedies went to such an extent that the real entomologists were inclined to frown down the whole idea of chemical insecticides." So strong was this feeling that it was expressed very forcibly in the opening editorial in the first number of the *Practical Entomologist* (Oct. 30, 1865). In view of the enormous use of insecticides of great value at the present time, it is worth while to quote two sentences from this editorial:

The agricultural journals have from year to year, presented through their columns, various recipes, as preventive of the attacks, or destructive to the life, of the "curculio," the "apple-moth," the "squash-bug," etc. The proposed decoctions and washes we are well satisfied, in the majority of instances, are as useless in application as they are ridiculous in composition, and if the work of destroying insects is to be accomplished satisfactorily, we feel confident that it will have to be the result of no chemical preparations, but of simple means, directed by a knowledge of the history and habits of the depredators.

About the middle of the last century agriculturists of the United States were made conscious of their need for effective insect-control methods by



TABLE 2. HISTORY OF INSECTICIDES AND SOME RELATED ECONOMIC POISONS  
ARRANGED CHRONOLOGICALLY

B.C.	
—	Early stone tablets are said to have referred to red squill as a rat poison.
1000.	About this time, Homer spoke of sulfur for fumigation and other forms of pest control.
—	The Romans applied hellebore for the control of rats, mice, and insects.
A.D.	
900.	By this time the Chinese were using arsenic to control garden insects.
1300.	Before this date, Marco Polo wrote of mineral oil being employed against mange of camels.
1669.	The earliest known record of arsenic as an insecticide in the Western world mentioned its use with honey as an ant bait.
1690.	Tobacco was employed as a contact insecticide.
1773.	Nicotine fumigation was performed by heating tobacco and blowing the smoke on infested plants.
1787.	Soap was mentioned as an insecticide.
1787.	Turpentine emulsion was recommended to repel and kill insects.
1800.	Before this date Persian insect powder (pyrethrum) was known in the Caucasus as an insecticide.
1800.	Spray mixtures of lime and sulfur were recommended in insect control previous to this time.
1800.	Tarred paper was utilized for banding trees.
1800.	Whale oil was advised as a scalecide.
1810.	A dip containing arsenic was recommended for the control of sheep scab.
1820.	Fish oil was advocated as an insecticide.
1821.	Sulfur was reported by John Robertson in England as a remedy for mildew.
1822.	A mixture of mercuric chloride and alcohol was recommended to kill bed bugs.
1825.	Quassia was used as an insecticide in fly baits.
1842.	Whale-oil soap was mentioned as an insecticide.
1845.	Phosphorus paste was declared "official" for rodent control by the Prussian Government and by 1859 was utilized in cockroach control.
1848.	Derris was reported being used in insect control in Asia.
1851.	Boiled lime-sulfur was employed at Versailles by Grison.
1854.	Carbon disulfide was tested experimentally as a grain fumigant.
1854.	A sulfur-tobacco dip was used to control sheep scab.
1858.	Pyrethrum was employed in the United States.
1860.	Mercuric chloride solutions were applied to destroy soil-inhabiting forms such as earthworms.
1867.	Paris green came into use as an insecticide.
1867.	Phenol and cresols (carbolic and cresylic acids) were known to have insecticidal value.
1868.	From this date to 1880 various formulas were proposed for preparation of kerosene emulsions.
1875.	Lecante divided insecticides into two kinds: "the poison by contact, or the poison by food."
1877.	Hydrocyanic acid gas was utilized for the first time as a fumigant, being employed to fumigate museum cases.
1878.	"London purple" was first recorded as a substitute for paris green.

TABLE 2. HISTORY OF INSECTICIDES AND SOME RELATED ECONOMIC POISONS  
ARRANGED CHRONOLOGICALLY.—(Continued)

A.D.	
1880.	Pyrethrum was cultivated commercially in California.
1880.	Lime-sulfur came into use in the United States, being applied as a scalecide against San José scale in California.
1881.	Pyrethrum culture was introduced into Japan.
1882.	Naphthalene cones were invented for the protection of insect collections.
1883.	Millardet discovered the value of bordeaux mixture in France.
1886.	Hydrocyanic acid gas was used by Coquillet for the fumigation of citrus trees in California.
1886.	Rosin fish-oil soap was utilized as a scalecide in California.
1890.	"Carbolineum," a coal-tar fraction, was employed at about this time in Germany on dormant fruit trees.
1890.	Hydrated lime was added to arsenicals to prevent the burning of foliage.
1892.	Lead arsenate was first prepared as an insecticide; it was utilized in connection with the gypsy moth eradication program in Massachusetts.
1892.	Earliest known record of a nitrophenolic compound, the potassium salt of 4,6-dinitro- <i>o</i> -cresol, for insecticidal use.
1894.	Webster proved honey bees are killed by arsenicals sprayed on fruit trees in bloom.
1896.	Crude petroleum emulsions were tested in New York.
1896.	A British patent referred to fluorine compounds as insecticides.
1897.	Oil of citronella was used as a mosquito repellent.
1902.	The value of lime-sulfur as a control for apple scab was discovered in New York.
1903.	The British established an arsenic tolerance for foods.
1905.	Haywood described the chemical reactions undergone by lime-sulfur exposed to the air.
1906.	Lubricating oil emulsions were applied to citrus trees.
1907.	Calcium arsenate was in experimental use as an insecticide by this time.
1907.	Chloropierin was proposed as an insecticide.
1909.	First tests with 40 per cent nicotine sulfate were made in Colorado.
1910.	Federal Insecticide Act was passed.
1911.	First publication of the use, outside the Orient, of derris as an insecticide (British patents).
1912.	Zinc arsenite was first recommended.
1912.	<i>p</i> -Dichlorobenzene was applied in the United States as a clothes moth fumigant.
1916.	Chemistry of lead arsenates was published by McDonnell and Smith.
1917.	Moore developed boiling-point theory of insecticide toxicity.
1917.	Liquid hydrocyanic acid was introduced commercially.
1917.	First use of nicotine sulfate in a dry carrier for dusting.
1921.	Airplane was first used for distributing insecticides, being utilized in a dusting experiment against catalpa sphinx at Troy, Ohio.
1922.	Calcium cyanide was in use.
1923.	Geraniol was discovered to be attractive to the Japanese beetle.
1924.	Staudinger and Ruzicka published the chemical structure of the insecticidal esters in pyrethrum.
1924.	Cube was first tested as an insecticide in the United States.

TABLE 2. HISTORY OF INSECTICIDES AND SOME RELATED ECONOMIC POISONS  
ARRANGED CHRONOLOGICALLY.—(Continued)

A.D.	
1924.	First insecticidal tests of cryolite were against the Mexican bean beetle.
1925.	Siegler and Popenoe correlated insecticidal action of soaps with length of the fatty-acid chain.
1925.	Selenium compounds were tested as insecticides.
1926.	Barium fluosilicate was reported experimentally.
1927.	Arsenic tolerance for apples was established by the U.S. Food and Drug Administration.
1927.	Ethylene dichloride was discovered to have fumigant value.
1928.	Pyrethrum culture was introduced into Kenya.
1928.	Peet-Grady fly spray test was described.
1928.	Ethylene oxide was patented as an insect fumigant.
1929.	Campbell and Filmer published the sandwich method of testing solid stomach insecticides quantitatively.
1929.	Alkyl phthalates were patented as insect repellents.
1929.	<i>n</i> -Butyl carbitol thiocyanate was produced commercially as a synthetic contact insecticide.
1930.	Method of preparing nicotine tannate was published, first fixed nicotine compound used successfully as a stomach poison.
1931.	Anabasine was isolated from plants as well as synthesized in the laboratory.
1932.	Methyl bromide was first employed as a fumigant (in France).
1934.	Phenothiazine was found to be highly toxic to insects.
1934.	Nicotine-bentonite combination was developed.
1936.	Pentachlorophenol was first produced commercially.
1936.	First experiments with dinitro- <i>o</i> -cyclohexylphenol were published.
1936.	Autogiro was first used to apply insecticides, in spraying Rhode Island woodland.
1939.	Diphenylamine was reported to prevent development of young stages of screw-worms in wounds in livestock.
1939.	About this time xanthone was introduced as an insecticide.
1940.	Sesame oil was patented as an activator of such insecticides as pyrethrum.
1941.	Benzene hexachloride was discovered in France to be valuable as an insecticide; likewise independently in England in 1942.
1942.	DDT was first imported to the United States for experimental use in late 1942.
1942.	Liquefied gases were utilized as aerosol propellants.
1945.	First report of extensive tests of chlordane as an insecticide was published.
1945.	At about the same time toxaphene was produced in significant experimental quantities.
1946.	Organic phosphates of German invention such as tetraethyl pyrophosphate and parathion were made available to American producers.
1947.	Federal Insecticide, Fungicide, and Rodenticide Act became law.
1948.	La Forge and associates synthesized insecticidal isomers of cinerin I, a normal constituent of pyrethrum flowers.

the appearance of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say). In 1859 this insect became established in potato fields in central Nebraska and made its way rapidly to the East Coast, which it reached at several points in 1874. Arsenicals were tried for the control of this

insect, and paris green soon became the first important stomach poison. The spread of other major pests, when it constituted a threat to large-scale agricultural production, was accompanied by outstanding developments in insecticides. The cottony-cushion scale, *Icerya purchasi* Mask., was largely responsible for bringing about practical fumigation of citrus trees with hydrocyanic acid; the San José scale, *Aspidiotus perniciosus* Comst., for the development of lime-sulfur and miscible oils.

An insecticide may be defined as a substance or mixture of substances intended for killing, repelling, or otherwise preventing insects. The term is derived from the Latin words meaning "insect" and "to kill." Similar terms are in use for special forms of insecticides, *i.e.*, ovicides and larvicides. Louse killers and mite killers are somewhat awkwardly called, respectively, "pediculicides" and "acaricides," or, etymologically less appropriately, "lousicides" and "miticides." The term "insectifuge," from the Latin for "insect" and "to put to flight" (*fugare*), was formerly rather generally applied to insecticides. Synthetic organic compounds developed today as insecticides are liable to be designated by such unfortunate nicknames as the original experimental or laboratory numbers of the initial letters of their chemical names. "DDT" is an example of the ease with which the latter can take place. "Nicotine" on the other hand is an example of a name in common use before the structure of the substance was described by the chemical name "3-(1-methyl-2-pyrrolidyl) pyridine." "Chlordane" is an instance of the deliberate choice of a common name to avoid establishment of an undesirable numerical nickname.

Federal regulation of insecticides and fungicides began under the Insecticide Act of 1910 as a means of overcoming adulteration and misbranding of commercial preparations in interstate commerce. Although in a few states insecticide laws regulating the sale of paris green and lead arsenate were in effect prior to 1910, a number of other states by 1915 passed laws similar in many respects to the Federal law. Under a new law, the Federal Insecticide, Fungicide, and Rodenticide Act signed by the President on June 25, 1947, and enforced by the Insecticide Division, Livestock Branch, Production and Marketing Administration, U.S. Department of Agriculture, interstate commerce in herbicides and rodenticides also is regulated and the registration of the economic poisons which come under the law is mandatory.

Adulteration of insecticides was formerly much more serious than today. The arsenic content of insecticides was often according to specifications but not in proper chemical combination, sometimes purposely, sometimes because of faulty manufacture (Haywood, 1900). In order to enforce regulations, it was necessary to develop rapid methods of

analysis for the various kinds of insecticides. In the second edition of Wiley's *Principles and Practice of Agricultural Analysis* (1908) is a chapter on the analysis of the insecticides of that time. Methods have been improved and added to continually by the Association of Official Agricultural Chemists and published by the Association in its *Journal* or in the various editions of the *Official Methods of Analysis*.

The Food and Drug Administration, responsible for enforcing the Federal "Pure Food Law," is concerned with the residues of economic poisons which may contaminate food products. Hence, methods of analysis have been devised for the determination of small amounts of poisons upon fruits and vegetables. The Food, Drug, and Cosmetic Act of 1938 is more stringent with respect to the contamination of foods with poisonous or deleterious substances than was the old act of 1906. In neither is there any reference to specific economic poisons, such as arsenic, lead, or fluorine, or indeed to insecticides in general. Under the act of 1906, it was necessary to establish that a contaminated food, in and of itself, was a potential hazard to health. On the other hand the act of 1938, in effect, holds a food to be adulterated if it contains any added poisonous or deleterious substance unless "such substance is required in the production thereof or cannot be avoided in good manufacturing practice." For those added poisons which *are* necessary, and certain economic poisons are admittedly in that class, the act provides machinery for the setting of safe tolerances by regulation. On Jan. 17, 1950, a hearing was initiated to establish such tolerances for all fresh fruits and vegetables. As in the case of insecticide regulation, Federal jurisdiction under the act cannot, in most cases, reach poisonous food which remains within the borders of a sovereign state. In general, Federal action can only be taken after a material has been shipped or offered for shipment in interstate commerce. Exceptions include shipments to and from foreign countries and sale within the Territories and the District of Columbia.

A short list of general works and of periodicals that are useful references to insecticides follows. Many official publications of Federal and state agencies which contain important contributions to the subject are included in the lists of cited references to be found at the ends of the several chapters.

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## CHAPTER 2

### ARSENICAL COMPOUNDS

#### MATERIALS AND THEIR USES

Ever since the discovery of their value in insect control, arsenical compounds have been the most generally useful inorganic stomach poisons. Although legal restrictions regarding their presence on harvested food crops encouraged the development of numerous substitutes, a steadily increasing demand for all insecticides resulted until recent years in a net gain for the arsenicals. The use of these compounds has become firmly established, and methods of manufacture are well standardized. The advent of synthetic organic insecticides more effective for many important uses has within the past few years upset the leadership of the arsenicals.

The toxic properties of arsenic were known to the Greek physician Dioscorides (A.D. 40 to 90). It is recorded that as early as A.D. 900 the Chinese employed arsenic sulfides, both orpiment and realgar, to control insects on garden plants. Arsenic doubtless was utilized as an insecticide in the Western world much earlier than 1669 when the first available record refers to the use of a mixture of white arsenic with honey as an ant bait.

Arsenic forms two oxides, the *trioxide*,  $\text{As}_2\text{O}_3$ , and the *pentoxide*,  $\text{As}_2\text{O}_5$ , which in solution become respectively *arsenious acid*,  $\text{H}_3\text{AsO}_3$ , and *arsenic acid*,  $\text{H}_3\text{AsO}_4$ . In combination with bases these acids form two corresponding series of salts, the *arsenites* from arsenious acid and the *arsenates* from arsenic acid. Arsenites and arsenates may be distinguished chemically by means of magnesia mixture, a reagent made by dissolving 110 gm. of magnesium chloride ( $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ), adding 280 gm. of ammonium chloride and 700 ml. of concentrated ammonia (sp. gr. 0.90), then diluting to 2 liters. When the reagent is added to ammoniacal solutions of arsenates, a white precipitate is formed. No such precipitate is produced by arsenites.

Arsenic acid is formed by the action upon arsenious acid of a fairly strong oxidizing agent. Nitric acid is usually employed commercially, although sometimes oxidation is by electrolytic means. Only one natural deposit of pentavalent arsenic in commercial quantities occurs in the United States, an outcrop of ferric arsenate (scorodite,  $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ ) at Gold Hill in Tooele County, Utah.

*White arsenic* (frequently referred to merely as "arsenic") is the common name applied to arsenic trioxide, source of arsenic in all commercial arsenical insecticides (Table 3). It is a white solid which sublimes when heated to about 150°C. The solubility of arsenic trioxide in distilled water is usually stated as being from 2 to 4 per cent at ordinary temperatures. Solution takes place slowly in pure water, but much more rapidly in rather strong acid or in alkali. Dilute solutions of arsenic trioxide of standard strength should be maintained slightly acid because they deteriorate when somewhat alkaline. A saturated solution of pure arsenic trioxide has a pH<sup>1</sup> of 6.5.

TABLE 3. WHITE ARSENIC EQUIVALENTS FOR COMMERCIAL ARSENICAL INSECTICIDES\*

Insecticide	As <sub>2</sub> O <sub>3</sub> equivalent to 100 lb. of insecticide, lb.	Insecticide equivalent to 100 lb. of As <sub>2</sub> O <sub>3</sub> , lb.
Lead arsenate.....	28.5	350.9
Calcium arsenate.....	36.2	276.2
Paris green.....	56.8	176.1
London purple.....	36.2	276.2

\* U.S. Bureau of Entomology and Plant Quarantine.

White arsenic is a by-product of those ore smelters which utilize arsenic-bearing ores, chiefly ores of copper and lead in the United States and of iron and certain other metals abroad. It is not profitable to mine arseniferous ores for arsenic production alone. Over 90 per cent of domestic arsenic is recovered in copper smelting, chiefly in Montana and Utah. The flue dust is resublimed so that arsenic 99 per cent pure is obtained by two or more roastings. The first commercial arsenic production in the United States was in 1901 when about 300 tons was produced by a gold smelter at Everett, Washington. Nearly 70 per cent of the present supply (combined domestic production and imports from abroad) is consumed in the manufacture of insecticides (Table 4). It has been estimated that 3,963 tons of white arsenic was utilized in grasshopper bait in 1934, a year of severe grasshopper outbreaks (Roark, 1935). This use of arsenic has been largely superseded by sodium fluosilicate or certain organic insecticides.

Prior to the Second World War the United States imported almost as much arsenic as was produced at home. In fact the United States was and is the world's leading importer of this commodity. From 1935 to

<sup>1</sup> pH is a measure of hydrogen ion concentration; a neutral solution of a strong acid titrated with a strong base has a pH of 7.0. The more acid the solution, the lower the pH value; the more alkaline, the higher the pH. The scale is exponential; hence pH values cannot be averaged.



TABLE 4. WHITE ARSENIC CONSUMPTION IN THE UNITED STATES IN 1941\*

Use	Percentage of Total
Insecticides (except cattle dip):	
Lead arsenate, standard.....	27.8
Calcium arsenate.....	27.7
Paris green.....	3.8
London purple.....	0.6
Sodium arsenite, for poison bait.....	1.0
Others, including zinc arsenate, basic lead arsenate, copper arsenate.....	1.2
Total.....	62.1
Weed killer (sodium arsenite).....	17.6
Glass.....	10.6
Wood preservative and wallboard.....	3.4
Miscellaneous (includes cattle dip).....	6.3
Total.....	100.0

\* U.S. Dept. of Commerce.

1939 large imports came from Mexico and Sweden, small amounts from France, Japan, Canada, and Belgium in that order of importance. The war forced an expansion of domestic production (Table 5). It also restricted imports to those from Mexico, Canada, and Peru. The United States exports finished arsenical insecticides, particularly to South America.

The *arsenites* as a class are not only more soluble than the arsenates, but they are more active poisons, both to plant and to animal life.

TABLE 5. SUPPLIES AND CONSUMPTION OF WHITE ARSENIC IN THE UNITED STATES, IN SHORT TONS\*

Year	Domestic production (all grades)	Imports	Domestic consumption†	Exports
1938	16,685	14,238	25,098	2,300
1939	22,341	14,674	33,913	3,178
1940	24,983	9,929	31,668	1,639
1941	32,481	10,292	40,442	2,154
1942	28,681	16,350	42,500	305
1943	31,202	16,112	48,235	1,950
1944	36,094	9,965	40,025	2,401
1945	24,349	13,194	38,100	858
1946	10,211	13,803	27,000	No data
1947	18,755	13,893	31,000	No data
1948	19,367	9,336	24,000	No data

\* U.S. Dept. of the Interior, and U.S. Dept. of Commerce.

† Consumption figures are not entirely comparable from year to year; from 1943 to 1948, apparent consumption data are quoted from U.S. Bureau of Mines.