

## INSECTS AS VECTORS OF PLANT PATHOGENS

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It is appropriate in particular degree that the rôle of insects as vectors of plant pathogens should have a prominent place in this Symposium. In 1881 Thomas J. Burrill, Professor of Botany at the University of Illinois, demonstrated for the first time that bacteria could cause disease in plants and were the cause of fireblight of pears and apples. In 1884 Stephen A. Forbes, then State Entomologist, expressed the opinion that fireblight was spread by the tarnished plantbug. And in 1891 M. B. Waite, until 1887 a student under Burrill, reported experiments proving that bees and wasps commonly spread fireblight from blossom to blossom. Thus, at the University of Illinois, was born the conception of an active and intimate association between insects and plant diseases.

The development of this conception by plant pathologists and entomologists is well exemplified by the time of publication of 655 research reports making notable contributions to the problem. Only seven of these reports appeared prior to 1900, but in succeeding years the number increased rapidly. From 1901 to 1905, ten reports appeared; from 1906 to 1910, twenty-one appeared; from 1911 to 1915, thirty appeared; from 1916 to 1920, forty-one appeared; from 1921 to 1925, seventy-one appeared; from 1926 to 1930, one hundred forty-six appeared; from 1931 to 1935, two hundred and two appeared; and from 1936 to 1940, one hundred twenty-seven appeared.

With so large a number of researches completed, it must be apparent that a large body of information has been developed and that within the time permitted today little more can be presented than a bold outline of what it contains, as illustrated by a number of selected examples of diseases and vectors.

## HISTORICAL

The first suggestion that an insect was associated as vector with a plant disease was made by Forbes in 1884. The first proof that insects function as vectors was

published by Waite in 1891. Milestones in the elaboration of knowledge of the vector rôle of insects may be listed as follows:

1901.—Takami, a Japanese, showed that the dwarf disease of rice, not then known to be a virus disease, resulted from the feeding of the leafhopper *Nephotettix apicalis*.

1906.—Ball, in America, showed that curlytop of sugar beet was associated with the leafhopper *Eutettix tenellus*.

1909-1910.—Petri, in Italy, showed that olive knot was transmitted by the olive fly (*Dacus oleae*) and that an intricate symbiotic association obtained between the pathogen, another bacterial organism, and the insect.

1911.—E. F. Smith, in America, showed that bacterial wilt of cucurbits was transmitted by the striped cucumber beetle (*Diabrotica vittata*).

1911.—Norton, in America, published a classification of insect injuries to plants, in which insect dissemination of pathogens was recognized.

1912.—Allard, in America, showed that tobacco mosaic was transmitted by aphids.

1913.—Heald, in America, summarizing the dissemination of plant pathogenic fungi, recognized the importance of insects as vectors.

1918.—Ball, in America, demonstrated that potato hopper burn resulted, as a toxic effect, from the feeding of the leafhopper *Empoasca fabae*. He thus established a new concept, that of disease being induced by toxicogenic insects.

1921.—Buchner, in Germany, published elaborate studies of the symbiotic phenomena occurring between microorganisms and insects.

1926.—Kunkel, in America, showed that an incubation period in the body of the insect is required for transmission of aster yellows.

1929.—Böning, in Germany, published an extensive critical review of the literature on insects as carriers of plant diseases.

1937.—Kunkel, in America, showed that the virus of aster yellows in the body of the leafhopper can be inactivated by exposure of the insect to a temperature of 31° to 32° C.

1937.—Hartzell, in America, reported the finding of intracellular inclusions in the intestinal walls and salivary glands of viruliferous *Macropsis trimaculata*, the leafhopper vector of peach yellows.

1937.—The American Phytopathological Society, the Entomological Society of America, and the American Association of Economic Entomologists staged an elaborate symposium on insects in relation to plant diseases.

1940.—Leach, in America, published the first book dealing with insects as vectors of plant pathogens.

#### EXAMPLES OF INSECT TRANSMISSION

**Diseases due to phytotoxic insect secretions.**—The outstanding example is the mealy bug wilt of pineapple, a disease known in Hawaii since 1910 as the most important cause of pineapple failure. Leaves of affected plants become flaccid, droop, turn pale or become pink or red. On young plants progress of the disease is rapid, but recovery occurs commonly. On old plants progress of the disease is slow and affected plants never recover. On young plants an initial population of fifty mealy bugs (*Pseudococcus brevipes*) is sufficient to induce the disease. On older plants the disease develops slowly, as a large population of mealy bugs develops from an initial small number, and is accompanied by collapse of the roots and final destruction of the plants.

The disease is not caused directly by the feeding of mealy bugs but by a phytotoxic substance injected into the plants by the bugs as they feed. The phytotoxic substance is apparently diffusible in the plant but is not capable of reproduction there. The failure of plants to wilt quickly when colonies of mealy bugs are built up slowly from small initial populations has been interpreted as the result of an anti-toxic reaction on the part of the plant. In general, the wilting of plants increases with the number of mealy bugs, but the increase is not directly proportional; and there appears to be a point on the bug dosage scale beyond which there is only a small increase in the number of wilting plants.

Another disease of the same kind, one familiar in America, is hopper burn of

potato. This disease follows the feeding of *Empoascus fabae*. It differs from the mealy bug wilt of pineapple in that it is not limited to just one of the hosts used by the causal insect. It affects alfalfa, clover, apple and other plants also, and may severely damage them.

Explanations other than that of a diffusible toxic substance have been offered for the injury done by toxicogenic insects. It has been suggested that accumulation in excess of carbohydrates above the point injured by the insect is sufficient cause for the injury. However, *Empoascus fabae* feeds almost exclusively in the phloem elements of the vascular bundle, and the line of penetration is surrounded by a region of disorganized cells not producible mechanically, as for example by probing with a fine glass needle. Presumably, then, pathological disorganization of plant cells must follow the injection of at least some toxic material. Since other leafhoppers that feed in the vascular elements of the plants cause less injury, or none at all, differences in amount of injury can most logically be attributed to differences in toxicity of the salivas of the different leafhopper species. The concept of toxicity is, nevertheless, poorly defined, and it is well, therefore, to consider that injury displayed by plants could result from excessive abnormal physiological reactions induced by toxic materials, as well as from the direct action of toxic substances.

**Fungus diseases transmitted by insects.**—A great variety of associations between fungi and insects is exhibited by the known cases in which insects serve as vectors of fungous pathogens. Commonly, these associations appear based on the search for food by insects. The ergot diseases of rye and other grasses furnish fine examples.

In the spring, ergot kernels that have lain dormant on the ground over winter send up globe-capped stalks. Beetles, and also other insects that visit the blossoms of grasses, are attracted to these globular caps and become contaminated with ascospores of the ergot fungus. Crawling or flying then to rye and grass heads, these insects deposit spores in the blossoms and infection is accomplished. As the new ergot develops, a conidial type of spore is borne in droplets of honeydew. More than forty kinds of insects, includ-

ing especially flies and a fungus gnat (*Sciara thomae*) have been observed feeding on this spore-bearing honeydew. Insects that habitually visit both healthy and diseased grass heads in their search for pollen and nectar are obviously effective agents in spreading ergot infection from blossom head to blossom head. The relationship between fungus and insect is, however, purely casual and accidental. The fungus evidently is not the food sought by the insect, since it has been demonstrated that its spores pass through the alimentary canal of the insect without losing their viability. The only obvious adaptation apparent in the relationship is that the fungus, as it develops in the grass head, produces a carrion-like odor that seems especially attractive to flies.

A more restricted relationship exists between a number of wood staining fungi and certain bark beetles. Fungi, chiefly of the genus *Ceratostomella*, attack the sapwood of certain coniferous and deciduous trees important in industry, not rotting but killing and staining in shades of blue and brown the wood they invade, and thus decrease the commercial value of lumber obtained from the trees. Affected trees usually have been weakened by fire or drought previous to infection. Inoculation with these fungi is accomplished chiefly, if not exclusively, by bark beetles as they bore into the trees and construct their galleries. The fungi, after penetrating the wood of the tree, fruit in the brood galleries of the insects and thus contaminate the young beetles. Invariably, spores of these fungi are borne in a sticky matrix, an adaptation assuring that new broods of beetles will be well contaminated externally as well as internally when they emerge from the trees.

In some instances, the association of stain-producing fungi, insect species and tree hosts is not closely restricted. For example, the blue stain fungus *Ceratostomella ips* is carried to Norway pine logs by two species of bark beetle, *Ips pini* and *I. grandicollis*. It can also be carried to other coniferous species by at least three other species of the same bark beetle genus. On the other hand, the association may be rather strict, as in the case of two brown stain fungi affecting white fir. One of these fungi, *Spicaria anomala*, is found only in the top and branches of the tree, where it is intro-

duced by *Scolytus praeceps* and *S. subscaber*. The second fungus, *Trichosporium symbioticum*, is found only in the base of the tree, where it is introduced by *Scolytus ventrales*. Although it has been shown experimentally that either of these fungi will grow in any part of the tree artificially inoculated with them, their occurrence in nature only in definite portions of the tree is clearly associated with their dependence on specific insect vectors.

The relationship existing between blue stain fungi and bark beetles may be regarded as an instance of mutualistic symbiosis. The fungi apparently are of no significance as food for the insects. Their rôle is apparently that of making the wood which they parasitize a more suitable habitat for the beetles, and this they accomplish by killing the cambium of the tree and reducing the moisture content of the sapwood. The service rendered by bark beetles to wood-staining fungi is apparently limited to that of transport and insertion into the tree.

The well known dependence of plants on insects for pollination is also a means for the spread of disease. In Russia and in Wales, red clover is affected systemically by a fungus known as *Botrytis anthophila*. This fungus fruits on the anthers of affected plants, destroying the pollen grains and replacing them with masses of spores. The vigor of the plant is not impaired, and blighted anthers constitute the only symptom of disease. Because of the destruction of pollen there is, however, a decrease in seed yield. Bees, upon which red clover is largely dependent for pollination, visit the flowers for nectar, become contaminated with the *Botrytis* spores, and carry them to the stigmas of flowers on healthy plants. Here the spores germinate. The mycelium penetrates the ovary, remains within the seed until it germinates, and then grows systemically within the young plants. It again appears in fruiting condition when the flowers mature.

Insects can be extremely important as vectors in indirect ways, as for example in the diploidization of fungi. One of the most recently discovered rôles is that of flies and perhaps other insects in the fertilization of heterothallic rust fungi. With these fungi, reduction division occurs in the germinating teliospore. Sporidia produced after this germination give rise to haploid mycelia. Infection

by these sporidia results in the formation of the structure known as a pycnium, in which are produced numerous minute pycniospores and certain elongated hyphae regarded as trichogynes. Pycniospores exude from pycnia in drops of a fragrantly scented, sugary solution eagerly sought by over 135 observed species of insects. As insects feed on the sugary solution, they become contaminated externally and internally with pycniospores, which they deposit in other areas of infection. Flies, perhaps because of their tendency to regurgitate, appear to be the most important carriers of these spores.

When pycniospores are deposited on infected areas other than the one from which they came, they adhere to trichogyne filaments, unite with them, and accomplish diploidization. This immediately results in production of the cluster cup stage of the rust fungus.

Constant cross-fertilization of rust races by insects increases opportunities for hybridization and variation. It not only accounts for the large number of physiologic forms occurring in such important rust species as the stem rust fungus, *Puccinia graminis*, but also makes it very probable that success in breeding economic plants for resistance to heterothalic rust fungi will always be only temporarily successful.

**Bacterial diseases transmitted by insects.**—The bacteria known to be pathogenic in plants exceed 200 species. With few exceptions they are unicellular, rod-shaped organisms of such simple structure that they are able to penetrate plants only through natural openings or injuries. Insects that penetrate the epidermis of plants are therefore especially useful as vectors; but in many instances insects also serve as chance or accidental carriers, depositing bacteria on or near natural openings in the plant—stomata, hydathodes, and nectaries.

A great many instances of insects serving as vectors for bacterial plant diseases are recorded in the literature of plant pathology and entomology. Many of these instances never have been substantiated experimentally but are based on observation, or especially when the method of dissemination of a bacterial pathogen is not understood, on assumption. The relationship between insects and bacteria has, however, been investigated care-

fully in a number of instances, and it has been definitely shown that this relationship may vary from the purely casual or accidental to an extremely complicated symbiosis.

The earliest of the bacterial diseases of plants to be recognized as being spread by insects was fireblight. In 1884 Forbes, from observational evidence, associated spread of the disease with the feeding activities of the tarnished plant bug. Nearly thirty years later this association was proved experimentally. In 1891 Waite proved experimentally that fireblight is transported from blossom to blossom by bees and wasps. Since this early work, it has been proved that bees are concerned almost solely with the increase of the phase of the disease known as blossom blight, and that aphids, tarnished plant bugs, and other insects carry infection from hold-over cankers to the growth of the current year. It seems that transmission by these insects is purely mechanical and that any insect feeding on a susceptible host is a potential vector. Thus the infection of large branches and trunks may be accomplished by the fruit tree bark beetle, *Scolytus rugulosus*. The beehive has been suspected as an overwintering haven of the fireblight bacterium, and there is evidence that at least in some parts of the United States it can serve this purpose.

The rôle of insects as transporters of fireblight has perhaps been investigated more extensively and by a greater number of researchers than any other insect-carried disease, yet after nearly sixty years investigators are by no means agreed as to the rôles to be assigned to various insects. Since many means of spread other than insects are utilized by fireblight bacteria, the one point of agreement in all of the data now available probably is that insects are casual or accidental, mechanical carriers.

At the opposite extreme is the olive knot disease, which in Italy has been proved to be closely associated with the olive fly, *Dacus oleae*. The bacterium, *Phytomonas savastanoi*, causing the disease is found constantly in the intestinal tract of this insect in all its stages of development, is transmitted internally through the egg, and survives in the puparium. In the female fly, the anal tract and the vagina unite at their posterior ends to form a common opening.

Near this opening, but in the wall of the anal tract, there are a number of sac-like evaginations, which are always filled with bacteria. Immediately opposite the openings of the evaginations is a longitudinal slit in the membrane separating the anal tract and the oviduct. An egg, passing along the vagina, spreads this slit open, so that its surface presses against the openings of the bacterium-filled evaginations. In this way the egg becomes smeared with bacteria, which find their way through the micropylar opening into the interior of the egg and into the body of the developing embryo. Larvae are, consequently, always contaminated internally before they hatch. Near the forepart of the mid intestine of the larva are four spherical caeca that harbor the bacteria, and from these caeca as points of origin bacteria are continually being distributed throughout the length of the intestinal tract. In the larva, during pupation, a spherical diverticulum develops off the esophagus and just in front of the brain of the pupa, and this diverticulum becomes filled with the bacteria. Here the bacteria persist, and when the fly emerges it also is always internally contaminated. Shortly after the imago emerges, the entire intestinal tract, including the anal sacs, becomes contaminated from the diverticulum. In this way, persistence of the bacteria in the body of the insect is assured. Transmission of the bacterium to the olive tree occurs by way of the wound made during oviposition.

Another, non-pathogenic bacterium, *Ascobacterium luteum*, occurs constantly in the body of the olive fly, in the same places as the olive knot bacterium, apparently in symbiosis with the olive knot bacterium, and frequently in much greater numbers than the olive knot bacterium. What relationship exists between the olive fly and the two bacteria it harbors has not been determined; but it may be assumed to be some high type of symbiosis, since special structures have developed in the body of the insect to further the relationship.

The olive fly is not the only means by which olive knot can be spread. The disease is not uncommon in California, but the olive fly does not occur in that state. There the disease is apparently distributed by wind-blown rains.

An instance in which a bacterial pathogen is entirely dependent for spread upon a definite kind of insect is furnished by the bacterial wilt of cucurbits. As a result of the presence of *Erwinia tracheiphila* in their vascular bundles, cucumber, cantaloupe, squash and pumpkin plants wilt and die. Primary infection of these plants always originates in the spring from the feeding of overwintered striped cucumber beetles, *Diabrotica vittata*, in the bodies of which the bacterium also overwinters. After the disease is established in a plant, it can be spread to other plants by both the twelve-spotted cucumber beetle, *D. duodecempunctata*, and the striped cucumber beetle. Experimental work has established that these two insects are the only insects capable of harboring and spreading the disease and that the squash bug, the squash ladybird, the melon aphid, the honey bee and the potato flea beetle are not vectors. Although the bacterium lives over winter in the body of the striped cucumber beetle, it is not known that any symbiotic relationship exists between the bacterium and either of its vectors.

#### Virus diseases transmitted by insects.

—Since 1912, when Allard showed that tobacco mosaic was transmitted by aphids, the number of proved instances of insect transmission of viruses has increased so greatly that now the number of insect vectors much exceeds the number of recognized plant pathogenic viruses. Here, also, the relationships between the viruses and their vector insects are variable, ranging from casual mechanical transmission to biologically obligatory associations.

An instance of a highly infectious virus being transmitted mechanically by many different insects is furnished by the spindle-tuber disease of potato. This disease, first recognized in 1922 and proved to be of a virus nature in 1923, is of considerable economic importance. Its virus is easily transmitted artificially by inoculation with infected sap, by contact between cut seed pieces, and especially by the cutting knife. Positive transmission has been proven experimentally for the following insects: the aphids *Macrosiphum gei* and *Myzus persicae*, the tarnished plantbug, larvae of the Colorado potato beetle, the flea beetles *Epitrix cucumeris* and *Systema taeniata*, the leaf

beetle *Disonycha triangularis*, and grasshoppers of the genus *Melanoplus*. The only insect that has failed to give positive transmission in tests is the leafhopper *Euscelis exitiosus*. The fact that so many insects are able to transmit the spindle-tuber virus suggest that almost any insect feeding on potato is a potential vector of the disease. This facility for insect spread undoubtedly accounts for the very rapid increase of the disease in the field, which may reach the extent of 42 to 95 per cent of the plants in as short a time as three years.

Leafroll of potato, also an economically important virus disease, is less readily transmitted than is spindle-tuber. It cannot be transmitted by mechanical inoculation with virus-infected sap. It can, however, be transmitted by such insects as the plantbug, *Calcoris bipunctatus*, and the leafhopper *Typhlocyba ulmi* and is transmitted chiefly by aphids. At least seven aphid species have been incriminated in experimental tests. Among the seven, *Myzus persicae* is most important, with *M. pseudosolani* and *M. circumflexus* in second place. One of the pathological aspects of leafroll is a necrosis of the phloem tissues of the potato plant, and this fact seems associated with the fact that the most efficient aphid transmitters habitually feed in the phloem.

After feeding on an infected plant, the aphid *M. persicae* requires several days before it is able to transmit leafroll, but after this period has elapsed it remains infective for a relatively long period of time. Apparently some biological relationship exists between the insect vectors and the leafroll virus.

Curly top of sugar beets, a disease historically important because its relationship to the leafhopper *Eutettix tenellus* was recognized before its virus nature was understood, presents an instance of still closer biological limitation between insect and virus. Although curly top virus can be transmitted artificially by sap inoculation, the only known means of transmission in nature is the beet leafhopper. This leafhopper is not known to transmit any other virus disease. Curly top virus overwinters in a number of wild plants, as well as in overwintered sugar beets. Leafhoppers, feeding on these plants, become infected. The virus then requires an incubation period in the body of the insect, ranging from as short

a time as twenty minutes to as long as seven hours, and the leafhopper is unable to transmit the disease until this period has elapsed. In plants a latent period of four to fourteen days is required before symptoms appear.

Curly top has been investigated extensively by a number of workers, who have determined numerous interesting and important facts bearing upon the interrelations of host, virus and insect. In affected plants the virus is localized in the phloem. Insects, when feeding, must reach the phloem to become viruliferous and to transmit the disease. In searching for phloem tissue, the insect seemingly is guided by the pH value of the tissues through which its feeding apparatus passes. Phloem tissue is said to have a pH value of 7.5, xylem a value of 6.2, and parenchyma a value of 6.0. Rickettsia-like microorganisms have been reported in the intestinal tract lining of infective leafhoppers but have not yet been discovered in the tissues of infected plants. In the body of the insect, curly top virus is apparently most abundant in the blood, from which it is most readily recovered; it can also be recovered from the salivary glands and the contents of the alimentary tract. The virus content of the insect decreases slowly as the insect feeds on uninfected plants, and the power of transmission may disappear after fifty-four days. Apparently the virus does not multiply in the body of the leafhopper, although it may survive the winter there. If a quantity of viruliferous juice is precipitated with an equal volume of 95 per cent alcohol, centrifuged, washed in 50 per cent alcohol, dried, and mixed with sufficient five per cent sugar solution to restore the original volume, the product may be fed to leafhoppers to make them viruliferous and able to infect healthy plants.

Besides these biological relationships, certain ecological aspects are of interest. The beet leafhopper is restricted to an arid climate, and the curly top disease, being restricted to one vector, is limited to the region occupied by the leafhopper. Sparse stands of Russian thistle provide optimum conditions for development of the leafhopper; high humidity in heavy stands checks development of the insect. In sugar beet fields, optimum conditions for the leafhopper obtain when the stand is poor or when the plants are small.

The virus the leafhopper transmits benefits its vector by contributing suitable environment. Sugar beet fields would be but little used by the leafhopper were it not for the effect of the curly top virus on the sugar beet plants.

Aster yellows and peach yellows are two additional virus diseases, research on which has yielded important knowledge of the relationship of plant pathogenic viruses and insect vectors. Aster yellows is an extremely destructive disease of cultivated asters and affects nearly 200 other species of plants in North America. It is transmitted exclusively by the leafhopper *Macrostelus divisa*. Both nymphs and adults are able to transmit the virus. However, incubation of the virus for at least ten days in the body of the insect is required before disease can be induced. Fully viruliferous leafhoppers, if held at a temperature of 31° C. or above for several days, become non-infective. Apparently the virus in the body of the insect is destroyed by prolonged heat. It is supposed that on this account spread of the disease is less during the hot weather of midsummer. If, however, the exposure of the insect to high temperature is of short duration, the virus is only partially inactivated and, after the elapse of a suitable period, may again become potent. Thus there is evidence of multiplication of the virus in the body of the insect.

Peach yellows, recognized for more than a hundred years as an extremely destructive disease of peaches, is transmitted only by the plum leafhopper, *Macropsis trimaculata*. It and aster yellows can be transmitted artificially only by grafting. The incubation period of the peach yellows virus in the leafhopper ranges from eight to 26 days. Both nymphs and adults are able to transmit the virus. The presence of intracellular inclusions has been demonstrated in the intestinal walls and salivary glands of viruliferous leafhoppers.

Taxonomic groups of insects vary greatly in importance as virus vectors, and the importance of different groups appears correlated with feeding methods. Grasshoppers, which have chewing mouth parts, transmit the spindle-tuber disease of potatoes, but are not specific transmitters. Thrips, which feed with a rasping-sucking action, transmit spotted wilt of tomato, pineapple yellow spot, and

streak of peas, and some degree of specific biological relationship exists between them and these viruses. Aphids, which feed by sucking, are the most important of the virus vectors, both as to number of vectors and number of viruses transmitted. Thirty-six aphid species transmit 38 viruses. One aphid, *Mizus persicae*, transmits 19 viruses. Next in importance are leafhoppers, and it is in this group that the highest type of biologically obligatory association between virus and vector is found. Fifteen viruses are transmitted by 19 leafhopper species. But no leafhopper transmits two unrelated viruses, and no virus is transmitted by more than four leafhoppers. Scale insects and mealy bugs, though common on a wide range of plants, transmit few viruses. Two lacebugs transmit the viruses of two sugar beet diseases, and plantbugs, especially the tarnished plantbug, transmit viruses that are easily transmitted mechanically. Only a small number of beetles transmit viruses and in those few cases probably do so mechanically and without displaying any biological relationship.

Sucking insects are the most effective vectors of plant pathogenic viruses, but even among them there are great differences in ability to transmit. Some are unable to transmit any virus; others transmit certain viruses mechanically; and still others transmit only single viruses in such a way as to indicate the existence of very highly specialized adaptations between vector and virus.

#### PROBLEMS NEEDING INVESTIGATION

Although the rôle of insects as vectors of plant pathogens has been recognized in numerous instances, there still is need for clarification in this basic field. Insect vectors are unknown for 54 out of a total of 129 recognized virus diseases of plants. There are numerous opportunities for research in special aspects of the relationship between plant pathogens and their insect vectors. In the field of viruses, for example, it is important to learn why one aphid species can transmit 19 kinds of virus, while at the other extreme one leafhopper species can transmit just one kind of virus not transmitted by any other leafhopper species. It would be of interest to know what the incubation period of a virus in an insect body actually represents. It would be valuable

to trace the progress of a virus in an insect body from the time it is accepted until it is given back to a plant. An especially intriguing field of research has been opened up by the discovery that cer-

tain plant viruses appear as protein crystals. That discovery may furnish the key to the question, "What form does a virus take in the body of its insect vector?"