



# Environmental Control in the Beehive

*Honeybees efficiently regulate temperature and humidity, eliminate polluted air, remove foreign objects, wastes and dead bodies and control parasites and pathogens that attack them and their food*

by Roger A. Morse

A colony of honeybees consists of as many as 50,000 individuals, which live together under conditions of much greater crowding than human beings ever do. Yet the bee colony can maintain its internal environment with remarkable constancy. It can regulate temperature and humidity, eliminate polluted air, remove foreign objects, wastes and dead bodies and, not least, control most of the parasites and pathogens that attack not only the bees but also their food supplies in the hive. How do the bees do it?

A bee colony consists of the queen, a large complement of worker bees and, during part of the year, as many as 3,000 drones. The function of the drones is to mate with the queen; only about six to eight of them do so, and the rest are superfluous. In the fall the drones are driven out of the colony.

The three castes live together in a natural cavity or a man-made hive. In nature a hollow tree seems to be preferred. Bees usually build their combs in a dark place; indeed, light appears to inhibit comb construction. The result is that bees seldom build combs in exposed areas where the colony could not survive the winter.

Honey is accumulated by bees as a reserve against the time when nectar is not available from flowers. Honey is the

bees' chief food; a normal colony will maintain a reserve of from 15 to 100 pounds of it. In the northern U.S. a colony requires at least 60 pounds of honey to get through the winter.

Bees obtain their protein from pollen. The pollen reserve of a colony will normally range between one pound and 15 pounds. Honey and pollen are the only foods the bees eat, and both are stored in the cells of the comb. Since honey is largely sugar and pollen is rich in protein and fats, the reserve could be an important source of food for organisms other than bees. Protecting the stored food against larger animals and parasites is therefore a matter of prime importance to the colony.

The home usually selected by bees in nature is strong enough to protect the nest against attack by other animals. If the nest fails to give sufficient protection, a second line of defense is the sting. Even in the winter bees too cold to fly can protrude their stingers; a mass of cold clustered bees with protruded stingers reminds one of a porcupine. Any animal that touches such a cluster is likely to retreat in haste. Predators are therefore more of an occasional hazard than a constant threat.

Protecting the reserve against parasites such as bacteria calls for other mechanisms. The problem is exacerbated by the fact that the bees maintain a temperature of about 92 degrees Fahrenheit in the nest during the period of about 10 months a year when they are rearing brood. Humidity is also maintained at a high level, although within wider limits. Such conditions would be favorable for the growth of yeasts and bacteria if the bee colony did not have protective mechanisms.

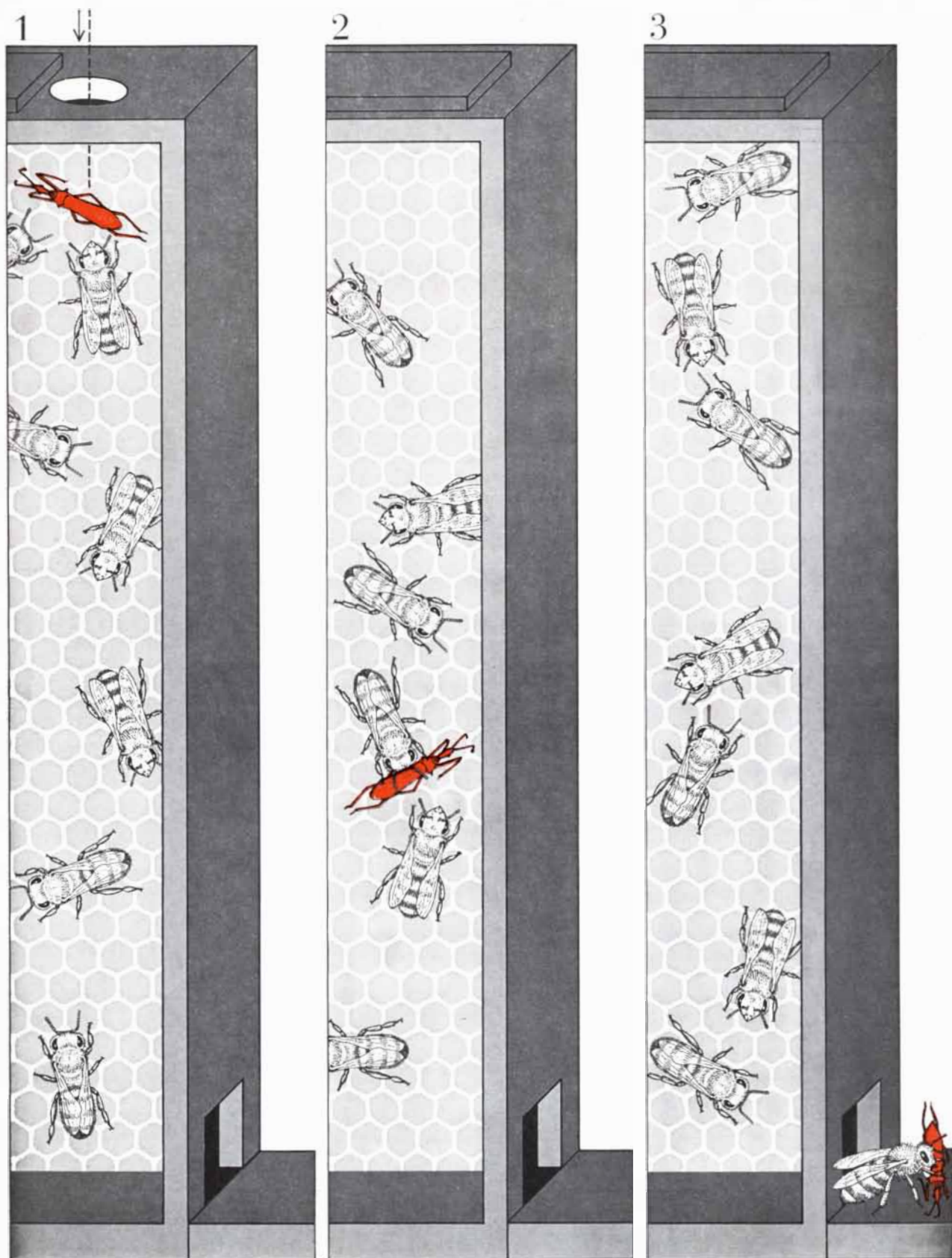
The investigation of these mechanisms

began early in this century, coincident with the establishment of pure food and drug laws. At the time there was much interest in foods as possible carriers of typhoid fever and other infectious diseases. Walter G. Sackett of the Colorado Agricultural College investigated honey as a possible carrier of intestinal diseases in 1919. He introduced 10 different microorganisms into honey, including the organisms that cause typhoid fever and bacterial dysentery. He also introduced the same bacteria into honey that had been diluted with water.

Sackett found that in the undiluted honey the microorganisms were dead within two days and that in honey diluted to 60 percent of its original sugar content they were dead within a day. (Undiluted honey is from 82 to 84 percent solids, mostly sugar.) In solutions of honey with less than 50 percent solids the organisms died more slowly, but even in a solution of 10 percent honey they were killed within a few days.

Sackett found the failure of the microorganisms to thrive in honey "rather surprising," particularly in the case of the diluted honey. He could only suggest that the phenomenon was related to the physical state of the sugar particles in the honey. Later investigation showed that one antibacterial mechanism has to do with the fact that honey has a low water content and a high osmotic pressure. In such an environment osmotic pressure, resulting from the imbalance between the amount of water in a bacterial cell and the amount in the honey, causes water to leak out of bacterial cells. The result is bactericidal or bacteriostatic: some bacteria are killed and others, although they remain viable, cannot grow. Osmotic pressure therefore accounts for the failure of bacteria to flourish in undiluted honey.

**INTERIOR OF HIVE** of a colony of bees active in Florida appears in the photograph on the opposite page. The absence of foreign objects is conspicuous; bees promptly remove such an object. The cells visible in the photograph are for storing pollen and honey. Pollen is the source of protein and fat in the bees' food as honey is the source of sugar. Protective devices for pollen cells include putting a layer of honey in the top fifth of the cell and capping the cell with wax.



**REMOVAL OF FOREIGN OBJECT** from a hive by worker bees is portrayed. Soon after the object is introduced (1) a worker bee grasps it and moves it some distance, usually toward the entrance. If the first bee abandons the object, another bee will pick it up

(2). Eventually the object reaches the entrance (3), where a bee flies away with it, carrying it at least 50 feet from the hive before dropping it. If the object is too large for a bee to carry in flight, the bee will try to drag it several feet over the ground.

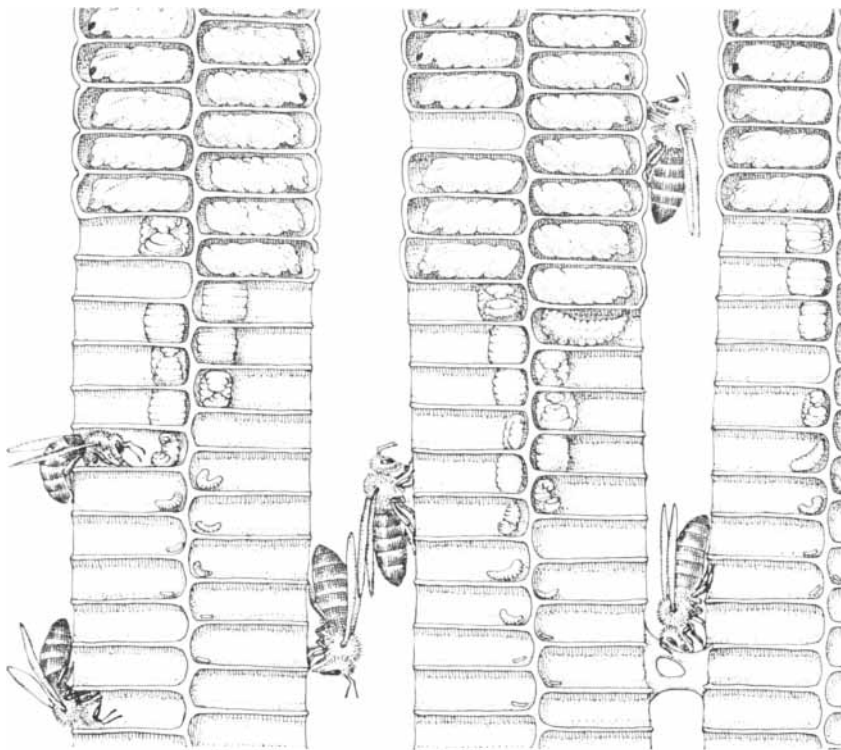
It took longer to find the mechanism that accounts for the stronger effect of partly diluted honey. In 1937 German experimenters called attention to the bactericidal effect of honey and termed it the "inhibine" effect. The laboratory investigating the phenomenon reported that whatever caused the effect was destroyed by heat and light. This finding was confirmed in other laboratories; indeed, the "inhibine number," a measure of bactericidal activity, has been used in some countries since the 1930's to indicate the quality of honey.

In 1962 Jonathan W. White of the U.S. Department of Agriculture discovered that honey contains the enzyme glucose oxidase, which is added to the honey by worker bees. Glucose oxidase attacks glucose, which is one of the two common sugars in honey. (The other is levulose, a form of fructose.) In the process hydrogen peroxide, which is of course a powerful bactericidal agent, is released. White's discovery showed the real basis of the inhibine effect.

Moreover, White found that glucose oxidase is largely inactive in ordinary honey with a moisture content of 19 percent or less. He showed that when honey is diluted, the generation of hydrogen peroxide rises sharply. Here, then, is the reason for the increased bactericidal effect of diluted honey. (It is an interesting fact that the honey fed to larvae in the colony is diluted by the nurse bees that do the feeding.)

Glucose oxidase is not commonly found in insects or in association with them. There is no reference to it in standard textbooks on insect physiology. It would be worthwhile to know how widely the enzyme is used by insects that collect or store food, including ants and solitary and semisocial bees.

Antibiotic activity is found in royal jelly, the rich creamlike substance worker bees secrete from glands in their head and feed to larvae. (Larvae that will become queen bees get more royal jelly than larvae destined to become workers; the difference is crucial, since queens and workers arise from the same eggs.) In 1959 Murray Blum and Arthur F. Novak at Louisiana State University and Stephen Taber III of the Department of Agriculture found that royal jelly contained a fatty acid with antibiotic properties. Although the antibiotic is only 20 to 25 percent as effective as penicillin and chlorotetracycline against the microorganisms exposed to it, its activity is still high enough to give the royal jelly considerable protection against bacteria.



**BEE SPACE** can be likened to corridors that bees maintain around and between combs. The space is seldom less than 1/4 inch or more than 3/8 inch wide. Larger spaces are filled with comb, and smaller ones are plugged with a varnish-like material called propolis (lower right), which apparently serves to fill cracks that might harbor microorganisms.

Another antibacterial agent that works for the bee colony is the natural acidity of honey. For many microorganisms an acid environment is inhospitable. Certain yeasts, however, will tolerate such an environment, and yeasts are found in honey. Because of the high osmotic pressure of honey, they are yeasts of the type called osmophilic, meaning that they live or thrive in a medium that has a high osmotic pressure.

Most yeasts, including the bread yeasts and the yeasts used to make beer and wine, belong to the genus *Saccharomyces*; they cannot grow or multiply in solutions that contain more than about 30 percent sugar. The osmophilic yeasts, belonging to the genus *Zygosaccharomyces*, will not grow in dilute sugar solutions. They flourish only in products such as maple syrup, which has a sugar concentration of about 66 percent, and in honey—provided that it contains more than the normal amount of water, which is about 19 percent.

Grading rules of the Department of Agriculture stipulate that Grade A honey must contain less than 18.6 percent water. Nectar that bees collect in the field usually contains between 10 and 50 percent sugar; the remaining content is mostly water. The bees "ripen" the nec-

tar, reducing its moisture content both by warming the hive and by passing large volumes of air over the droplets of honey that have been put in comb cells. Further processing is visible among the house bees that receive nectar from the field bees; the house bees manipulate the nectar with their long tongue, swallowing it, regurgitating it, forming a droplet on the tip of the tongue and taking it into the honey stomach again. This repeated treatment of the honey drives off water and adds enzymes.

Fortunately for both bees and beekeepers normal honey containing less than 19 percent water does not ferment even though it contains yeasts. The high osmotic pressure and lack of water keep the yeasts from growing, although they remain alive. Fermentation in stored honey is occasionally a problem for bees and more often vexes the beekeeper after he has removed honey from the hive. Honey is hygroscopic: it absorbs moisture from the air. When stored honey crystallizes, as it usually does because it is a supersaturated sugar solution, a certain amount of water is incorporated into the crystal nuclei. The amount is proportionately less than is found in the honey overall, however, so that the liquid por-



tion of partly crystallized honey has a higher water content than the honey had before crystallization started. As soon as the moisture content of the uncrystallized portion rises above about 19 percent, the osmophilic yeasts begin to grow (unless they have been killed by heat treatment) and fermentation becomes evident.

In colonies with a large population of bees the high interior temperature helps to remove the excess moisture. In colonies that cannot protect all their stores, either because the stores are too large or because the bee population is too small, one can see bubbles of carbon dioxide forming as a result of yeast growth in the honey. The fermenting honey will leak from the cells and run down the surface of the comb, where it is likely to attract more moisture. At this point the glucose oxidase system offers a degree of protection, but mold may nonetheless appear on the dilute honey. Alcohol produced by the yeasts is attacked by *Acetobacter*, the organism that converts alcohol into acetic acid, or vinegar. The odor of the vinegar may attract flies, particularly fruit flies (*Drosophila*). Under these rare circumstances food stores within a bee colony may be destroyed because of the

failure of the sanitation and protection system.

The honey sold in grocery stores is usually pasteurized to prevent fermentation. The treatment requires heating the honey to 140 degrees F. for 30 minutes or 160 degrees for one minute or some intermediate combination. Such heating also destroys the glucose oxidase; some people feel it further harms the honey, although the claim is questionable. Overheating can certainly damage the flavor of honey.

**H**ow do bees protect their stores of pollen? Again the mechanisms vary. One of them is the glucose oxidase system, which comes into play because bees add nectar or honey to pollen as they collect it.

In 1966 Janine Pain and Jacques Mauget of the French government's bee-research station at Bures-sur-Yvette near Paris found that the bacteria producing lactic acid (*Lactobacillus*) serve to protect pollen stored in the hive. The lactic acid makes the pollen mixture a natural ensilage, protecting the pollen against destruction by other microbial agents. Other bacteria (*Pseudomonas*) and ordinary yeasts (*Saccharomyces*) were also

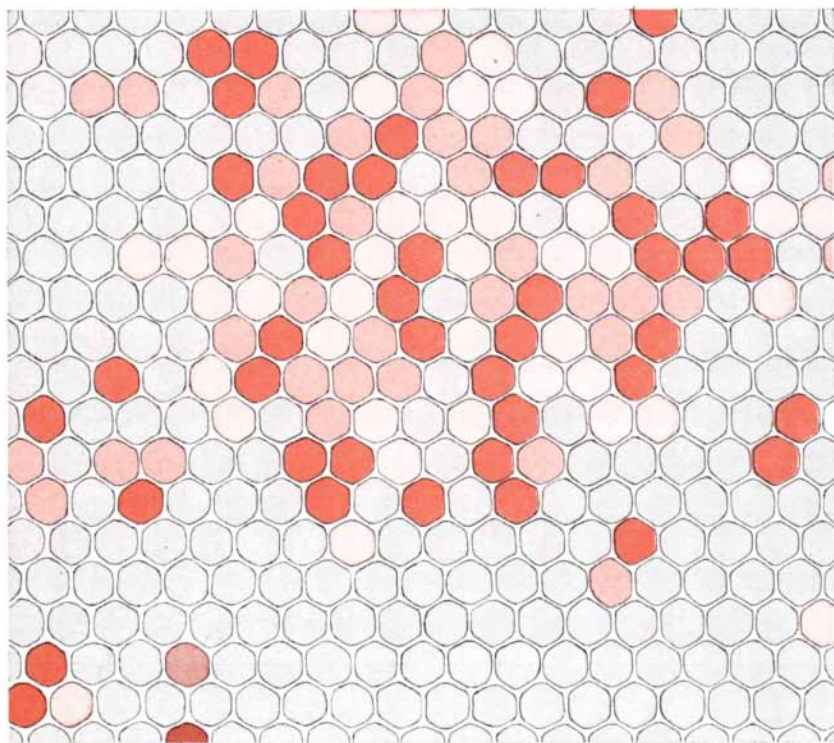
found in stored pollen. The effect of *Pseudomonas* is probably to remove oxygen, making the pollen a better growth medium for *Lactobacillus*. Yeast apparently serves to break down the pollen, making its use by the bees easier.

Although the honey cells in the comb are filled to the brim, the cells containing pollen are never filled to more than about 75 or 80 percent of their depth. When the pollen is being consumed rapidly, as it is in the early spring for brood-rearing, there is little danger of spoilage because the supply turns over quickly. If pollen is stored for any length of time, as it is in winter for the early spring activity, the pollen cells need further protection and are covered with honey and then with wax caps. That is why the pollen cells are only partly filled. The addition of honey and a cap helps to protect the pollen cell against contamination and bacterial spoilage.

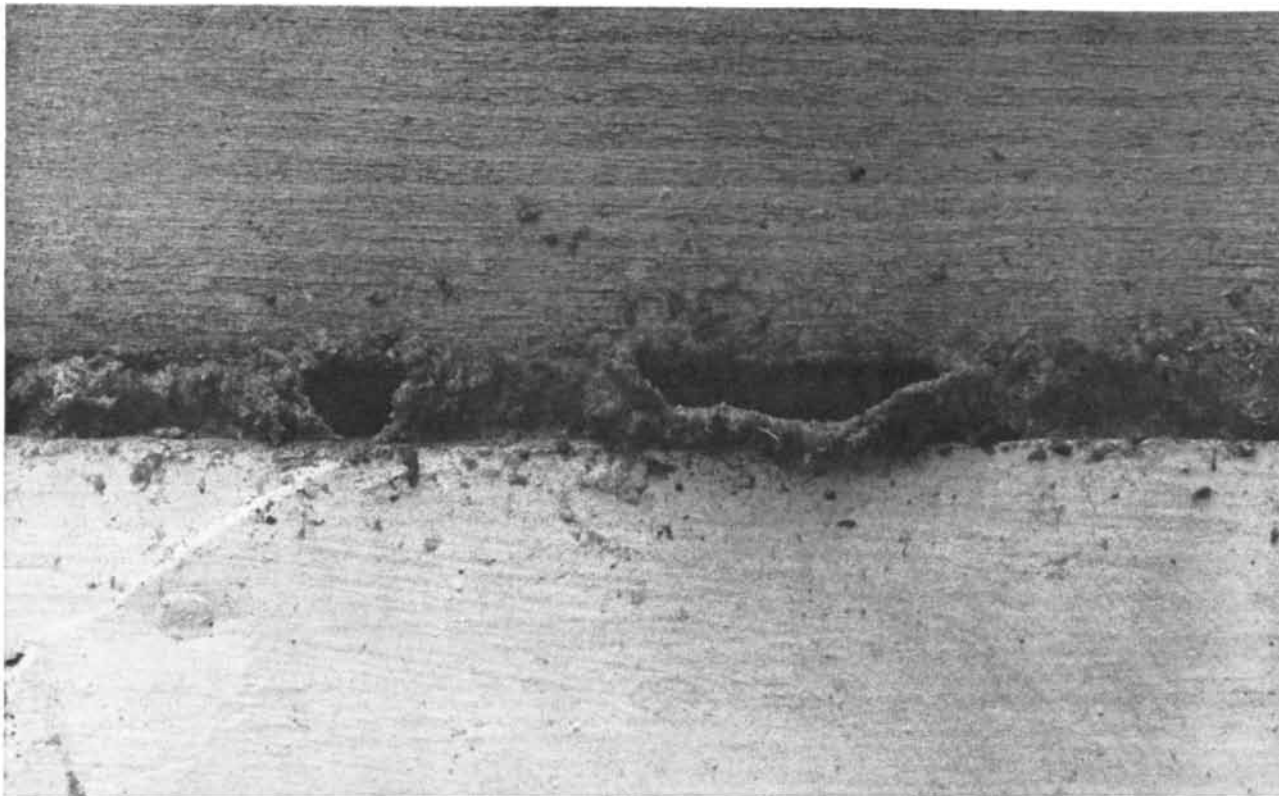
**A**nother protective measure appears to lie in the fact that bees store honey and pollen by color: a given cell will have honey or pollen of a given color. (Since it is dark in the hive, one must assume that pollens and honeys of different colors also have different odors, which provide the basis for the bees' discrimination.) It seems probable that this separation of food from different sources might serve to protect the colony in the event that food from any one source had poor storage qualities.

It may be that human beekeepers, by failing to take sufficient advantage of the bees' ability to distinguish colors, have contributed to a malfunction of the bee colony's sanitation system. In an apiary the colonies may be only a foot or two apart, which is a situation that would not be found in nature. A returning bee may therefore enter the wrong hive. Such a bee is usually accepted, particularly if it is carrying a load of nectar or pollen. If the stray bee is performing a housecleaning task, however, having perhaps removed a dead larva or adult from its own hive, it may by entering the wrong hive spread the disease that killed the insect. It is believed American foulbrood, a bacterial disease of honeybee larvae, has been spread in this way. Since part of the sanitation system is that bees recognize their own hive, beekeepers are advised to paint the hives different colors and to provide landmarks such as small trees that would help bees return to the right hive.

If a bit of grass or straw is placed in a hive just under the cover, an observer watching the entrance will usually see a bee carrying the object out of the hive



**STORAGE BY COLOR** is apparently another protective device employed by honeybees. A given cell is filled with pollen or honey of a given color; stored pollen is shown here. Presumably the procedure serves to protect the colony by separating food from different sources in case the food from a particular source has poor storage qualities. Since the interior of a hive is usually dark, odor is probably the basis for the storage procedure.



**PROPOLIS FILLS SPACE** between two boards in a man-made hive. Propolis is obtained from gums and resins that bees gather

from trees such as the pine and the poplar. After the material has been exposed to air in a hive it dries to form a hard surface.

within about five minutes. Moreover, if the object is small enough so that the bee can fly with it, the bee carrying it will take it 50 feet or more from the hive before dropping it. If the object is too heavy to be carried in flight, the bee will try to carry it at least several feet from the entrance by dragging it over the ground.

If one watches this housecleaning operation in an observation hive, which has glass sides, an interesting fact of bee behavior becomes apparent. The first bee to detect and pick up a foreign object is usually not the one that flies out of the entrance with it. My students at Cornell University, who do this exercise as part of a laboratory course, have observed that as many as five bees (the average is three) will participate in the removal of a single piece of debris, even though the distance from the place where the object is introduced to the entrance of the hive is seldom more than 12 inches. Usually only one bee at a time grasps the object. Occasionally a worker may actually carry it away from the entrance, since not all the workers are aware of where the entrance is.

Three points about the colony's housecleaning system emerge in a debris-removing action. The first is that most of the bees in a hive are quick to take action

against a foreign object; any bee that encounters the object will carry it at least some distance away from where the bee is working. Second is the priority that worker bees give emergency tasks, such as removing a foreign object. Even if a bee is already occupied, it will switch at almost any time to an emergency task. Collectively the phenomenon is important to the hive in times of danger, when a sudden need may arise for guards, attackers, ventilators and so on. Third, foreign objects are not merely removed from the hive; they are carried some distance from it, so that if they represent a source of danger or infection, they are rendered unlikely to cause trouble.

**B**ees have still another sanitational mechanism involving the gums and resins they gather from trees such as the pine and the poplar. This material, which beekeepers call propolis, serves to protect the hive in several ways. One effect arises from the fact that the resins contain terpenes, which have both a bactericidal and a bacteriostatic action. In addition propolis is employed by the bees to put a hard coating over surfaces and objects that might create health hazards.

Plant resins, being gummy and sticky, are not easy for bees to collect. It is also

a major operation for the house bees to remove propolis from the field bees that bring it into the hive. A field bee uses its mandibles and legs to work propolis into the pollen baskets on its hind legs. In the hive the field bee holds on to the comb or a part of the hive while several house bees pull long threads of propolis from the pollen baskets. After exposure to the air in the hive the propolis dries and forms a hard surface.

Large insects or small animals that enter a hive (either by mistake or in search of food) are usually killed by the bees. Such objects are too large for the bees to remove. Instead they encase them in propolis. It is not uncommon for beekeepers to find these entombed animals in a hive. The layer of propolis, usually at least a sixteenth of an inch thick, serves to remove the odor and, in effect, the dead animal.

If one puts a rough object, such as a piece of unsanded wood, into a hive, the bees will cover it with propolis and thus make its surface smooth. They also use propolis to close cracks in the hive wall. Indeed, they plug with propolis any space that is too small to serve as what beekeepers call "bee space," which can be likened to corridors that the bees maintain around and between combs to provide working room and walking

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we hurt  
each other  
less if we  
touched  
each other  
more?



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room. Bee space is from a quarter to three-eighths of an inch wide; anything larger is used to build comb, and anything smaller is closed with propolis.

One can only conjecture that the function of propolis as a space-filler is to eliminate cracks and crevices that might harbor bacteria, mold and small insects. Since the natural home of bees is usually a hollow tree, one can see how propolis might serve to protect the nest and make it more habitable. It has also been suggested that propolis protects the inside of the hive against water. Bees normally choose a dry place for a nest, however, and have been known to abandon nests that became wet.

The life-span of a worker bee during the summer is about six weeks. The death rate in a colony may therefore be more than 1,000 bees per day during the busy season, but if one checks the ground near the entrance to a colony, one will usually find no more than one or two bodies of newly dead bees per day. What happens in many cases is that worker bees die in the field. They do not retire or reduce their activity in old age; they simply keep working until they die. Laboratory examination has revealed that old bees may suffer from a variety of diseases, many of them infectious; the fact that they die away from the hive in such large numbers appears to be still another defense mechanism for the hive.

If a bee does die in the hive, the body is treated as a foreign object. Workers carry it to the entrance, and the worker that flies away with it carries it a considerable distance from the hive before dropping it. The tendency of the bees is not so much to keep the ground near the entrance to the hive clean (although if the entrance is near the ground, they do include the area around the entrance in their cleaning activity) as it is to conduct their affairs in such a way that the ground near the hive never gets dirty.

Ventilation figures importantly in the sanitation program of a colony. Bees ventilate the hive to cool it and also when they are collecting nectar in large amounts and need to evaporate water from exposed droplets of nectar in order to make it into honey of the right moisture content. The same ventilation system may be used to rid the hive of smoke or some other contamination in the air, provided that the contamination is solely internal.

Bees can be easily seen ventilating a hive on a warm day. The entrance will be crowded with bees, gripping the bottom board with their feet to remain stationary and fanning with their wings. In

a standard hive air will be forced in one side of the entrance and out the other side. Within the hive additional fanners will be found moving the air around. It is possible to blow a little smoke into a hive through a hole made for the purpose and to observe it being forced out at the entrance or elsewhere by a ventilating response from the bees.

A major contribution to the cleanliness of the colony comes from the fact that bees do not void feces inside the hive. They do so only in flight and when they are some distance from the hive. As a result the colony sometimes confronts a problem in winter when a succession of cold days prevents the bees from flying out. If bees are confined too long, one bee may void its feces in the hive. In such a case other bees shortly do the same, and within a few hours the social order of the hive breaks down. In these circumstances the colony perishes within a few days. The need for an occasional warm day or part of a day—at least about half an hour—is critical for the survival of a honeybee colony in winter.

An unsolved question is what is done with the queen's feces. A queen takes flight only to mate when she is six to 12 days old; on rare occasions a queen will leave a hive to accompany a swarm to a new nest. The assumption is that worker bees remove the queen's feces. To my knowledge, however, no one has observed a queen voiding feces or seen a worker removing a queen's fecal matter.

I would not want to leave the impression that bees have no major disease problems. Honeybees suffer from a variety of bacterial, fungal, viral and protozoan diseases and also from certain pests. Contaminated water is occasionally a source of disease. Bees gather water from the nearest source, and if it is stagnant, it can cause illness in individual bees and can also contaminate the hive; bees often deposit droplets of water in the hive to assist in the cooling achieved by the ventilation system.

Bee diseases have been carefully studied, and methods of controlling them have been developed. Some methods work better than others. Men have complicated the problem of bee diseases by crowding colonies into apiaries. Nonetheless, it is usually possible to maintain the health of bees in apiaries by appropriate measures. The methods of the bee contribute significantly to the health of the colony. The honeybee is an example of an animal that has evolved good methods of protecting itself, its nest and its stored food from attack and damage by predators, parasites and microorganisms.

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