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The acquisition of food by the honeybee

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UMI
THE ACQUISITION OF FOOD BY THE HONEYBEE

BY

Oscar Wallace Park

A Thesis submitted to the Graduate Faculty for the Degree of

DOCTOR OF PHILOSOPHY

Major subject: Apiculture

Approved
Signature was redacted for privacy.

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INTRODUCTION

Fundamental studies on the life-history and habits of the honeybee date back at least to Aristotle, that ancient pioneer in the development of science who lived in the fourth century B.C. Aristotle made extensive studies of various life-histories, and, according to Haeckel (1), knew that drone bees develop without previous fertilization of the eggs. Locy (2) says of Aristotle, "He made a direct appeal to nature for the facts, and founded his natural history only on observation of the structure, physiology and development of animals."

Practically no advance was made until 2000 years later when Swammerdam (3), a brilliant naturalist of Amsterdam, made his extensive studies on the honeybee which were completed in 1673 and published before his death in 1680. Swammerdam was extremely exact in all that he did. His works are illustrated by numerous original figures, some of which are still used in modern works on the honeybee. He worked out the life histories of about
a dozen insects but the one on the honeybee is the most elaborate of all. Swammerdam's work constitutes the first comprehensive investigation of the life-history and habits of the honeybee of which we have any knowledge.

The invention of the movable frame hive by Langstroth (4) in 1852, heralded the close of a 200-year epoch of fundamental investigations which had followed in the wake of the renowned Swammerdam. The only outstanding figure belonging to the fore part of this period is Reaumur (5) whose nine "Memoires" on the honeybee, published in 1740, entitle him to a conspicuous place in the front rank of investigators of the life-history and habits of the honeybee. The history of the latter half of this epoch is replete with the names of men who have made valuable contributions to our fundamental knowledge of bees. Schirach, Donhoff, Dzierzon, Quinby, Langstroth, and many others deserve our homage; but, the incomparable Huber (6) stands head and shoulders above all others since Reaumur. Huber performed a two-fold service to fundamental research in apiculture. He checked up on practically all important observations of earlier workers; and, in addition, made many new ones, which stand today as classic examples of fundamental research in apiculture.

Close upon the heels of the invention of the movable frame hive (1852), followed a period during which the development of methods for the commercial production of honey took precedence over fundamental research. It appears, that at the present time,
the development of improved methods of honey production probably
has advanced nearly to the limit of perfection possible with our
present knowledge of the fundamentals of bee-behavior. In spite
of the important observations of Swammerdam, Reaumur, Huber, and
a host of others, our knowledge of this subject is yet far from
complete. Therefore, it is not to be regretted that, within the
last decade, the pendulum of research in beekeeping has started
back towards its former field of fundamentals.

The writer's interest in bees and the literature of
apiculture dates from the summer of 1905 when he was given for
his very own, the half dozen unproductive colonies of hybrids which
had adorned the back yard of the farmstead even before his earliest
recollecteds. The possibilities for financial gain loomed
large to the boy in his early teens. This fact, coupled with a
natural bent for nature study, was sufficient to insure his per­
manent interest in bees.

The reading of literature on bees soon became almost
an obsession; and, as the years passed, the lack of definite in­
formation concerning the activities of individual bees became
only too apparent to him. The behavior and the accomplishments
of the colony as a whole, it seemed to him, were much better known
than were those of the individuals, but the behavior and the ac­
complishments of the colony are end products - the sum total of
the activities of the component parts of the colony. Hence, a
thorough understanding of the fundamental activities of the colony
itself can be based only upon a knowledge of the activities of the individual bees.

In presenting the work in hand, the writer realizes its incompleteness perhaps even more than anyone else, but he has been encouraged to publish his results at this time, fragmentary though many of them may be. And it is his hope that the present discussion may stimulate further research along these and similar lines.
METHODS

By far the most difficult and time consuming phase of many investigations is the development of methods which will yield satisfactory results. Studies of the activities of individual bees are not exceptions to the general rule in this respect. This fact is attested by the great dearth of reliable data on the subject.

DEVELOPMENT OF METHODS

Many of the habits and activities of bees can be studied to best advantage in an observation hive. Those on the market were found to be costly and not particularly adapted to the needs of the problem. The first task to be undertaken was, therefore, the development of an observation hive suited to the needs of the work to be undertaken.
The next step was to find some way of marking individual bees so conspicuously that each one could be recognized instantly. This proved to be no easy matter as will appear in the detailed description to follow. This phase of the work has not yet brought forth a method which is all that is to be desired; but means were found which were used with considerable success.

An attempt to secure data upon marked bees showed at once that either the bees must be marked on the venter as well as the dorsum, or it would be necessary to devise some means to force all the bees to enter and leave the hive "right side up" through a passage way which could be easily watched by one person. As it did not appear practical to mark bees on the venter, the third step in the development of methods was the perfecting of a special entrance device.

A fourth phase of the work called for some means for determining the nature of the contents of the honey-sac without injury to the bee. A simple test was discovered almost by chance which has proven its value many times.

The fifth phase in the development of methods resulted from the need for a factor which may be called the minimum flying weight of the bee. Such a factor was necessary before the nectar-carrying capacity of the honeybee could be found. The load carried could then be determined by deducting this factor from the gross weight of the loaded bee.

The necessity for the sixth phase arose in connection with a study of the time factors involved in the gathering of nec-
tar, pollen and water, by the honeybee. It was desired to know how much of the time spent away from the hive was consumed in going to and from the field. The determination of the average speed of the bee in flight, together with a knowledge of the approximate limits of the range of its flight, gives a figure which, although lacking exactness, enables us to arrive at a useful approximation. The time spent in the gathering of the load can then be found by deducting this figure from the total time the bee is gone from the hive.

THE OBSERVATION HIVE

Most of the observations on bees, prior to the time of Reaumur (1740) were made on colonies in straw skeps, or at best, in boxes having one or more panes of glass somewhere about the periphery. Root (7, p. 565) mentions the invention of such a hive by W. How of Haslington, Gloucestershire, England, about 1650. Such hives are of comparatively little value for observation purposes. One can imagine some of the difficulties under which the very early workers made their observations. Langstroth (4, p. 164) says, "Swammerdam, who wrote his wonderful treatise on bees before the invention of the glass hive, was obliged to tear hives to pieces in making his investigations." We may well be astonished that the early pioneers acquired as much accurate information as they did; nor is it any wonder that some of them called their fancies into use to help them account for things they could not otherwise explain.
Reaumur made studies on bees in glass hives but the distance between the glass sides of his hives was great enough so that the bees built two combs therein. This was an advance over the hives used by the earlier investigators but, of course, much of the colony's activity escaped observation by being carried on between the two combs. Huber's first observation hives were patterned after those of Reaumur but at the suggestion of the celebrated naturalist, Bonnet (6, p.2), he constructed hives only an inch and a half wide, inside measurement, and found that this distance allowed the bees sufficient liberty, but prevented them from building more than one comb, and from collecting in too large numbers on the surface of the comb.

Huber realized that by compelling the bees to live in a hive having only one comb, there was a possibility that their instinct might be affected. In order to check upon the observations made on bees in such hives, he invented his "leaf" hives which were made up of several combs side by side and hinged at one end so that the combs could be opened and shut like the leaves of a book. These hives provided an environment which was entirely normal, yet they permitted the ready inspection of any part. Huber (6, p.7), says "In these hives, I have repeated all my observations, and obtained exactly the same results as in the thinnest. Thus, I think already to have obviated any objections that may arise concerning the supposed inconvenience of flat hives."

It has usually been recommended that observation hives be provided with panels of wood or other means for darkening them when not being watched. It was thought that bees would not con-
tinue to work in the light, and it is still quite generally supposed that bees will plaster the glass with propolis in an effort to exclude the light. But Langstroth (4, p. 16 and 25), in the summer of 1851, discovered that, with proper precautions, colonies in observation hives could be exposed continually to the full light of day; so that observations could be made at all times, without interrupting the ordinary operations of the bees by any sudden admission of light.

The first observation hive used by the author was provided with panels but they were soon discarded. The only need found for them was to protect the bees from the direct rays of the sun or in cold weather to provide additional insulation. Continual use of observation hives for a period of six years has not shown any marked tendency of the bees to exclude the light. In long use, however, the glass walls, become travel stained. A thorough cleaning in spring is usually sufficient for the season. When the colony is prosperous there is a great tendency to build burr-comb against the glass. This trouble is not serious if the space between the glass walls is not over an inch and a half. The giving of additional room in the form of an upper story helps to relieve the trouble. It has sometimes been found desirable to reduce the strength of the colony by removing a frame of brood.

The essential features of an observation hive are few. All combs must be so placed that both sides of every one are exposed to full view. In the opinion of the writer, no hive in which there are two or more frames side by side is worthy to be
called an observation hive. The distance between the glass walls should not be more than an inch and one-half. Greater space permits the building of burr-combs. For certain types of work, it is desirable to have the glass sides swung on hinges, or situated in grooves so they may be quickly removed to permit access to any portion of the hive. The details of construction are relatively unimportant and may be varied to suit the desires or special needs of the operator.

Most of the observation hives used during the present investigations were of a sectional or unit type, each unit being built to take one Langstroth frame. (See Fig. 1). The units are used as supers and can be tiered up to any desired height to accommodate the needs of the colony or the whim of the operator. There are certain advantages in using hives of this type. The queen can be given the run of the entire hive or may readily be confined to any part of it; and, when provided with movable sides, the operator has access to any one comb without exposing the others.

The plain but serviceable hive shown in Fig. 1 can be constructed in a few hours without special tools and at a very small cost. Supers may be made after the same general plan, only the super ends should be three-fourths of an inch shorter than for the first story. A narrow strip of tin, run from end to end under each of the glass sides, gives stability and keeps the glass from falling out when handled. Three-inch strap hinges have been found useful in fastening on additional stories.
Fig. 1. Observation Hive.

Dimensions

1. 33 x 14 x 30
2. 33 x 14 x 20
3. 11 x 14 x 94
4. 11 x 14 x 94
5. 3 x 11 x 214
6. 3 x 11 x 24
An auger hole at the rear of the hive near the bottom forms a convenient passage into a glass covered vestibule which may be added at the rear for the purpose of supplying syrup or water.

For the purpose of certain observations it is necessary to have combs built crosswise of the glass hive so that one side of numerous cells is formed by the glass wall of the hive. Such a hive was designed by Arthur C. Miller (7, p. 566) who has made some interesting observations by means of one of them. It was found possible for our purposes to have the bees build combs crosswise in one of the regular units by replacing the usual Langstroth frame with two strips of glass, one for a top bar and the other for a bottom bar. To the underside of this glass top-bar, strips of foundation were fastened at right angles to the long way of the hive, at intervals of one and one-half inches. When placed as a super on a thriving observation colony during a good honey flow, the combs were fully built within less than a week.

Throughout the past six years, at least one observation hive has been in operation in the research laboratory, summer and winter. From time to time, additional hives have been stationed there and in the apiary or wherever needed for the purpose of securing special data, such as in the case of flight studies to be described farther on in this paper. Except on special occasions, there was no secretary available for recording data on bee-behavior; hence, in many instances, the notes
recorded at the end of a period of observation were, of necess-
ity, in the nature of a summary. This lack which is much to
be regretted, may be partially off-set by the fact, that all
observations were repeated a great many times and that in all
cases, the writer's observations have been repeatedly pointed
out and demonstrated to others, and always to Professor F. B.
Paddock who is able to confirm their accuracy.

MARKING BINS

Honeybees, house flies, cucumber beetles and perhaps
other insects have been marked for purposes of identification.
Some of the methods employed for this purpose have given fairly
good results in certain types of investigations; but up to the
present, no wholly satisfactory method has been developed. The
lack of a dependable method of marking has held up investiga-
tions on the activities of individual bees more than any other
phase of technique involved. Owing to its extremely impor-
tant bearing on investigations pertaining to bees and other in-
sects, the subject is presented more fully here than would other-
wise be justified by the scope of the present studies.

Some of the general features to be desired in any
method of marking insects are: means for positive identification,
non-interference with the normal activities of the insects, and,
ease of application. The special requirements demanded in a
given case, will depend largely upon the nature of the investiga-
tion. In securing data upon the distance bees forage from their hives, a temporary mark may answer the purpose, and may be applied to any number of individuals. In studies on the dispersion of flies or other insects, the same mark may be used for an indefinite number of individuals, but it is important in this case that the mark be permanent although it need not necessarily be conspicuous. These insects are usually trapped and killed so that they may be examined at leisure and at close range; furthermore, chemical reagents and microscopes may be employed if necessary for distinguishing the marked insects. But one often hesitates to employ such aids to identification when dealing with the honeybee. In studies involving the age of bees, permanence is of utmost importance, and conspicuousness is usually a decided advantage. Some problems demand the use of several different marks to provide a distinctive mark for each of several groups. Such cases as those mentioned above apply particularly to investigations dealing with comparatively large numbers of insects but requiring only a very limited number of different marks.

Studies dealing with the activities of individual insects often necessitate the use of a considerable number of different marks, or even a whole system of combinations of marks, in order to provide means for distinguishing every one of a considerable number of individuals. In working with individual bees, each mark or combination of marks must be so conspicuous and so distinctive that any marked bee may be recognized at a glance, since under ordinary conditions it is not practical to examine
bees leisurely and at close range as can often be done when working with many other insects.

A considerable number of methods for marking insects have been developed, which for convenience may be discussed under three main heads: mutilations, branding, and pigments.

Mutilations.

The amputation of an antenna and the clipping of a portion of one or more wings are to be considered under the head of mutilations. Several drawbacks are common to this group of methods. First, insects so marked can be distinguished only by careful scrutiny; sometimes even involving the use of the microscope. In most investigations on bees, this objection alone is sufficient to cause these methods to be discarded. The second difficulty is that the number of different marks or combinations that can be used is very limited. The one redeeming feature is that such marks are not readily lost or obliterated.

Marking bees by means of slight mutilations, (such as the amputation of one antenna or the clipping of a portion of one or more of the wings), probably was the first method used by Huber for marking bees. This is inferred from the letter written to him by Charles Bonnet (6, p. 34), the noted Swiss naturalist, under the date of August 13, 1789, in which the latter advised the use of paint as "a more secure method than slight mutilations". Later, when marking bees with paint, Huber (6, p. 102) also amputated one antenna as an additional safeguard. In more recent times, Pixell-Goodrich (8, p. 195) found clipping the tip of one or more wings to be "the least unsatisfactory method" she had
tried, but her problem was the determination of age in the
honeybee; and, as has been pointed out already, permanent marks
are absolutely necessary.

Branding

During the present investigation, the writer con­
ceived the idea of branding the bees by means of an electric
needle. It was found, however, that branding the thorax or ab­
domen was fatal to the bee and that branding the wings inter­
fered with their flight. While the method was not usable with
bees, it would seem that the idea of branding might sometime be
found useful in marking the elytra of beetles or the wing covers
of other insects.

Pigments

Pigment is defined as coloring matter of any kind
whatever. The use of pigments in one form or another is, of
course, one of the most obvious ways of marking insects. The
greatest difficulties to be overcome have been to secure a com­
bination containing pigment which dries almost instan­
tly and
sticks permanently. (A method to be mentioned later has been
published recently which bids fair to be an advance over anything
previously tried in this line). There is also the difficulty of
adapting any of these methods to use for marking a large number
of individuals with distinctive marks or combinations. There
are, however, about seven or eight colors that may be readily
distinguished, and by using them in various combinations a con­
siderable number of individuals may be distinctively marked.
Other advantages in the use of colors for marking insects are:
their conspicuousness, ease of application, and lack of interference with the normal activities of the insects.

Pigments for marking insects have been used in powdered form, in the form of dyes and stains, and in various combinations in which some kind of coloring matter was combined with an adhesive.

**POWDERED PIGMENTS.** - Ordinary flour, although not exactly a pigment, has been successfully used by numerous observers who sprinkled it over the backs of bees in order to trace them to their hives. From among the older writers, Huish (9, p. 352) may be cited as having used this means for marking bees which he found two miles from home. He was, thereby, enabled to ascertain that these bees were from his own hives. Bishop (10), who worked on the dispersion of the house fly, obtained good results by dusting them with colored chalk. On the whole it may be said that powdered pigments by themselves have a very limited usefulness for marking honeybees.

**DYES AND STAINS.** - Parker (11), also working on the dispersion of the house fly, successfully employed solutions of acid fuchsin, rosolic acid, aqueous eosin, trypanblau, and methylene green. The stains were sprayed onto the flies while in traps by means of atomizers. Any method in which marking material is applied as a spray is admirably adapted for administering a uniform mark to a large number of insects all at one time. It does not, however, lend itself so well to use in marking indi-
viduals, for the number of individuals that can be given distinctive marks is limited to the seven or eight colors which are sufficiently distinct to permit instantaneous recognition. The method was tried out on bees by the writer without success. It was found to be almost impossible to get enough of the stain to remain on the bee to permit easy recognition. Dudley and Searles (12, p. 364), report similar difficulties in attempting to use this method for marking cucumber beetles. In the work with flies, a minute quantity of the stain on any fly was sufficient because the flies were killed, and after being spread out on paper were sprayed with other chemicals which dissolved the stain and left a colored spot on the paper beneath. Such a process is scarcely to be considered for use with honeybees.

Von Frisch (12, p. 21) cites Giltay as having thought out a unique method in which simple Arabic numerals are written upon the backs of the bees by means of white India ink, applied with a very fine camel's hair brush. It would seem that this might be a very excellent method for use in certain types of investigations. The fine marks of white India ink become obscure very quickly, according to Von Frisch, but it might be possible to find some other material which would not be so easily obliterated. The method is open to the further objection that such marks could be distinguished only at close range.

Pixell-Goodrich (8, p. 195) made attempts "to tinge the wings by applying a dye dissolved in water, alcohol, chloroform or ether, but no penetration could be effected". Tests
made with similar combinations during the present investigations yielded no better results. Thus, the experiences of various workers would indicate that dyes and stains which are not combined with an adhesive are of comparatively little value for marking honeybees.

**PIGMENT PLUS AN ADHESIVE.** - The marking of bees, especially queens, by means of paint, for purposes of identification, is a French invention according to Perret-Haisonneuve (14, p. 94); and it is inferred from his footnote, "Reaumur mar­quait en rouge ses reines", that he believes Reaumur to have been the first or at least one of the first to make use of the idea. On the eighteenth of August, 1789, Charles Bonnet wrote to Huber (6, p. 34) in part as follows: "To ascertain that the queen, which has left the hive for impregnation, is the same that returns to deposit her eggs, you will find it necessary to paint the thorax with some varnish that resists humidity. It will also be right to paint the thorax of a considerable number of workers in order to discover the duration of their life". Huber reports the use of this method in at least three different experiments, (6, p. 102, 103, 271).

Pixell-Goodrich (8, p. 195) found that "A dab of white or light-colored oil-paint on the thorax would sometimes remain visible for two or three weeks if it dried quickly enough and was of the correct consistency." Von Frisch (13, p. 21), mentions the use of oil colors, and apparently found them fairly satisfactory for his needs.
In the early stages of the present work, use was made of prepared oil paints such as artists use. These paints were put up in small collapsible tubes so they kept well and were very convenient to use. The paint dried rather quickly and often remained for a couple of weeks but the majority of bees marked by this method were not seen after four or five days. In some cases, the bees would get rid of her mark by scratching it off with her claws. Whether many of the marks were eliminated in this manner it is impossible to say. The most of the studies were on field bees and since their death rate is exceedingly high, it seems that many of the marked bees probably were eliminated by death.

Perret-Maisonneuve (14, p.97) warns against the use of oil paints and oil varnish. He says that the bees are fond of these and will remove them. This may account for the disappearance of some marks, although, during the present work, bees were not observed to eat paint of any kind, nor were they seen to assist one another in removing the marks. It is possible, however, that Perret-Maisonneuve's observations have been made on marked queens; whereas, mine have been on workers which might account for the difference in our observations on this point. Oil paints probably have been employed more widely in marking bees than any other combination, with the possible exception of mixture of pigment and shellac which are yet to be discussed.
A paint prepared with alcohol and ether instead of oil is recommended by Stockli (15) for marking queens. She directs that the pigment be soaked in alcohol to make a thick paste which is then diluted with sulfuric ether until liquid. With a blade of grass, a small drop of the color mixture is touched to the back of the queen. Stockli says that the color dries in a few seconds and will last as long as the queen lives. While this combination may remain a year or more on a queen, our tests indicated that it lacks much of being a permanent mark on workers.

Varnish has been tried out as an adhesive in conjunction with pigments as has already been mentioned in the passage quoted from Bonnet's letter to Huber, and in the citation from Perret-Maisonneuve just above. Commercial enamels, such as are used in painting automobiles and which contain a considerable proportion of varnish, were tried by the writer. They dried rather slowly and no particular advantage was discovered in their use.

Glue is another adhesive which has been combined with coloring matter for marking insects. Dudley and Searles (12, p. 364) report as follows: "Glue, dyed with an India ink, dried so slowly that beetles marked with it soon became entangled and incapable of flight". Pigment mixed with gum-arabic was tried by Piell-Goodrich (8, p. 195) who found it to be "no good at all, for on drying it came off in a lump with any hairs of the thorax that it touched."
"New-skin" (collodion) in combination with pigment, although not widely used, gives some promise, according to Pixell-Goodrich (8, p. 196, foot note) who says: "Since writing this, I have heard from Mr. Bullemore that at the Cambridge Institute of Beekeeping, they have added to the pigment used, some of the preparation known as "new-skin" and in this way managed to distinguish bees for three or four weeks". Pixell-Goodrich states that from preliminary tests the "new-skin" appeared to "give elasticity and so prevent the pigment from coming off so quickly. However, even this has a tendency to peel off and bring the thoracic hairs with it".

Shellac appears to be the most satisfactory adhesive that has been used in combination with pigments for marking honey-bees. It is just possible that Bonnet (6, p.34) had this substance in mind when he wrote Huber the suggestion of painting the thorax of bees "with some varnish that resists humidity". With the possible exception of the citation just given, no references to the use of shellac in marking bees has been found previous to 1914 when Brunnich (16) reported favorably on the use of shellac-pigment mixtures for marking bees, particularly queens. Since that time, Queen, (17), Perret-Maisonneuve (14, p.94), Von Frisch (18, p. 23), the writer, and others have used this combination with fairly satisfactory results. It is difficult to give an exact formula for the preparation of this color mixture but the following description should enable one to obtain good results after a little experience.
Mix about equal parts (by volume) of white shellac in alcohol, powdered pigment of the desired color, and 95 percent alcohol. The amount of alcohol needed will depend on the consistency of the shellac used, but when ready for use, the preparation should be of such a consistency that it will just barely drop from the end of a toothpick which has been dipped into it and then held in a perpendicular position. In order to secure good results in marking, it is important that this preparation be neither too thick nor too thin. Experience alone will enable one to get it just right. Perret-Maisonneuve (14, p. 94) advocates the use of ether instead of alcohol for thinning the mixture. With reference to the use of the shellac-pigment combination, Brunnich, (16) says, "If the marks are well made, they remain clearly for four years." It would seem that a mark which lasts four years on a queen ought to last at least a like number of weeks on a worker, but we have found to our disappointment that, in some cases, it has not lasted even four days. But when the painting was carefully done, the marks usually remained a week or two and sometimes longer.

Shellac has recently been used in combination with coloring matter in two other ways by Dudley and Searles (12) who developed these methods for use in marking cucumber beetles. These investigators have done considerable work in an attempt to improve the technique of marking insects, and since both methods described by them give promise of usefulness for marking honeybees, their report covering the development of these methods is quoted in full.
"Experiments in Marking"

"Experiments in marking beetles were begun in 1920, considerable time being devoted to finding a material and a method which would allow rapid and successful marking. The principal difficulty was in securing adherence of the marking colors to the elytra. Among the substances tested were glue, colored chalks, aniline dyes, India inks, and shellac, and although tested singly and in various combinations all proved unsuitable. Glue, dyed with an India ink, dried so slowly that beetles marked with it soon became entangled and incapable of flight. Colored chalks, which had been used successfully by other workers in marking bees and many insects, failed to adhere to the almost hairless bodies of the beetles. Aniline dyes or India inks, used without an adhesive, were almost indiscernible on drying. Commercial shellac had the same objectionable qualities as glue. The pigment finally employed was a precipitate resulting from thoroughly mixing two parts shellac and one part of various India inks. This precipitate was very adherent to the elytra of the beetle. It retained its color well and dried quickly but could not be suitably applied except by means of a small camel's hair brush. In order to make the normally very active beetles more easy to handle while being marked, a method of chilling by placing them in test tubes in ice water, was employed. By this process the beetles were marked effectively. It was used also with complete success by H. P. Howard at Birmingham, Ala., in marking the Mexican bean beetle. This method, however, is very laborious, about 2,000 beetles per day requiring two men's work. The principal problem during the season of 1922 was, therefore, to find some equally good marking agent which could be applied with much greater rapidity.

"A coloring agent was finally produced by diluting shellac with alcohol, using alcohol-soluble aniline dyes as the coloring matter. The most satisfactory solution was one composed of six parts alcohol and four parts commercial shellac, colored with a saturated solution of the aniline dye in alcohol. This dried quickly, adhered well to the body of the beetle, retained its color indefinitely, and did not interfere in any way with the normal functions of the insect. An added advantage of the diluted shellac over former materials used was that it could be sprayed on the beetles with an atomizer. This material also provided a very effective marking agent for other insects, especially for bees. Bees marked with a solution of seven parts alcohol and three parts shellac dyed with aniline green, remained vividly colored seven days after they had been marked. A solution of eight parts alcohol and two parts shellac with aniline green as the coloring agent proved satisfactory for house flies and the potato aphis, the color being particularly conspicuous on the wings."
Methods Suited To This Study

In order to satisfy the needs of the present study, a method of marking was required which would permit instant recognition and positive identification of each one of a number of individuals belonging to the same colony, and which would not interfere with the normal activities of the bees. Ease of administration and permanency of the mark were much to be desired, but not so essential as the qualities just mentioned. On this basis, it was necessary to discard all methods involving mutilations and branding; also those employing such substances as chalk dust and stains because none of them could provide distinctive marks for more than about half a dozen individuals. The only method that was found suitable was the use of various pigments combined with some adhesive and which could be applied as small spots on the thorax or abdomen or both. Artists oil colors in tubes were used with moderate success. A mixture of powered pigment, shellac and alcohol gave marks that as a rule remained longer than oil colors. The precipitate resulting from thoroughly mixing two parts of shellac and one part of various India inks, developed by Dudley and Searles (12), was not known to the writer at the time this work was in progress but he plans to give it a trial at the first opportunity.

Systems of Color Combinations

The distinctive marking of individuals in excess of the number of colors that can be instantly recognized, involved
the use of some sort of a system of color combinations. The following seven colors were found to be most readily distinguished; white, pink, yellow, orange, red, light green, and blue. Seven bees could then be marked on the thorax each with a different color, and seven more could be marked on the abdomen. Then by using two spots of color, one on the thorax and the other on the abdomen, it was possible to mark forty-nine more individuals or a total of sixty-three bees. It was never found desirable to have more than this number of marked bees in any one colony because it would have been impossible at times to record the desired data on a greater number, even though there was a secretary who did nothing but record the data as reported by the two observers.

Von Frisch (13, p. 23) describes a system of combination of color spots which permits the making of as many as 599 different combinations. The system which he describes probably is as good as has ever been devised for marking a great number of individuals. He used the following colors; 1. white, 2. red, 3. orange, 4. yellow, and 5. light green. A spot of color placed on the fore part of the thorax represented the numeral 1, if white; 2, red; 3, orange; 4, yellow; 5 light green. The numerals 6, 7, 8, 9 and 0, were respectively represented by a spot of white, red, orange, yellow or light green when located on the posterior half of the thorax. A white spot on the abdomen represented 100; red, 200; orange, 300; yellow, 400; and light green, 500. Whenever two spots appear on the thorax,
the one intended to represent units place is located towards the bee's right side, while the one intended to represent tens place is located towards the bee's left side. Thus the number 21 would be represented by a red spot and a white one, both located on the anterior half of the thorax with the red toward the bee's left side and the white towards the right, which, of course, is quite the natural way to read them when one stands at the rear of the bee.

During the early stages of the writer's experience in marking bees, the use of two color spots on the thorax was tested out. It was found that, although such combinations were quite satisfactory for use on bees that could be observed at rest or moving slowly, they could not be identified on rapidly moving bees with sufficient certainty to permit their use in the investigations under way. Indeed, the simpler plan of using only one color spot on either thorax, abdomen, or both, proved to be complicated enough when taking data rapidly from marked bees that were entering and leaving the entrance of a full colony having eight Langstroth frames of brood, in spite of the slowing down effect brought about by the special entrance device soon to be described.

Technique of Marking

The marking of bees in connection with the present studies was done largely, although not exclusively, on bees that were field workers, engaged in gathering either nectar, pollen, or water. This being the case, it is thought desirable
to describe the marking process as applied particularly to this phase of the work. The actual process of applying the paint would, of course, be the same in all cases.

The fact has been previously pointed out that the marks are sometimes lost within a few days. The very high death rate for field bees, no doubt accounts for the disappearance of a considerable number of marked bees. It was found best, therefore, to mark the bees immediately before beginning to take records; and in order that data might be secured over a period of several consecutive days, Monday was usually selected for marking and getting a start at taking records.

The colony to be used was first fitted out with one of the special entrance devices to which reference has already been made. This slowed down the ingress and egress of the bees very markedly when first put on, but after it had been in place for one day most of the bees seemed to have learned how to get through with only a slight slackening of their usual gait. This slowing down was especially desirable on the first day because it made easier the capture of the bees that were to be marked. In catching a bee for marking, the only points considered were that it should not show signs of extreme old age and that it must carry the right kind of a load. The former point was judged on general appearances, including such well known indications as frayed wings and hairlessness. The latter point was variously determined depending upon the nature of the load. A pollen-carrier, in order to be eligible to receive the dis-
tiguishing mark, must carry a pollen load gathered from a particular kind of plant such as ragweed, corn, or something else as the case might be. Usually it was easy enough to determine the source of a load of pollen from its color alone, but frequently the shape of the pollen load was an aid in distinguishing between pollens that were somewhat similar in color.

The selection of nectar-carriers and water-carriers was not so simple, because these loads were carried inside the bee's body and, anyway, they could not have been distinguished from each other had they been in plain sight. Experience soon enables one to recognize bees that have loads in their honey-sacs from the size and shape of the abdomen and the way it is carried in flight or when crawling; but to determine whether the load is of nectar or of water requires an actual test. A description of the method which was discovered for making such a test will follow soon.

It was found helpful to contract the entrance to a passage only large enough for one or two bees to pass at a time, for then one had a better opportunity to select bees showing the desired characteristics and to capture them. Prospective candidates for marking were caught in glass vials measuring fifteen millimeters inside diameter. Vials both larger and smaller than this were tried out. It was found that with the larger ones it was not easy to get the bee to crawl up into the vial and with the smaller ones it was difficult to get the vial over a bee without pinching her; but with those of the
proper diameter, she would begin to crawl up the side of the vial almost as soon as it was placed over her.

The captured bee was then transferred to a smaller vial having a diameter of only ten millimeters, from which she could be removed with less danger of letting her escape than could be done when using a larger vial. A number of bees would be captured before proceeding to another step, each bee being placed in a separate ten-millimeter vial and confined there by means of a cork having notches cut in its sides to admit the air. In dealing with pollen-carriers, the character of the load could, now be examined more closely, and if found to be from the desired source, the bee was ready for marking. Nectar-carriers and water-carriers, however, were not ready for marking until the test was made which would show whether the honey-sac contained nectar or water.

The testing for water versus nectar was done as follows: A sheet of filter paper was laid on the table or hive cover, as the case might be. A ten-millimeter vial containing a bee was laid upon the filter paper. While holding the vial with the left hand, its cork was removed and the open mouth quickly guarded by means of a small piece of window screen held in the right hand. The piece of screen wire used measured about forty by sixty millimeters and had a rectangular notch at one end just wide enough to permit the end of the vial to pass through it so that a portion of the screen extended on either side of the vial, thus helping to prevent the escape of the bee.
When the bee crawled out of the vial, the screen was brought down on top of her with just enough pressure to prevent her escape. A little gentle pressure on the abdomen usually caused the bee to disgorge a small quantity of her load which immediately soaked into the filter paper. The bee was replaced in her vial which bore a number, to await the outcome of the test. A circle was drawn around the spot on the filter paper and marked with the number corresponding to the vial containing the bee. By the time each of half a dozen bees had been induced to give up a sample of its load, the result of the first test could be told and we were ready to proceed with the marking.

The color mixtures were kept in small glass vials which were tightly corked and held in an upright position by being placed in auger holes bored into a block of wood. Eight soft pine sticks, six inches long and a quarter inch in diameter completed the outfit. One stick was whittled so as to form a spatula-like portion at one end, and then a notch was cut in the end of the spatula. This notched stick was to be used to hold the bee while applying the paint. A small nail-hole made in one end of each of the other seven little sticks admitted the end of a toothpick which was used instead of a brush for applying the spot of color. One such stick was for use with each different color of paint, and when one toothpick became too thickly covered with paint it was thrown away and replaced by a new one.
The bee to be marked was released from the ten-millimeter vial under the rectangle of screen just as before when testing for water or nectar. Once under the screen, she was permitted to crawl out to the edge of it when the notched stick was thrust down over her narrow waist, holding her securely but permitting great freedom in applying the color to both thorax and abdomen. When only the thorax was to be marked, it was not necessary to use the notched stick because a very satisfactory job could be done by painting right through one of the meshes of the wire screen, but when putting a color spot, on the abdomen, it was found necessary to hold the bee in such a way that the wings could be kept out of the way while applying the paint. By means of this notched stick the wings were effectively kept out of the way and could be kept there long enough to permit the paint to dry somewhat before giving the bee her freedom. The bee was usually released within a minute or so after painting, when generally she would sail off into the air and be gone for a few minutes before returning to the hive to dispose of the load she had been prevented from delivering on schedule time. When such a flight was taken, the paint was usually dried nicely, and frequently the bee would go right along with her work without paying any attention to the paint on her back.

Reactions of Bees to Marking

Different individuals reacted differently upon bearing painted. Some paid little, if any, attention to the presence of the paint, while others tried to scratch it off with their claws or rub it off with the brushes of the planta, de-
pending on the location of the spot of paint; and the sad part of it is they sometimes succeeded. Usually, however, the bee soon ceased to notice the paint and went on about her business as usual. Much was found to depend on the consistency of the paint and the nicety with which it was gotten onto the bee. A small spot well located and made with paint of the proper consistency seldom received much attention from the bee and was much more likely to remain than a daub of thick color smeared promiscuously over the bee. Care had to be used to avoid getting paint on the eyes as a bee seldom worked normally when her eyes were smeared, but would spend all her time trying to rub off the paint.

Conclusions

The use of pigments in one combination or another was the only method of marking bees found which was at all suited to the needs of the problem in hand. Considerable data of value were secured through the use of artist's oil colors. Shellac colored with various powdered pigments was used more than any other combination, but no material tried, so far, has been found entirely satisfactory for use in investigations in which a permanent mark is essential. The lack of a satisfactory method for marking bees has always been and, in the opinion of the writer, still remains one of the greatest obstacles to those who seek to ferret out the life history of the individual honeybee.
SECURING THE RECORDS

Records were kept of the time of departure and return of each marked bee. Observations were begun as soon as possible after marking the bees and were continued without interruption until bees ceased flying at night. They were begun again early each morning and continued all day long for a number of days in succession. Two observers were watching the entrance practically all of the time, so that the chances for a marked bee to pass unnoticed were reduced to a minimum. So long as the number of bees to be watched was small, one of the two observers recorded the necessary data on a sheet so ruled that only the hour and minute needed to be written in the proper square each time a marked bee passed the entrance. But when data were being secured from a larger number of individuals, a third person acted as recorder while both observers gave their full attention to the entrance. At such times the marked bees often kept all three of us working full speed to keep up.

The system used in recording the data for a few bees was not so well suited for a larger number because too much time was consumed in locating the right square on such a large sheet. The record sheet was then reduced to two double columns, one for records of outgoing, the other for incoming bees. The left hand side of each double column was for the time while the right was for the designation of the individual. Frequently several marked bees would enter or leave the hive almost together, and in such cases it was necessary to make only one entry in the time column. In reading the mark on any bee, the color combina-
tion was spoken by the observer who always gave the thorax color first, thus, "green-yellow, which indicated green on the thorax and yellow on the abdomen, and was recorded by the abbreviation "g y". A bee having no mark on the thorax, but having yellow on the abdomen was denoted as "blank-yellow" and recorded "-y". If there was a red spot on the thorax and no color on the abdomen, the bee registered "r-". A designating number was assigned to each marked bee and, at a later date, all the records for that bee were brought together in their proper order, thus giving practically a complete record of the number and duration of her field trips and hive stays for the entire period.

ENTRANCE DEVICES

Normal colonies of medium strength in ordinary ten frame Langstroth hives were used exclusively in securing data on the number of trips per day, and the time spent in the field and in the hive by field bees. Colonies in observation hives wore not used for this purpose because of the possible objection that data secured from them might not be typical of average colonies.

It should be remembered that, in order to know when each marked bee passed into or out of the hive, it was necessary for the observer to see the back of every bee that went through the entrance. And while it often is difficult enough to see every bee that enters or leaves an observation hive,
it requires strenuous watching to see every one that enters or leaves a full sized colony. There are three reasons for this. A much larger number of bees must be scanned constantly, the ingress and egress often is more rapid, and bees leaving the hive frequently appear at the entrance upside down, clinging to the lower edge of the hive body. Such bees very commonly take wing from this position so that marks on their backs cannot be seen. While the two last named difficulties are encountered to some extent in the observation hive, they are vastly greater when observing at the entrance of an ordinary hive. A special entrance device was constructed, the object of which was to reduce these difficulties as much as possible without materially interfering with the activities of the bees. In fact, several different devices were constructed.

The first device constructed was nothing more than a screen-covered tunnel six inches wide and five sixteenths of an inch deep which extended eight inches in front of the hive. This arrangement reduced the width of entrance by half and it was hoped that the bees would soon become accustomed to their new entrance and would pass back and forth in plain view under the wire screen. They had no trouble finding their way out, but they certainly had no notion of how to get in through it. Incoming bees alighted on the top of the screened tunnel and clustered on the top of the tunnel and on the front of the hive where they would remain indefinitely. To remedy this defect, a board eighteen inches wide and two feet high was erected
at the outer end of the tunnel as a false hive-front. This was a great improvement but it lacked much of perfection. An occasional bee would find its way behind the false front, and would alight on the screen over the tunnel where it would remain, trying to find a place to get through the screen. The number of bees there increased constantly. Brushing them away did no good. Killing them was little better. A pane of glass laid over the screen improved matters slightly, but it was more difficult to see the bees passing beneath than through the screen alone. After the false front was erected, one observer watched the bees at the mouth of the tunnel while the other watched them from above as they passed through the tunnel, but neither observer could watch both places at one time nor did either position enable the observer to be entirely certain of all his observations. One of the worst features of this device was the fact that many bees crawled through the tunnel upside down, and took wing without giving either observer a chance to see whether they were marked.

The second entrance device was made along lines quite similar to the first but with several improvements. The tunnel was made narrower and longer, being only three and one-half inches wide and twelve inches long, thus providing a passage way still more easily watched. The greatest improvement, however, was made by allowing the screen cover of the tunnel to protrude nearly half an inch in front. The cross-strands of wire were removed from the protruding portion so that a row
of little prongs projected just above the entrance to the tunnel. These prongs were then bent downward until there was barely room for a bee to pass beneath their points. The object of this row of downward pointing prongs was to cause bees crawling out through the tunnel upside down to turn right side up before taking wing. It proved to be a long step in the right direction for not only did it cause outgoing bees to right themselves before taking wing but also prevented incoming bees from alighting and entering in an inverted position as they would sometimes do, otherwise. It also produced a more marked slowing up of traffic than had the first device. But it was not wholly satisfactory because the false front had to be used in connection with it and as was pointed out above, the false front does not allow a view of the entrance and the tunnel at one and the same time; moreover, the observer was compelled to maintain an uncomfortable position in order to view the tunnel properly.

The third attempt was not "the charm" but rather a digression. It was a radical departure from the two previous devices in more ways than one. The plan was to construct a combination device which would provide adequate opportunity to observe the passing bees and at the same time provide a means for catching and painting bees expeditiously. It did neither. But a knowledge of things that will not work is often useful, so a brief description of this apparatus follows. Numerous narrow, glass-covered tunnels were arranged to occupy the full width of the hive. Half of these tunnels were wide enough for a bee to
pass each other. The remainder of the tunnels were just wide enough to permit two bees to travel side by side or to pass each other. Instead of a pane of glass over the whole set of tunnels, narrow strips of glass were used in such a way that each strip of glass covered nearly one-half of each of two adjacent tunnels. The glass strips did not fit close to each other but were spaced apart leaving a crack about one-sixteenth of an inch wide right over the middle of each tunnel and running the full length of it. Provision was made for closing both ends of any or all tunnels so that bees might be confined while being touched with a spot of color through the crack between the glass strips.

As might be expected, the narrower tunnels were continually blocked because an outgoing and an incoming bee would meet and, in the absence of room to pass each other, a deadlock would ensue unless one bee could succeed in forcing the other to back out of the tunnel. The wider tunnels were not so much troubled in this respect. But the device was a flat failure because such a large proportion of the bees walked on the side-walls of the tunnels where their backs could neither be seen nor be painted.

The success of the device which was provided with a row of down-turned prongs at its entrance, pointed the way to a still more simple and more satisfactory apparatus. If all the bees could be compelled to enter and leave the entrance "right side up with care" there was little need for the tunnel. Experience in using the device with the row of prongs suggested that a similar set of down-turned prongs, installed on the in-
side of the hive at the entrance, ought to be instrumental in causing the outgoing bees to right themselves before going through the entrance. A very simple piece of apparatus embodying these ideas was soon constructed by tacking a strip of wire screen two inches wide to the under side of a regular entrance-reducer block. The wire projected about half an inch on each side of the reducer block and all the cross wires were removed from the projecting portions, leaving only a row of prongs on either side of the block. The prongs were then curved down on both sides of the block and the device shoved into the regular hive entrance. The results were all that could be expected. The width of this entrance was only three inches so it was easily watched. The presence of those down-turned prongs prevented bees from getting through the entrance at too rapid a pace. There was scarcely one bee per day that succeeded in getting through this arrangement in such a manner that its back could not be seen; and it was less tiresome to make observations with this type of apparatus than with any other that was tried.

The only other device known to the writer which corresponds in any way to the apparatus just described, is one used by Von Frisch, (13, p.12). It is constructed along very different lines from those used in the present studies, being a large tunnel constructed of boards, and extending about six feet in front of the hive. The tunnel is about eighteen inches square in cross-section at its outer end and for about half its entire length. From this point, the tunnel tapers to an opening only
two and one-half inches square at the front of the hive. Three glass covered openings are provided in each of the two side-walls, thus giving opportunity for observing the bees as they pass through the long tunnel.

It would appear that Von Frisch's entrance arrangement might have some distinct advantages over even the most satisfactory one devised by the writer. It likewise presents possibilities for disadvantages, so it will be the safer policy to withhold judgment until the new device is given a trial.

A TEST FOR NECTAR VERSUS WATER

Nectar-carriers cannot be distinguished from water-carriers by their appearance because nectar and water are both carried in the honey-sac, which is located inside the abdomen of the bee. Yet it became necessary to be able to determine whether a given bee was engaged in carrying the one or the other. One way to find out was to kill the bee, dissect out its honey-sac and taste the contents. This manner of determining the honey-sac contents was used frequently to find out what proportion of incoming bees were carrying nectar and what proportion were carrying water. But a bee subjected to this test was not a promising subject from which to determine the number of trips a bee would make in a day. Hence, a means for finding the nature of the honey-sac contents without injury to the bee was greatly desired.

The solution to this, apparently, difficult, problem worked itself out quite unexpectedly in the following manner.
One day when dissecting out the honey-sacs from a considerable number of bees, it chanced that they were laid out on a sheet of filter paper. When an attempt was made to remove them, several adhered to the paper so that they were ruptured and their contents spilled on the filter paper. It was observed that the content of some honey-sacs was absorbed very rapidly while that of others was observed to be slightly sticky and of course were nectar, while the latter showed no stickiness and was judged to be water. A further observation which indicated the latter to be water, was that, in a number of cases, a conspicuous deposit of fine particles of soil was left on the filter paper. Subsequent observation in the field showed that many bees were sipping their loads of water from puddles and muddy furrows. These observations were interesting but did not appear to have any special significance. The sheet of filter paper was shoved aside with a sigh; and an unsatisfactory afternoon's labors were closed.

The following morning, recalling the "mud" obtained from some of those honey-sacs the previous afternoon, the filter paper was sought in order that it might bear witness to any who should doubt such a case. Upon reaching for the paper, the thing that attracted my attention was not the spots of "mud", but the spots as of oil on paper - translucent spots. The spots of "mud" were there all right to show where the water had soaked in, but the translucent spots were scattered about on various parts of the filter paper at the exact places where honey-sacs
had lost their contents, and a shriveled honey-sac was still to be found on every one of the translucent spots. The situation was entirely clear. A sugar solution, as is well known, upon drying on paper leaves a translucent spot. Wherever the muddy water had evaporated, the dirt remained and there was no translucent area. The translucent spots on the filter paper showed which honey sacs had contained nectar.

If only the bee could somehow be induced to give up a portion of her load, the problem, would be solved. Somebody said: "Choke 'em". Well, the idea seemed to have merit. The bee could disgorge voluntarily, so why not under the persuasion of gentle pressure on the abdomen. It was tried. It worked. Thereafter, bees to be tested were simply held on top of a sheet of filter paper while gentle pressure was applied to the abdomen. A fraction of a load is sufficient for the test, and if the bee is properly handled, no apparent injury is done the bee. Bees subjected to this test have continued to yield data as satisfactorily as pollen-carriers which, of course, did not have to undergo the test.

Investigation of the limits of this test showed that it was useless for detecting the presence of sugar in aqueous solutions of honey containing less than about thirty percent sugar. It is, therefore, less sensitive than the average human taste but is more convenient to apply. So far, it has been found entirely trustworthy for detecting water-carriers and nectar-carriers, and in no case have the results obtained from
such individuals, indicated in any way that an error had been made in this respect. The investigation further indicated that the approximate concentration of nectar could be detected by this test.

The fact that analyses of nectar taken from various flowers, have been shown by De Planta (7, p.559) to contain sugar in quantities of only about twenty to forty percent might lead some to doubt the trustworthiness of this test. It has been observed, however, by Brunnich (18) and others that nectar is already somewhat concentrated by the bees by the time it reaches the hive, and De Planta himself concluded from his observations that the bees throw off a considerable quantity of the water while it is in their stomachs. It is probable, therefore, that the test is sufficiently reliable for practical use, and since it is so simple and so easily applied, it may be more serviceable than a more sensitive test that would be more complicated.

DETERMINATION OF THE MINIMUM FLYING WEIGHT

The first published account of weights of honeybees of which we have record is that quoted by Wildman (19, p.77) from the unknown author of the "Natural History of Bees". It is assumed that the book referred to is the "Histoire Naturelle des Abeilles" published in Paris, 1744, or the English translation of the same work which was published in London the same year. This author weighed bees killed in a robbing episode and found that 168 were required to weigh half an ounce, which would
be 84.4 mg. per bee. To satisfy himself on this point, Wildman weighed bees which he took from a hive on a very cold day. They were allowed to fly to a window where they soon became chilled and inactive. He found that of these, only 154 were required to weigh half an ounce, which is equivalent to 92 mg. per bee. During the last century, Cotton, (20, p.327), Collin (21), Gelieu (22, p.250), Koons (23 and 24), Gillette (25), Lazenby (26), Macdonald (27) and some others have published data on the weight of bees.

A dependable method for finding the numerical strength of colony has long been sought by the practical apiarist as well as the scientific worker. Bees are now sold extensively by the pound at prices that are about ten times that of honey. The purchaser should be able to check up on the number of bees he gets per pound in order to know whether he is getting full value in bees. Both of these problems require for their solution the use of a factor which may be designated as the minimum flying weight. As has been pointed out already, the particular need for such a factor in connection with the studies at hand was for determining the nectar-carrying capacity of the honeybee. With this factor established, the load carried could be found by deducting it from the gross weight of the loaded bee.

Several previous investigators have attempted to determine the carrying capacity of the bee by deducting the average weight of outgoing bees from that of incoming bees. Whether or not the average weight of outgoing bees may safely be used as a basis for this determination may be determined from Table I.
which contains a fairly complete list of weights previously published for outgoing bees, together with records secured during the present investigation. A variation of from 71 to 123 mg. is shown for individual bees and from 75 to 104 mg. for averages. These are wide variations especially as all but a few of these figures are for the Italian race. Figures from Koons (23 and 24) are for Italians and Italian-Black hybrids; those from Gillette (25) and those secured by the writer are for Italians. In the other cases, the race used is not stated. Not only is there variation in weights obtained from different colonies, but also in records taken from a single colony on different days and even for different times on the same day, as is shown by the data from colony 62.

Table I. - Weights of outgoing bees

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Number</th>
<th>Aver. wt.</th>
<th>Hour</th>
<th>Date</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>168</td>
<td>84.4</td>
<td></td>
<td>1744</td>
<td>Bees killed in robbing episode.</td>
</tr>
<tr>
<td>Gelieu</td>
<td>83.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koons</td>
<td>1</td>
<td>80.0</td>
<td></td>
<td>1893</td>
<td>Probably outgoing bees.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>109.5</td>
<td></td>
<td></td>
<td>Lightest of 10 bees.</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>93.9</td>
<td></td>
<td></td>
<td>Heaviest of 10 bees.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>82.5</td>
<td></td>
<td>1895</td>
<td>Lightest of 10 bees.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>123.2</td>
<td></td>
<td></td>
<td>Heaviest &quot; &quot; &quot;</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>94.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gillette</td>
<td>29</td>
<td>75.2</td>
<td>6-15-'94</td>
<td></td>
<td>Robbers</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>75.2</td>
<td>10-5-’96</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>90.7</td>
<td>6-28-’97</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>86.9</td>
<td>&quot; &quot; &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>82.3</td>
<td>&quot; &quot; &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lazenby</td>
<td>1</td>
<td>71.0</td>
<td>5-17-’99</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>92.0</td>
<td>&quot; &quot; &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>79.0</td>
<td>&quot; &quot; &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macdonald</td>
<td>82.5</td>
<td></td>
<td></td>
<td>1912</td>
<td></td>
</tr>
</tbody>
</table>

* Quoted by Wildman (19, p.77).
In the present investigations, the weighings were made as follows: As a rule, 25 bees were caught as they left the hive and were placed in a cyanide bottle long enough to render them inactive, but not long enough to kill them outright. They were then placed in a small glass weighing jar having a tight fitting, ground glass cover to reduce the chances for
loss of weight by evaporation. The weighing was done as soon as possible on chemical balances which are considered accurate to the tenth of a milligram. This is less than one-millionth of a pound.

The series of ten weights from colony 62 was obtained at different hours on four different days, as may be seen from the table. Honey-flow conditions represented on these days ranged all the way from a dearth on September 11, to a heavy honey-flow on August 28. The lightest average weight found for any lot was 81.2 mg. and the heaviest, 104 mg., while the others can be arranged in a series running from the one extreme to the other with no two of them the same. It will be noticed that there is an extreme variation of 52 mg. in the weight of outgoing bees from different colonies and possibly different races. Even in the weighings from a single colony, a variation of 23 mg. is shown together with irregular variations from day to day, indicating that other factors are probably involved. It therefore seemed necessary to approach the problem from other angles in an attempt to eliminate the other factors.

Low Outgoing Weights

In studying this table, we are confronted by the fact that there is a minimum below which outgoing weights seldom fall. This minimum must approach the actual minimum flying weight. It is to be expected, then, that the average of a few of the lowest weights taken from a series such as that from colony 62,
would represent an approximation to the normal minimum flying weight for that colony.

The three lowest of these weights were obtained at times when the bees were scarcely able to secure nectar enough for their daily needs. There were, however, abundant stores in the hive. We have found that under such conditions, outgoing bees weigh much less than when nectar is abundant in the fields. This is shown very clearly by the records from colony 62 as given in Table I. As will be noticed, August 28 and September 5 were in a period of honey-flow. Colonies on scales registered strong gains for both days, and outgoing bees showed high weights. On the other hand, August 4, was in a period during which the bees neither gained nor lost, while September 11 was the first day in a period of loss. Moderate to low weights were recorded for outgoing bees on both these days. If, from this series of ten weighings from colony 62, we take the average of the three lowest, 81.2, 82.5 and 83.3 mg. we obtain 82.5 mg.

Other low weights secured were 82.9 and 81.5 mg. from colonies 1 and 59 respectively, and the average of all five low weights is 82.3 mg.

Comparing minimum weights given by other workers, for outgoing bees, with this average of 82.3 mg., we find that the unknown author of the "Histoire Naturelle des Abeilles", quoted by Wildman (19, p.77), found 84.4 mg. as the average weight of 168 bees that lost their lives in a robbing episode; and, altho not outgoing bees in the strictest sense of the term, they were undoubtedly bees that were practically devoid of any load, and
may properly be classed with outgoing bees. The minimum weight found by Gelieu (22) was 83 mg., but we are not informed of the number of bees used in this determination. The lightest weights recorded by Koons '23 and 24) are 80 and 82.5 mg. respectively. Each of these figures represents the weight of a single bee.

Gillette (25) gives 75.2 mg. as the lightest average weight for outgoing bees found by him. This average is so much lower than that obtained by any other worker from weights based upon a similar number of bees, that there is reason to suspect that some unusual and unrecognized factor was responsible for this exceptionally low weight. There is, obviously, an error in Gillette's figures as there is a difference of only 2.7 mg. in the weights of loaded and unloaded pollen-bearers recorded under date of June 15. It may be that this same error effected the weight of the outgoing bees quoted above. Lazenby (26) weighed sixteen outgoing bees individually. Of the sixteen, eleven weighed less than 82 mg. and the average of all sixteen was 79 mg. Figures given by Macdonald (27) indicate that he found 82.5 mg. as the average minimum weight for bees.

Summarizing the low weights given by previous workers, we find that Gillette's 75.2 mg. may well be eliminated on account of reasons already given. Those figures known to be based upon the weight of a single bee can, in all fairness, be used in the determination of an average, only when accorded their proper values by means of a weighted average.
The low averages obtained by other workers may be tabulated as follows:

<table>
<thead>
<tr>
<th>Worker</th>
<th>Average of</th>
<th>Bees</th>
<th>Weight (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>168 bees</td>
<td></td>
<td>84.4</td>
</tr>
<tr>
<td>Gelieu</td>
<td>15 bees</td>
<td></td>
<td>82.0</td>
</tr>
<tr>
<td>Lazenby</td>
<td>16 bees</td>
<td></td>
<td>79.0</td>
</tr>
<tr>
<td>Macdonald</td>
<td>15 bees</td>
<td></td>
<td>82.5</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td><strong>82.2</strong></td>
</tr>
</tbody>
</table>

This average together with that found during the present investigation, gives a grand average of 82.2 mg. for the minimum flying weight as determined from low outgoing weights.

The Weight of Unloaded Pollen-Carriers

It is stated by both Gillette (25) and Lazenby (26), that incoming pollen-bearers carry very little honey or nectar in the honey-stomach and that bees do not gather both pollen and nectar on the same trip. As shown by Casteel (28, p. 29) outgoing pollen-bearers carry a small quantity of nectar or honey which they mix with the pollen as it is gathered. Our investigations show that this honey or nectar is almost entirely gone when the bee returns with a large load of pollen.

It was found, however, that when working on certain flowers, some bees do gather more or less of both nectar and pollen at one trip. But in general, only a small proportion of the pollen-bearers will be found to return with much nectar. Such bees usually carry a noticeable quantity of nectar and only a medium or small load of pollen.
so that it is not difficult for a trained eye to recognize them and thus avoid weighing them along with those that carry pollen only. When bees are carrying pollen from corn or other sources which produce no nectar, such precaution is not necessary.

In order to determine the amount of honey carried by returning pollen-bearers, fifty bees carrying heavy loads of pollen were caught. The honey-stomachs were removed from these and were found to average 1.8 mg. The weight of the average empty honey-stomach was found to be 1.5 mg. or less. This leaves approximately one-half milligram as the weight of the possible load carried in the honey-stomach of these selected pollen-carriers. Examination of honey-stomachs from other lots of heavily loaded pollen-carriers has shown that the case given above is not exceptional. It was found practical, therefore, to use heavily loaded pollen-carriers for the purpose of getting at the normal minimum flying weight of the bee. The only thing necessary to prepare such bees for weighing was to stupefy them in a cyanide bottle as usual and carefully remove the pellets of pollen from their legs.

Average weights of unloaded pollen-carriers appear in Table II. Six weighings were made from colony 62. Only bees carrying the same kind of pollen were weighed together. The intention was to weigh 25 bees in each lot, but that was found to be impractical in two cases due to the lack of bees carrying the desired kind of pollen at those particular times. The average for all six weighings is 81.7 mg. One lot of unloaded pollen-bearers from colony 57 averaged 83.4 mg., while two groups taken
from colony 59 on different days, averaged 85.5 and 83.2 mg., respectively.

Table II. - Weights of unloaded pollen-carriers.

<table>
<thead>
<tr>
<th>Colony</th>
<th>Unloaded pollen-carriers</th>
<th>Loaded pollen-carriers</th>
<th>Hour</th>
<th>Date</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>83.5 mg.</td>
<td>15.2 mg.</td>
<td>8:30</td>
<td>6-15-'94</td>
<td>Gillette ('97)</td>
</tr>
<tr>
<td>57</td>
<td>82.5 mg.</td>
<td>15.2 mg.</td>
<td>8:00</td>
<td>6-28-'97</td>
<td>&quot;</td>
</tr>
<tr>
<td>54</td>
<td>96.6 mg.</td>
<td>8.7 mg.</td>
<td>2:30</td>
<td>7-28-'19</td>
<td>corn</td>
</tr>
<tr>
<td>59</td>
<td>81.9 mg.</td>
<td>10.7 mg.</td>
<td>8:00</td>
<td>8-4-'19</td>
<td>&quot;</td>
</tr>
<tr>
<td>62</td>
<td>80.0 mg.</td>
<td>18.2 mg.</td>
<td>8:00</td>
<td>9-11-'19</td>
<td>red clover</td>
</tr>
<tr>
<td>102.0</td>
<td>82.0 mg.</td>
<td>20.0 mg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95.9</td>
<td>85.4 mg.</td>
<td>12.5 mg.</td>
<td>2:30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>102.0</td>
<td>84.0 mg.</td>
<td>18.0 mg.</td>
<td>1:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>98.5</td>
<td>85.5 mg.</td>
<td>13.0 mg.</td>
<td>2:00</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>112.2</td>
<td>83.2 mg.</td>
<td>29.0 mg.</td>
<td>1:30</td>
<td>5-7-'20</td>
<td>hard maple</td>
</tr>
<tr>
<td>111.9</td>
<td>89.5 mg.</td>
<td>22.3 mg.</td>
<td>9:30</td>
<td>5-20-'20</td>
<td>Apple</td>
</tr>
<tr>
<td>106.4</td>
<td>81.3 mg.</td>
<td>25.1 mg.</td>
<td>9:40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>108.4</td>
<td>84.8 mg.</td>
<td>23.6 mg.</td>
<td>9:50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>117.3</td>
<td>90.2 mg.</td>
<td>27.1 mg.</td>
<td>10:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>113.5</td>
<td>86.2 mg.</td>
<td>27.3 mg.</td>
<td>10:00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average 83.9 mg.

*These bees carried an average of 4 mg. of nectar.

Gillette (25) gives average weights from two groups of 29 and 10 unloaded pollen-carriers as 83.5 and 82.5 mg., respectively, but evidently attached no importance to them for they are not mentioned in his discussion.

Summarizing these results, we find the averages from five colonies as follows:

<table>
<thead>
<tr>
<th>Colony</th>
<th>Bees</th>
<th>Unloaded pollen-carriers</th>
<th>Loaded pollen-carriers</th>
<th>Date</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>75</td>
<td>84.5 mg.</td>
<td>15.2 mg.</td>
<td>8-4-'19</td>
<td>&quot;</td>
</tr>
<tr>
<td>62</td>
<td>127</td>
<td>81.7 mg.</td>
<td>81.7 mg.</td>
<td>6-15-'94</td>
<td>Gillette ('97)</td>
</tr>
<tr>
<td>57</td>
<td>25</td>
<td>83.4 mg.</td>
<td>15.2 mg.</td>
<td>6-28-'97</td>
<td>&quot;</td>
</tr>
<tr>
<td>54</td>
<td>102</td>
<td>83.5 mg.</td>
<td>15.2 mg.</td>
<td>7-28-'19</td>
<td>corn</td>
</tr>
<tr>
<td>59</td>
<td>75</td>
<td>84.5 mg.</td>
<td>15.2 mg.</td>
<td>8-4-'19</td>
<td>&quot;</td>
</tr>
<tr>
<td>Gillette</td>
<td>29</td>
<td>82.5 mg.</td>
<td>15.2 mg.</td>
<td>5-7-'20</td>
<td>hard maple</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>82.5 mg.</td>
<td>15.2 mg.</td>
<td>5-20-'20</td>
<td>Apple</td>
</tr>
</tbody>
</table>

Grand average 82.5 mg. (266 bees)
The Weight of the Bee Minus the Contents of Its Honey-Sac.

Another method by which the actual weight of an unloaded bee was obtained was by collecting bees and removing their honey-sacs. The weight of a bee after removal, plus the average weight of an empty honey-sac was considered as the minimum weight of the bee. This called for the determination of the average weight of empty honey-sacs.

THE WEIGHT OF THE EMPTY HONEY-SAC was determined as follows: When weighing honey-stomachs removed from incoming pollen-bearers, it was found that many of them contained no honey or nectar that could be discovered. The three lots in which the least contents were found, averaged 1.8, 1.7 and 1.5 mg. and were determined from groups of 50, 25, and 25 respectively. These lots were all from normal colonies that had abundant stores. Nectar was plentiful in the field on the day the two lightest averages were obtained, and some carried small amounts of nectar, so the averages obtained may be considered normal. We can expect the figure, 1.5 mg. to be high enough, since some stomachs contained an appreciable amount of nectar or honey. Then the weight of the empty honey-stomach must be something less than 1.5 mg. and for practical purposes, this figure is sufficient.

Weights of bees minus the contents of their honey-stomachs will be found in Table III. The average for all weights secured by this method is 82.6 mg.
Table III. - Weights of bees minus contents of honey-stomachs

<table>
<thead>
<tr>
<th>Average weight in mg.</th>
<th>Honey-stomachs</th>
<th>Not loaded</th>
<th>Date</th>
<th>Number</th>
<th>Colony weighed</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>137.0</td>
<td>53.5</td>
<td>*81.5</td>
<td>6-28-'97</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>126.2</td>
<td>41.1</td>
<td>85.1</td>
<td>8-4-'19</td>
<td>20</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>119.5</td>
<td>32.0</td>
<td>87.5</td>
<td>8-11-'19</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>89.2</td>
<td>9.4</td>
<td>79.8</td>
<td>8-4-'19</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>83.3</td>
<td>5.7</td>
<td>77.6</td>
<td>8:30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83.2</td>
<td>0.3</td>
<td>82.9</td>
<td>1:30</td>
<td>5-7-'19</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>89.4</td>
<td>5.7</td>
<td>83.7</td>
<td>1:30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>89.6</td>
<td>3.9</td>
<td>85.7</td>
<td>9:30</td>
<td>5-20-'20</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>81.3</td>
<td>0.2</td>
<td>81.1</td>
<td>9:40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>84.8</td>
<td>1.3</td>
<td>83.5</td>
<td>9:50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.2</td>
<td>1.8</td>
<td>88.4</td>
<td>10:00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86.2</td>
<td>0.8</td>
<td>86.2</td>
<td>10:10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average 83.6

*Computed from Gillette's (25) table by subtracting the average weight of loaded honey-stomachs from the weight of incoming bees taken at the same time, and then adding 1.5 mg. as the average weight of an empty honey-stomach.

The Minimum Flying Weight

Three averages of minimum flying weights have now been determined, each by a different method. These averages are as follows:

Low outgoing weights 82.2 mg.

Unloaded pollen-bearers 82.5

Bee minus content of honey-stomach 83.6

Grand average 82.8 mg.

As it is impossible for a bee to weigh less than a bee does weigh, and the weight as determined from low averages of outgoing bees is based upon a large number of weighings obtained under many different conditions and by different workers,
it is to be expected that 82.2 mg. is, at least, high enough. The average obtained from unloaded pollen-bearers is slightly higher, but this can be accounted for by the fact that at least a part of these bees carried appreciable amounts of honey or nectar, and by the fact that all particles of pollen were not removed from the bee.

Provided the technique is sufficiently good, the most nearly accurate results might be expected from the third method, that of deducting the weight of the bee. The averages secured by this method, however, are higher than those secured by either of the other two methods. There is, undoubtedly, another factor involved. This factor seems to have been practically eliminated in the case of the other two methods. By choosing only the lower weights, in which this factor probably was not present, we would get an average of 82 mg. instead of 83.6 mg. This would reduce the grand average by .6 mg., giving a grand average of 82.2 mg.

The grand average of 266 unloaded pollen-bearers should fairly represent the minimum weight of a bee. Apparently, in selecting the pollen-carriers, the other factors that add to the weights in Tables I and III, have been eliminated. The fact that this average and the one obtained by selecting only the low weights of outgoing bees, approach each other so closely, indicates that a fairly stable minimum has been found. If 82 mg. is accepted as the better average for bees with their
honey-stomach content removed, we will have a remarkable agree-
ment in the three figures from different methods, and the
grand average of 82.2 mg. which they will give, must even then
be above rather than below the absolute minimum flying weight,
but close enough to be serviceable for all practical purposes.

Conclusion

The minimum flying weight of the Italian bee is
approximately 82 mg.

DETERMINATION OF SPEED IN FLIGHT

Bees have been considered speedy fliers as is indi-
cated by various estimates, some of which run as high as 120
miles per hour. Conservative writers have put their esti-
mates at 30 miles and less. Those of Cheshire (29), Cowan
(30), Cook (31), Buttel-Reepan (32) and Sabine (33) are based
on more or less careful observations, but apparently, none of
the previous observers took particular account of that very
important factor, the wind.

Experiments were carried on at the Iowa Experiment
Station in 1920 and 1921, not only to secure more definite
information about the speed of the bee but also to study the
reactions of the bee to the influence of the wind.

Procedure

On a day after the close of the honey flow, a marked
bee was taken across an open field to a point about a fifth of
a mile from its hive where it was allowed to fill up on syrup.
The bee made repeated trips to this spot. One observer stood
by the hive with a stop watch in hand while another was sta-
tioned near the dish of syrup. As the marked bee left the
hive, the watch was set going and a signal given to notify
the second observer that the bee was on its way. The instant
the bee alighted, a signal was given to stop the watch. The
return trip was timed in a similar manner. Records were ob-
tained of about twenty-five consecutive round trips on each
of four different days.

The velocity of the wind was determined at the be-
ginning and at the end of the period by means of a portable
anemometer, placed at about the height of the bee's flight.
The average of the two readings was used in the calculations.
The exact distance was determined by running a line with a
surveyor's chain.

The experiments were carried out in such a way that
one set of data (A) was secured when the wind was directly
against the bee as it left for the field and with its flight
on the return. When the second set (B₁) was obtained, the
wind was at right angles to the line of flight. In the case
of the third (B₂) and fourth (C) sets, the bee left the hive
with the wind and returned against it. The designations B₁,
and B₂ were employed to indicate that the same bee was used
in securing these two sets of data.
Results

In accordance with one of nature's laws, a bee traveling with the wind is assisted in its flight to the extent of the velocity of the wind, or if traveling against the wind the bee's progress is hindered to the extent of the wind's velocity. If the bee flies at an angle to the wind, its rate of progress will be the resultant determined by triangulation. Then the fair way to compute the normal speed of the bee is to reduce all results to terms of calm. This was done and the results appear in the fourth and eighth columns of Table IV. And, except where stated otherwise, these are the figures under discussion throughout the remainder of this paper.

Table IV. - Influence of the wind on speed of honeybees

<table>
<thead>
<tr>
<th>Bee</th>
<th>Observed speed</th>
<th>Correction for wind</th>
<th>Speed in a calm</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2</td>
<td>19.7</td>
<td>-7.7</td>
<td>12.0</td>
</tr>
<tr>
<td>C</td>
<td>11.3</td>
<td>-4.5</td>
<td>6.8</td>
</tr>
<tr>
<td>With wind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>12.4</td>
<td>+5.6</td>
<td>18.0</td>
</tr>
<tr>
<td>Against wind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>8.8</td>
<td>+4.7</td>
<td>13.3</td>
</tr>
<tr>
<td>At right angles to wind</td>
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<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Bee</th>
<th>Observed speed</th>
<th>Correction for wind</th>
<th>Speed in a calm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18.6</td>
<td>-5.6</td>
<td>13.0</td>
</tr>
<tr>
<td>B</td>
<td>8.3</td>
<td>+7.7</td>
<td>16.0</td>
</tr>
<tr>
<td>Against wind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>11.5</td>
<td>+4.5</td>
<td>16.0</td>
</tr>
<tr>
<td>At right angles to wind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
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<td>+3.9</td>
<td>14.6</td>
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<tr>
<td>Average</td>
<td></td>
<td></td>
<td>14.9</td>
</tr>
</tbody>
</table>

* Speed is given in miles per hour.
# Wind velocity was 10 miles per hour.
It will be noticed that the speed found for loaded bees varied only a little, the lowest being 13 and the highest 16 miles per hour, while the average was approximately 15 miles. But the speed of empty bees varied from 6.8 to 18 miles per hour, and averaged 12.5 miles, or 2.4 miles per hour less than the average for homeward-bound bees.

The fact that the speed shown for outward-bound bees varied much more than that for homeward-bound bees, suggests the probability that a bee on its outward journey often does not make a so-called "bee-line" for the source of supply but may do more or less scouting on the way. If this is the case, the distance actually traveled was greater than the measured distance. Then the speed for outgoing bees would be somewhat greater than indicated by the data. But the amount of time recorded was actually consumed during the outward trip, so calculations must be based on the recorded time.

It is significant that when flying at right angles to the wind, the outgoing bee flew at the rate of 13.3 and the incoming bee, 14.6 miles per hour, since each approaches rather closely the general average for its respective class. Furthermore, this case emphasizes the fact that, in spite of the heavier load, the homeward journey was usually accomplished in less time than the outward journey. As may be seen from the table, the only case in which the outgoing bee made better time than the incoming bee, was when flying directly against the wind.
Another noteworthy fact is that the least speed was shown when flying with the wind, on both outward and homeward trips; whereas, the greatest speed in each case was attained when flying directly against the wind. It appeared that when going with the wind, the bee showed a tendency to slacken its own efforts; whereas, in traveling against the wind, it increased them in an attempt to overcome the retarding influence of the wind.

Temperatures were relatively high during these experiments, being between 70 and 80 degrees Fahrenheit at all times. No relationship between temperature and rate of flight was apparent within this range. A wider range in temperature, however, might yield a correlation.

A maximum speed of twenty-five miles per hour was recorded for both outgoing and incoming bees, but it was found that bees would not long continue to work in a wind blowing fifteen or more miles per hour. This is another indication that the bee's normal rate of flight in a calm is little, if any, more than fifteen miles per hour.

A CHECK ON THE RESULTS. - A pure streak of good luck is responsible for a very satisfactory check on the experiments just related. On August 20, 1921, one of our marked water-carriers was discovered by Mr. R. L. Parker while getting its load from a watering place for bees in Mr. Parker's yard. He at once got in touch with the writer by telephone and, after setting our watches together, we proceeded to record the time of arrival and departure of this bee at both ends of the line.
The bee flew at right angles to a light breeze having an estimated velocity of three miles per hour. Later, the distance traveled by the bee was found to be just two-thirds of a mile in a direct line. The records, when brought together, showed that the average rate of flight, whether loaded or empty, was 14 miles per hour which, in terms of calm, would be 14.3 miles.

Conclusions

1. Time records for homeward-bound bees showed considerably less variation than did those for outward-bound bees.

2. On the average, less time was consumed on the homeward trip than on the outward trip, but, when flying directly against the wind, the empty bee flew slightly faster than did the loaded bee.

3. The effort put forth both by empty and by loaded bees was least when flying with the wind and greatest when flying against it.

4. A maximum speed of 25 miles per hour was found for both outgoing and incoming bees.

5. Bees made but little progress against a wind having a velocity of 15 miles per hour.

6. The average speed found for the flight of bees in a calm was a little less than 15 miles per hour.
FOOD GETTING HABITS

"Aristotle", more than two-thousand years ago, observed that "a bee in gathering pollen, confines herself to the kind of blossom on which she begins, even if it is not so abundant as some others" (4, p.83). During the twenty odd centuries that have intervened since Aristotle, a long list of observers have studied one phase or another of the food getting habits of the honeybee. The names of Butler, Swammerdam, Reaumur, Thorley, Wildman, Huber, Cotton, Langstroth, and others, from among the earlier writers, are intimately associated with the slow and tedious development of our still too scant knowledge of this subject. Among the more recent authors whose names are prominent because of their outstanding researches and observations on the food getting habits of the honeybee, those of Bonnier and Casteel should be mentioned. Many other names are worthy of mention but space forbids.

Various early writers recognized a division of labor in the honeybee colony. Aldamiri (20, p.348), who died in 1405, wrote, "The bees assemble together and divide the work; some
some make the wax, and some the honey; others bring water, and others again build their cells." Numerous investigators have reported on various phases of the division of labor within the hive, while but very few have made contributions on the division of labor outside the hive. In a general way, it has been recognized since early times that some bees carry nectar, some pollen, and some water; but beyond that we have been and still remain, pretty much in the dark. A ray of light was shed upon this field in 1906 when Bonnier (34, p. 120) published the results of his researches on "The Division of Labor Among Bees", but there is need of more light.

NECTAR GATHERING

How doth the little honey bee
Improve each shining hour!
And gather honey all the day
From every opening flower!

The honeybee has induced the poet's song and the moralist's approbation, but, in the light of data which have been published on the number of trips made in a day, some are inclined to question whether we may not have been deceived in the matter.

Time Factors

REVIEW OF LITERATURE. - According to Hommel (35, p.202), Reaumur, Girard and Sylviac, after studying the habits of field bees, all came to the conclusion that "the better average for the number of trips of a worker is 6 per day". Hommel is inclined to take issue on this point, for he cites experiments made by Astor who took data on trips made by marked bees feeding on various
dilutions of nectar and honey. Astor's results indicated that the time required to make a trip varied according to the dilution and the temperature. The bees made trips in the shortest time when feeding on thin nectar and when the temperature was comparatively high. The averages varied from 4 minutes and 3 seconds to 15 minutes and 55 seconds, or in terms of trips per hour the variation was from 13.3 to 3.8. One bee, for two days, made an average of 10 trips per hour and 110 trips in the eleven hours between 6 a.m. and 5 p.m. Hommell considers these results to be typical for bees that are getting their supplies from another hive or from a dish, but says it is certain that their work is less rapid when gathering from the flowers. He goes on to say, "M. DeMeure has observed that a marked bee made 60 trips in 12 hours, or 5 per hour, including the 2 minutes which she employed each time to dispose of her load." Hommell argues that, "Under favorable conditions, with the flowers near the apiary and a strong honeyflow, the bee needs at most 2 minutes to go to the field, 4 for gathering the nectar, 2 for returning, and 2 for the storing of the load; this makes, in all 10 minutes". Then with reference to the average of 6 trips per day found by Reaumur, Girard and Sylviac, he adds, "and since the bee can make only 6 trips per day, it requires the conclusions that she spends an interval of 2 hours between trips". "It is painful", says Hommell, knowing the activity of the bee, to admit that she rests for 2 hours after 10 minutes of labor. These figures, are, however, in contradiction with the direct experience which
one must have in observing with care the going and coming of workers, marked previously by a sprinkling of flour, or with a colored dust of any kind. Huenjean found from direct experiments that the workers thus marked returned to the same cluster of flowers after an absence of 32 minutes, which gives 22 trips per day. This figure evidently is not absolute and may be greater or less depending on the distance from the apiary, the temperature, and the more or less favorable honeyflow.

About 1815, Huish (9, p. 352) sprinkled flour on some field-going bees. All but one of the marked bees proved to be pollen-carriers. He says, "It was however, thirty-five minutes before the last returned but without any farina (pollen). I was, however, convinced from the shape of the body that it had been in pursuit of honey."

In 1914, Luden (36), a beekeeper of Holstein, caught and marked six bees - each a different color - on the afternoon of July 14. He found that marked bees behaved no differently from others and at six o'clock the next morning he took up his station near the hive prepared to keep time records on the marked bees. The weather was fine, except for a thunderstorm between four and five in the afternoon and he continued his observations until seven in the evening, even taking his meals near the hive. The honeyflow was from clover, the net gain for that day was about 4 pounds. His results showed that a field-bee makes about 10 trips per day, each trip consuming from about 30 minutes to 2 hours, with an average of about 1 hour. The marked bees re-
mained but a short time in the hive between trips - from 5 to 10 minutes. Observations were continued the next day with similar results.

Commenting on the results obtained by Luden, Lovell (37) says, "Clearly, the observation is only approximately correct, even for this particular day, since it was found practically impossible to record exactly the number of trips made by any individual bee for so many hours, where so many bees were constantly passing in and out of the hive. For any other day it might be very inaccurate. The number of trips a field-bee makes in a day depends upon: 1. The distance of the honey plants from the hive; 2. the abundance of nectar; 3. Temperature and weather; 4. Length of day; 5. Incidental factors; and and condition of bee, location of nectar in flowers; place of storage in hive, etc.

"The best way to proceed, I think, is to make observations not at the hive, but at the field end, and note how many visits an individual bee will make in an hour under ideal conditions, to a quantity of free honey. In this way exact data can be obtained, which can be used as a basis for further estimates".

Lovell then gives the results of an experiment which he conducted after the manner just outlined. "On September 12, one bee was trained to visit honey placed on a glass slide about 100 feet from the apiary. The bee was kept under observation for 2 hours in the forenoon and 2½ hours in the afternoon."
In discussing the data he secured, he says:

"In the forenoon, the average length of 12 visits to the honey was about 4 minutes each. In the afternoon the average length of 9 visits was 7 minutes. In the forenoon the average length of the interval during which the bee was at the hive was 7 minutes; in the afternoon, 9 minutes. It will be noted that on the average the bee required in the afternoon 3 minutes more to load and 2 minutes to unload than in the forenoon. The average number of minutes at the honey during the entire 4½ hours was 5 minutes; and the average number of minutes at the hive was 8 minutes. In some instances the bee flew about a little while before alighting near the honey. The average number of trips per hour was 4 2-3, which would be at the rate of 46 trips for a day 10 hours long. Where the conditions were ideal - for example, if the apiary were located near a large buckwheat field or a basswood forest - a bee would probably make about the number of trips stated.

"If, however, the honey-plants were distant some two miles, then a much longer time would be required. I doubt if the flight of a bee will average more than 10 miles an hour; and very likely, when loaded, or it is late in the afternoon, or there is a strong wind, it will be much less. Assuming the rate to be 10 miles an hour, then 24 minutes would be required to make the round trip of 4 miles. Allowing 5 minutes to obtain the load, and 8 minutes to unload, then each trip would require 37 minutes; and there would be only 16 trips in 10 hours.

"Again, if the nectar was deeply concealed, as in white clover, or was scarce, then the bee would be unable to gather a load in 5 minutes, but 10 or 15, or even a longer time, would be necessary, so that the bee would make but one trip each hour. It is clear that the number of trips a bee makes in a day varies constantly, and depends upon many factors; but under the most favorable conditions it probably very rarely or never exceeds 50 trips in 10 hours, ranging downward from this number to a few occasional trips made during the middle of the day".

The editor of "Gleanings in Bee Culture", E. R. Root, in a note at the close of Lovell's article asks, "Is it not possible that, since the bees were working on honey instead of nectar, they became excited and worked more hurriedly than if
they had been visiting flowers and getting nectar instead of honey?"

Demuth's experiment (38), in which he found 4 trips as the average number a bee makes to the field in a day probably has invoked more discussion of the subject than any other results along this line ever given to the public. Details of the way in which this experiment was carried out have never been published, but in conversation with Mr. Demuth, the writer received the information that the results were not obtained by direct evidence, but by a system which involved weighings and certain computations. C. P. Dadant (38) editor of the "American Bee Journal", in reporting Demuth's figure says, "I was astounded to hear that the average worker makes only 4 trips. I hope further tests will be made, in the time of a bouncing honey crop."

The editor of "L'Apicoltore", an Italian bee magazine, in referring to Dadant's remarks says (39), "The Signor Dadant had cause to be astonished, and we are glad to report on this question the experience of a beekeeper, mentioned in July 1914, by Die Bienen and ihre Zucht". He then gives the results obtained by Luden, which have already been related. He adds, however, an item bearing on the subject which was not mentioned by Heberle who reported Luden's experiment in "Gleanings in Bee Culture" in 1914. It is: "As result of this experiment, the perserving observer, (Luden) stated that he now knows that bees make neither 40 trips, as reported by Zander, nor 25, according to Klaus, but only about 10". The Italian editor further com-
ments. "The evident result of variety of observations is that the number and duration of flights are, and must be, varied, according to the extension of the bloom, the abundance of nectar secretion which is exceedingly variable, and the distance to be traveled. An accurate study of this question may be of value to calculate the divers convenience in the location of an apiary".

**OBSERVATIONS.** - Individual bees were marked and records were kept of the time of departure and return of each marked bee. Observations began early each morning and continued without interruption until the bees ceased flying at night. During the most of the time there were two observers, so that the chances for a marked bee to pass unnoticed were reduced to a minimum. Only full strength colonies were used in securing data.

Since honeyflow and weather conditions have such a direct, influence upon the gathering of nectar, the time records secured under any given set of conditions are not likely to be duplicated except under similar conditions. During the period of observation in 1920, average colonies stored about five pounds per day from white sweet clover, *Melilotus alba*, while in 1921, average colonies gained only a little over one pound per day from the same source. Weather conditions were highly favorable for honey production in the former instance but were only fair in the latter. Summarizing, it may be
said that one set of data was secured under very favorable conditions, whereas, the other was obtained under conditions which were from mediocre to poor. The data for field-trips, hive-stays and round-trips have been plotted as frequency curves in which the records obtained under favorable and unfavorable conditions are compared.

Of the records obtained for field-trips made by nectar-carriers in 1920, 31 percent fell within the 21-30 minute class, as shown in Fig. 2. About 68 percent fell between 10 and 40 minutes, and 95 percent occupied less than 1 hour. The mean time was about 34 minutes but the modal interval spent in the field was 26.8 minutes.

In 1921, only 19 percent of the field-trip records fell within the 41-50 minute class in which the peak of the curve appeared. About 48 percent fell between 30 and 60 minutes, and 76 percent were completed within 1 hour. The mean time for field-trips was 49 minutes but the modal interval was 45 minutes.

The average speed of the bee, as has already been shown under the heading, "Determination of Speed in Flight", was found to be approximately 15 miles per hour. Then it takes a bee about 4 minutes to go a mile. Estimating the average distance to the field as three-fourths of a mile during the favorable season and as one mile during the less favorable season, we find 6 minutes as the probable time spent in going to and

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# Modal values have been determined by use of W.I. King's formula given in his "Elements of Statistical Method", p. 124.
Fig. 2. Field Trips by Nectar-Carriers
from the field in 1920, and 8 minutes in 1921. By subtracting the time thus spent from the total time the bee was absent from the hive, the net time spent in gathering the load may be found. The most frequent interval spent away from the hive was 27 minutes in 1920 and 45 minutes in 1921, and by subtracting 6 and 8 minutes respectively, we find the probable time spent in gathering the load to have been 21 minutes for 1920 and 37 minutes for 1921.

As shown in Fig. 3, the 3 and 4 minute records of hive-stays by nectar-carriers comprised nearly 40 percent of the total number recorded in 1920. Over 75 percent were completed within 10 minutes. The average time for all hive-stays was 11.6 minutes, but the figure is not very significant owing to the markedly skew form of the curve. The modal or most frequent interval spent in the hive between field-trips was 3.9 minutes.

In 1921, the records of hive-stays were more widely scattered than in the preceding year. The peak of the curve fell within the 5-6 minute period which included only about 23 percent of the records; but nearly 68 percent were completed in 10 minutes or less. The mean time was about 16 minutes, while the modal interval was 5.5 minutes.

Nearly 25 percent of the round-trips recorded for 1920 fell within the 31-40 minute period as shown in Fig. 4. Just 66 percent occupied between 20 and 50 minutes each, and 90 percent were completed in less than 1½ hours. The mean time
Fig. 3. Hive Stay by Nectar-Carriers
Fig. 4. Round Trips by Nectar-Carriers
was 45 minutes, whereas, the modal or most frequent time was only 35 minutes.

In 1921, about 21 percent of the recorded round-trips belonged in the 41-50 minute class. Scarcely 50 percent fell between 20 and 50 minutes, and only 80 percent were completed in less than 1½ hours. The mean time was 63 minutes but the modal time was 46 minutes. Samples of time records made by marked nectar-carriers are graphically illustrated in Fig. 5.

The maximum number of trips recorded in one day for a nectar-carrier was 24 in 1920 and 17 in 1921. The average number of trips per day was found to be 13½ in 1920 while in 1921 the average was only 7. If the mean time for round trips for each year be multiplied by the average number of trips per day for the same year, we arrive at an approximation of the average time per day spent in nectar gathering. This gives about 8½ hours for field work in 1920 and about 7½ in 1921.

DISCUSSION. - In order to compare the results obtained by the different workers, it is necessary to bring them together on some common basis. The various results have, therefore, been transcribed into figures which indicate the average number of trips per day, as follows:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Astor</td>
<td>85 trips</td>
<td>Huish</td>
<td>17 trips</td>
</tr>
<tr>
<td>demeure</td>
<td>50</td>
<td>Ludon</td>
<td>10</td>
</tr>
<tr>
<td>Lovell</td>
<td>46</td>
<td>Reaumur</td>
<td>6</td>
</tr>
<tr>
<td>Klaus</td>
<td>40</td>
<td>Girard</td>
<td>6</td>
</tr>
<tr>
<td>Zander</td>
<td>25</td>
<td>Sylviac</td>
<td>6</td>
</tr>
<tr>
<td>maujean</td>
<td>18</td>
<td>Demuth</td>
<td>4</td>
</tr>
</tbody>
</table>
Fig. 5. Time Records Illustrated.
In those cases in which sufficient data were given, the figures in the above list were calculated on the basis of a ten-hour day. Those marked with the asterisk (*) are based on the record of a single bee in each instance; while in the case of those marked with a cross (x) there was nothing to indicate whether the results were obtained from one bee or many.

Astor's 85 and Lovell's 46 trips were obtained from bees that were working under conditions that were equivalent to robbing, and it is well known that under such conditions, bees work with feverish haste. Furthermore, a bee can secure from a dish in 2 minutes, a load which it would scarcely be able to obtain from flowers in 10 minutes even under unusually favorable conditions. Data obtained under such abnormal conditions may be interesting enough but cannot be accepted as in any way representing the number of trips a bee will make under normal conditions of gathering from the flowers.

Of Demeure's 50 trips, we are told only that the record is based on the work of one bee for one day, and since the figure corresponds more closely to the results obtained under conditions of robbing than it does to those obtained under normal conditions, it cannot be given much weight. No details, are given in connection with either Klaus's 40 or Zander's 25 trips.

Maujean's 18, Huish's 17 and Luden's 10 trips per day are based on direct observations as probably are also the
6 trips of Reaumur, Girard and Sylviae. It will be noticed that these results are all below 20 trips per day and correspond very well with the results obtained during the present investigation. Huish's figure is for only one bee for one trip, hence it is not in itself very significant. Hanjean's figure is for one bee working one day. Nothing is known as to how Reaumur, Girard and Sylviae arrived at their figure but Reaumur's reputation goes far in giving weight to this result.

Luden's figure of 10 trips per day is based on records of six bees working for two days under absolutely normal conditions and, therefore, it cannot be refuted successfully. The bees were working on clover under honeyflow conditions slightly less favorable than those of 1920 when the writer found bees making an average of 13½ trips per day, by actual observation covering a period of nearly a week at one time.

Demuth's result of 4 trips per day is, obviously, too low to be representative. Being based on computations, his results probably are in error due to the influence of some unknown factor or factors, which are automatically excluded when direct observations are made.

Most of the results tabulated above fell naturally into two classes or series, one series running from 40 up, and the other from 25 down. In the light of all the data at hand, it appears most likely that figures showing 40 or more trips per day have been based on observations on bees working
under the robbing impulse and on that account cannot be accepted as the results of bees working naturally on the flowers. Zander's figure of 25 trips seems high for an average but compares favorably with the maximum of 24 trips found by the writer in 1920. Maujean's 16 and Huish's 17 are not averages but lend weight, nevertheless, in behalf of the latter series. Demuth's 4 trips is hardly comparable as has been pointed out already. Reaumur, Girard and Sylviac with 6 trips perhaps are not far wrong for poor honeyflow conditions. The results, found by the writer during the unfavorable season of 1921 showed an average of only 7 trips.

Luden's figure of 10 trips per day and the writer's two averages of 13 1/2 and 7, respectively, are in very close agreement. Considering the fact that honeyflow, weather conditions, and other factors have a great influence on the number of trips bees will make in a day, a considerable variation in results is to be expected. Under favorable conditions, 10 to 15 trips per day may be expected; under unfavorable conditions, anywhere from about 7 down; while, under exceptionally favorable conditions, bees will make 20 or more trips in a day.

CONCLUSIONS.— The time required for gathering a load of nectar varies greatly, but, under favorable conditions an hour is ample time for a nectar-carrier to make a round-trip. Ten trips per day under favorable conditions probably is as reliable as an average can be deducted from the data at hand.
The Nectar Carrying Capacity

REVIEW OF LITERATURE. — The carrying capacity of the honeybee has been investigated by a number of workers also. Astor (35, p.200) weighed bees carrying various dilutions of nectar and honey and obtained results showing that the loads varied from 60 to 85 mg. Commenting on Astor’s results, Hommell (35, p.200) remarks, "One sees that the weight of nectar is always a little less than that of honey because of its less density, and that the load may attain a weight equal to that of the insect, which is from 80 to 100 mg. But these loads are rare, especially when the bee works on the flowers. In a strong honeyflow, the average load would be about constant and vary between 45 and 60 mg. per trip. The load would vary, however, a great deal according to the abundance of the honeyflow. It may vary from zero to the maximum indicated, through all the intermediate values".

Hasty (40), using scales of his own devising, obtained figures which are equivalent to 97 mg. for the weight of an unloaded bee and 248 mg. for a loaded bee, a difference of 151 mg.

Koons (24) also attempted to determine the weight of honey carried by incoming bees. He weighed incoming bees and outgoing bees from the same hive and took the difference so obtained as the weight of the bee’s load. He used from 20 to 46 bees in each lot and figured their average weight. By this
method, he found 45 mg. as the greatest load, 10 mg. as the
smallest, and 22.5 mg. as the average.

Gillette (25), using methods similar to those em-
ployed by Koons, found 75 mg. as the minimum average weight for
outgoing workers. The lowest average for incoming bees was 113
mg. and the highest, 141 mg. Figuring as before the average
weight of loads varied from 38 to 66 mg. A single heavily
loaded individual weighed 155 mg., thus indicating a load of
about 80 mg., which is just about equal to the bee's own weight.

Lazenby (26) weighed sixteen incoming and sixteen out-
going bees. Each bee was weighed separately. Averages obtained
were 79 mg. for outgoing, and 94 mg. for incoming bees, and the
difference is 15 mg.

Maupy (35) obtained results in a different manner.
He collected and weighed the nectar which he forced the bees
to disgorge. In this way he found loads of 9, 33, 36, and 55 mg.
of nectar, and on a day of heavy honeyflow, one bee disgorged
132 mg.

Sylviac (35) attempted to arrive at the carrying capa-
city of the bee still by another method. He estimated the vol-
ume of the average honey-sac to be about 15 cu. mm. and the
density of new honey as 1.35. The maximum capacity of the
honey-sac would then be 20 mg.

Brummich (41) also estimated the capacity of the
honey-sac, stating that it "may contain about one decigram of
water." That would be 100 mg. of water, and if we use Sylviac's
estimate for the density of new honey, we obtain 135 mg. as a maximum load of nectar.

A statement which seems to have been rather generally accepted is that 1000 bees can carry 30 grams of nectar at one trip. The average load would then be 30 mg.

OBSERVATIONS. - Incoming bees which gave evidence of carrying nectar were selected, the purpose at this time being to determine the capacity of the bee to carry nectar rather than to find the average amount carried. Unless otherwise stated, 25 bees were used in each lot. The rest of the procedure was the same as that described for outgoing bees. Table V gives average weights of incoming nectar-carriers. From these averages, the gross weight of nectar loads was determined by deducting 82 mg. as a minimum flying weight. The two highest averages for gross loads of nectar found by the writer, were secured during the heartsease honeyflow, as may be seen from the table. By averaging a few of the heaviest loads so determined, it may be expected that the figure obtained will approach the average maximum nectar carrying capacity of the bee. If we take the mean of all averages of gross loads of nectar above 50 mg. we secure 65.3 mg. as the maximum nectar carrying capacity of the bee.
Table V. - Weights of nectar-carriers and their loads.

<table>
<thead>
<tr>
<th>Average weight in milligrams:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoming:</td>
<td></td>
</tr>
<tr>
<td>nectar-carriers:</td>
<td></td>
</tr>
<tr>
<td>bees</td>
<td></td>
</tr>
<tr>
<td>load</td>
<td></td>
</tr>
<tr>
<td>weighed</td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td></td>
</tr>
<tr>
<td>Gross</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>Nectar</td>
</tr>
<tr>
<td>source</td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>126.3</td>
<td>83.3</td>
<td>43.0</td>
<td>44.3</td>
<td>25</td>
<td>red clover</td>
</tr>
<tr>
<td></td>
<td>102.3</td>
<td>95.0</td>
<td>7.3</td>
<td>20.3</td>
<td>&quot;</td>
<td>heartsease</td>
</tr>
<tr>
<td></td>
<td>149.2</td>
<td>100.8</td>
<td>48.4</td>
<td>67.2</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>145.0</td>
<td>104.0</td>
<td>41.0</td>
<td>63.0</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>106.0</td>
<td>88.8</td>
<td>17.2</td>
<td>24.0</td>
<td>&quot;</td>
<td>coral berry</td>
</tr>
<tr>
<td></td>
<td>115.4</td>
<td>94.5</td>
<td>20.9</td>
<td>33.4</td>
<td>&quot;</td>
<td>heartsease</td>
</tr>
<tr>
<td></td>
<td>119.5</td>
<td>84.4</td>
<td>35.1</td>
<td>37.5</td>
<td>20</td>
<td>coral berry</td>
</tr>
<tr>
<td></td>
<td>121.6</td>
<td>82.5</td>
<td>39.1</td>
<td>39.6</td>
<td>25</td>
<td>heartsease</td>
</tr>
<tr>
<td></td>
<td>117.1</td>
<td>81.2</td>
<td>35.9</td>
<td>35.1</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>141.8</td>
<td>89.4</td>
<td>52.4</td>
<td>59.8</td>
<td>50</td>
<td>hard maple</td>
</tr>
<tr>
<td></td>
<td>120.8</td>
<td>100.4</td>
<td>20.4</td>
<td>38.8</td>
<td>20</td>
<td>dandelion</td>
</tr>
<tr>
<td></td>
<td>124.1</td>
<td>91.3</td>
<td>32.8</td>
<td>42.1</td>
<td>Average</td>
<td></td>
</tr>
</tbody>
</table>

From figures on gross loads, it would appear that the maximum nectar carrying capacity of the bee is approximately 65 mg. or nearly 80 percent of its own weight, with individual loads running as high as 73 mg. or 80, percent of the bee's own weight; while the heaviest load found for a bee carrying honey weighed 76.3 or 93 percent of the average weight of a bee.

It should be noticed that the figures in column four of the table are called gross loads and represent the total load carried by the bee, as determined by subtracting the factor 82 mg. from the weight of the loaded bee. The figures in column three were obtained by subtracting the weight of outgoing bees from that of the incoming nectar carriers taken from the same hive at the same time. They may be said to approximate the net load or the amount deposited in the hive by a bee at one trip.
As will be noticed from the table, the average of all net loads recorded by the writer was nearly 10 mg. less than the average gross loads determined from the very same bees. This means that the outgoing bees weighed nearly 10 mg. more than the average minimum flying weight. Why the outgoing bee should burden itself to the extent of one-fourth of its normal capacity or one-sixth of its maximum capacity is not clear. Before this problem can be discussed intelligently, it will be necessary to determine some other factors which are as yet unknown.

DISCUSSION. — Before entering into this discussion, it will be necessary to point out again the fact that there is a difference between the net load and the gross load carried by a nectar-carrier. During the present investigation it was found that outgoing bees carry with them an average of about 10 mg. of honey, hence the amount deposited which is the net load, is approximately 10 mg. less than the total or gross load carried in. So far as could be learned, all the figures cited from previous workers have been determined by deducting the weight of outgoing bees from that of the incoming bees, thus giving the net load.

The bees weighed by Astor had gorged themselves with stolen sweets and no doubt had loaded up heavily as bees are accustomed to do under such circumstances, so his results would not represent normal loads. His figure of 85 mg., however,
may be accepted as a maximum load. Hasty's weighings were made on scales of his own devising and the results, when compared with those from other sources, show clearly that the scales were inaccurate. His results must, therefore, be discarded.

The maximum and average net loads found by previous workers are given in Table VI.

Table VI. - Net loads of nectar.

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Net loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
</tr>
<tr>
<td>Astor</td>
<td>85 mg.</td>
</tr>
<tr>
<td>Koons</td>
<td>45</td>
</tr>
<tr>
<td>Gillette</td>
<td>80</td>
</tr>
<tr>
<td>Lazenby</td>
<td>43</td>
</tr>
<tr>
<td>Maupy</td>
<td>55</td>
</tr>
<tr>
<td>Average</td>
<td>62</td>
</tr>
<tr>
<td>Park</td>
<td>73</td>
</tr>
<tr>
<td>Grand Average</td>
<td>67 mg.</td>
</tr>
</tbody>
</table>

Of those tabulated above, Gillette's results probably represent the greatest number of weighings. The maximum load of 80 mg. which he records for a single individual corresponds with a load of 76 mg. found by the writer in the case of a single robber bee which carried honey and not nectar. His average of 50 mg. is considerably higher than any other in the same column and is nearly double the average load of 33 mg. found during this investigation.
Koon’s figures are based on comparatively few weighings and should not be given too much importance. No doubt they are accurate for the bees he weighed, but conditions probably were not favorable for securing large loads from the flowers at that time. Maupy’s figures appear to have been based on a very limited number of weighings. His one record of 132 mg. for the load of a single bee can scarcely be accepted since it is so vastly greater than any other reported. Lazenby weighed only 32 bees all told, 16 outgoing and 16 incoming, each weighed separately, so his results do not show as wide a range nor as high an average as might be expected from a larger series of data.

The average for maximum loads as found from these data is 62 mg. which is exactly double the average of average loads. It is interesting to note that in the results obtained in the present study, the maximum net load was found to be 75 mg. which is only a little more than twice the average net load found. It may also be pointed out that the grand average of 32 mg. for average net loads, directly supports the oft quoted statement that 1000 bees can carry about 30 grams of nectar at one trip.

CONCLUSIONS. - The maximum capacity of the Italian bee to carry nectar is almost equal to the bee’s own weight. The average weight of net loads is about 30 mg. or three-eighths of the minimum flying weight.
Pollen Gathering

Pollen is no less essential to the honeybee than is honey, because brood cannot be reared without it. It is not used in such great quantities as honey but a colony deprived of pollen is doomed as certainly, although less speedily than one which has no honey. In fact it may be said that its doom is even more certain, because bees can thrive on substitutes for honey such as cane sugar, while up to the present time no substitute has been found for pollen. Rye meal and various other pulverized cereals, have been advocated and success is often claimed from their use. In times of scarcity, the bees do carry such materials to the hive and store them in the comb. It has never been definitely established, however, that any such substitute has actually been used by the bees in the elaboration of larval food.

It has been claimed by some that pollen is needed by adult bees when secreting wax, but Huber (30) found by a series of experiments, that bees fed on nothing but honey and water produced wax, while if only fed on pollen, none was produced. Neither is it positively known that adult bees use pollen for their own consumption although it is generally supposed that they can and probably do make use of it in this way, at times. It is known, however, that adult bees winter better on stores that contain no pollen than on those that do.

According to Langstroth and Dadant (22, p.60) a young bee's first visit to the flowers occurs when it is about fifteen days old when she brings in a load of pollen. It may
be observed that the pollen carried by a bee at one load is always uniform in color and texture, showing that the bee gathered from one kind of flower exclusively. The fidelity of a bee to her flower was noticed by Aristotle (4, p.85).

The great importance of the honeybee as a fertilizing agent depends largely on this fidelity. The value of the honeybee in this connection can not be computed, but it has been remarked repeatedly that the honeybee is of more value to agriculture in general than to apiculture in particular.

Time Factors

REVIEW OF LITERATURE. - Aside from a few very general and indefinite statements (20, p.195, 197, 221, 222), no data have been found in bee literature on the time required for a bee to gather a load of pollen, except a brief statement by Huish (9, p.352) whose "Treatise on Bees" was published in 1815. The paragraph referred to, follows:

"In regard to the number of journeys which a bee can make in a day, no positive data can be laid down, as it depends in a great measure on the distance of the food. Some criterion may however be formed from the following circumstances. I, one day visited my hives when the weather was very cloudy, and the bees were kept prisoners at home. Being detained near the apiary for about an hour, the weather in that time became fine, and the bees were seen crowding from the hives into the fields. I sprinkled some of the bees with flour, and taking my watch in my hand, and observing the exact moment of their departure, I waited until their return. A quarter of an hour elapsed before the first returned, and both its legs were well loaded with farina (pollen). It was however, thirty-five minutes before the last returned, but without any farina. I was however convinced, from the shape of the body, that it had been in pursuit of honey, and this circumstance gave me reason to believe that the bee which collects farina, will make many more journeys in a day than that which collects honey, and perhaps in the proportion of five to two".
OBSERVATIONS. - Time records for field-trips, hive-stays, and round trips by bees gathering pollen from corn were secured in 1920 and again in 1921. The weather conditions in both instances were favorable enough for the production of pollen by the plant and for field work on the part of the bee. But in 1920, the data were taken at times when there was an abundance of corn in bloom, whereas, in 1921 the main period of bloom had passed before the records were obtained. We have, then, as for nectar-carriers, one set of data secured under favorable conditions, and the other under less favorable conditions. The records for the two seasons have been plotted against each other in the form of frequency curves which appear in Figs. 6, 7 and 8. In every case the curve is a decided skew, so for purposes of comparison, the mode is used in preference to the mean.

Field-trips by pollen-bearers were found to be considerably shorter as a rule than those made by nectar-carriers. As shown in Fig. 6, almost 40 percent of the field-trip records for 1920 fell within the 6-10 minute class, and 97.5 percent were completed in 30 minutes or less. None of the 1921 records for field-trips fell within the 2-6 minute class, and only 20 percent fell within the 6-10 minute class, yet 99 percent were accomplished in 30 minutes or less. The modal time, however, was 15.5 minutes as against only 8.6 minutes in 1920.
Fig. 6. Field Trips by Pollen-Carriers

Percent

Minutes

1920
1921

No. 223-M-2
THE COLE CO., COLUMBUS, OHIO.
Fig. 7. Hive Stays by Pollen-Carriers
The curves for hive-stays appear in Fig. 7, and are very similar for the two seasons. The peaks both fell within the 2-4 minute class. In 1920, this class received 38 percent of the records as against 36 percent in 1921, but the percentage of hive-stays that occupied 15 minutes or less was 98 in 1921 as against 88 in 1920. The most frequent interval spent in the hive between trips was 3.4 minutes in 1920 and 3.7 minutes in 1921.

In Fig. 8, we have the curves for round-trips. The modal interval for the 1920 records was 12.6 minutes but was 16.5 minutes in 1921. The percentages of records falling within the modal class were nearly the same in both cases. In fact, the two curves are much alike as to area and shape, but the one for 1921 stands about 4 minutes farther to the right than does the other. This indicates in a general way that the bees that gathered corn pollen during the period of observation in 1921 consumed about 4 minutes per trip more than did those in 1920 when corn pollen was more plentiful.

The maximum number of trips recorded in one day for a bee gathering pollen from corn was 20 in 1920 but only 11 in 1921 while the averages were about 8 and 5½, respectively. As a rule, corn pollen was not available in the afternoon so these figures represented only about half a day in actual working time.
DISCUSSION. - As in the case of nectar gathering it is clear that the time required to gather a load of pollen is influenced by the numerous factors which go to make up what we call favorable or unfavorable conditions. Most of these factors were pointed out in connection with nectar gathering and will be passed over here. It may well be mentioned, however, that humid, cloudy days, if not too cool, seem to be more favorable for pollen gathering than hot sunny days which are to be desired for nectar gathering. The reason for this is that on a hot sunny day the anthers of the flowers shed their pollen quickly so that by noon or before, no more pollen is available, whereas, on humid, cloudy days the flowers continue to yield pollen most of the day. The kind of flower is another factor which has much to do with the length of time required for a bee to get its load of pollen. Other things being equal, a load of pollen can be gathered more quickly from corn or ragweed than from clover or heartsease because of its greater abundance and ease of access.

With reference to the data given herewith, it is noteworthy that in both 1920 and 1921, practically all the field-trips made by bees carrying corn pollen, were completed in less than 30 minutes. Huish's observations corresponds with this figure. The influence of the less favorable conditions in 1921 showed up mostly in lengthening the field-trips which is just what might be expected. The poor season made very little difference in the length of the hive-stays. It seems almost strange
that the number of trips made by pollen-carriers should have been so small when such a comparatively short time was required for each trip. It should be pointed out, however, that the amount of pollen available often began to decrease rapidly after about 9 a.m. because of the hot dry weather.

With reference to Huish's estimate of 5 to 2 for the ratio of pollen trips to nectar trips, it may be stated that if this ratio held true, pollen-carriers should have made 32 trips per day in 1920 and 16 in 1921 when nectar-carriers were found to average 13 and 7 respectively. No doubt Huish assumed pollen would be available as much of the day as nectar, but this is not often the case.

CONCLUSIONS.- The time required for a pollen-carrier to make a round-trip varies greatly, but under favorable conditions, they are commonly made in a quarter of an hour and often in less time. The number of trips per day is not great as a rule, because pollen seldom is available for more than a few hours each day; consequently an unqualified statement for the average number of trips made in a day by pollen-carriers would scarcely be justified.

Loads Carried

REVIEW OF LITERATURE.- According to Hommell (55, p. 178), Reaumur found that from 150 to 155 pellets of pollen were required to weigh a gram. On this basis, two pellets would weigh 13.2 mg, and about 75000 loads would be required to make a pound. Richards, also cited by Hommell, found that the weight of a pellet of pollen varies from 4.6 to 8.3 mg. Then a load consist-
ing of two pellets would weigh from 9.2 to 16.6 mg., with a mean of 12.8 mg. Gillette (25) and Lazenby (26) found 11.3 and 6.0 mg., respectively for average loads of pollen.

**OBSERVATIONS.** - Incoming pollen-bearers which carried large loads of pollen were selected in order to determine the pollen carrying capacity of the bee. As a rule, 25 bees were caught and weighed as in other cases already described. The pollen loads were then removed and the bees weighed again. The difference between these two weighings gave the weight of the pollen load. The averages obtained appear in Table VII.

<table>
<thead>
<tr>
<th>Loaded pollen-carriers</th>
<th>Unloaded pollen-carriers</th>
<th>Pollen load</th>
<th>Number of bees</th>
<th>Pollen source</th>
</tr>
</thead>
<tbody>
<tr>
<td>96.6</td>
<td>83.4</td>
<td>13.2</td>
<td>25</td>
<td>corn</td>
</tr>
<tr>
<td>97.2</td>
<td>81.9</td>
<td>15.3</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>89.4</td>
<td>78.7</td>
<td>10.7</td>
<td>7</td>
<td>&quot;</td>
</tr>
<tr>
<td>98.2</td>
<td>80.0</td>
<td>18.2</td>
<td>25</td>
<td>red clover</td>
</tr>
<tr>
<td>102.0</td>
<td>82.0</td>
<td>20.0</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>95.9</td>
<td>83.4</td>
<td>12.5</td>
<td>25</td>
<td>heartsease</td>
</tr>
<tr>
<td>102.0</td>
<td>84.0</td>
<td>18.0</td>
<td>20</td>
<td>red clover</td>
</tr>
<tr>
<td>98.5</td>
<td>85.5</td>
<td>13.0</td>
<td>25</td>
<td>elm</td>
</tr>
<tr>
<td>112.2</td>
<td>83.2</td>
<td>29.0</td>
<td>50</td>
<td>hard maple</td>
</tr>
<tr>
<td>111.9</td>
<td>89.6</td>
<td>22.3</td>
<td>25</td>
<td>apple</td>
</tr>
<tr>
<td>106.4</td>
<td>81.3</td>
<td>25.1</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>103.4</td>
<td>84.8</td>
<td>23.6</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>117.3</td>
<td>90.2</td>
<td>27.1</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>113.5</td>
<td>86.2</td>
<td>27.3</td>
<td>25</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Average 83.9 mg. 19.7 mg.

# These bees carried an average of 4 mg. of nectar.
It will be seen that weights found for pollen from a given source do not vary greatly, but that there is a great difference in the weight of loads obtained from different sources. Tabulating the pollen loads according to sources, we have:

<table>
<thead>
<tr>
<th>Source</th>
<th>Loads (mg)</th>
<th>Average (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn pollen</td>
<td>13.2, 13.2, 15.3, 10.7</td>
<td>13.2</td>
</tr>
<tr>
<td>Red clover pollen</td>
<td>18.2, 20.0, 18.0</td>
<td>18.7</td>
</tr>
<tr>
<td>Apple pollen</td>
<td>22.3, 25.1, 23.6, 27.1</td>
<td>25.1</td>
</tr>
<tr>
<td>Hard maple pollen</td>
<td>29.0</td>
<td></td>
</tr>
<tr>
<td>Elm pollen</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Heartsease pollen</td>
<td>12.6</td>
<td></td>
</tr>
</tbody>
</table>

The loads carried from corn apparently were just as large as those from apple or hard maple, but they weighed only half as much. It appears then that there must be a great difference in the specific gravity of various pollens. In the
case of heartsease pollen, however, large loads are seldom secured by the bees. Of the sources from which the bees carried large loads, elm and corn were found to be the lightest, while hard maple gave the heaviest average load, with apple a close second. All of the weights of pollen loads given by Gillette (25) and Laazenby (26) are rather low. This may be due to the lightness of the pollen carried.

As the heaviest average gross weight recorded for incoming pollen-bearers is only 113.5 mg., as against a much greater weight for incoming nectar carriers, it would appear that the limiting factor in a bee's capacity to carry pollen must be its inability to pile up and hold in its pollen baskets, a bulk beyond a certain limit. It is possible, also, that the position of the pollen load on the body makes it more difficult for the bee to fly than is the case when the load is carried in the honey-stomach.

The maximum pollen loads appear to be about one-third of the weight of the bee and less than one-half as much as the maximum nectar load.

DISCUSSION. - It has just been pointed out that pollen loads from different sources vary a great deal, corn pollen averaging 13 mg. as against 29 mg. for hard maple, while other pollens give still more averages. Since the kind of pollen weighed by previous workers has not been specified, it is impossible to judge of their probable accuracy or even make careful comparisons between their results and those obtained by the
About the only thing that can be done is to tabulate their results, using the grand averages obtained in the present work for comparison with them, thus:

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Average weight of pollen loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaumur</td>
<td>13.2 mg.</td>
</tr>
<tr>
<td>Richards</td>
<td>12.8</td>
</tr>
<tr>
<td>Gillette</td>
<td>11.3</td>
</tr>
<tr>
<td>Lazenby</td>
<td>6.0</td>
</tr>
<tr>
<td>Park</td>
<td>19.7</td>
</tr>
</tbody>
</table>

The average obtained in the present work is considerably greater than any of the others but the difference in the kinds of pollen may easily account for such a difference. The figure 6 mg. given by Lazenby seems particularly low. Perhaps pollen was scarce when he made his weighings or else he may have chanced to get hold of unusually small loads. At any rate his figures are based on weighings of only a few bees, so cannot be assigned much importance. The other three figures, 11.3, 12.8, and 13.2 mg., likely were obtained from bees carrying pollen from corn or some other plant whose pollen has a low specific gravity.

CONCLUSIONS. - Pollen loads apparently differ according to the source, ranging in weight from 6 to 30 mg. Maximum loads appear to be about one-third the weight of the bee and less than one-half as much as the maximum nectar load.

WATER CARRYING

Everyone is familiar with the fact that bees visit watering places, and no doubt there are those who have never given the matter a second thought but take it for granted that all animals drink water to slake their thirst. Indeed, Cotton(20)
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...0.298) says, "In the Isle of Wight, the people have a notion that every bee goes down to the sea to drink once a day". But it was pointed out by Aldamiri (20, p.348) as long ago as 1405, in a passage already quoted, that some bees are water-carriers. The first time the writer watched (in an observation hive) the activities of the water-carriers as they came in heavily loaded and proceeded to give drink to this bee and that, he was reminded of the well known small boy who earned admittance to the circus by "carrying water to the elephants".

Time Factors

REVIEW OF LITERATURE. - Langstroth (4, p.544) says, "that bees cannot raise brood without water has been known since the times of Aristotle". Butler (42, ch.6, paragraph 53), whose quaint old book was published in 1623, was of the opinion that bees needed water chiefly for their brood, for he had observed that "when the drones are done away and breeding is ended, the bees are nothing so frequent at the watering places."

Buera of Athens (20, p.104), about the year 1797, wrote, "bees daily supply the worms with water; should the state of weather be such as to prevent the bees from fetching water for a few days the worms will perish". Sydserff (20, p.190) writing in 1792, mentioned the "bladder or bag in which the bee fetcheth water to mix up the bee-bread for feeding the young; in this bag also they carry their honey".

According to Hommell (35, p.162),"it is always the younger bees which, at the time of their first flights, are charged to search for water, and, if the weather is bad, they
perish in large numbers. By the aid of balances, De Layens found, from this cause, a mortality of from 3,000 to 3,500 bees from a single very strong colony in a single day". Hommell also mentions the experiments of De Layens from which it was found that 40 colonies consumed 187 liters of water between April 10 and July 31, a period of 112 days, the greatest quantity taken in one day being 7 liters. This was exclusive of whatever water the bees may have obtained from other sources. He found the consumption of water to be inversely proportional to the intensity of the honey gathering. Hommell gives 25,000 as the number of trips required to transport one liter of water. That would call for average loads of 40 mg.

Observations. - So far as the writer is aware, no data have been published previously on the time required for water-carriers to make their trips or the number of trips they make in a day.

On the afternoon of August 17, 1921, which was after the close of the honeyflow, a number of bees suspected of being water-carriers were caught and submitted to the test described earlier in this paper. Seven of those which were shown by the test to be water-carriers, were marked and released. Of the seven, three made no more trips that day but the other four made from 3 to 8 trips each. The hive entrance was carefully watched by two observers from early morning until late evening on August 18 and 19. Observations were begun again on the 20th but the
day was so cool that very few bees left the hive and at 10:30 a.m. observations ceased. In the afternoon of that day, the entrance was watched from 1:30 to 3:05 p.m. when the bees practically ceased flying. No further observations were attempted until August 24, when the entrance was watched from 8:45 until noon, when, on account of the inactivity of field bees, the series of the observations was ended for all.

Very little brood was being reared at that time and the weather was exceptionally cool for August, so the data secured can scarcely be considered representative in the matter of average number of trips per day. The results found for average time spent in making field-trips, hive-stays and round-trips, however, probably are not very different from results which might be obtained under conditions which would induce the water-carriers to work longer hours. And the maximum number of trips found in this experiment for one bee in a day, perhaps might be found to be only slightly above the average under conditions of warmer weather and heavy brood-rearing.

The number of trips made by each bee on each day during the period of observation is given in Table VIII.

<table>
<thead>
<tr>
<th>Bee</th>
<th>Aug. 17#</th>
<th>Aug. 18</th>
<th>Aug. 19</th>
<th>Aug. 20#</th>
<th>Aug. 24#</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 94</td>
<td>8</td>
<td>51</td>
<td>111</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>95</td>
<td>3</td>
<td>48</td>
<td>28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>96</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>97</td>
<td>5</td>
<td>31</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>98</td>
<td>-</td>
<td>10</td>
<td>46</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>99</td>
<td>-</td>
<td>40</td>
<td>14</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>*100</td>
<td>5</td>
<td>32</td>
<td>33</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Average 31 46

# Records are for part of a day only.
* This bee was found to be going a distance of two-thirds of a mile to obtain salt water in preference to the fresh water available within a few yards of its hive.
Of the five days on which data were taken, only two can be recognized as in any way representing normal conditions. On the 18th, all seven bees made trips for water and the average for all seven was 31 trips, with 51 as the maximum for that day. On the 19th, bees 96 and 97 failed to show up and were not seen again. Whether they lost their marks or their lives, or both, no one will ever know. But the other five averaged 46 trips, with No. 94 making 111 which was the greatest number recorded for one bee in a day.

The detailed time records obtained for field-trips, hive-stays, and round-trips for water-carriers are graphically summarized in Fig. 9. As would be expected, the time required for a bee to secure a load of water is quite short-only about three minutes—when the supply is near the apiary as was the case when these data were secured. As may be computed from Fig. 9, 67 percent of all recorded field-trips for water were completed in 3 minutes or less, and 92 percent in 10 minutes or less.

The time spent in the hive by water-carriers was found to be from 2 to 3 minutes as a rule and very seldom did one remain as long as 5 minutes. The percentage of hive stays which occupied 3 minutes or under, was 54; 5 minutes or under, 79; and 10 minutes or under, 95 percent. And the longest hive-stay was only 15 minutes.

The most frequent time interval consumed by water-carriers in making round-trips was between 5 and 6 minutes, as may be seen from Fig. 9. Fifty percent of all round-trips
Fig. 9

Trips by Water Carriers

Field
Hive
Round Trip

Minutes

Percent
were completed in 6 minutes or under, 77 percent in 10 minutes or under, and 91 percent in 15 minutes or less. Thus it is seen that less than 10 percent of all round-trips recorded were of more than a quarter hour duration.

DISCUSSION. - The need for water for the elaboration of food for the larvae has already been pointed out. According to Langstroth and Dadant (22, p.101), "They can raise a certain amount of brood without water, but they always seem to suffer more or less in consequence". Observations on colonies wintered in observation hives in the writer's office for several winters indicate that it is only with great difficulty that a colony housed in a warm dry atmosphere is able to produce even a few cells of brood so long as they have no access to water. In two distinct instances, observation colonies attempted to rear brood so early in the spring that they were unable to secure water. Hundreds of eggs were laid but barely two or three ever matured into adult bees. But in both cases, as soon as water was supplied to them they began to rear brood without further difficulty. It is possible that a colony more numerous in bees might have succeeded better in rearing brood without water. And no doubt some of the cases in which bees have been found to rear brood at times when they could not fly from their hives, can be explained on the grounds that moisture from the respiration of the bees themselves probably condensed inside the hive and thus supplied the needs of the colony.
Berlepsch and Eberhardt (4, p.342.) have stated, "The Creator has given the bee an instinct to store up honey and pollen which are not always to be procured, but not water, which is always accessible in her native regions". While it probably is true that bees do not store water in the same sense that they store honey and pollen, it has been observed by the writer (45) that during early spring when bees were able to obtain water only on occasional warm days, they carried it feverishly during the first good flight day; but carried little or none the next day even though the day was pleasanter and water readily accessible. It was observed further that the water-carriers did not deposit their loads in the comb, but transferred them to other bees which served as "reservoirs" for the colony.

A somewhat similar phenomenon is known in the case of another Hymenopterous insect, the Honey-ant. In this species, certain workers having enlarged abdomens serve as storage vats for a sort of honey which the other workers collect from oak galls. And, according to Comstock (44, p.462), "When the season for obtaining this food is past, these living cells disgorge their supply through their mouths for the use of their hungry fellows".

The writer does not care to go into a discussion concerning the loads carried by water-carriers because of insufficient data.

CONCLUSIONS. - Water is needed by bees in order to rear brood.
Water is sometimes stored in the honey-sacs of numerous bees of the colony, usually in combination with honey.

A water-carrier can make a round trip in from 5 to 10 minutes when the supply is near at hand.

A water-carrier sometimes makes 100 or more trips in a day, but the average is probably less than 50 trips per day.
SUMMARY

1. Of all the various methods for marking honeybees, tried by the author, the one best adapted to the needs of the present investigations was that of applying one or two spots of pigment combined with white shellac in alcohol.

2. A simple system of recording time data on field bees was developed which permitted the work of recording to be reduced to a minimum.

3. An entrance contrivance of simple construction was devised which, when placed in the entrance of a hive, caused practically every incoming and outgoing bee to pass through the entrance right side up.

4. A convenient method was discovered for distinguishing between nectar-carriers and water-carriers without injury to the bee.

5. The minimum flying weight of the Italian bee, as determined by three different methods, was found to be approximately 82 mg.
6. The average speed found for the flight of worker bees during a calm, was a little less than 15 miles per hour.

7. The time required for gathering a load of nectar varies greatly, but, under favorable conditions, 1 hour has been found ample time for a nectar-carrier to make a round-trip.

8. Ten trips per day, under favorable conditions, probably is as reliable an average as can be deduced from the data at hand.

9. The maximum capacity of the Italian bee to carry nectar is almost equal to its own weight.

10. The average weight of net loads of nectar is about 30 mg, or approximately three-eighths of the minimum flying weight.

11. The time required for a pollen-carrier to make a round trip varies greatly, but, under favorable conditions, such trips are completed in a quarter of an hour or less, on the average.

12. The number of trips made by one pollen-carrier in a day is not great as a rule, because pollen seldom is plentiful for more than a few hours each day; consequently an unqualified statement for the average number of trips made in a day would scarcely be justified.

13. Pollen loads apparently differ according to the source, ranging in weight from 6 to 30 mg.

14. Maximum loads are about one-third the weight of the bee and less than one-half that of maximum nectar loads.
15. Water is necessary for brood-rearing.

16. A water supply sufficient for the needs of the colony for several days is sometimes stored in the honey-sacs of numerous bees of the colony, usually in combination with honey.

17. A water-carrier can make a round-trip in about 6 minutes on the average, when the supply is near at hand.

18. A water-carrier sometimes makes 100 or more trips in a day, but the average is probably less than half that number.
LITERATURE CITED

29. Cheshire, Frank R. Bees and Beekeeping. 1:139, 1866.