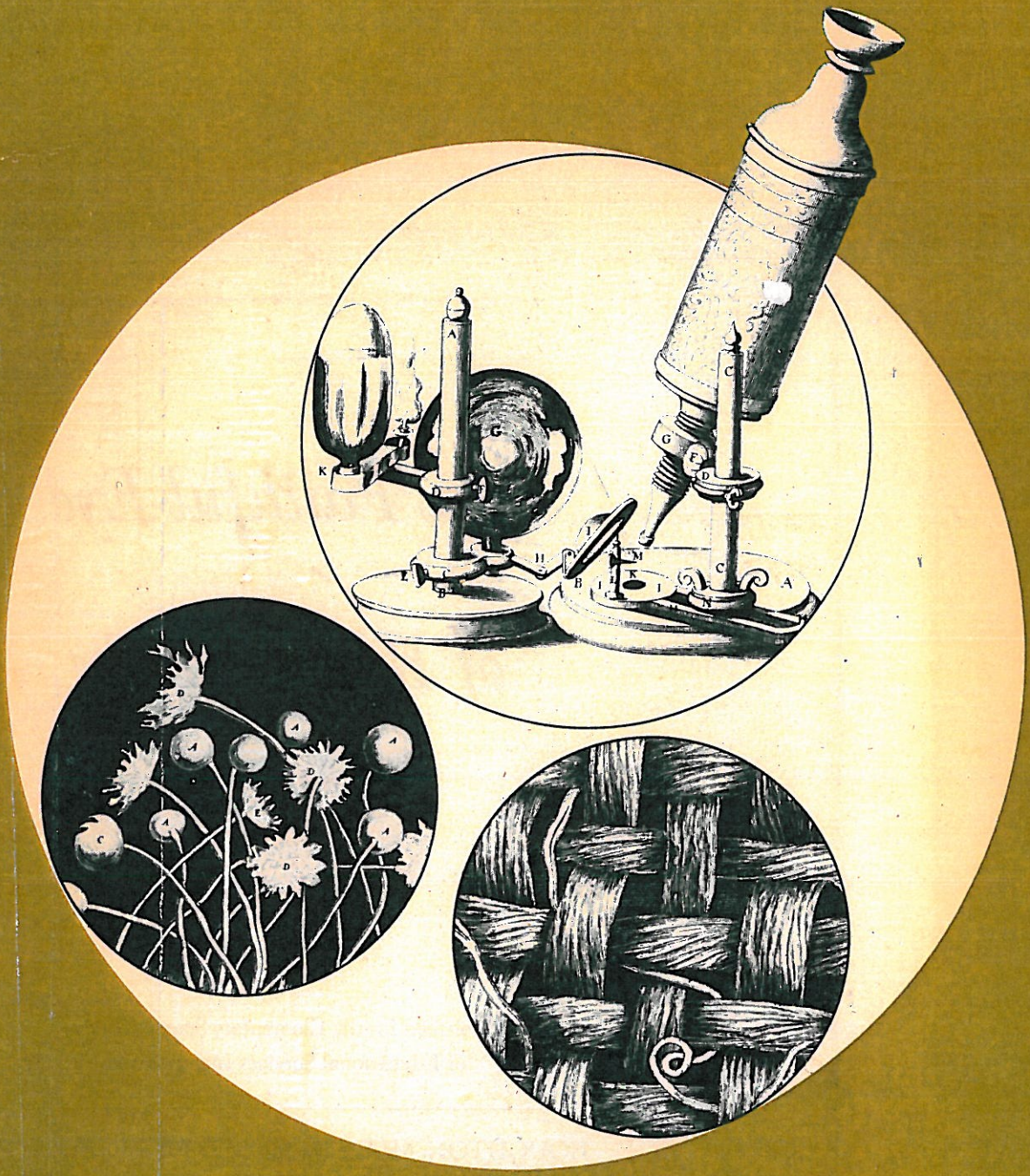

The Faithful Eye of Robert Hooke

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of Robert Hooke

Published for the Elementary Science Study
of Educational Services Incorporated

HOUGHTON MIFFLIN COMPANY • BOSTON
New York • Atlanta • Geneva, Ill. • Dallas • Palo Alto

ELEMENTARY SCIENCE STUDY, supported by the National Science Foundation, is a project of Educational Services Incorporated, a nonprofit corporation sustained by grants from private foundations and from the Federal Government.

This is a preliminary edition to accompany the ESS unit SMALL THINGS: An Introduction to the Microscopic World.

". . . a sincere Hand and a faithful Eye, to examine, and to record, the things themselves as they appear."

—Robert Hooke

Fish Scales

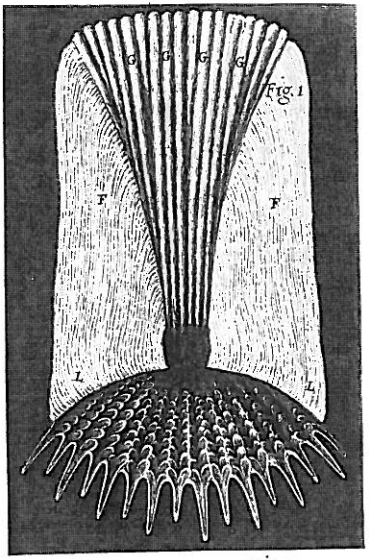
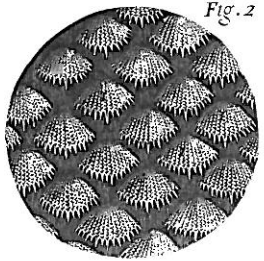


Fig. 2



The world between 1600 and 1700 was the stage for many exciting events. The Pilgrims sailed from Europe to start a new way of living on the continent that Columbus had discovered about a hundred years earlier. In dozens of plays William Shakespeare showed kings, queens, hunters, mechanics, actors. Explorers traveled all over the earth, searching out details of the globe on which we live. With the invention of the telescope the heavens themselves opened up: old stars, new stars, old planets and new moons. (It wasn't until the next hundred years that there were newly found planets.)

One of the most remarkable of the new explorations was of the world of very small things. This exploration could not begin until the microscope was invented, shortly before 1600. Fifty years later an Englishman named Robert Hooke spent hours peering through one of these instruments. He explored a new world without leaving London.

Robert Hooke had an interested and curious mind, as you will see for yourself. He put many different things on his small stage, lighted them, turned them, puzzled them out. Indeed, he was the very first man to see many of the small things at which he looked.

In London a group of men, called the Royal Society, were busy poking into the world around them and asking questions. These men of science held meetings to share their discoveries, at which they regularly asked Robert Hooke to tell about his explorations. He showed them drawings of the things that he had seen with his microscope. After a time Hooke made his account of the world of small things into a book which he called "Micrographia."

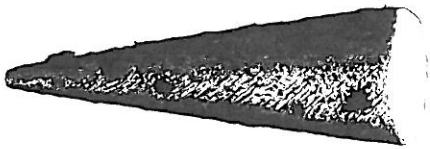
Needles' points and the dot of an "i"

At the beginning of his book Hooke speaks of starting by looking at simple things. He says:

> We will begin these our inquiries therefore with the observations of bodies of the most simple nature first.

One of the things he chose was the point of a needle.

> . . . made so sharp that the naked eye cannot distinguish any parts of it . . . But if viewed with a very good microscope, we may find that the top of a needle . . . appears a broad, blunt, and very irregular end.



A Needle's Point

> But to proceed. The image we have here exhibited in the first figure, was the top of a small and very sharp needle, whose point "*a* – *a*" nevertheless appeared through the microscope . . . broad, not round, nor flat, but irregular and uneven; so that it seemed to have been big enough to have afforded a hundred armed mites [*small insects*] room enough to be ranged by each other without endangering the breaking of one another's necks by being thrust off on either side. The surface of which, though appearing to the naked eye very smooth, could not nevertheless hide a multitude of holes and scratches and ruggedness from being discovered by the microscope.

The manufacture of needles may have changed in the past 300 years. Does the point of a modern needle resemble this drawing? Does it make a difference if the needle is new or used?

Hooke also discusses points sharper than sewing needles.

> Now, though this point be commonly accounted the sharpest (. . . we say, as sharp as a needle) yet the microscope can afford us hundreds of instances of points many thousand times sharper, such as those of the hairs, and bristles, and claws of multitudes of insects, the thorns, or crooks, or hairs of leaves, and other small vegetables.

These are all natural rather than man-made points. But it may be different today. How does the point of a modern phonograph needle compare with a rose thorn?

Having finished with the needle's point, Hooke goes on to examine another "point" — a period or the dot of an "i".

A Period

> I observed many, both printed ones and written, and among multitudes I found few of them more round or regular than this which I have delineated [*drawn*] . . . but very many abundantly more disfigured [*distorted*].
>
> You may have sufficient reason to guess that a point may appear much more ugly than this which I have here represented, which though it appeared through the microscope gray, like a great splatch of London dirt about three inches over, yet to the naked eye it was black and no bigger than that in the midst of the circle A.

Find out for yourself if a modern printed period or the dot of an "i" also resembles a "great splatch" of dirt. Are periods different in magazines, newspapers, and books? (The photographs in magazines — especially the colored ones — are also well worth your examination.)

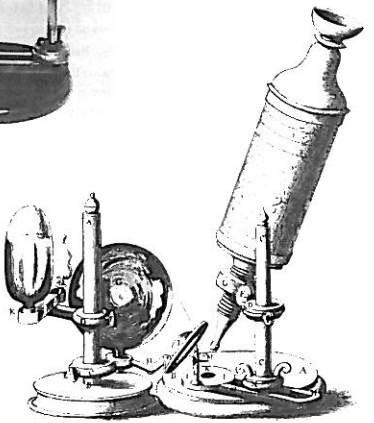
Some remarks on looking

Nowadays when looking at small things through a microscope we mostly put them on glass slides, lighting them from below. This is partly because so many things are transparent when they are very thin. Hooke, however, stuck the things he examined on the end of a pin. (This is marked M in the drawing. In the photograph you can see the pin of the microscope under the tube.) Placing his specimens on a pin allowed Hooke to look at them in many ways: not only when they were in various positions, but also when the light came from different directions.
He describes how he did this in the introduction of his book:

> I endeavored (as far as I was able) first to discover the true appearance, and next, to make a plain representation of it. And therefore, I never began to make any draft [drawing] before by many examinations in several lights, and in several positions to those lights, I had discovered the true form. For it is exceedingly difficult in some objects, to distinguish between a prominency [bump] and a depression, between a shadow and a black stain, or a reflection and a whiteness in the color. Besides, the transparency of most objects renders them yet much more difficult than if they were opaceous [opaque].

At the left is a photograph showing how one of Hooke's microscopes actually looked.

Below is a drawing of the same microscope from Hooke's Micrographia. *It shows the complicated arrangement he designed for lighting — before electricity!*



Here is a glimpse at the working manner of a scientist, and it is worth following his lead in order to see things well through an instrument. For instance, a small flashlight, which can be moved about and held near what you would examine, can increase your understanding of what you see. Playing around with the mirror on a microscope can also be surprisingly rewarding. It is in fact astonishing how much better an understanding you get of what you see, if you look at it from various angles and in various lights.
Hooke has also a clever way of finding out the approximate magnification of a hand lens or microscope:

> My way for measuring how much a glass magnifies an object is this . . . at the same time that I look upon the object through the glass with one eye, I look upon other objects at the same distance with my other eye, by which means I am able, by the help of a ruler divided into inches and small parts, and laid on the pedestal of the microscope, to cast, as it were, the magnified appearance of the object upon the ruler, and thereby exactly to measure the diameter it appears of through the glass, which being compared with the diameter it appears of to the naked eye, will easily afford the quantity [power] of its magnification

Looking at cork

Sometimes Hooke tells particularly clearly how he prepared his specimens and made his observations:

> Observation 18. Of the Texture of Cork
>
> I took a good clear piece of cork, and with a penknife sharpened as keen as a razor, I cut a piece of it off, and thereby left the surface of it exceeding smooth

His piece of cork was just what you'd suppose. The same material was used in his day that we use today to make stoppers for bottles. It comes from the bark of the cork oak tree. Today corks can be bought in hardware stores and supermarkets.
Hooke continues:

> Then examining it very diligently with a microscope, me thought I could perceive it to appear a little porous; but I could not so plainly distinguish them, as to be sure that they were pores, much less what figure [shape] they were of.

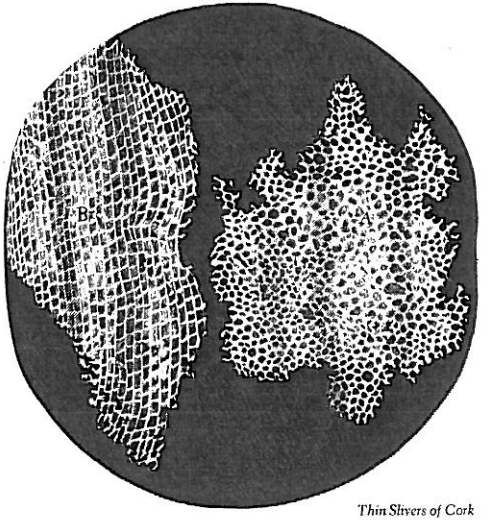
He tells — and you can check this for yourself — that it's very hard to see the structure of the cork in this way. But he said he was willing to keep trying, so:

> I with the same sharp penknife, cut off from the former smooth surface an exceeding thin piece of it . . .

He means very thin. The easiest way to do this is to use a very sharp knife or a single-edged razor blade. Cut a wedge-shaped piece of cork, rather like a small serving of birthday cake. The thinnest part will be as "exceeding thin" as Hooke's slice of cork was.
He continues to describe how he got the details to be clearly visible:

> Placing it on a black object plate, because it was itself a white body . . . I could exceeding plainly perceive it to be all perforated and porous, much like a honeycomb, but that the pores of it were not regular.

You yourself might try looking at a slice of cork with both white and black paper under it, as well as on a slide with light coming through it.



Thin Slivers of Cork

But to proceed.

It was not unlike a honeycomb in these particulars.

First, in that it had a very little solid substance, in comparison of the empty cavity that was contained between, as does more manifestly appear by the Figure A and B. . . .

Next, in that these pores, or cells, were not very deep, but consisted of a great many little boxes, separated out of one continued long pore by certain diaphragms [*partitions*], as is visible by the Figure B, which represents a sight of those pores split the long ways.

In the 1600's a "cell" meant a monk's cell or a prison cell. Nobody before had ever noticed the little compartments in living matter or called them cells. Robert Hooke here invented a use for the word cell that we still use today.

I no sooner discerned [saw] these (which were indeed the first microscopical pores I ever saw, and perhaps, that were ever seen, for I had not met with any writer or person, that had made any mention of them before this) but me thought I had with the discovery of them, . . . the reason of all the phenomena of cork

Why the weight of cork is so small

First, if I enquired why it was so exceeding light a body? My microscope could presently inform me that here was the same reason evident that there is found for the lightness of froth, an empty honeycomb, wool, a sponge, a pumice stone, or the like; namely, a very small quantity of a solid body extended into exceeding large dimensions.

You need no microscope to tell this about soap froth and honeycombs, but wool, pumice and sponge (both the natural and the artificial kinds) are worth putting under your microscope.

Why cork, unlike sponge, doesn't get waterlogged

Next, it seemed nothing more difficult to give an intelligible reason why cork is a body so very unapt to suck and drink in water, and consequently preserves itself, floating on the top of water, though left on it ever so long, and why it is able to stop and hold air in a bottle . . . For, as to the first, since our microscope informs us that the substance of cork

is altogether filled with air, and that that air is perfectly enclosed in little boxes or cells distinct from one another, it seems very plain, why neither the water, nor any other air can easily insinuate itself into them.

Why cork is squeezable

And thirdly, if we enquire why cork has such a springiness and swelling nature when compressed? . . . Our microscope will easily inform us that the whole mass consists of an infinite company of small boxes or bladders of air, which is a substance of a springy nature. . . .

He goes on to do some arithmetic that gets him into the billions!

I told [counted] several lines of these pores, and found that there were usually about threescore [one score is twenty] of these small cells placed end-ways in the eighteenth part of an inch in length, whence I concluded there must be near eleven hundred of them, or somewhat more than a thousand in the length of an inch, and therefore in a square inch above a million, or 1,166,400 and in a cubic inch, about twelve hundred millions, or 1,259,712,000, a thing almost incredible, did not our microscope assure us of it by ocular demonstration [seeing].

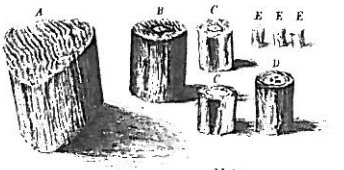
Looking at various things under a microscope

This man put everything imaginable under his microscope. He found it all new and beautiful. Each thing taught him to see more in the next thing that he looked at.
The descriptions of the things that follow have been chosen from Micrographia because you yourself can easily get many of them. You'll not only learn more by looking for yourself, you'll also enjoy more what Robert Hooke has to say about the things.

He looked at hair

Viewing some of the hairs of my head with a very good microscope, I took notice of these particulars:

1. That they were, for the most part, cylindrical . . . very near round, such as are represented by . . . the cylinders E E E. . . .



Hairs

A is of a boar, B a cat's "mustachios," C and D the "long hairs of horses," E E E are Hooke's own hair.

2. That that part which was next the top was bigger than that which was nearer the root

3. That they were all along from end to end transparent, though not very clear, the end next the root appearing like a black transparent piece of horn, the end next the top more brown. . . .

4. That the root of the hairs was pretty smooth, tapering inwards, almost like a parsnip; nor could I find that it had any filaments . . . such as the fibers of plants

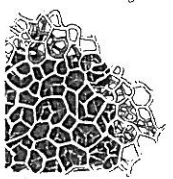
5. That the top when split (which is common in long hair) appeared like the end of a stick, beaten till it be all flittered, there being not only two splinters, but sometimes half a score and more

Spiders' webs

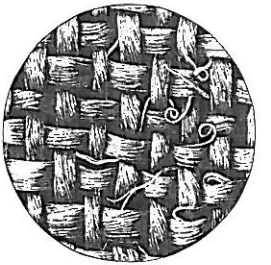
I observed further that the radiating chords [spokes] of the web were much bigger and smoother than those that were woven round, which seemed smaller, and all over knotted or pearled with small transparent globules, not unlike small crystal beads or seed pearls

The nature of a sponge

It consists of an infinite number of small short fibers, or nervous parts, much of the same bigness, curiously jointed . . . together in the form of a net



Hooke's drawing is of only one of many kinds of sponges



Linen from a Fine Handkerchief

Silk

Fine cloth

The threads were scarce discernable [could scarcely be seen] by the naked eye and yet through an ordinary microscope you may perceive what a goodly piece of coarse matting it is.

Poppy seeds

Do poppy seeds, such as come on top of some buns, look different from their "300-great" grandfathers?

The small seeds of poppy . . . both for their smallness, multiplicity and prettiness . . . deserve to be taken notice of among the other microscopical seeds of vegetables. For first, though they grow in a case . . . oftentimes bigger than one of these pictures of the microscopical appearance, yet are they for the most part so very little, that they exceed not the bulk of a small nitt [*an insects' tiny egg*] being not above $\frac{1}{32}$ part of an inch in diameter, whereas the diameter of the hive of them oftentimes exceeds two inches, so that it is capable of containing near two hundred thousand, and so in all likelihood does contain a vast quantity, though perhaps not that number.

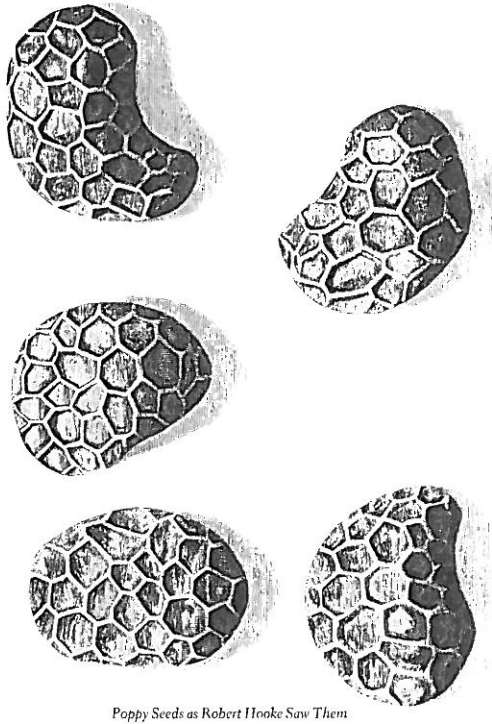
Can you check Hooke's arithmetic? It will help you if you suppose that both the seeds and their case are little cubes.

Next, for their prettiness, they may be compared to any microscopical seed I have yet seen, for they are of a dark brownish red color, curiously honeycombed all over with a very pretty variety of network.

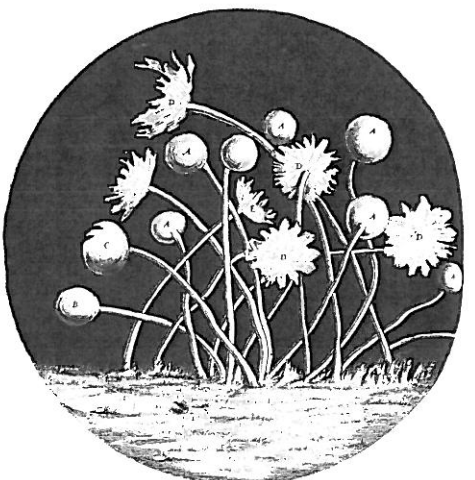
A small round charcoal

There will appear an infinite company of exceedingly small, and very regular pores, so thick and so orderly set, and so close to one another, that they leave very little room or space between them to be filled with a solid body for the . . . separating sides of these pores seem so thin in some places that the texture of a honeycomb cannot be more porous.

Most of these small pores seemed to be pretty round, and were ranged in rows that radiated from the pith to the bark.



Poppy Seeds as Robert Hooke Saw Them



A Small White Spot of Hairy Mold

A moss plant

Moss . . . though among plants it be in bulk one of the smallest, yet it is not the least considerable . . . it has a root almost like a seedy parsnip, furnished with small strings and suckers, which are all of them finely branched, like those of the roots of much bigger vegetables. Out of this springs the stem or body of the plant, . . . on the sides of this are close and thick set a multitude of fair, large, well-shaped leaves. . . . Also, from the top of the leaves there shoots out a small white and transparent hair . . . on which grows a large seed case.

A spot of mold

Hooke found a small spot of mold growing on the cover of a book. A slice of bread kept for a few days in a plastic bag will provide you with a different but similar mold

These spots appeared, through a good microscope, to be a very pretty shaped vegetative body, which . . . shot out multitudes of small . . . transparent stalks, not exactly straight, but a little bended with the weight of a round and white knob that grew on the top of each of them, many of these knobs I observed to be very round, and of a smooth surface, such as AA. Others smooth likewise, but a little oblong, as B. Several of them a little broken . . . as C. Others flittered as 'twere, or flown all to pieces, as D D.

Snowflakes

Exposing a piece of black cloth, or a black hat to the falling snow, I have often with great pleasure, observed such an infinite variety of curiously figured [*shaped*] snow, that it would be impossible to draw the . . . shape of every one of them. . . .

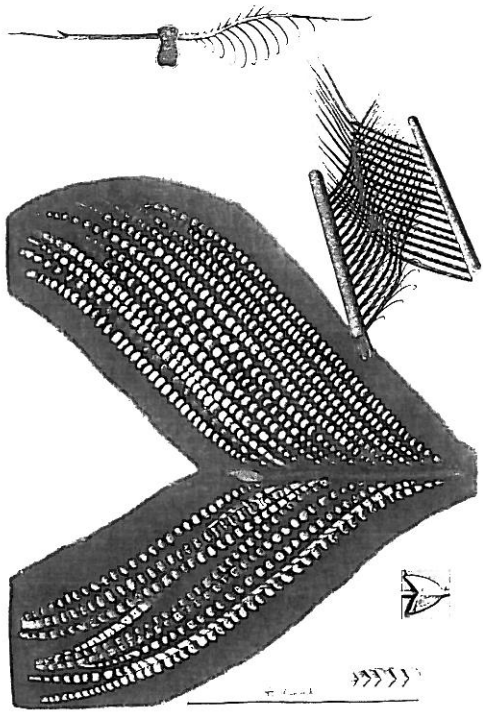
In all which I observed that if they were of any regular figures, they were always branched out with six principal branches, all of equal length, shape, and make from the center, being each of them inclined to the branches on either side of it by an angle of sixty degrees. . . . In a very little time I have observed above an hundred several sizes and shapes of these starry flakes.

Snowflakes

With an apology for the crudeness of his drawing, Hooke still shows his delight at these "starry flakes." A hand glass will show you much detail on snowflakes. A microscope will show you even more. But you must leave your instrument out-of-doors for an hour or so to get cold and then work very quickly in order to see the little crystals, for to snowflakes you are like a fireplace. Not many people have ever seen a real snowflake so magnified, and it is well worth the effort.

Of the shape of feathers

As for the make . . . of the down itself, it is indeed very rare and admirable, and such as I can hardly believe that the like is to be discovered in any other body in the world, for there is hardly a large feather in the wing of a bird, but contains near a million of distinct parts, and every one of them shaped in a most regular and admirable form, adapted to a particular design.



Parts of Feathers

A bee sting

The sting of a bee . . . seems to be a weapon of offense, and is as great an instance that nature did really intend revenge as any, . . . first, because there seems to be no other use of it. Secondly, by reason of its admirable shape, seeming to be purposely shaped for that very end. Thirdly, from the virulency of the liquor it ejects and the sad effects and symptoms that follow it.

A Bee's Weapon of Offense

The end of this dart was very sharp, and it was armed . . . with . . . tenterhooks or claws

A Fly and Its Wing

Various parts of flies

I took a large drone fly . . . examining it according to my usual manner, by varying the degrees of light, and altering its position to each kind of light, I drew that representation . . . and found these things to be as plain and evident as notable and pleasant.

Many insects have eyes of this general sort, flies, bees and wasps are all easy to see.

The greatest part of the face, nay, of the head, was nothing else but two large bunches, the surface of each of which was all covered over, or shaped into a multitude of small hemispheres . . . the bottoms of which were perfectly entire and not at all perforated or drilled through, which I most certainly was assured of, by the regularly reflected image of certain objects which I moved to and fro between the head and the light.

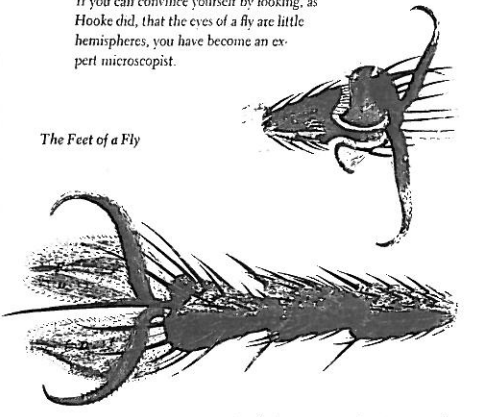
Eyes of a Fly

In each of these hemispheres I have been able to discover a landscape of those things which lay before my window.

You can see two windows of Robert Hooke's study reflected in the eyes of a fly under his microscope. You even can tell how many panes of glass those long ago windows had. Hooke mentions the difficulty of being sure of the shape of insects' eyes in his introduction.

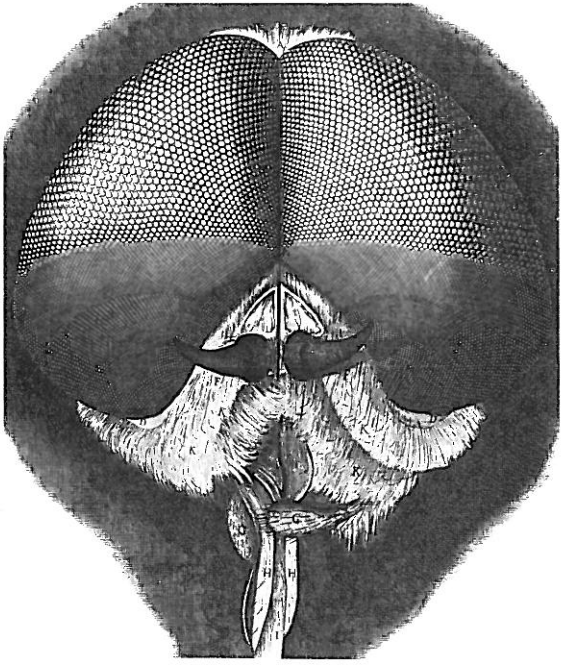
The eyes of a fly in one kind of light appear almost like a lattice, drilled through with abundance of small holes . . . . In the sunshine they look like a surface covered with golden nails; in another posture, like a surface covered with pyramids; in another with cones; and in other postures of quite other shapes.

If you can convince yourself by looking, as Hooke did, that the eyes of a fly are little hemispheres, you have become an expert microscopist.



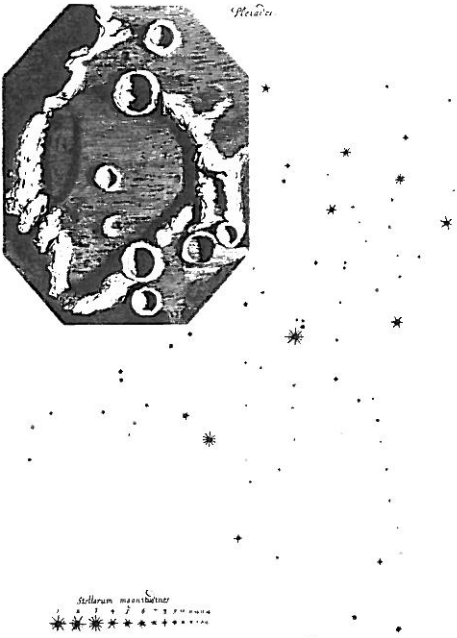
The Feet of a Fly

The foot of a fly which represents three joints is of a most admirable and curious construction, for by this the flies are enabled to walk against the sides of glass perpendicularly upward, and to contain themselves in that posture as long as they please. Nay, to walk and suspend themselves against the under surface of many bodies as the ceiling of a room or the like.



The Head of a Fly

All the face of a fly is nothing almost but eyes.



Hooke was interested in the world of the very large as well as the very small. Here he shows what he saw when he examined a constellation and a part of the moon through his telescope.

A note about the Hooke book

Micrographia was first printed in October of 1664. It became and has remained a great success. Today it is available, entire, with all its old spellings, letters, and pictures, from Dover Books, Inc., New York.

The pictures

Hooke first made his own drawings of what he saw for himself. He had these copied by expert engravers until he was satisfied they clearly showed what he had seen. Photography had not yet been invented and those books which had pictures in them had wood prints or metal engravings.

With the exception of the photograph of Hooke's microscope, used with the permission of Brown Brothers, all of the pictures in this book are photographs of the pictures in Micrographia. They were made from one of the remaining copies of the 1664 book one kept at Harvard University.

The words

A note about the quotations from Micrographia

Words printed in this type are exact quotes from Micrographia. Only the spelling has been changed.

. . . This means that some words have been left out.

[ ] This is a word or phrase added to make a meaning clear.

At the right is a page from the original edition of Micrographia.
Each "f" without a crossbar is an old-fashioned "s." Spelling was less orderly in those days, easier on the writer but harder on the reader.

curious, but that possibly, if I could use some further diligence, I might find it to be discernable with a *Microscope*, I with the same sharp Penknife, cut off from the former smooth surface an exceeding thin piece of it, and placing it on a black object Plate, because it was it self a white body, and casting the light on it with a deep *plano-convex Glass*, I could exceeding plainly perceive it to be all perforated and porous, much like a Honey-comb, but that the pores of it were not regular; yet it was not unlike a Honey-comb in these particulars.

First, in that it had a very little solid substance, in comparison of the empty cavity that was contain'd between, as does more manifestly appear by the Figure A and B of the X I. *Scheme*, for the *Interstitia*, or walls (as I may so call them) or partitions of those pores were neer as thin in proportion to their pores, as those thin films of Wax in a Honey-comb (which enclose and constitute the *six angular cells*) are to theirs.

Next, in that these pores, or cells, were not very deep, but consisted of a great many little Boxes, separated out of one continued long pore, by certain *Diaphragms*, as is visible by the Figure B, which represents a sight of those pores split the long-ways.

I no sooner discern'd these (which were indeed the first *microscopical* pores I ever saw, and perhaps, that were ever seen, for I had not met with any Writer or Person, that had made any mention of them before this) but me thought I had with the discovery of them, presently hinted to me the true and intelligible reason of all the *Phænomena* of Cork; As,

First, if I enquir'd why it was so exceeding light a body? my *Microscope* could presently inform me that here was the same reason evident that there is found for the lightness of froth, an empty Honey-comb, Wool, a Spunge, a Pumice-stone, or the like; namely, a very small quantity of a solid body, extended into exceeding large dimensions.

Next, it seem'd nothing more difficult to give an intelligible reason, why Cork is a body so very unapt to suck and drink in Water, and consequently preserves it self, floating on the top of Water, though left on it never so long: and why it is able to stop and hold air in a Bottle, though it be there very much condens'd and consequently presses very strongly to get a passage out, without suffering the least bubble to pass through its substance. For, as to the first, since our *Microscope* informs us that the substance of Cork is altogether fill'd with Air, and that that Air is perfectly enclosed in little Boxes or Cells distinct from one another. It seems very plain, why neither the Water, nor any other Air can easily insinuate it self into them, since there is already within them an *antus existens*, and consequently, why the pieces of Cork become so good floats for Nets, and stopples for Vials, or other close Vessels.

And thirdly, if we enquire why Cork has such a springiness and swelling nature when compress'd? and how it comes to suffer so great a compression, or seeming penetration of dimensions, so as to be made a substance as heavie again and more, bulk for bulk, as it was before compression, and yet suffer'd to return, is found to extend it self again into the same space? Our *Microscope* will easily inform us, that the whole mass

All of the microscopes recommended in the Teacher's Guide to The Elementary Science Study unit Small Things *are fine for seeing the sorts of things Hooke saw, about as well as or perhaps a little better than he saw them.*

Some — not all — of the $2-$15 microscopes available in hobby stores and such are satisfactory. Test them before purchase by looking at a Hooke thing: a needle's point or the dot of an "i." Aside from clear seeing, choose only the instrument that seems sturdy enough to last. Two particularly fine ones that meet all these tests and that you might aspire to own for yourself are a simple (one lens) microscope made by American Science and Engineering Inc. and a Bausch and Lomb 100X microscope (model ESM 100).

The teachers and scientists of the Elementary Science Study would like to know what you think of this book, and about the small things that you have looked at with your magnifying glass or microscope.

If you would like to share your discoveries, thoughts, and questions, please write and send your drawings to

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