Translation

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Christopher K. Starr, July 2025

Contents of volume 2

CHAPTER VIII. ON THE RESPIRATION OF BEES. (pp 309-362)

The same air that destroys everything in time, also has a salutary effect on organized beings. Plants modify it in their way and, just like animals, owe to it their very existence. Air is an indispensable element of all living things. Should we suppose, then, that insects are somehow exempt from this universal law? We know that all animals, from quadrupeds all the way down to mollusks, break down this fluid, combine the respirable component with the ubiquitous carbon, and exhale it in a new form that arises from their lungs or gills, that the heat needed for existence is released at the moment of decomposition, etc.

This well-known phenomenon is of such broad generality that it seems unlikely to admit of exceptions. Still, a fact that has received too little attention presents us with circumstances that are hard to harmonize with prevailing ideas. If there were insects that lived -- without evident distress -- in very large numbers in enclosed spaces that do not readily change their air supply, the respiration of such insects would present us with a novel problem.

This is precisely the singular condition of honey bees. Their hive, the volume of which is not more than one or two cubic feet, harbours a multitude of active, hard-working individuals. The doorway to their domicile is always very small and often obstructed by a mass of bees entering and departing in the busy summer season, yet it is the only route by which air can enter. Nonetheless, it evidently serves their needs. Furthermore, the hive, sealed inside with wax and propolis by the bees themselves and fitted outside through the beekeeper's efforts, provides none of the conditions to maintain a natural air current.

Seen in proportion, theatres and hospitals present much less of an obstacle than does a beehive to keeping the air fresh. After all, if a building has just a single doorway that is not situated so as to facilitate the exchange of air between the outside and inside, the air cannot be renewed. This is shown by the following experiment in which, even if the hive doorway is much larger, outside air does not penetrate the interior in the absence of a separate force.

Take a box or glass vase of the volume of a hive with an opening at the bottom somewhat larger than normal in a beehive. Place it on a solid platform and put a lit candle inside. Within a few minutes, the flame will weaken, turn bluish and then go out. Fresh air does not come in quickly enough to keep the candle burning, because there is no opposing opening to allow a flow of air through the container.

If one were similarly to enclose a large number of insects or other small animals, this would provide a more exact analogy than the lit candle. So, why do we not see a comparable misfortune in a hive full of bees? How is it that these insects do not perish where a candle could not keep burning? Are they constituted so differently from nature as a whole, or is their respiration so very different from that of other animals? Or do they, perhaps, not respire at all?

It is hard to imagine a situation more sharply opposed to the general order of things. However, motivated by considerations that are explained below, I wished to know if it might be of some interest to those more enlightened than me. I had already expressed by doubts to Mr Charles Bonnet who, surprised by the singular nature of this problem, urged me to give it my attention. I regret that Mr Bonnet's death has deprived me of the satisfaction of communicating my results to him, but I did report them to a renowned physicist, whose enthusiastic response encouraged me to further investigations. Mr [Horace-Bénédict] de Saussure listened with interest to the details of my experiments, and our conversation gave me added confidence and motivation to continue.

Having little expertise in the analysis of gases, however, I would have been hard pressed to succeed in this area if not for the able assistance -- as I have noted elsewhere -- of Mr [Jean] Senebier. To my good fortune, he was willing to take an active part in my experiments and to devote time to the eudiometric tests required for my researches. As a confidant of Mr [Lazzaro] Spallanzani, who studied respiration in insects, Senebier was aware -- as I was not -- of the agreement between Spallanzani's observations and my own.

The Pavia professor had applied that active intelligence for which he is known to understanding the respiration of both insects and reptiles, both at rest and active. He compared the two groups, examining the effects on air composition of whether an animal is alive or dead, etc. His work as a whole shows unequivocally that insects respire and that they consume and degrade the air, proportionally, more than other animals, even that their dead bodies give off carbonic acid gas.

In my own experiments on honey bees, I had the advantage of being able to work on a larger scale, as it is easy enough to put a considerable number of these insects together in a single vessel. These tests gave rise to circumstances that put a sharper point on a particular problem and led to results as satisfying as those of my Italian colleague.

Part II. Proofs that bees respire

In order to proceed methodically, we began by observing the effects on adult bees of the presence or absence of different gases, later carrying out the same tests on larvae and pupae. We also deemed it advisable to examine with renewed care the external breathing organs.

These first attempts were intended to reveal whether bees are somehow differently constituted in this respect from all other animals. If they have no need to breathe, they should remain unaffected by the effects of a vacuum pump and should remain alive just as well in a hermetically sealed chamber as in the open air. In short, they should be quite indifferent to any change in the air around them.

<u>1st experiment</u>

We began by putting some bees into the vacuum chamber. The first few strokes of the piston did not appear to affect them, so that for a time they continued walking and flying as before. Then, before the mercury in the test tube reached three lines above the level, the bees fell to the ground and remained motionless. However, they were merely unconscious and recovered fully on exposure to the air.

The following experiments corroborate our results from the vacuum tube, and their scrutiny shows conclusively that a certain quantity of air is indispensable to these insects.

<u>2nd experiment</u>

I wanted to know the effect on bees of a non-renewable atmosphere and at the same time to judge how the bees affect the quality of the air around them.

I selected three bottles of 16 fluid ounces, containing only fresh air. I introduced 350 worker bees into the first, the same number into the second, and 150 drones into the third. The first and third were tightly sealed. The second, which served as a basis for comparison, was closed only enough to keep the bees from escaping.

We began the experiment at noon. At first we noted no difference between the bees in the sealed vessels and those with access to ambient air. They all seemed impatient in their captivity, but gave no sign that they were suffering. At 12:15 the bees in the sealed vessels started to show some distress. Their [abdominal] segments contracted and expanded more rapidly, and the vapour clinging to the vessel walls show that they were exhaling a great deal.

At 12:30 the cluster of bees hanging from the honey-smeared blade of straw suddenly came apart. They all fell to the bottom and were unable to rise. By 12:45 all were asphyxiated. We then took them out of the enclosure to expose them to fresh air, and within a few minutes the workers had regained their power of movement. The males, however, manifested more serious effects of the enclosure to which we had subjected them, and none recovered.

The bees in the second vessel, into which air could enter freely, showed no ill effects.

We analysed the air from the hermetically sealed vessels, in which the bees had fallen motionless, and found it much altered. When other workers were enclosed with this air they were quickly asphyxiated. A candle was also extinguished by such air. And a sample of the air stirred in water was found to be diminished by 14%; it precipitated the lime [calcium carbonate] in lime water [calcium hydroxide solution], lettuce seeds would not germinate, and eudiometric tests with nitrous gas [nitrous oxide] showed an almost complete exhaustion of the gaseous oxygen (eudiometric tests 1).

<u>3rd experiment</u>

In order to determine whether the absence of oxygen had been responsible for the bees' immobility and whether its presence had accounted for their revival when removed from the enclosure, I undertook the following experiment.

I poured nine ounces of water into a 10-ounce tube, keeping the last ounce for bees, which were separated from the water by a sheet of cork. At this point the bees were in communication with the ambient air. Once the vessel was sealed, as in the previous experiment, the air became degraded and the bees were soon asphyxiated. Then I opened the lower part of the tube below the hydro-pneumatic tank to introduce a measure of oxygen.

This test gave a decisive result. As soon as the [oxygen] gas reached the part occupied by the bees, we observed some slight movements of the proboscis and antennae, while the abdominal segments resumed their pulsations. And a new dose of oxygen restored them to normal activity.

<u>4th experiment</u>

We enclosed some other bees in an atmosphere of pure oxygen. They remained active eight times as long as those in ordinary air, a very striking result. However, these, too, ended up asphyxiated after converting all of the oxygen into carbon dioxide (eudiometric tests 2).

We analyzed two cubic inches of the gas produced by 50 bees placed in an oxygen atmosphere for five hours. Approximately 2¼ grains of lime [calcium oxide] precipitated from lime water [calcium hydroxide solution].

<u>5th experiment</u>

When placed in carbon dioxide extracted from lime, bees immediately fell insensible, although they revived quickly in fresh air.

<u>6th experiment</u>

When placed in nitrogen gas obtained by mixing sulphur with corroded iron filings, the bees perished immediately and irrevocably.

7th experiment

Placing bees in hydrogen gas extracted from zinc produced the same result.

8th and 9th experiments

We placed bees in an artificial atmosphere of three parts hydrogen to one part oxygen, with a combined volume of six fluid ounces. During the first 15 minutes there was no change in their condition, but after that their strength diminished, and after an hour they were motionless and lifeless.

In an atmosphere of three parts nitrogen (extracted from sulphur and corroded iron filings) to one part oxygen, the bees likewise perished immediately.

It would be quite superfluous to seek new proofs that bees respire. Even so, before leaving this subject we wanted to be sure of the effects of these and other factors on the bees when chilled.

10th experiment

We enclosed some bees in a glass receptacle surrounded by crushed ice. A thermometer placed in the vessel fell from the ambient temperature of 14° to 6° above freezing. It was at this point that the insects began to be chilled. We then removed them and placed them in tubes filled with the gases that had been so fatal in early experiments and left them there for three hours. At the end of this time, they returned to life when placed on my warm hand and gave every sign of a full recovery.

This experiment is conclusive. The cause of death in the previous tests could not have been the degraded air, as this had no such effects in the present experiment. Rather, it was the entry of these gases into the respiratory channels, as was shown by their viability in these same gases when the function of their organs had been arrested by chilling.

11th experiment

We subjected the eggs, larvae and pupae to the same experiments as the adult bees, with entirely the same results. This demonstrated the consumption of oxygen and the production of carbon dioxide.

12th experiment

Two larvae in a medium of nitrous gas and carbon dioxide resisted the deleterious effects better for a short time than the adult bees would have done.

13th experiment

Pupae subjected to the same gas mixture survived in only a few cases (eudiometric tests 3).

14th experiment

When eggs were placed in air that had been breathed by adult bees, they lost all ability to develop. However, larvae and pupae slowed by cold tolerated such an altered atmosphere for several hours without ill effect.

These experiments show that immature bees also respire, which indicates that they are subject to the same laws as the adults. This was to be expected, since [Jan] Swammerdam had already detected three pairs of spiracles on the thorax and seven pairs on the abdomen in pupae.

I thought it important to be certain that these same organs remained in the adult insect. I will report here the results of experiments in this question. To that end I utilized the well-known technique of immersion in fluid, which I warmed lightly to avoid chilling the insects.

15th experiment

I will give here only the main results. If the head only is submerged in water or mercury for half an hour, the bee does not appear to suffer any ill effects.

16th experiment

If, on the other hand, one leaves only the head above the fluid, the insect stretches out its proboscis and rapidly asphyxiates.

17th experiment

If we submerge the head and thorax, leaving the abdomen free in the air, the bee wavers for a few moments and then ceases all signs of life.

18th experiment

As the head and abdomen appear insufficient to serve the bee's respiratory needs, the organs of air exchange must have their openings on the thorax. We demonstrated that this is the case by the experiment of simultaneous immersing the head and abdomen, leaving only the thorax free in the air. The bee bore this trial -- which certainly must have been unpleasant for her -- patiently enough and took flight as soon as we released her.

<u>19th experiment</u>

If we submerge a bee completely in water, she soon asphyxiates, and it is under these conditions that one can best observe the working of the spiracles. Four bubbles of air appear on each side: two between the neck and the bases of the wings, a third on the neck near the base of the proboscis, and the fourth at the posterior end of the thorax alongside the waist that connects the thorax and abdomen. These bubbles do not immediately rise to the surface of the water, as if the bee were trying to hold them back. The bubbles can be seen being drawn back in through the spiracles several times. They only float away when they have enough volume to overcome the resistance of the breathing organs or the adhesion of the spiracle walls. The two last bubbles that I mentioned above are evidence of spiracles that escaped Swammerdam's attention.

<u>20th experiment</u>

In other experiments we submerged each of these spiracles in turn, while leaving the others out of water. From this we learned that if just one of these external organs remains open in air, it is enough to support respiration. Furthermore, we noted that the submerged openings gave off no bubbles, which in my view shows that they communicate with each other inside the body.

<u>21st experiment</u>
The same test with lime water convinced us that the emission of carbon dioxide in earlier experiments was due in large part to the bees' respiration, as the bubbles agitated the water and precipitated lime when they floated free of the body.

<u>Part III. Experiments on the internal atmosphere of the hive</u>

We initially thought to explain the problematic existence of bees in their hive by supposing that these organisms have no need to respire. However, having been convinced that this was quite mistaken, the difficulty remained unresolved. It did not seem believable that the atmosphere surrounding 25 thousand, 30 thousand or even more bees in a closed space could remain fresh enough to allow them to breathe. Nonetheless, only experiment could show with certainty whether the air inside the hive is altered or not, so that we deemed it necessary to carry out an analysis. Our procedures are set forth here.

<u>1st experiment</u>

We prepared a tubular receptacle to serve as a hive and lodged a swarm of bees in it. We then allowed the colony to establish itself and build comb, just as in an ordinary hive. We attached to this a flask provided with a faucet in order to allow the entry of air into the interior. This was displaced by the descent of the air or rise in the mercury of the bottle mounted in the vessel until the faucets were opened, and we closed it again with all necessary precaution.

The mercury or water used in this experiment flowed into a funnel leading into a basin placed at the bottom of the hive in such a way that the bees were not at all incommoded.

We took air samples at various times of day, which Mr Senebier analysed by means of a nitrous-air eudiometer. The result that he reported to us was quite different from what we expected, as the samples were within a few percent as fresh as the outside air. In the evening we observed a modest change, but only by several percent, which could be due to several causes (eudiometric tests 4).

In another experiment a bottle was put in contact with air inside the hive for six hours. When we analysed its contents, it was found to be as fresh as ambient air.

Did the bees, then, have within themselves or in the hive a source of oxygen (eudiometric tests 5)?

One of our experiments showed that the presence of wax and pollen does not at all favour the production of oxygen gas. New cells weighing 42 grains and an identical number of cells stored with pollen, enclosed in a six-ounce receptacle and exposed to the warmth inside the hive for 12 hours, did not at all improve the air around them. The air worsened in fact, by several percent.

As I was not satisfied with these results, which still did not answer the questions before us, I determined to try an experiment that I thought should clear up all my doubts once and for all. It seemed to me that, if the bees have any source of oxygen in the hive that could meet their needs, it should not matter to them whether the entranceway is open or shut. We could, then, deny them all access to ambient air and then assess the condition of the hive's inner atmosphere. This experiment answered all objections that one might raise against the earlier ones in which, by separating the test bees from their nestmates, we might have brought an additional, indirect factor to bear.

2nd experiment

It was simply a matter of sealing the insects in a hive with transparent walls that would allow us to observe what happened inside. The colony in the tubular receptacle -- one characterized by strength and vigour -- met these requirements. If one came within 10 feet of it, one could hear a powerful buzzing.

We elected to do this experiment on a rainy day, so that the bees would all be inside the hive. We began at 3 o'clock by tightly sealing the entranceway and then stood back -- with some anxiety, it must be admitted -- to observe the effects of this closure.

It was not until after a quarter of an hour that the bees began to show some distress. Until then, they appeared unaware of their imprisonment, but from that point on all work was suspended, and the entire aspect of the hive changed. We soon heard an extraordinary noise coming from inside the hive. All the bees, both those who covered the comb faces and those hanging in clusters, stopped their activity and beat the air with their wings in great agitation. This effervescence lasted about 10 minutes. Gradually, the wing movements slowed and became less regular.

At 3:37 the bees had completely lost their strength. They could no longer hold on with their legs and soon fell to the bottom. The number of falling bees kept on increasing, so that the table was strewn with them. Thousands of workers and drones fell to the floor of the hive. Not a single bee was left on the combs, and three minutes later all were asphyxiated. The hive suddenly became colder, its internal temperature falling from 24° to that of the ambient air.

Hoping to warm and revive the asphyxiated bees by giving them fresh air, we opened both the entranceway and the faucet attached to the tubing of the receptacle. The air current established in this way had an unequivocal effect. In just a few minutes the bees were breathing again; their abdominal segments resumed pumping, and they once again set to beating their wings. This was quite a remarkable circumstance, as we had already observed something very similar, as noted above, at the moment when the interruption of all air flow from outside began to be felt in the hive. Soon the bees climbed back up to the combs, the temperature rose to the level that they usually maintain, and by 4 o'clock order was restored in their domicile. This experiment furnished undeniable proof that the bees have no means inside the hive to substitute for the air that comes in from outside.

Part IV. Researches into the means of refreshing the air inside the hive

Keeping the air fresh in the hive interior is critical to the life of the bees, and it certainly takes place. This fluid must come from outside the hive, as sealing the hive entranceway is fatal to the bees. But what, exactly, is the means of refreshment?

At first, we suspected that the bees' own body heat might have sufficed to bring pure air back into the hive by breaking the equilibrium and setting up a current between the outside and inside. However, we soon abandoned this idea in view of the experiment in which we had placed a lit candle beneath a vase with an entranceway larger than found in a beehive. The result of this was that the candle went out for lack of air, even as the temperature inside the vessel rose to 50° Réaumur [=50° C].

There remained only one hypothesis to explain how the air inside the hive could remain so pure. This was that the bees possess the amazing capacity to draw air in from the outside, while at the same time expelling air that has become degraded by their own respiration.

In that case, it was necessary to examine whether some particular feature of the bees' activities might account for this phenomenon. After reviewing all other activities and being satisfied that they could not plausibly serve this function, our attention turned anew to the beating of the wings, which produces such a continuous buzzing. Might this have a role in the circulation of the air? We suspected that the play of these little membranes, which moves the air with such force as to produce this distinct noise, could also account for the air flow that allows the bees to keep breathing. Could one really believe that something so apparently insignificant could compensate for the effects of all that respiration inside the hive? At first we were very skeptical, but in view of the constancy and vigour of these movements we began to think that, in fact, this might be the simple and satisfactory explanation that we sought.

If one brings one's hand close to a ventilating bee, one can feel that she has quite perceptibly set the air in motion, although her wings move so rapidly that one can hardly see them. The two wings on each side of the body are held together along their length by a set of tiny hooks, so that they meet the air with the maximum surface area. In addition, the wings are cupped slightly in such a way as to exert considerable force as they move perpendicular to the body. One can readily see the full arc of the wingbeat, because the two extremes are visible at the same time.

While fanning, the insects' feet tightly grip the floor. Those of the forelegs are stretched out in front, those of the midlegs are splayed out to the left and right of the body, while those of the hindlegs are held close together straight behind the abdomen and tend to lift up the bee at the rear.

Always during the summertime a certain number of bees can be seen beating their wings in front of the hive entrance, but it can be confirmed by observation that the number fanning inside their domicile is even greater, usually on the bottom board of the hive. Those bees that are thus occupied on the outside always stand facing the entrance, while inside face away from it.

It would appear that these insects place themselves in symmetry in order to fan more conveniently. They form lines that abut the hive entrance and are sometimes arrayed like diverging sunbeams, although the pattern is far from regular. It is probably caused by the fanning bees' need to make way for those entering and leaving, whose rapid movement forces them to array themselves in a line in order not to be jostled or pushed aside at any moment.

Sometimes more than 20 bees fan in the lower part of the hive, while at other times fewer do. Every one of them has her wings in play for a shorter or longer time. We have seen some fanning for as long as 24 minutes at a time. During this interval they did not at all flag in their efforts, although they appeared at times to pause the vibration of their wings for just an instant in order to catch their breath. As soon as they stopped, other took their place, so that there was never any interruption in the buzzing of this populous company.

In winter, if they are obliged to fan near the center of the mass of bees clustering high inside the hive, they undoubtedly carry out this important function among the combs. The comb surfaces leave a neat space between them that allows the wings to beat. This space has to be at least six lines in order to afford the wings free movement.

Do honey bees have as much need for ventilation in their natural state as when they are domesticated? Their habitations in hollow trees and rock cavities offer greater space, a circumstance that could give rise to variation in their means of refreshing the air. Accordingly, we tried to simulate the conditions found in the wild by placing bees in a hive five feet tall. The glass walls made it easy to observe from all sides the pyramidal mass [of bees] hanging from the combs on the ceiling. The entranceway was placed at the bottom of the glass box, as in an ordinary hive.

We have noted that only very few bees were fanning in front of the entrance. The greatest number was always holding fast on the vertical wall on the same side, the bees keeping close to each other and to the path of nestmates returning from the field.

Fanning by the bees or the buzzing that indicates it are manifest not only in the heat of summer but at all seasons. It even sometimes appears to take on greater strength in the middle of winter than when the temperature is moderate. A phenomenon of such constancy and occupying a certain number of bees may have a real effect on the atmosphere inside the hive. The air column, once shaken, should give way to air from the outside, thus setting up a refreshing current.

Such a remarkable effect, if it exists, must be manifested in one way or another. Nothing could be easier than to show that this is so. We decided to set up in front of the entranceway some miniature anemometers of paper, feather or cotton. Such devices, hanging freely from a thread, should reveal any perceptible air current at the entrance, as well as its strength.

We chose for this experiment a calm day and carried it out at an hour when the bees had come back into the hive. We also took the precaution of setting up a screen at some distance in front of the entranceway in order not to be confused by any gusts of the ambient fluid.

The anemometers were hardly in place in the bees' air space when we saw them moving. Sometimes shifting with the same rapidity, they stayed one or two inches from the perpendicular. This attraction and repulsion seemed proportional to the number of bees fanning. At times the motions of the anemometers were less conspicuous, but they were at no time entirely absent.

This experiment proved the existence of currents produced at the hive entrance, thereby showing that the air degraded by the bees' respiration was constantly being replaced by ambient air. This accounts for the freshness of the internal air that we had found earlier.

One might raise the objection that there are beekeepers who close the entranceways of their hives in winter. To be sure, if this process stopped all air from entering or leaving it would prove that the bees can dispense with it during this season. However, this practice applies only to straw skeps, which can hardly be sealed completely, so that air still passes through the seams.

Beyond this, we make no claims with respect to the winter season. We carried out only a single experiment at that time, although I must say it was enough to remove all of our doubts on this point. It was again to [François] Burnens that I confided the conduct of the experiment, as I had come to do as a matter of course. His letter on the topic is copied here.

"Sir,

"I have just carried out the same experiment that we undertook in the summer, which Mr Senebier asked me to replicate during this season.

"For this I chose a well-populated skep whose inhabitants seemed to be very lively, as seen by the plentiful activity inside their domicile. After having fastened the edges of the skep to the table, I attached at the top end a fairly strong iron wire ending in a hook. From this I suspended a loop of hair bearing a little square of the thinnest paper that I could find. This hung one inch from the entranceway. As soon as the apparatus was in place, I could see the hair and its paper oscillating to one degree or another. In order to measure the movements, I had placed a little horizontal ruler marked in lines of Paris inches[2], which corresponded to the bottom of the paper and right by the upper part of the paper. At a distance of an inch from the opening the paper was attracted to it and pushed back to the same distance, several times in succession. The greatest oscillation was of one inch from the perpendicular toward one of the extremes. When I moved the paper to a greater distance, there were no such oscillations, and the apparatus remained still.

"Following your advice, Sir, I made an opening in the top of the skep and poured liquid honey into the hive. Soon afterward the bees began to buzz. Movement picked up in the interior, and several bees flew out. I watched the apparatus closely and saw that the paper's oscillations were more frequent and stronger than before the honey was introduced. Having fixed the perpendicular at 15 lines from the entrance of the hive, the paper was unmistakeably drawn in and pushed away several times. I wanted to see if the vibrations would still occur at a greater distance, but the paper remained still.

"All that remains for me to report to you, Sir, is today's temperature. I had an alcohol thermometer, which read 5¼° above freezing in the shade. The sun was shining when the experiment was carried out at 3 o'clock in the afternoon.

"If you desire anything further, please let me know, and it will be my great pleasure to carry out your instructions.

"I have the honour to remain, sir, your most humble and obedient servant,
"F. Burnens
"Oulens, 3 February 1797"

Part V. Proofs from the effects of artificial ventilation

The preceding experiments left me in no doubt as to the purpose of fanning. We could no longer suppose any chemical influence of materials in the hive, and I had shown that the specific gravity of the air did not at all produce an exchange so essential to the insects between breathable air and that which they had altered. Even so, not daring to trust to my own knowledge alone, I wanted to consult with Mr de Saussure before establishing a hypothesis that, in several respects, must of be of interest to a physicist. This learned man, surprised by my results and struck by the originality of the means by which nature saves the bees from certain death, proposed a test that he thought must abolish all doubt.

We could see just one means of deciding whether one could attribute the renewal of air in hives to natural ventilation, which was to mimic the bees' movements by a mechanical device in a location of the same dimensions as an ordinary hive, and from which all other source of air current had been removed. He advised me to utilize an artificial fan, the blades of which could be moved rapidly so as to produce an effect like that of fanning insects. One of my friends, Mr Schwepp, as much an able mechanic as an ingenious physicist, and inventor of the machine to produce artificial effervescent water, helped me in making this machine and coöperated in all of the experiments for which it was designed.

Instead of a number of little fans, we constructed a sort of windmill with 18 tinplate blades. We adapted to it a large cylindrical vase, whose capacity was increased further by that of a hollow platform to which it was solidly attached.

An opening made in this platform, which could be tightly closed, allowed a candle to be introduced into the bell jar. The fan was placed on top of the platform and fastened at the points of contact. On one side of this arrangement we had carefully made a fairly large opening.

This part of the apparatus communicated with the upper vase, but it was arranged in such a way as to stand in the way of the main air current, so that the fan could not blow out the candle.

We hung some light-weight objects in front of the entrance of the box, in order to determine the direction of air currents, and began the following experiment, in which the windmill was not brought into play.

<u>1st experiment</u>

We introduced a candle into the bell jar, leaving open the hole that represented the hive entrance. The capacity of the vessel was about 3228 cubic inches.

The flame did not flare for long but soon diminished and went out after eight minutes. The top of the bell jar was found to be considerably hotter, and the anemometer gave no sign of any air current.

<u>2nd experiment</u>

We repeated the previous experiment, this time closing the entrance to the apparatus after clearing out the air that had been altered by combustion. The candle remained lit the same number of minutes, which proves that an open entranceway by itself, without any external cause to put the air in motion, does not allow a renewal of the air.

<u>3rd experiment</u>

After refreshing the air in the vase, we placed a candle in it and suspended a number of anemometers in front of the entrance. With these in place, we set the fan in motion, and immediately two air currents developed. The anemometers made this effect very evident, as they moved toward and away from the entrance. The liveliness of the flame remained undiminished through this experiment, which we could have prolonged indefinitely. A thermometer under the apparatus read 40 degrees, while the temperature was evidently higher in the upper part of the chamber.

<u>4th experiment</u>

I wanted to find out if my fan could overcome the effect of two candles. These burned for 15 minutes and then went out at the same time. In another test in which the windmill was not put into play, the flame lasted only three minutes.

5th experiment

We undertook to make several openings in the sides of the box, equal in number to the blades of the fan. The effect did not correspond to expectation. One of the two candles went out at the end of eight minutes, while the other burned without interruption for as long as the fan remained in motion. Increasing the number of openings, then, did not result in a stronger air current.

By showing that the air can be refreshed even if there is an opening only on one side, as long as the air is mechanically displaced, these experiments, appear to confirm our conjectures on the effect of fanning by the bees on their hive.

Part VI. The immediate causes of fanning

It would be a misunderstanding of nature's ingenuity to think that her real aim in this or that behaviour of animals is always what it appears to be. This grand feature, capable of such beautiful manifestations, is one of those in which the invisible hand that governs the universe is most apparent.

In beating the air with their wings, the bees cannot be aware of the true purpose of what they are doing. Perhaps some urge or a very simple need makes itself felt, and their instinct invites them to put into play these membranes that appear to be given to them for flight alone. They undoubtedly beat their wings in order to relieve themselves of some immediate sensation, as one cannot grant them that understanding that might bring us to act in an analogous way. Nonetheless, it is curious to note these charms that nature presents, crude as they are, since it brings her to an intended goal.

The simplest possibility that occurred to us was that the bees fan for no other reason than to bring about a sensation of relief. An experiment convinced us that this could, in fact, be among the immediate causes of fanning.

We opened the flap of a glass hive, so that the rays of the sun shone directly onto the nest combs, which were covered with bees. Presently, those that felt the heat most keenly began to buzz, while those that were still in shade remained quiet.

An observation that anyone can make confirms the result of this experiment. The bees that make up the clusters that one sees in front of the hives in the summer, discomfited by the heat of the sun, fan very vigorously. But then, if anything throws a shadow over part of the cluster, fanning stops in the darkened area, while it continues where bees are lit and warmed by the sun.

The same fact is noticeable in insects of a related genus. Bumble bees that we had nesting on a window were ordinarily at rest, but as soon as the sun shone on the box in which they lived they became very noisy, all beating their wings and sending up a strong buzzing sound.

The same noise is sometimes heard around nests of yellowjackets and hornets, so that it appears to be a general rule that heat brings about fanning in honey bees and some other insects.

However, there is still the remarkable circumstance that bees fan even in the middle of winter, and that their buzzing is often the sign that the colony is still alive at that time of year.

The heat in this case is no more than a secondary or supernumerary cause that in summer adds to the bees' disposition. One must, therefore, examine whether there are other stimuli that provoke the bees to fan.

We undertook to surround them with emanations that are thought to be disagreeable to them and found that penetrating odours did, indeed, provoke fanning.

We removed some bees from their hive by attracting them with honey, after which we brought some cotton soaked with ethyl alcohol close to them. In order to elicit an aversive response, we had to bring it close to the head, but then the effect was unmistakeable. The bees moved away while beating their wings, and then they approached again to feed. As soon as they were well settled, we began the experiment. The bees again retreated, but without entirely withdrawing the proboscis; they went no further than beating their wings while feeding.

However, it sometimes happened that the individuals most strongly affected by these disagreeable stimuli suddenly moved away and took flight. Many times a bee turned her back on the honey and started beating her wings until the sensation or its cause had diminished by the effect of this movement, after which she returned to the repast. These experiments were never more successful than right at the hive entrance, since the bees held there by the double attraction of the honey and their home were less inclined to flee in the face of the stimuli to which we subjected them. The furry bumble bees of which we spoke earlier use the same procedure to get rid of noxious odours. However, what is truly remarkable and can, up to a point, show the importance of beating the wings is that in both bumble bees and honey bees the males appear unable to protect themselves from these of emanations, even though they show the same sensitivity as do the workers.

Fanning, then, is an activity of the workers alone. The author of nature, in assigning to these insects a lodging in which air can only penetrate with difficulty, has given them the means of putting a stop to the deadly effects that could arise from changes in the internal atmosphere. Of all animals, this is perhaps the only one on which so critically important a function has been conferred. Let us note in passing that this is a sign of the sophistication of their organization. An indirect consequence of fanning is the elevated temperature that these insects produce in their hive without any special effort. This is a result of respiration, itself, the natural body heat of all animals. This heat, which an author has gratuitously attributed to the fermentation of honey, is certainly derived from the aggregation of a great number of bees in one place. It is essential to these insects and their brood that it be independent of the ambient temperature. The existence of the bees, then, is tied to the continuation of fanning in more than one respect. Nonetheless, because her concerns include so many tasks, an individual cannot turn her attention exclusively to maintaining the necessary level of purity of the internal air. This function, while exercised in turn by just a small number of bees, does not excuse them from attending to various other branches of the colony's industry.

In this way, an insect society is able to satisfy as needed the different functions demanded of the populace as a whole, corresponding to the creator's beneficent aims, having its counterparts to the institutions that we have established for our own benefit.

CHAPTER IX. ON THE SENSES OF BEES AND IN PARTICULAR THE SENSE OF SMELL. (pp 363-393)

The infinite variety of habits that we see in the different races of insects and animals quite naturally gives rise to the idea that physical objects do not elicit from them the same sensations as in man. Their faculties are not the same, and their nature does not admit the light of reason, so that they must be moved by other forces. Perhaps the conception of their senses that occurs to us on the basis of our own senses is far from accurate. Senses that are subtler or differently constituted from our own could perhaps represent objects in ways that are beyond our perception and form impressions that are quite alien to us. Even if they were simply more developed, it would open a new field of research. In this way, what man can discover with the aid of lenses comes into view, while the ancients had no idea of the objects that we perceive since the development of optics.
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Might we not admit in the intelligence available to each animal the organization to match its inclinations and habits, the power to modify its very senses beyond all that art has taught us?

Is it not possible that the same designer who created for us, according to our needs, these five great avenues by which our mind takes in all of our perceptions of the physical world, could likewise open for other beings less favoured in terms of judgement routes that are more direct, more certain or more numerous, which extend throughout the domain open to them?

Art teaches us to judge objects by means that are not most immediately within the reach of the senses, where judgement operates with the greatest certainty. Physics and chemistry provide a thousand examples. Thermometers, menstrua, and other instruments with the help of which we can penetrate the nature of objects that escapes our own senses, amount to new sensory organs. There could, in fact, be new ways to regard material things. Those that belong to us only through inventions speak only to the mind, but when nature wishes to establish communication between the physical and the mental, she accomplishes this by the route of feelings or senses, and nothing contradicts the idea that she could create other senses for beings that differ from us in so many other respects.

Those insects that live in a republic -- among which honey bees certainly stand at the top -- often present features that can be explained in no other way, even if we suppose that these small beings lack the same senses as we possess. It is this that makes the mobile secrets of their behaviour so hard to penetrate. Nonetheless, we find in them senses of a less subtle nature, and as it suits us to approach as closely as possible to a knowledge of their faculties, it would be a mistake to overlook the study of those others that are more within our grasp and according to which we can judge the least of their appetites and aversions.

Sight, touch, smell and taste are the senses most usually attributed to bees. Up to now, we have seen no good evidence that they are blessed with the sense of hearing, although the country people seem for the most part not to share this view. I refer to their practice of beating on a sounding instrument when a swarm is about to leave the hive in order to prevent it flying off.

On the other hand, the organs of sight are of wonderful perfection. This insect recognizes her home from afar in an apiary with a great many hives that all look alike. She flies to it in a straight line at high speed, which implies that she can distinguish it from a distance by features that are obscure to us. The bee departs and flies directly to the most abundantly flowering field. As soon as she is underway, you can see her following a path as straight as a gunshot. And as soon as she has collected her load, she flies up to where she can see her hive and takes off a lightning speed.

Their sense of touch is perhaps even more admirable, as it compensates completely for the lack of sight inside the hive. The bee builds her combs in darkness, delivers the honey into the storage cells, feeds the brood, assesses their age and needs, recognizes the queen, all with the use of her antennae, even though their form is less suitable for perceiving things than are our own hands. Should we not attribute to this sense modifications and perfections beyond those of man's sense of touch? If we had only two fingers to measure and compare such a variety of objects, what subtlety would they not need in order to be of equal service?

Taste is possibly the least perfect of the bees' senses. Insofar as this sense appears to afford general choices in its aim, and against the received view, bees certainly make little use of it in the honey they collect. Plants whose odour and flavour seem distinctly disagreeable to us do not repel the bees at all. Even poisonous flowers are not outside their selections, and it is said that the honey collected in certain provinces of the new world is dangerously poisonous. Besides this, bees do not at all disdain the excreta ejected by aphids in the form of honeydew, despite its impure origin. They are evidently not even fastidious about the water they drink, as they seem to prefer water from the most stagnant ponds and ditches to that from the clearest springs or even from dew.

Accordingly, there is nothing so variable as the quality of honey. That from one canton does not at all have the same taste as that from another; springtime honey is quite different from autumn honey; and that from one hive is not always like that from the neighbouring hive.

It is true, therefore, that bees exercise little discrimination in their food. However, if they are not choosy about the quality of honey, they are not indifferent to the quantity present in the flower. These insects always go where is more. They leave the hive at times that have much less to do with a pleasant temperature or fine weather than with the expectation of an abundant harvest. When the linden tree or buckwheat is in flower, the bees brave rain, fly out before sunrise, and stop foraging later than usual. However, this eagerness diminishes as soon as the flowers wilt, and when the scythe has mown everything that spangled the meadows, the bees remain at home, not matter how brightly the sun may shine. To what should we attribute this knowledge that the entire colony seems to have, without even leaving the hive, of the greater or lesser abundance of honey out in the field? Are they alerted by a more subtle sense than the others, including smell?

There are odours that attract bees, other that repel them. They find tobacco smoke and all other kinds of smoke noxious, an aversion that human industry has learned to turn to advantage. But as soon as it satisfies their aims, it does not encroach on the domain of a philosophical curiosity.

Motivated by these questions, we will seek to learn how different odours affect these insects, to what degree they are attracted by some and repelled by others, to the extent that we are able to at present. Perhaps one day our understanding will allow us to go further.

Of all odorous substances, honey attracts bees most strongly. Other odours perhaps lack the same capacity for announcing the presence of a liquor they regard as so precious.

In order to learn whether it is the odour of the honey that announces its presence and not just the sight of the flower, it is necessary to conceal this substance where it cannot be seen. To this end we first tried placing the honey near the apiary, on a windowsill whose counterpane, almost closed, allowed the bees to come in if they so desired. In less than a quarter of an hour four bees, a butterfly and several house flies had entered between the counterpane and the window, and we found them engaged in consuming the honey that we had placed there. This observation was sufficiently conclusive in favour of the view set forth above. Nonetheless, I wanted a more decisive confirmation.

We took boxes of differing size, colour and shape and attached to them cards corresponding to various holes in their covers. We put honey inside the boxes and placed them 200 paces away from my apiary. At the end of half an hour we saw bees arriving close to the boxes, flying attentively about them, and they soon found where they could enter. We saw them pushing aside the cards and reaching the honey.

We can judge by this test the extreme sensitivity of the sense of smell in these insects. Not only was the honey well hidden from view but its odour could not have been well dispersed, since it was covered and enclosed.

Flowers have an organization similar to our masking cards. In many kinds the nectary is situated at the bottom of a tube that is partly enclosed or hidden by the petals, and even so the bee finds it. However, her instinct is less refined than that of the furry bumble bee (*Bremus*) and so offers her less reward. When the bumble bee cannot penetrate flowers by their natural opening, it knows to cut a hole at the base of the corolla or even the calix so that her proboscis may reach the spot where nature has placed the honey reservoir. Thanks to this stratagem and the length of the proboscis, the bumble bee can procure the honey, while the honey bee reaches it only with difficulty.

One might suppose, given the difference in the honey produced by the two kinds of bees, that they do not collect it from the same flowers. However, honey bees are as much attracted to the honey of bumble bees as to their own. We have seen them in a season of dearth coming to pillage a bumble bee nest placed in a half-open box fairly close to the apiary. They were almost seized. Some individuals who remained in spite of the disaster to their colony flew out to the field and brought replenishing supplies back to their old home. The honey bees followed them back to the nest and into it, not departing until they had robbed the bumble bees of the fruits of their renewed foraging. The honey bees licked them with the proboscis extended, enveloped them and did not let them go until they had drained them of their sugary liquid. They did not in any way seek to kill the insects to whom they owed this meal. No one made any move to sting, and the bumble bees, themselves, were evidently accustomed to the exactions to which they were subjected. They yielded their honey and took flight again. This novel phenomenon lasted more than three weeks. Wasps, attracted for the same reason, were not at all on such terms of familiarity with the original occupants of the nest. The bumble bees remained at home only at night, and finally they disappeared and the parasites no longer came. Less surprisingly, we are informed that the same scene develops between robber honey bees and those in weak hives.

Not only do the bees have a very acute sense of smell but this advantage is enhanced by their memory of sensation. Here is an example. In the autumn we had placed honey on a windowsill, to which bees came in a crowd. We removed the honey, and the counterpane was closed throughout the winter. The next spring, as soon as we re-opened it, the bees returned over and over, even though there was now no honey on the windowsill, undoubtedly recalling that it had been there before. An interval of several months had not sufficed to efface a learned impression.

Let us now look for the site or organ of this sense, whose existence is so amply in evidence.

We have still not identified nostrils in these insects, so that it is unknown in what part of the body this organ or its analogue in this class of animals is situated. It was probably that the odour sensation reaches the common sensorium by a similar mechanism to what we possess. That is to say, the air should enter through an opening where there is a plethora of olfactory nerves. We needed to know, then, whether the spiracles might not exercise this function, or whether the sought-after organ might reside in the head, or if it was in another part of the body.

<u>1st experiment</u>

We presented to all parts of the body in turn the tips of forceps dipped in oil of turpentine, one of the substances that the bees most dislike. However, a bee who were engaged in eating seemed not at all affected, regardless of whether the oil was placed near the abdomen, the thorax, the head, or the thoracic spiracles.

<u>2nd experiment</u>

Having seen that these tests led nowhere, we thought to present the forceps to all the various parts of the head in turn. For this, we used extremely fine forceps, in order to avoid any uncertainty caused by touching several parts at once. The bee, engaged in her meal, had her proboscis extended in front. We brought the forceps close to the eyes, the antennae and the proboscis without effect, but it was not the same when we brought it close to the mouth cavity above the base of the proboscis.

The bee instantly recoiled, stepped back from the honey, beat her wings while walking about in agitation, and would have taken flight if we had not withdrawn the forceps. She resumed feeding, and we again presented the essence of turpentine, placing it close to the mouth. The bee turned away from the honey pot, held fast to the substrate and fanned for several minutes. The same test conducted with oil of oregano produced the same effect, but even more quickly and lastingly.

This experiment appears to indicate that the organ of smell in these insects resides in the mouth, itself, or in the parts that arise from it.

The bees that were not eating seemed more sensitive to this odour. They perceived the scented forceps from further away and immediately fled from it, while those with the proboscis inserted in the honey could be touched with it on various parts of the body without interrupting their feeding.

Were they absorbed in their appetite for honey and distracted by its odour, or were their sense organs less accessible? There are two ways to answer this question. One is to mask by covering all parts of the body except the one to be tested for sensitivity. The other is to mask the part where we think the sense resides, leaving all others untouched. This latter seemed more certain and practical, so we took several bees, forced them to keep the proboscis extended, and then filled the mouth with flour paste. When this was dry enough that the bees could not remove it, we released them. This procedure did not at all appear to discomfit them, and they moved about and breathed with the same ease as their nestmates.

We presented these bees with honey, but they did not approach it or appear at all attracted by its presence. The bees did not appear at all affected by the most contrary odours. We soaked the forceps in turpentine oil and clove oil, in ether, fixed volatile alkalis, and in nitric acid, and brought the tip quite close to the mouth. None of these odours, which would normally have caused prompt aversion, produced any evident response in any of the bees. On the contrary, several of them climbed onto the poisoned forceps and walked about on it as if it was not coated in any of these substances.

These bees, then, had temporarily lost the sense of smell, and it seemed to us sufficiently well demonstrated that its seat is in the mouth cavity.

We wanted once again to test how the bees would be affected by different types of odours. Mineral acids and volatile alkali, presented on forceps at the mouth, produced in these insects the same response as spirit of turpentine, with greater energy. Other substances did not have such a pronounced effect. We presented musk to bees feeding in front of the doorway to their hive. They stopped feeding, retreated a little, but not abruptly and without beating their wings. We spread pulverized musk on a drop of honey, and they inserted the proboscis into it, but just the tip and keeping as far back from the honey as they could. At the end of this test the drop of honey, which would have disappeared in a few minutes if not covered with musk, had not perceptibly diminished after a quarter of an hour, although the bees had inserted the proboscis into it a great many times.

*Mr Senebier, having noted that certain odours have an effect on bees because they foul the air and not by a direct action on the nerves. I thought to repeat the same test with substances that do not undergo perceptible change, such as camphor, asafoetida, etc.

<u>3rd experiment</u>

We mixed pulverized asafoetida with honey and put it at the doorway of the hive. However, this substance, whose odour is unbearable, did not at all seem to displease the bees. They avidly took up all the honey that was in contact with the strange molecules. They made no attempt to distance themselves, did not at all beat their wings, and left behind no part of the mixture except the asafoetida.

<u>4th experiment</u>

I put camphor at the doorway of the a hive and observed that the bees that returned and those that departed for the field turned in flight so as not to pass directly over this substance. I attracted several of these with honey on a card. As soon as their proboscises were extended into the honey, I brought the camphor near their mouths, and they all took flight. They flew for a time in my work room and clustered at last around the honey. While they were taking it with the proboscis, I threw into it some small fragments of camphor. The bees backed away a little, but kept the tip of the proboscis in the honey, and we observed that henceforth they took only what was not covered with camphor. One of these insects beat her wings in agitation while she fed, while some others were only occasionally troubled and still others not at all. I wanted to see what a greater quantity of camphor would do, so I covered the honey completely with it. In that moment, the bees all took flight.

I placed a card close to my hives in order to learn whether other bees would be less attracted to the odour of honey than repelled by that of camphor. I also put pure honey on another card at their doorway. This was soon perceived by the bees, and in a few minutes the honey was all taken. In contrast, for more than an hour no worker bee approached the camphored card, until at last one or two landed on it and inserted the proboscis at the edge of the drop of honey. Their number increased little by little, and two hours later the camphored honey was completely covered with bees. All the honey was soon taken, so that the camphor alone remained on the card.

These experiments prove that even while camphor is noxious to the bees, their attraction to honey can overcome this repugnance and that there are odours that, without fouling the air, repel these insects up to a point.

A large number of experiments also convinced me that the influence of the odours on the bees' nervous system is incomparably more active in a closed vessel than in the open air. I will give just one example.

I already knew that they found the odour of alcohol disagreeable and that they beat their wings in order to be rid of it, but I had not yet done the test in an enclosed space.

<u>5th experiment</u>

I put alcohol in a small glass under a vessel and left the glass uncovered in order to let the liquor evaporate. However, I took care that any bees that happened to fall onto the glass wouldn't get wet. With this precaution, I gave some honey to a bee and, when she had had her fill, I enclosed her below the receptacle. She traversed it in every direction in attempting to escape. For an hour she did nothing but beat her wings and search for an exit. At the end of this time I observed a continuous trembling in her legs, proboscis and wings. She soon lost the capacity to walk and even to stand and just lay on her back, and we saw her moving in a rather singular manner. She moved about on the table top in this upside-down posture, using her four wings as oars or legs. We also noticed that she regurgitated several times, giving up all the honey that she had consumed before being exposed to the alcohol fumes. The water in mixture with alcohol was able to offset this effect and bring about the bee's recovery. I rinsed her twice in cold water, which gave her some flexibility without returning her strength. Vinegar seemed to revive her, but this effect did not last, and she perished despite all my efforts.

Some house flies and shield bugs also lost their lives when exposed to alcohol fumes, but a large spider bore this test without appearing affected.

<u>6th experiment</u>

Because honey-bee venom gives off a penetrating odour, I thought it might be of interest to know the effect of these emanations on the bees themselves. This experiment proffers a fairly piquant result.

With forceps we extracted the stinger and venom apparatus of a bee. We presented this complex to some workers who were sitting quietly in front of the entrance. In an instant the small band was in an uproar. None of them took flight, but two or three launched themselves onto the envenomed instrument, and others threw themselves furiously at us. But it was not at all the threatening experimental apparatus that had annoyed them, for, as soon as the venom had dried at the point of the stinger and on the rest of the apparatus, we could present this weapon without consequence. The bees seemed quite unaware of it. The following experiment showed even more decisively that the odour of venom by itself suffices to rouse them to anger.

We put a few bees in a glass tube closed only at one end and chilled them halfway, so that they could not go out by the open end. We then revived them by degrees by exposing them to sunlight. After that we introduced an ear of wheat into the tube and stimulated the bees by touching them with the bristles. The bees all extended the stinger, and droplets of venom appeared at the very end of this dagger.

Their first signs of life, then, were manifestations of rage, and I do not doubt that they would have stung each other to death or thrown themselves at the observer if they had been at liberty. However, they could neither move nor leave the tube where I had placed them.

One by one, I took them with the forceps and enclosed them in a receptacle where they could not affect my experiment. They had left a disagreeable odour, that of the venom that they had sprayed against the inner walls. I presented the open end of the tube to a group of bees in front of their hive. They became agitated as soon as they scented the venom, but this emotion was not one of fear. Rather, they manifested their fury in the same way as in the first test.

There are, then, odours that not only have a physical effect on these insects but, up to a certain point, produce in them a mental impression.

It is undoubtedly here that there begins a series of sensations of a particular class, which elude our investigations and of which we can form only a vague idea. In this regard, animals are in a way superior to us. What a variety of odour impressions a hunting dog must gather. So highly developed a sense, in awakening in the imagination the ideas of fear, anger and love, ignites in the animal everything that can affect its security, tendencies and industry.

In order to make sense of the insects' behaviour in many circumstances, one must be able to balance the influence of different sensations that, without departing from their natural realm, combine with their habits and modify them in an instant.

Certain odours or too high a temperature excite the bees to flee, but if another cause, such as the attraction to honey, acts on them in the opposite direction and motivates them to remain, they know to keep the present pleasure and shield themselves from the sensation that is disagreeable to them by causing the air to move about. The bees that are kept in their hive by all the attractions that nature has united there in them, unable to be rid of the dreadful smell of the gas without leaving behind their brood and the provisions that they have amassed, have recourse to the ingenious means of fanning, so that the air is renewed.

But why do all the bees affected in the same way not bring their wings into play at the same time? To what should we attribute the tranquillity of the populace as a whole while a small number of individuals excite themselves to obtain a more salubrious atmosphere? Might there be sensations of a nature so subtle as to alert these insects that it is now their turn to beat their wings?

It is not believable that one part of the colony is affected by a cause that does not at all act on the majority, but it could perhaps depend on a more or less strong inclination of the moment.

We have seen all the bees of a colony becoming excited at the same time when the hive is too tightly closed and the air inside is not refreshed to their satisfaction, but we do not meet such an emergency situation under natural conditions. Normally, only a small number of bees fan at one time.

Insects of the same species, stimulated by the same cause, do not manifest its influence so equally that there is no difference to be seen in their responses to these tests. Some are affected more quickly than others. Some circumstances or the task in which they are engaged may make them more or less sensitive at a given moment, and it is only an extreme cause that acts on them with full force.

It may, then, be that when a certain number of fanning bees is engaged in bringing the air to a sufficient level of purity, the others, who do not experience the same sensation to such a degree as to make them set their wings in motion, are excused from this function in order to attend to more pressing tasks. If the number of fanners decreases at a given moment, the first workers to perceive the change in the condition of the air will turn to fanning, their number increasing up to the point where their united efforts are capable of rendering this fluid pure enough for the respiration of so many thousands.

Such is the manner in which we conceive that this endless chain of fanning bees is maintained, since we perceive no communication among the insects in this case. This hypothesis supposes a finely-tuned organization in the bees. It is evident that for the perpetuation of their existence, as it depends on the care they give to renewing the air supply, they must be provided with senses so subtle as to alert them to the slightest change in the fluid that they breathe.

Air can be degraded to a large extent before we perceive it, even if it has become quite harmful to our health. However, nature has not placed us in the same circumstances as the bees, and we would never need to suffer the inconvenience of breathing in too enclosed a space as long as we do not depart too much from the state of being adapted to our physical constitution.

1. Eudiometric tests
One part fresh air to one part nitrous gas [nitrous oxide], residue: 0.99[3].
One part air breathed by worker bees to one part nitrous gas, residue: 1.93.
One part air breathed by drones to one part nitrous gas, residue: 1.85.

2. Eudiometric tests
One part fresh air to one part nitrous gas, residue: 0.99.
One part oxygen to three parts nitrous gas, residue: 1.98.
One part oxygen breathed by bees to one part nitrous gas, residue: 1.58.
One part oxygen breathed by bees to one part nitrous gas (second test), residue: 1.61.

3. Eudiometric tests
One part fresh air to one part nitrous gas, residue: 1.03.
One part air in which these eggs had been kept to one part nitrous gas, residue: 1.08.

4. Eudiometric tests
One part fresh air to one part nitrous gas, residue: 1.05.
Air from inside the hive sampled at 9 o'clock, reduced to 1.10.
... 10 o'clock, reduced to 1.12.
... 11 o'clock, reduced to 1.13.
... 12 o'clock, reduced to 1.13.
... 1 o'clock, reduced to 1.13.
... 2 o'clock, reduced to 1.13.
... 3 o'clock, reduced to 1.13.
... 4 o'clock, reduced to 1.13.

... 5 o'clock, reduced to 1.13.
... 6 o'clock, reduced to 1.16.
... 7 o'clock, reduced to 1.15.
... 8 o'clock, reduced to 1.16.

5. Eudiometric tests
One part fresh air to one part nitrous gas, residue: 1.02.
Air from inside the hive, residue: 1.05.
Air from inside the hive (another test), residue: 1.06.

Translator's notes
1. Thanks to Rachael Wyse-Mason as my chemistry advisor.
2. The Paris inch is an archaic measure equal to about 2.7 cm. Each Paris inch was divided into 12 lines.
3. Huber did not explain the "residue", which is presumably the percent of the mixture that was among the named parts.