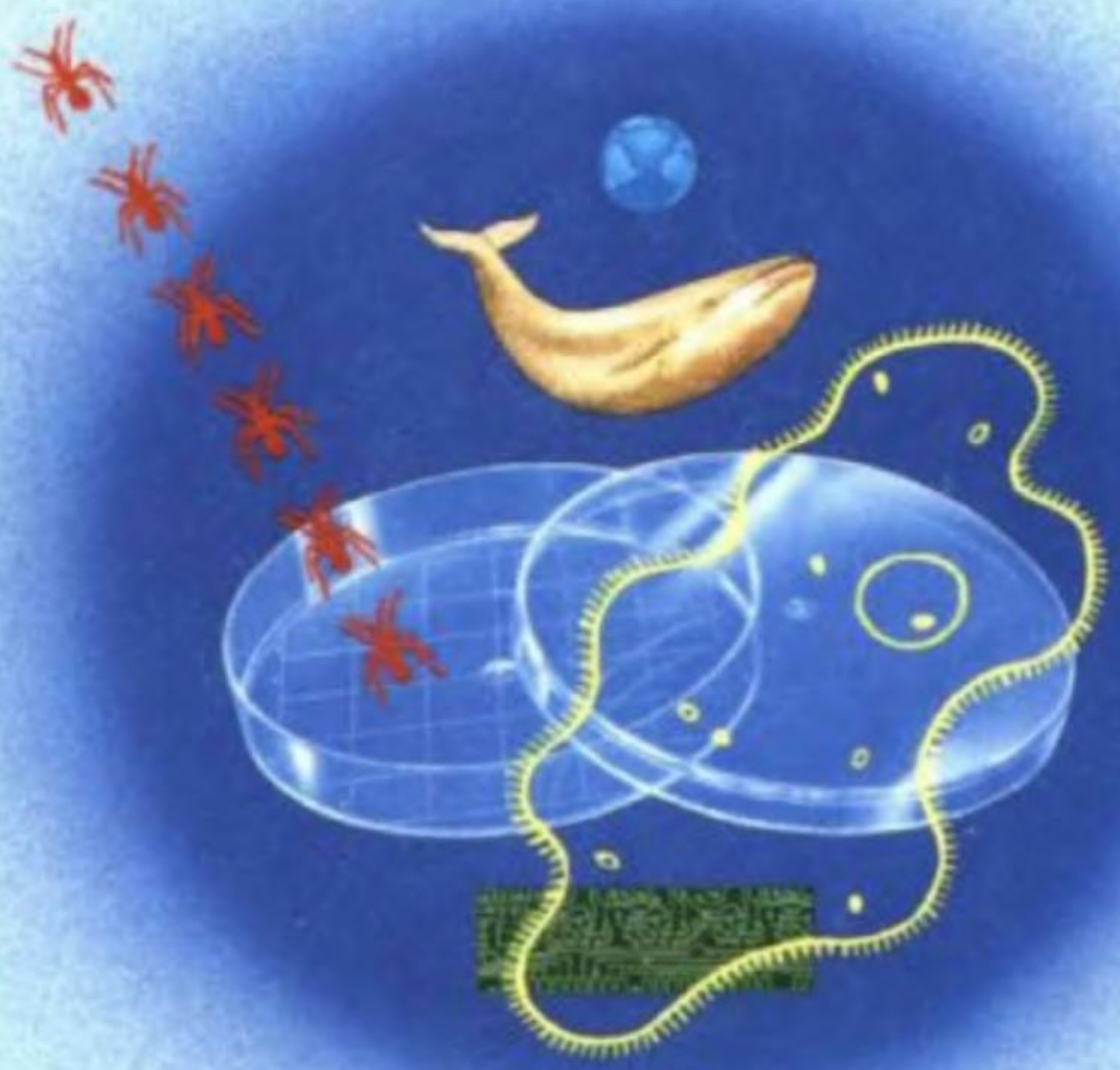
WINNER OF THE NATIONAL BOOK AWARD

"A blend of hard science, elegant language and thoughtfulness...
guaranteed to intrigue both scientist and poet"
—*ROLLING STONE*

The Lives of a Cell

NOTES OF A BIOLOGY WATCHER



LEWIS THOMAS

author of *THE MEDUSA AND THE SNAIL*

THE LIVES OF A CELL

Notes of a Biology Watcher

LEWIS THOMAS

PENGUIN BOOKS

PENGUIN BOOKS
An imprint of Penguin Random House LLC
375 Hudson Street
New York, New York 10014
penguin.com

First published in the United States of America by The Viking Press 1974
Published in Penguin Books 1978

All of these essays appeared originally in the *New England Journal of Medicine*. Copyright © Massachusetts Medical Society, 1971, 1972, 1973

LIBRARY OF CONGRESS CATALOGING-IN-PUBLICATION DATA
Thomas, Lewis, 1913–1993
The lives of a cell.
Essays which appeared in the New England journal of medicine, 1971–73.
Reprint of the ed. published by The Viking Press, New York.
Bibliography: p. 149.
1. Biology—Philosophy—Addresses, essays, lectures.
I. Title.
{QH331.T45 1978} 303.31'01 77-23765
ISBN 978-0-14-004743-1

Printed in the United States of America
54 55 56 57 58 59 60

Set in Goudy Old Style
Designed by Sabrina Bowers

CONTENTS

THE LIVES OF A CELL

THE LIVES OF A CELL

We are told that the trouble with Modern Man is that he has been trying to detach himself from nature. He sits in the topmost tiers of polymer, glass, and steel, dangling his pulsing legs, surveying at a distance the writhing life of the planet. In this scenario, Man comes on as a stupendous lethal force, and the earth is pictured as something delicate, like rising bubbles at the surface of a country pond, or flights of fragile birds.

But it is illusion to think that there is anything fragile about the life of the earth; surely this is the toughest membrane imaginable in the universe, opaque to probability, impermeable to death. We are the delicate part, transient and vulnerable as cilia. Nor is it a new thing for Man to invent an existence that he imagines to be above the rest of life; this has been his most consistent intellectual exertion down the millennia. As illusion, it has never worked out to his satisfaction in the past, any more than it does today. Man is embedded in nature.

The biologic science of recent years has been making this a more urgent fact of life. The new, hard problem will be to cope with the dawning, intensifying realization of just how interlocked we are. The old, clung-to notions most of us have held about our special lordship are being deeply undermined.

Item. A good case can be made for our nonexistence as

entities. We are not made up, as we had always supposed, of successively enriched packets of our own parts. We are shared, rented, occupied. At the interior of our cells, driving them, providing the oxidative energy that sends us out for the improvement of each shining day, are the mitochondria, and in a strict sense they are not ours. They turn out to be little separate creatures, the colonial posterity of migrant prokaryocytes, probably primitive bacteria that swam into ancestral precursors of our eukaryotic cells and stayed there. Ever since, they have maintained themselves and their ways, replicating in their own fashion, privately, with their own DNA and RNA quite different from ours. They are as much symbionts as the rhizobial bacteria in the roots of beans. Without them, we would not move a muscle, drum a finger, think a thought.

Mitochondria are stable and responsible lodgers, and I choose to trust them. But what of the other little animals, similarly established in my cells, sorting and balancing me, clustering me together? My centrioles, basal bodies, and probably a good many other more obscure tiny beings at work inside my cells, each with its own special genome, are as foreign, and as essential, as aphids in anthills. My cells are no longer the pure line entities I was raised with; they are ecosystems more complex than Jamaica Bay.

I like to think that they work in my interest, that each breath they draw for me, but perhaps it is they who walk through the local park in the early morning, sensing my senses, listening to my music, thinking my thoughts.

I am consoled, somewhat, by the thought that the green plants are in the same fix. They could not be plants, or green, without their chloroplasts, which run the photosynthetic enterprise and generate oxygen for the rest of us. As it turns out, chloroplasts are also separate creatures with their own genomes, speaking their own language.

We carry stores of DNA in our nuclei that may have come in, at one time or another, from the fusion of ancestral cells

and the linking of ancestral organisms in symbiosis. Our genomes are catalogues of instructions from all kinds of sources in nature, filed for all kinds of contingencies. As for me, I am grateful for differentiation and speciation, but I cannot feel as separate an entity as I did a few years ago, before I was told these things, nor, I should think, can anyone else.

Item. The uniformity of the earth's life, more astonishing than its diversity, is accountable by the high probability that we derived, originally, from some single cell, fertilized in a bolt of lightning as the earth cooled. It is from the progeny of this parent cell that we take our looks; we still share genes around, and the resemblance of the enzymes of grasses to those of whales is a family resemblance.

The viruses, instead of being single-minded agents of disease and death, now begin to look more like mobile genes. Evolution is still an infinitely long and tedious biologic game, with only the winners staying at the table, but the rules are beginning to look more flexible. We live in a dancing matrix of viruses; they dart, rather like bees, from organism to organism, from plant to insect to mammal to me and back again, and into the sea, tugging along pieces of this genome, strings of genes from that, transplanting grafts of DNA, passing around heredity as though at a great party. They may be a mechanism for keeping new, mutant kinds of DNA in the widest circulation among us. If this is true, the odd virus disease, on which we must focus so much of our attention in medicine, may be looked on as an accident, something dropped.

Item. I have been trying to think of the earth as a kind of organism, but it is no go. I cannot think of it this way. It is too big, too complex, with too many working parts lacking visible connections. The other night, driving through a hilly, wooded part of southern New England, I wondered about this. If not like an organism, what is it like, what is it *most* like? Then, satisfactorily for that moment, it came to me: it is *most* like a single cell.

THOUGHTS FOR A COUNTDOWN

There is ambiguity, and some symbolism, in the elaborate ritual observed by each returning expedition of astronauts from the moon. They celebrate first of all the inviolability of the earth, and they re-enact, each time, in stereotyped choreography, our long anxiety about the nature of life. They do not, as one might expect, fall to their knees and kiss the carrier deck; this would violate, intrude upon, contaminate the deck, the vessel, the sea around, the whole earth. Instead, they wear surgical masks. They walk briskly, arms up, untouching, into a sterile box. They wave enigmatically, gnotobiotically, to the President from behind glass panes, so as not to breathe moondust on him. They are levitated to another sealed box in Houston, to wait out their days in quarantine, while inoculated animals and tissues cultures are squinted at for omens.

It is only after the long antiseptic ceremony has been completed that they are allowed out into the sun, for the ride up Broadway.

A visitor from another planet, or another century, would view the exercise as precisely lunatic behavior, but no one from outside would understand it. We must do things this way, these days. If there should be life on the moon, we must begin by fearing it. We must guard against it, lest we catch something.

It might be a microbe, a strand of lost nucleic acid, a molecule of enzyme, or a nameless hairless little being with sharp gray eyes. Whatever, once we have imagined it, foreign and therefore hostile, it is not to be petted. It must be locked up. I imagine the debate would turn on how best to kill it.

It is remarkable that we have all accepted this, without hooting, as though it simply conformed to a law of nature. It says something about our century, our attitude toward life, our obsession with disease and death, our human chauvinism.

There are pieces of evidence that we have had it the wrong way round. Most of the associations between the living things we know about are essentially cooperative ones, symbiotic in one degree or another; when they have the look of adversaries, it is usually a standoff relation, with one party issuing signals, warnings, flagging the other off. It takes long intimacy, long and familiar interliving, before one kind of creature can cause illness in another. If there were to be life on the moon, it would have a lonely time waiting for acceptance to membership here. We do not have solitary beings. Every creature is, in some sense, connected to and dependent on the rest.

It has been estimated that we probably have real knowledge of only a small proportion of the microbes of the earth, because most of them cannot be cultivated alone. They live together in dense, interdependent communities, feeding and supporting the environment for each other, regulating the balance of populations between different species by a complex system of chemical signals. With our present technology, we can no more isolate one from the rest, and rear it alone, than we can keep a single bee from drying up like a desquamated cell when removed from his hive.

The bacteria are beginning to have the aspect of social animals; they should provide nice models for the study of interactions between forms of life at all levels. They live by collaboration, accommodation, exchange, and barter. They, and the fungi, probably with help from a communication

system laid on by the viruses, comprise the parenchyma of the soil (someone has suggested that humic acid, to which the microbes contribute, is a sort of counterpart for the ground substance of our own connective tissue). They live on each other. Sometimes they live inside each other; the *Bdellovibrio* penetrate the walls of other bacteria, tuck themselves up inside, replicate, and burst out again as though they thought themselves phages. Some microbial communities extend so deeply into the affairs of higher forms of life as to seem like new kinds of tissue in plants and animals. The rhizobial bacteria that swarm over the root hairs of leguminous plants have the look of voracious, invasive pathogens, but the root nodules that they then construct, in collaboration with the plant cells, become the earth's chief organ for nitrogen fixation. The production of leghemoglobin in the membrane-lined space between plant and bacterial cells is an example of the high technology of symbiosis; the protein is synthesized by the plant, but only on instructions from the bacteria, and it is possible that the plant DNA for coding this substance came originally from the microbe, early in the evolution of the arrangement.

The bacteria that live in the tissues of insects, like those incorporated into the mycetocytes of cockroaches and termites, have the appearance of specialized organs in their hosts. It is not yet clear what they accomplish for the insect, but it is known that the species cannot survive long without them. They are transmitted, like mitochondria, from generation to generation of eggs.

It has been proposed that symbiotic linkages between prokaryotic cells were the origin of eukaryotes, and that fusion between different sorts of eukaryotes (e.g., motile, ciliated cells joined to phagocytic ones) led to the construction of the communities that eventually turned out to be metazoan creatures. If this is true, the marks of identity, distinguishing self from non-self, have long since been blurred. Today, in the

symbiotic associations that dominate so much of the life of the sea, there is rarely a question of who is who, even when the combination functions like a single animal. The anemones that fasten themselves to the shells, even to the claws, of certain crabs are capable of recognizing precisely the molecular configurations that identify those surfaces: the crab, for his part, can recognize his own anemone, and will sometimes seek him out and attach him to the shell like an ornament. The damsel fish that have become, from their point of view, functioning parts of certain species of anemones adapt themselves when very young to life among the lethal tentacles of their host; they cannot just swim in forthwith—they must dart around the edges until labeled at their surfaces by markers acceptable to the anemone.

Sometimes, in the course of the modulation of relations between animals, there are inventions that seem to have been thought up on the spur of the moment, like propositions to be submitted for possible evolution. Some are good-humored, even witty. Certain Australian surf bathers, several years ago, were stung by tiny creatures that turned out to be nudibranchs armed with the stingers of Portuguese men-of-war. Having fed on jellyfish, the Glaucus community had edited their meal and allowed the stinging cells to make their way to the surface of their new host, thus creating, for the time, a sort of instant hybrid with, allowing for some asymmetry, the essential attributes of each partner.

Even when circumstances require that there be winners and losers, the transaction is not necessarily a combat. The aloofness displayed for each other by members of the marine coelenterate species of Gorgonaceae suggests that mechanisms for preserving individuality must have existed long before the evolution of immunity. The gorgonians tend to grow in closely packed, branching masses, but they do not fuse to each other; if they did, their morphogenesis would doubtless become a shambles. Theodor, in a series of elegant

experiments, has shown that when two individuals of the same species are placed in close contact, the smaller of the two will always begin to disintegrate. It is autodestruction due to lytic mechanisms entirely under the governance of the smaller partner. He is not thrown out, not outgamed, not outgunned; he simply chooses to bow out. It is not necessarily a comfort to know that such things go on in biology, but it is at least an agreeable surprise.

The oxygen in the atmosphere is the exhalation of the chloroplasts living in plants (also, for our amazement, in the siphons of giant clams and lesser marine animals). It is a natural tendency for genetically unrelated cells in tissue culture to come together, ignoring species differences, and fuse to form hybrid cells. Inflammation and immunology must indeed be powerfully designed to keep us apart; without such mechanisms, involving considerable effort, we might have developed as a kind of flowing syncytium over the earth, without the morphogenesis of even a flower.

Perhaps we will find it possible to accommodate other forms of life, from other planets, out of sheer good nature. We are, after all, a planet where the rain contains vitamin B_{12}! There is enough of it, by Parker's calculation, when convective windstorms occur at the time of farmland cultivation and swirl it from the soil into the upper atmosphere, to produce a visible bloom of Euglena in a fair-sized pond.

ON SOCIETIES AS ORGANISMS

Viewed from a suitable height, the aggregating clusters of medical scientists in the bright sunlight of the boardwalk at Atlantic City, swarmed there from everywhere for the annual meetings, have the look of assemblages of social insects. There is the same vibrating, ionic movement, interrupted by the darting back and forth of jerky individuals to touch antennae and exchange small bits of information; periodically, the mass casts out, like a trout-line, a long single file unerringly toward Childs's. If the boards were not fastened down, it would not be a surprise to see them put together a nest of sorts.

It is permissible to say this sort of thing about humans. They do resemble, in their most compulsively social behavior, ants at a distance. It is, however, quite bad form in biological circles to put it the other way round, to imply that the operation of insect societies has any relation at all to human affairs. The writers of books on insect behavior generally take pains, in their prefaces, to caution that insects are like creatures from another planet, that their behavior is absolutely foreign, totally unhuman, unearthly, almost unbiological. They are more like perfectly tooled but crazy little machines, and we violate science when we try to read human meanings in their arrangements.

It is hard for a bystander not to do so. Ants are so much

like human beings as to be an embarrassment. They farm fungi, raise aphids as livestock, launch armies into wars, use chemical sprays to alarm and confuse enemies, capture slaves. The families of weaver ants engage in child labor, holding their larvae like shuttles to spin out the thread that sews the leaves together for their fungus gardens. They exchange information ceaselessly. They do everything but watch television.

What makes us most uncomfortable is that they, and the bees and termites and social wasps, seem to live two kinds of lives: they are individuals, going about the day's business without much evidence of thought for tomorrow, and they are at the same time component parts, cellular elements, in the huge, writhing, ruminating organism of the Hill, the nest, the hive. It is because of this aspect, I think, that we most wish for them to be something foreign. We do not like the notion that there can be collective societies with the capacity to behave like organisms. If such things exist, they can have nothing to do with us.

Still, there it is. A solitary ant, afield, cannot be considered to have much of anything on his mind; indeed, with only a few neurons strung together by fibers, he can't be imagined to have a mind at all, much less a thought. He is more like a ganglion on legs. Four ants together, or ten, encircling a dead moth on a path, begin to look more like an idea. They fumble and shove, gradually moving the food toward the Hill, but as though by blind chance. It is only when you watch the dense mass of thousands of ants, crowded together around the Hill, blackening the ground, that you begin to see the whole beast, and now you observe it thinking, planning, calculating. It is an intelligence, a kind of live computer, with crawling bits for its wits.

At a stage in the construction, twigs of a certain size are needed, and all the members forage obsessively for twigs of just this size. Later, when outer walls are to be finished, thatched, the size must change, and as though given new

orders by telephone, all the workers shift the search to the new twigs. If you disturb the arrangement of a part of the Hill, hundreds of ants will set it vibrating, shifting, until it is put right again. Distant sources of food are somehow sensed, and long lines, like tentacles, reach out over the ground, up over walls, behind boulders, to fetch it in.

Termites are even more extraordinary in the way they seem to accumulate intelligence as they gather together. Two or three termites in a chamber will begin to pick up pellets and move them from place to place, but nothing comes of it; nothing is built. As more join in, they seem to reach a critical mass, a quorum, and the thinking begins. They place pellets atop pellets, then throw up columns and beautiful, curving, symmetrical arches, and the crystalline architecture of vaulted chambers is created. It is not known how they communicate with each other, how the chains of termites building one column know when to turn toward the crew on the adjacent column, or how, when the time comes, they manage the flawless joining of the arches. The stimuli that set them off at the outset, building collectively instead of shifting things about, may be pheromones released when they reach committee size. They react as if alarmed. They become agitated, excited, and then they begin working, like artists.

Bees live lives of organisms, tissues, cells, organelles, all at the same time. The single bee, out of the hive retrieving sugar (instructed by the dancer: "south-southeast for seven hundred meters, clover—mind you make corrections for the sundrift"), is still as much a part of the hive as if attached by a filament. Building the hive, the workers have the look of embryonic cells organizing a developing tissue; from a distance they are like the viruses inside a cell, running off row after row of symmetrical polygons as though laying down crystals. When the time for swarming comes, and the old queen prepares to leave with her part of the population, it is as though the hive were involved in mitosis. There is an agitated moving of bees back


image
not
available