How Honeybees Produce Honeycomb—II*

From Nectar the Bees Make Both Honey and Wax, from Wax They Build Cylinders to Hold the Honey

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WE would recall that old saying by Cheshire: "All nature apart from the mystery of life solves everything mathematically. The cricket ball flying from the bat of the tyro, the spray from the maiden's mop, the tiny soap-bubbles of the laundress's lather, as much conform to perfect mathematical solution as the path of a comet or the form of a star." A child may blow a soap bubble and toss it in the air. No credit can inure to the child for the beautiful spherical form of the mid-air bubble. That form is simply the result of a natural law. If the child blows several soap bubbles in contact with one another, they become beautifully hexagonal, but here again no credit is due the child. The hexagons are physically not biologically produced.

Each button has six others touching it. A hexagon is "a circle surrounded by 6 circles that have flattened its sides"

The edge of the honeycomb built wholly by bees is never hexagonal nor angular. The side is a curve and the cells immediately on that curve are spherical at their bottom and circular at their rim. All solitary bees work in circles. I have felt about this like Lowell when he argues in regard to the straight canals on Mars. He maintains that nature does nothing in straight lines. You never saw an absolutely straight tree, a straight mountain ridge, a straight brook in a meadow. You never have known a woodchuck to dig a square hole nor any other kind with angles, neither does the woodpecker make an angular hole. If we enter the realm of the honeybee and of other members of the Hymenoptera, we shall observe that no mud wasp makes angles on the sides of its cells. The carpenter bee does not bore an angular opening. All excavations and all nests of all forms of animal life are normally free from angular outlines. He that gives the matter consideration will naturally feel that the hexagons of the honeybee's comb are associated with something beyond and outside of biological law. This circular habit continues even with some of the social Hymenoptera. It is known to every boy that has dug out a bumblebee's nest, that the honey is in tubes of wax, or in separate and irregularly rounded cells of wax. Darwin was puzzled by this fact, because at one end of the series he had the cells of the hive bee in a double layer, each one hexagonal prism, and at the other the bumblebees that utilize their old cocoons which are circular, or make a wax tube. He reasoned regarding the intermediate form of the *Melipona domestica*, which was carefully described and figured by Pierre Huber, and decided:

"The *Melipona* itself is intermediate in structure between the hive and the bumblebee, but more nearly related to the latter; it forms a nearly regular waxen comb of cylindrical cells in which the young are

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Spherical soap bubbles, confined between glass plates become hexagonal cells

hatched, and, in addition, some large cells of wax for holding honey. These latter cells are nearly spherical and of nearly equal sizes, and are aggregated into an irregular mass. But the important point to notice is that these cells are always made at that degree of nearness to each other that they would have intersected or broken into each other if the spheres had been completed; but this is never permitted, the bees building perfectly flat walls of wax between the spheres which thus tend to intersect."

Therein is the secret. The honeybee has not *learned* to make hexagons, but she crowds so much into a little space, putting her tubes so close together that they intersect. The sides are flattened, and the cells become hexagonal. Only three forms can be put together without interstices—the square, the triangle, and the hexagon. The hexagon most nearly approaches the circle and would be well adapted to curved or circular larvae. If the honeybee had plenty of room, she would make all her cells circular. This is proved by the circumstantial evidence, that when she has a sufficiently important larva to care for, she takes plenty of room and makes a circular cell for the queen. The cells at the edge of the comb, where there is no pressure on the sides, are in outline always circular, never hexagonal.

As pointed out years ago by Cowan, an English investigator, these "cells behave mutually like soap bubbles, which when isolated are round; but if they touch each other, the united films form a perfectly flat wall. If there are many, those in the center will be hexagonal, while those on the outside will have their free sides curved." This is exactly the situation though, as Cowan states, it is denied by some.

After the bees have manipulated the wax they press it down in a crowded irregular mass, which, under a microscope, looks about like a mass of mortar slumped off from the hod of the carrier. Then the bees scoop out the wax into little holes, and that scooping manifests itself as vestigial, circumstantial evidence in

the pittings all over the queenbee cell which give it its peanut-shell roughness. Regarding this Cowan says:

"As the wax is scooped out it is put on the side walls, which are thereby thickened, and give the mouth of the cell a circular form, in all stages of its progress. Many cells are found into which a bee cannot enter, but as the wax is always added to the top edge she has only to work down inside a very little way, and we presume she does much in the same way that a brick-layer would do when building a chimney from the outside, into which he could not introduce his whole body."

Darwin made extended experiments regarding this, and found that the bees always scoop out the wax from spherical cavities.

"I separated two combs, and put between them a long, thick, rectangular strip of wax: the bees instantly began to excavate minute circular pits in it; and as they deepened these little pits, they made them wider and wider until they were converted into shallow basins, appearing to the eye perfectly true or parts of a sphere, and of about the diameter of a cell. It was most interesting to observe that, wherever several bees had begun to excavate these basins near together, they had begun their work at such a distance from each other, that by the time the basins had acquired the above-stated width (i. e. about the width of an ordinary cell), and were in depth about one-sixth of the diameter of the sphere of which they formed a part, the rims of the basins intersected or broke into each other. As soon as this occurred, the bees ceased to excavate, and began to build up flat walls of wax on the lines of intersection between the basins, so that each hexagonal prism was built upon the scalloped edge of a smooth basin, instead of on the straight edges of a three-sided pyramid as in the case of ordinary cells."

But the bee is a scraper as is the mason when he builds a chimney or makes a cement and stone wall. Have you ever noticed how he slaps on roughly a trowel full of mortar and spends most of his time in scraping the sides? So it is with the honeybee. She keeps piling up the end of a cylinder and then constantly goes into her cylinder and scrapes the sides to make them thin. It is this going in that does the hexagonal work and is the exact equivalent of what I did when I pressed a solid on the soap bubbles. She does more than scrape. Her body is covered with hair, even feathers one might almost call them when they are viewed under a microscope. She is like a gun swab and when she pushes into that cell she pushes out the sides. If there is only one cell as in the case of the queen bee cell the pushing out of the sides makes a cylinder, but there are other bees making other cells and they are close to this and it is this pressure on the sides, with not the slightest intent nor skill on the bee's part, but purely the effect of a mathematical law,

Where the comb cells are released from pressure along one side they are round; they are *not* hexagonal

that makes the hexagon. As Cheshire told us years ago, "The geometrical relations, which embellish the wax tracery of the bee are the necessary result of her mode of proceeding. And mathematics is no more her endowment than it is that of the soap and water we have been considering. These wonders come because the whole creation is founded and sustained by the great Geometer, whose laws of weight and measure neither falter nor vary, so that, for the advantage of man, the experience and observation of the past make him the prophet of the future." And Cheshire proceeds to make it perfectly plain that a single cell made by a honeybee is always circular. The queen cell is an example of this. "It is circular—the typical form—in cross section, because it is built alone, and is made to grow with the growth of the grub it contains."

If a number of wax cups, such as are supplied by the manufacturers for queen cell starters, are placed compactly together and then warmed until the wax is plastic, and into each one of these is thrust a small circular brush, so as to push out the interior, the cups will, by the pressure of the brush, become hexagonal in outline.

Note carefully that whenever comb is turned out on the artificial foundation that the bee commences at the very start to build circular piles of wax upon the hexagons. The cells of honeycomb are always circular in outline on the edges of the comb where there

Wax tubes heated to the temperature of the hive become hexagons when expanded by inserting brushes

are no others to press against them. We give the honeybee hexagons as a foundation, but when she makes comb she never makes hexagons. There are no hexagons *made* at the base of growing comb nor at the top of the cells. There never has been and there never will be, for the reason that the honeybee always *works* in roughly circular lines.

THEY ALWAYS WORK IN CIRCLES.

Just one more photograph, but a remarkable one, that I have recently secured, to show that in every stage of the upward growth of the cells the work of the honeybee is in circles, it has been strenuously maintained by some opposers, who ingeniously yet incorrectly argue, that the circular coping is only for the finish at the top of the cells, to be there used for strengthening purposes. But why the cells need to be any stronger at the top than at the bottom is a puzzle unexplained.

The accompanying illustration shows how the bees build up the cell from artificial comb. The lower edge, and the first angular line, with the first row of full-sized cells, shows the comb foundation exactly as it is when it comes from the manufacturer's machine. It will be observed that on the upper edges of this lower row of cells the bees have begun their work by changing the outline from angular to circular. The top row is of nearly full depth, and practically completed. The two intermediate series are at varying degrees of depth. If any one can ask for more definite proof than this, the problem is to discover what would be for him an absolutely convincing argument.

It should be said, in addition, that this is not an unusual occurrence, but an ordinary observation that may be made time and again in the change from the angles, as manufactured, to the circles in all stages, as made by the bees.

The optical illusion hexagons on the surface of any growing honeycomb disappear the moment they are examined with eyes wide open. Take a collection of

circular dots, or look at the ends of a pile of lead pencils with the eyes partly closed and looking through the eyelashes, and immediately they all become hexagonal. It is the old argument about the markings of the diatom called *Pleurosigma angulatum*. Note the accompanying expanse of circular black dots. Does any one doubt for a moment that these are circular? Look at them through your eyelashes with the eyes half closed and see what beautiful hexagons you will have. The appearance is really all owing to *imperfect eyes*. It is an optical illusion. All growing honeycomb held at a distance or reduced by photography will show the thing dimly. Examine the comb with clear strong light and under a pocket lens of an inch focus, and every one of those hexagons will vanish and the comb will become a plane of circles.

I have entered extensively into this monographic exposition, because of the many attacks that have been made upon my claims by some of the most practical authorities in the United States. Articles on this subject, in which I have asserted these facts, have

Below, artificial foundation geometrical hexagons; above, converted into circles by the bees

been refused by two important bee journals and I have been not a little ridiculed because I believe and say that the bee does not build hexagons. Some things are the outcome of definite physical laws and have nothing to do with intent nor with learning.

Perhaps this opposition is based on the fact that it exposes the error of making artificial comb foundation in hexagons. Theoretically this is wrong, yet I believe that the error makes no practical difference. The manufacturers of artificial comb may have reasoned in this way: "If we examine the middle division of a honeycomb, we find that it is formed of the sides of cubes. We will therefore mold our sheets of wax with cubical indentations." But this comb foundation is for the beginning, not the end nor the middle. The bee starts with parts of spheres and circles, and physical law only, not the bees, finishes with cubical indentations. The bees ask for circles, and you give them cubical depressions. It is a plain example of getting the cart theoretically before the horse. In the production of comb foundation, circles and spheres should come first in what we supply to the honeybee in starter sheets of wax. I assert, without hesitation, that all comb foundations that offer such cubical indentations are logically and theoretically wrong. I doubt whether any so-called practical beekeeper will support this statement, but I am confident that the manufacturers will oppose it. Opposition cannot change the facts in the case. *I cheerfully admit that practically the foundation as supplied by the manufacturers may be even better than flat sheets of circular surface ridges.* I am not discussing the prac-

tical point, but the theoretical, the purely scientific point. A thing theoretically right may be practically wrong. Any bee-keeper may witness an exemplification of this claim if he will place some of this artificial comb foundation within the hive and note that the honeybees will invariably, in their very first work, change hexagons and cubical indentations into simple circular rings. I have examined hundreds of specimens of natural honeycomb made wholly by the bees, and as many others of the beginning of artificial comb foundation, from the moment when the first masticated particle of wax was placed on the ridge, but without a single exception I have found that the bees worked circularly or spherically. In such cases like comb built between the top of the frame where there is room for only one or two rows of cells, or on the edge of the honeycomb next to the attachment to the wood, the cells invariably are circular in outline.

The foregoing illustrations and discussion called forth a large number of commendatory and confirmatory comments from the ablest students in this and correlated fields and should forever establish the fact that the hexagons in the combs of honeybees are the outcome of strictly physical laws and not the result of blind instinct nor of any biological "intent" and still less of anything in any way approaching an intelligence almost superior to human intelligence.

Queen cells and points of attachment free from pressure, are circles

MY THESIS AND THE DARWIN THEORY.

In my article on "How Honeybees Produce Honeycomb," I made this statement in regard to the bees:

"They never yet have been able to make a hexagon nor to learn how to make one, Darwin and a host of minor lights chiefly the utilitarian beekeepers, to the contrary notwithstanding."

I did not mean to imply that I disagree wholly with Darwin and with the utilitarian beekeepers for on some phases of the discussion I am in perfect agreement with them. In developing the demonstration I could not explain all points of view, but several scientific friends who cordially support my thesis say that Darwin held a similar opinion and that I am in accord with him. One learned professor says that I do injustice to Darwin when I imply that there is any disagreement.

Darwin was a careful observer, and was nearly always correct in his observations and in the statement of facts, but not all of us will agree with all his deductions. He was so intent upon strengthening his thesis of the struggle for existence, natural selection, survival of the fittest, etc., that he used some facts as a part of his philosophy that in my opinion do not belong there. The very fact that in "The Origin of Species" he devoted space to the subject of comb building shows that he regarded it as part of his theory of evolution. Many aspects of honeybees and perhaps even of comb building, rightly belong in a philosophy of evolution but the structure of the hexagons does not. I quote from him:

"By such modifications of instincts which in themselves are not very wonderful,—hardly more wonderful than those which guide a bird to make its nest,—I believe that the hive-bee has acquired, through natural selection, her inimitable architectural powers." . . .

"That individual swarm which thus made the best

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