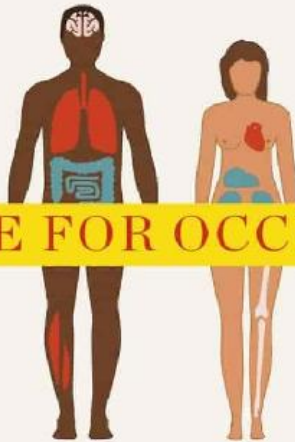


THE BODY



A GUIDE FOR OCCUPANTS

BILL BRYSON

Bestselling author of
A Short History of Nearly Everything

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The Lost Continent

The Mother Tongue

Neither Here Nor There

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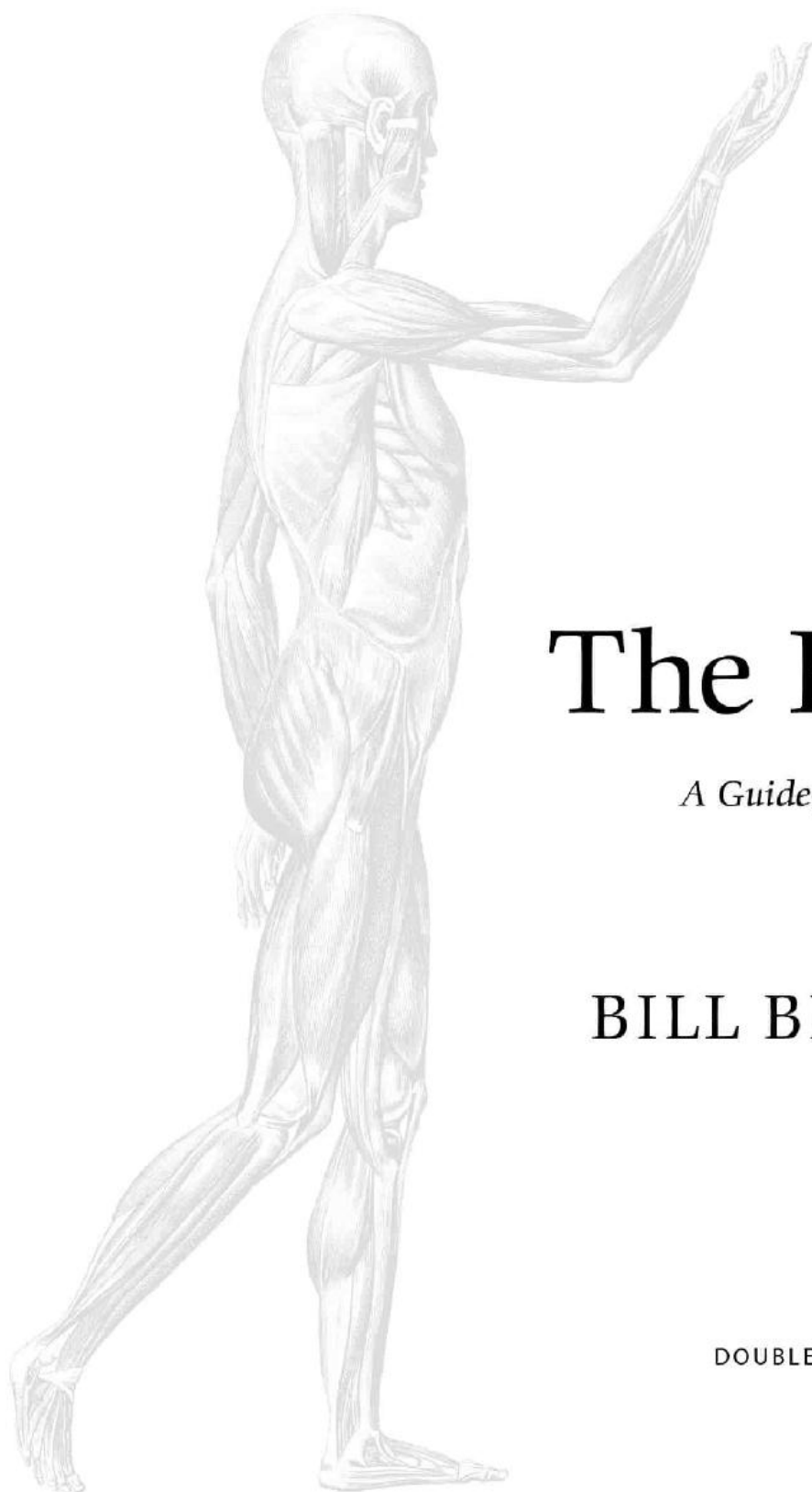
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One Summer

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The Body

A Guide for Occupants

BILL BRYSON

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To Lottie. Welcome to you, too.

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1 HOW TO BUILD A HUMAN

How like a god!

—WILLIAM SHAKESPEARE

LONG AGO, WHEN I was a junior high school student in Iowa, I remember being taught by a biology teacher that all the chemicals that make up a human body could be bought in a hardware store for \$5.00 or something like that. I don't recall the actual sum. It might have been \$2.97 or \$13.50, but it was certainly very little even in 1960s money, and I remember being astounded at the thought that you could make a slouched and pimply thing such as me for practically nothing. It was such a spectacularly humbling revelation that it has stayed with me all these years. The question is, was it true? Are we really

worth so little?

Many authorities (for which possibly read “science majors who don’t have a date on a Friday”) have tried at various times, mostly for purposes of amusement, to compute how much it would cost in materials to build a human. Perhaps the most respectable and comprehensive attempt of recent years was done by Britain’s Royal Society of Chemistry when, as part of the 2013 Cambridge Science Festival, it calculated how much it would cost to assemble all the elements necessary to build the actor Benedict Cumberbatch.

(Cumberbatch was the guest director of the festival that year and was, conveniently, a typically sized human.)

Altogether, according to RSC calculations, fifty-nine elements are needed to construct a human being. Six of these—carbon, oxygen, hydrogen,

nitrogen,

calcium,

and

phosphorus—account

for

99.1 percent of what makes us, but much of the rest is a bit

unexpected. Who would have thought that we would be incomplete without some molybdenum inside us, or vanadium, manganese, tin, and copper? Our requirements for some of these, it must be said, are surpassingly modest and are measured in parts per million or even parts per billion. We need, for instance, just 20 atoms of cobalt and 30 of chromium for every 999,999,999½ atoms of everything else.

The biggest component in any human, filling 61 percent of available space, is oxygen. It may seem a touch counterintuitive that we are almost two-thirds composed of an odorless gas. The reason we are not light and bouncy like a balloon is that the oxygen is mostly bound up with hydrogen (which accounts for another 10 percent of you) to make water—and water, as you will know if you have ever tried to move a wading pool or just walked around in really wet clothes, is surprisingly heavy. It is a little ironic that two of the lightest things in nature, oxygen and hydrogen, when combined form one of the heaviest, but that's nature for you. Oxygen and hydrogen are also two of the cheaper elements within you. All your oxygen will set you back just \$14 and your hydrogen a little over \$26 (assuming you are about the size of Benedict Cumberbatch). Your nitrogen (2.6 percent of you) is a better value still at just forty cents for a body's worth. But after

that it gets pretty expensive.

You need about thirty pounds of carbon, and that will cost you \$69,550, according to the Royal Society of Chemistry. (They were using only the most purified forms of everything. The RSC would not make a human with cheap stuff.) Calcium, phosphorus, and potassium, though needed in much smaller amounts, would between them set you back a further \$73,800. Most of the rest is even more expensive per unit of volume, but fortunately only needed in microscopic amounts. Thorium costs over \$3,000 per gram but constitutes just 0.0000001 percent of you, so you can buy a body's worth for thirty-three cents. All the tin you require can be yours for six cents, while zirconium and niobium will cost you just three cents apiece. The 0.000000007 percent of you that is samarium isn't apparently worth charging for at all. It's logged in the RSC accounts as costing \$0.00. [*1](#)

Of the fifty-nine elements found within us, twenty-four are traditionally known as essential elements, because we really cannot do without them. The rest are something of a mixed bag. Some are clearly beneficial, some may be beneficial but we are not sure in what ways yet, others are neither harmful nor beneficial but are just along for the

ride as it were, and a few are just bad news altogether. Cadmium, for instance, is the twenty-third most common element in the body, constituting 0.1 percent of your bulk, but it is seriously toxic. We have it in us not because our body craves it but because it gets into plants from the soil and then into us when we eat the plants. If you are from North America, you probably ingest about eighty micrograms of cadmium a day, and no part of it does you any good at all.

A surprising amount of what goes on at this elemental level is still being worked out. Pluck almost any cell from your body, and it will have a million or more selenium atoms in it, yet until recently nobody had any idea what they were there for. We now know that selenium makes two vital enzymes, deficiency in which has been linked to hypertension, arthritis, anemia, some cancers, and even, possibly, reduced sperm counts. So, clearly it is a good idea to get some selenium inside you (it is found particularly in nuts, whole wheat bread, and fish), but at the same time if you take in too much you can irremediably poison your liver. As with so much in life, getting the balances right is a delicate business.

Altogether, according to the RSC, the full cost of building a new human being, using the obliging Benedict Cumberbatch as a template,

would be a very precise \$151,578.46. Labor and sales tax would, of course, boost costs further. You would probably be lucky to get a take-home Benedict Cumberbatch for much under \$300,000—not a massive fortune, all things considered, but clearly not the meager few dollars that my junior high school teacher suggested. That said, in 2012 *Nova*, the long-running science program on PBS, did an exactly equivalent analysis for an episode called “Hunting the Elements” and came up with a figure of \$168 for the value of the fundamental components within the human body, illustrating a point that will become inescapable as this book goes on, namely that where the human body is concerned, the details are often surprisingly uncertain. But of course it hardly really matters. No matter what you pay, or how carefully you assemble the materials, you are not going to create a human being. You could call together all the brainiest people who are alive now or have ever lived and endow them with the complete sum of human knowledge, and they could not between them make a single living cell, never mind a replicant Benedict Cumberbatch. That is unquestionably the most astounding thing about us—that we are just a collection of inert components, the same stuff you would find in a pile of dirt. I’ve said it before in another book, but I believe

it's worth repeating: the only thing special about the elements that make you is that they make you. That is the miracle of life.

We pass our existence within this warm wobble of flesh and yet take it almost entirely for granted. How many among us know even roughly where the spleen is or what it does? Or the difference between tendons and ligaments? Or what our lymph nodes are up to? How many times a day do you suppose you blink? Five hundred? A thousand? You've no idea, of course. Well, you blink fourteen thousand times a day—so much that your eyes are shut for twenty-three minutes of every waking day. Yet you never have to think about it, because every second of every day your body undertakes a literally unquantifiable number of tasks—a quadrillion, a nonillion, a quindecillion, a vigintillion (these are actual measures), at all events some number vastly beyond imagining—without requiring an instant of your attention.

In the second or so since you started this sentence, your body has made a million red blood cells. They are already speeding around you, coursing through your veins, keeping you alive. Each of those red blood cells will rattle around you about 150,000 times, repeatedly delivering oxygen to your cells, and then, battered and useless, will

present itself to other cells to be quietly killed off for the greater good of you.

Altogether

it

takes

7

billion

billion

billion

(that's

7,000,000,000,000,000,000,000,000, or 7 octillion) atoms to

make you. No one can say why those 7 billion billion billion have such

an urgent desire to be you. They are mindless particles, after all,

without a single thought or notion between them. Yet somehow for the

length of your existence, they will build and maintain all the countless

systems and structures necessary to keep you humming, to make you

you, to give you form and shape and let you enjoy the rare and

supremely agreeable condition known as life.

That's a much bigger job than you realize. Unpacked, you are

positively enormous. Your lungs, smoothed out, would cover a tennis

court, and the airways within them would stretch nearly from coast to coast. The length of all your blood vessels would take you two and a half times around Earth. The most remarkable part of all is your DNA (or deoxyribonucleic acid). You have a meter of it packed into every cell, and so many cells that if you formed all the DNA in your body into a single strand, it would stretch ten billion miles, to beyond Pluto.

Think of it: there is enough of you to leave the solar system. You are in the most literal sense cosmic.

But your atoms are just building blocks and are not themselves alive. Where life begins precisely is not so easy to say. The basic unit of life is the cell—everyone is agreed on that. The cell is full of busy things—ribosomes and proteins, DNA, RNA, mitochondria, and much other cellular arcana—but none of those are themselves alive. The cell itself is just a compartment—a kind of little room: a *cell*—to contain them, and of itself is as nonliving as any other room. Yet somehow when all of these things are brought together, you have life. That is the part that eludes science. I kind of hope it always will.

What is perhaps most remarkable is that nothing is in charge.

Each component of the cell responds to signals from other components, all of them bumping and jostling like so many bumper

cars, yet somehow all this random motion results in smooth, coordinated action, not just across the cell but across the whole body as cells communicate with other cells in different parts of your personal cosmos.

The heart of the cell is the nucleus. It contains the cell's DNA—three feet of it, as we have already noted, scrunched into a space that we may reasonably call infinitesimal. The reason so much DNA can fit into a cell nucleus is that it is exquisitely thin. You would need twenty billion strands of DNA laid side by side to make the width of the finest human hair. Every cell in your body (strictly speaking, every cell with a nucleus) holds two copies of your DNA. That's why you have enough to stretch to Pluto and beyond.

DNA exists for just one purpose—to create more DNA. A DNA molecule, as you will almost certainly remember from countless television programs if not school biology, is made up of two strands, connected by rungs to form the celebrated twisted ladder known as a double helix. Your DNA is simply an instruction manual for making you. A length of DNA is divided into segments called chromosomes and shorter individual units called genes. The sum of all your genes is the genome.

DNA is extremely stable. It can last for tens of thousands of years.

It is nowadays what enables scientists to work out the anthropology of the very distant past. Probably nothing you own right now—no letter or piece of jewelry or treasured heirloom—will still exist a thousand years from now, but your DNA will almost certainly still be around and recoverable, if only someone could be bothered to look for it.

DNA passes on information with extraordinary fidelity. It makes only about one error per every billion letters copied. Still, because your cells divide so much, that is about three errors, or mutations, per cell division. Most of those mutations the body can ignore, but just occasionally they have lasting significance. That is evolution.

All of the components of the genome have one single-minded purpose—to keep the line of your existence going. It's a slightly humbling thought that the genes you carry are immensely ancient and possibly—so far anyway—eternal. You will die and fade away, but your genes will go on and on so long as you and your descendants continue to produce offspring. And it is surely astounding to reflect that not once in the three billion years since life began has your personal line of descent been broken. For you to be here now, every one of your ancestors had to successfully pass on its genetic material to a new

generation before being snuffed out or otherwise sidetracked from the procreative process. That's quite a chain of success.

What genes specifically do is provide instructions for building proteins. Most of the useful things in the body are proteins. Some speed up chemical changes and are known as enzymes. Others convey chemical messages and are known as hormones. Still others attack pathogens and are called antibodies. The largest of all our proteins is called titin, which helps to control muscle elasticity. Its chemical name is 189,819 letters long, which would make it the longest word in the English language except that dictionaries don't recognize chemical names. Nobody knows how many types of proteins there are within us, but estimates range from a few hundred thousand to a million or more.

The paradox of genetics is that we are all very different and yet genetically practically identical. All humans share 99.9 percent of their DNA, and yet no two humans are alike. My DNA and your DNA will differ in three to four million places, which is a small proportion of the total but enough to make a lot of difference between us. You also have within you about a hundred personal mutations—stretches of genetic instructions that don't quite match any of the genes given to you by

either of your parents but are yours alone.

How all this works in detail is still largely a mystery to us. Only 2 percent of the human genome codes for proteins, which is to say only 2 percent does anything demonstrably and unequivocally practical.

Quite what the rest is doing isn't known. A lot of it, it seems, is just there, like freckles on skin. Some of it makes no sense. One particular short sequence, called an Alu element, is repeated more than a million times throughout our genome, including sometimes in the middle of important protein-coding genes. It is complete gibberish, as far as anyone can tell, yet it constitutes 10 percent of all our genetic material.

No one has any idea why. The mysterious part was for a while called junk DNA but now is more graciously called dark DNA, meaning that we don't know what it does or why it is there. Some is involved in regulating the genes, but much of the rest remains to be determined.

The body is often likened to a machine, but it is so much more than that. It works twenty-four hours a day for decades without (for the most part) needing regular servicing or the installation of spare parts, runs on water and a few organic compounds, is soft and rather lovely, is accommodately mobile and pliant, reproduces itself with enthusiasm, makes jokes, feels affection, appreciates a red sunset and

a cooling breeze. How many machines do you know that can do any of that? There is no question about it. You are truly a wonder. But then so, it must be said, is an earthworm.

And how do we celebrate the glory of our existence? Well, for most of us by eating maximally and exercising minimally. Think of all the junk you throw down your throat and how much of your life is spent sprawled in a near-vegetative state in front of a glowing screen. Yet in some kind and miraculous way our bodies look after us, extract nutrients from the miscellaneous foodstuffs we push into our faces, and somehow hold us together, generally at a pretty high level, for decades. Suicide by lifestyle takes ages.

Even when you do nearly everything wrong, your body maintains and preserves you. Most of us are testament to that in one way or another. Five out of every six smokers won't get lung cancer. Most of the people who are prime candidates for heart attacks don't get heart attacks. Every day, it has been estimated, between one and five of your cells turn cancerous, and your immune system captures and kills them. Think of that. A couple of dozen times a week, well over a thousand times a year, you get the most dreaded disease of our age, and each time your body saves you. Of course, very occasionally a

cancer develops into something more serious and possibly kills you, but overall cancers are rare: most cells in the body replicate billions and billions of times without going wrong. Cancer may be a common cause of death, but it is not a common event in life.

Our bodies are a universe of 37.2 trillion cells operating in more or less perfect concert more or less all the time. [*2](#) An ache, a twinge of indigestion, the odd bruise or pimple, are about all that in the normal course of things announces our imperfectability. There are thousands of things that can kill us—slightly more than eight thousand, according to the *International Statistical Classification of Diseases and Related Health Problems* compiled by the World Health Organization—and we escape every one of them but one. For most of us, that's not a bad deal. We are not perfect by any means, goodness knows. We get impacted molars because we have evolved jaws too small to accommodate all the teeth we are endowed with. We have pelvises too small to pass children without excruciating pain. We are hopelessly susceptible to backache. We have organs that mostly cannot repair themselves. If a zebra fish damages its heart, it grows new tissue. If you damage your heart, well, too bad. Nearly all animals produce their own vitamin C, but we can't. We undertake every part of the process

except, inexplicably, the last step, the production of a single enzyme. The miracle of human life is not that we are endowed with some frailties but that we aren't swamped with them. Don't forget that your genes come from ancestors who most of the time weren't even human. Some of them were fish. Lots more were tiny and furry and lived in burrows. These are the beings from whom you have inherited your body plan. You are the product of three billion years of evolutionary tweaks. We would all be a lot better off if we could just start fresh and give ourselves bodies built for our particular *Homo sapien* needs—to walk upright without wrecking our knees and backs, to swallow without the heightened risk of choking, to dispense babies as if from a vending machine. But we weren't built for that. We began our journey through history as unicellular blobs floating about in warm, shallow seas. Everything since then has been a long and interesting accident, but a pretty glorious one, too, as I hope the following pages make clear.

[*1](#) The RSC calculations were done in British pounds and have been converted here into U.S.

dollars at the rate that prevailed in the summer of 2013 of £1 = \$1.57.

[*2](#) That number is of course an educated guess. Human cells come in a variety of types, sizes, and densities and are literally uncountable. The figure of 37.2 trillion was arrived at in 2013

by a team of European scientists led by Eva Bianconi from the University of Bologna in Italy

and was reported in the *Annals of Human Biology*.

2 THE OUTSIDE: SKIN AND HAIR

Beauty is only skin deep, but ugly goes clean to the bone.

—DOROTHY PARKER

I

IT MAY BE slightly surprising to think it, but our skin is our largest organ, and possibly the most versatile. It keeps our insides in and bad things out. It cushions blows. It gives us our sense of touch, bringing us pleasure and warmth and pain and nearly everything else that makes us vital. It produces melanin to shield us from the sun's rays. It repairs itself when we abuse it. It accounts for such beauty as we can muster. It looks after us.

The formal name for the skin is the cutaneous system. Its size is about two square meters (approximately twenty square feet), and all told your skin will weigh somewhere in the region of ten to fifteen pounds, though much depends, naturally, on how tall you are and how much buttock and belly it needs to stretch across. It is thinnest on the eyelids (just one-thousandth of an inch thick) and thickest on the heels of our hands and feet. Unlike a heart or a kidney, skin never fails. "Our

seams don't burst, we don't spontaneously sprout leaks," says Nina Jablonski, professor of anthropology at Penn State University, who is the doyenne of all things cutaneous.

The skin consists of an inner layer called the dermis and an outer epidermis. The outermost surface of the epidermis, called the stratum corneum, is made up entirely of dead cells. It is an arresting thought that all that makes you lovely is deceased. Where body meets air, we are all cadavers. These outer skin cells are replaced every month. We shed skin copiously, almost carelessly: some twenty-five thousand flakes a minute, over a million pieces every hour. Run a finger along a dusty shelf, and you are in large part clearing a path through fragments of your former self. Silently and remorselessly we turn to dust.

Skin flakes are properly called squamae (meaning "scales"). We each trail behind us about a pound of dust every year. If you burn the contents of a vacuum cleaner bag, the predominant odor is that unmistakable scorched smell that we associate with burning hair. That's because skin and hair are made largely of the same stuff: keratin.

Beneath the epidermis is the more fertile dermis, where reside all

the skin's active systems—blood and lymph vessels, nerve fibers, the roots of hair follicles, the glandular reservoirs of sweat and sebum. Beneath that, and not technically part of the skin, is a subcutaneous layer where fat is stored. Though it may not be part of the cutaneous system, it's an important part of your body because it stores energy, provides insulation, and attaches the skin to the body beneath.

Nobody knows for sure how many holes you have in your skin, but you are pretty seriously perforated. Most estimates suggest you have somewhere in the region of two to five million hair follicles and perhaps twice that number of sweat glands. The follicles do double duty: they sprout hairs and secrete sebum (from sebaceous glands), which mixes with sweat to form an oily layer on the surface. This helps to keep skin supple and to make it inhospitable for many foreign organisms. Sometimes the pores become blocked with little plugs of dead skin and dried sebum in what is known as a blackhead. If the follicle additionally becomes infected and inflamed, the result is the adolescent dread known as a pimple. Pimples plague young people simply because their sebaceous glands—like all their glands—are highly active. When the condition becomes chronic, the result is acne, a word of very uncertain derivation. It appears to be related to the

Greek *acme*, denoting a high and admirable achievement, which a faceful of pimples most assuredly is not. How the two became twinned is not at all clear. The term first appeared in English in 1743 in a British medical dictionary.

Also packed into the dermis are a variety of receptors that keep us literally in touch with the world. If a breeze plays lightly on your cheek, it is your Meissner's corpuscles that let you know.* When you put your hand on a hot plate, your Ruffini corpuscles cry out. Merkel cells respond to constant pressure, Pacinian corpuscles to vibration.

Meissner's corpuscles are everyone's favorites. They detect light touch and are particularly abundant in our erogenous zones and other areas of heightened sensitivity: fingertips, lips, tongue, clitoris, penis, and so on. They are named after a German anatomist, Georg Meissner, who is credited with discovering them in 1852, though his colleague Rudolf Wagner claimed that he in fact was the discoverer. The two men fell out over the matter, proving that there is no detail in science too small for animosity.

All are exquisitely fine-tuned to let you feel the world. A Pacinian corpuscle can detect a movement as slight as 0.00001 millimeter, which is practically no movement at all. More than this, they don't

even require contact with the material they are interpreting. As David J. Linden points out in *Touch*, if you sink a spade into gravel or sand, you can feel the difference between them even though all you are touching is the spade. Curiously, we don't have any receptors for wetness. We have only thermal sensors to guide us, which is why when you sit down on a wet spot, you can't generally tell whether it really is wet or just cold.

Women are much better than men at tactile sensitivity with fingers, but possibly just because they have smaller hands and thus a more dense network of sensors. An interesting thing about touch is that the brain doesn't just tell you how something feels, but how it *ought* to feel. That's why the caress of a lover feels wonderful, but the same touch by a stranger would feel creepy or horrible. It's also why it is so hard to tickle yourself.

—

One of the most memorably unexpected events I experienced in the course of doing this book came in a dissection room at the University of Nottingham in England when a professor and surgeon named Ben Ollivere (about whom much more in due course) gently incised and peeled back a sliver of skin about a millimeter thick from the arm of a

cadaver. It was so thin as to be translucent. “That,” he said, “is where all your skin color is. That’s all that race is—a sliver of epidermis.”

I mentioned this to Nina Jablonski when we met in her office in State College, Pennsylvania, soon afterward. She gave a nod of vigorous assent. “It is extraordinary how such a small facet of our composition is given so much importance,” she said. “People act as if skin color is a determinant of character when all it is is a reaction to sunlight. Biologically, there is actually no such thing as race—nothing in terms of skin color, facial features, hair type, bone structure, or anything else that is a defining quality among peoples. And yet look how many people have been enslaved or hated or lynched or deprived of fundamental rights through history because of the color of their skin.”

A tall, elegant woman with silvery hair cut short, Jablonski works in a very tidy office on the fourth floor of the anthropology building on the Penn State campus, but her interest in skin came about almost thirty years ago when she was a young primatologist and paleobiologist at the University of Western Australia in Perth. While preparing a lecture on the differences between primate skin color and human skin color, she realized there was surprisingly little

information on the subject and embarked on what has become a lifelong study. “What began as a small, fairly innocent project ended up taking over a big part of my professional life,” she says. In 2006, she produced the highly regarded *Skin: A Natural History* and followed that six years later with *Living Color: The Biological and Social Meaning of Skin Color*.

Skin color turned out to be more scientifically complicated than anyone imagined. “Over 120 genes are involved in pigmentation in mammals,” says Jablonski, “so it is really hard to unpack it all.” What we can say is this: skin gets its color from a variety of pigments, of which the most important by far is a molecule formally called eumelanin but known universally as melanin. It is one of the oldest molecules in biology and is found throughout the living world. It doesn’t just color skin. It gives birds the color of their feathers, fish the texture and luminescence of their scales, squid the purply blackness of their ink. It is even involved in making fruits go brown. In us, it also colors our hair. Its production slows dramatically as we age, which is why older people’s hair tends to turn gray.

“Melanin is a superb natural sunscreen,” says Jablonski. “It is produced in cells called melanocytes. All of us, whatever our race, have

the same number of melanocytes. The difference is in the amount of melanin produced.” Melanin often responds to sunlight in a literally patchy way, resulting in freckles, which are technically known as ephelides.

Skin color is a classic example of what is known as convergent evolution—that is, similar outcomes that have evolved in two or more locations. The people of, say, Sri Lanka and Polynesia have light brown skin not because of any direct genetic link but because they independently evolved brown skin to deal with the conditions of where they lived. It used to be thought that depigmentation probably took perhaps ten thousand to twenty thousand years, but now thanks to genomics we know it can happen much more quickly—in probably just two or three thousand years. We also know that it has happened repeatedly. Light-colored skin—“de-pigmented skin,” as Jablonski calls it—has evolved at least three times on Earth. The lovely range of hues humans boast is an ever-changing process. “We are,” as Jablonski puts it, “in the middle of a new experiment in human evolution.”

It has been suggested that light skin may be a consequence of human migration and the rise of agriculture. The argument is that

hunter-gatherers got a lot of their vitamin D from fish and game and that these inputs fell sharply when people started growing crops, especially as they moved into northern latitudes. It therefore became a great advantage to have lighter skin, to synthesize extra vitamin D.

Vitamin D is vital to health. It helps to build strong bones and teeth, boosts the immune system, fights cancers, and nourishes the heart. It is thoroughly good stuff. We can get it in two ways—from the foods we eat or through sunlight. The problem is that too much UV exposure damages DNA in our cells and can cause skin cancer. Getting the right amount is a tricky balance. Humans have addressed the challenge by evolving a range of skin tones to suit sunshine intensity at different latitudes. When a human body adapts to altered circumstances, the process is known as phenotypic plasticity. We alter our skin color all the time—when we tan or burn beneath a bright sun or blush from embarrassment. The red of sunburn is because the tiny blood vessels in the affected areas become engorged with blood, making the skin hot to the touch. The formal name for sunburn is erythema. Pregnant women frequently undergo a darkening of the nipples and areolae, and sometimes of other parts of the body such as the abdomen and face, as a result of increased production of melanin.

The process is known as melasma, but its purpose is not understood.

The flush we get when angry is a little counterintuitive. When the body is poised for a fight, it mostly diverts blood flow to where it is really needed—namely, the muscles—so why it would send blood to the face, where it confers no obvious physiological benefit, remains a mystery.

One possibility suggested by Jablonski is that it helps in some way to mediate blood pressure. Or it could just serve as a signal to an opponent to back off because one is really angry.

At all events, the slow evolution of different skin tones worked fine when people stayed in one place or migrated slowly, but nowadays increased mobility means that lots of people end up in places where sun levels and skin tones don't get along at all. In regions like northern Europe and Canada, it isn't possible in the winter months to extract enough vitamin D from weakened sunlight to maintain health no matter how pale one's skin, so vitamin D must be consumed as food, and hardly anyone gets enough—and not surprisingly. To meet dietary requirements from food alone, you would have to eat fifteen eggs or six pounds of swiss cheese every day, or, more plausibly if not more palatably, swallow half a tablespoon of cod liver oil. In America, milk is helpfully supplemented with vitamin D, but that still provides only a

third of daily adult requirements. In consequence, some 50 percent of people globally are estimated to be vitamin D deficient for at least part of the year. In northern climes, it may be as much as 90 percent.

As people evolved lighter skin, they also developed lighter-colored eyes and hair—but only pretty recently. Lighter-colored eyes and hair evolved somewhere around the Baltic Sea about six thousand years ago. It's not obvious why. Hair and eye color don't affect vitamin D metabolism, or anything else physiological come to that, so there seems to be no practical benefit. The supposition is that these traits were selected for as tribal markers or because people found them more attractive. If you have blue or green eyes, it's not because you have more of those colors in your irises than other people but because you simply have less of other colors. It is the paucity of other pigments that leaves the eyes looking blue or green.

Skin color has been changing over a much longer period—at least sixty thousand years. But it hasn't been a straightforward process.

“Some people have de-pigmented; some have re-pigmented,”

Jablonski says. “Some people have altered skin tones a lot in moving to new latitudes, others hardly at all.”

Indigenous populations in South America, for instance, are lighter-skinned than would be expected at the latitudes they inhabit. That is because in evolutionary terms they are recent arrivals. “They were able to get to the tropics quite quickly and had lots of gear, including some clothing,” Jablonski told me. “So in effect they thwarted evolution.” Rather harder to explain have been the KhoeSan people of southern Africa. They have always lived under a desert sun and have never migrated any great distance, yet have 50 percent lighter skin than would be predicted by their environment. It now appears that a genetic mutation for lighter skin was introduced to them sometime in the last two thousand years by outsiders—but who these mysterious light-skinned outsiders were and how they came to be in southern Africa are unknown.

The development in recent years of techniques for analyzing ancient DNA means that we are learning more all the time and much of it is surprising—and some is confusing and some disputed. Using DNA analysis, in early 2018 scientists from University College London and Britain’s Natural History Museum announced to widespread astonishment that an ancient Briton known as Cheddar Man had had “dark to black” skin. He seems also to have had blue eyes. Cheddar

Man was among the first people to return to Britain after the end of the last ice age some ten thousand years ago. His forebears had been in Europe for thirty thousand years, more than sufficient time to have evolved light skin, so if he was truly dark-skinned, it would be a real surprise. However, other authorities have suggested that the DNA used in the analysis was too degraded and our understanding of the genetics of pigmentation too uncertain to allow any conclusions about the color of Cheddar Man's skin and eyes. If nothing else, it was a reminder of how much we have still to learn.

“Where skin is concerned, we are still in many ways at the very beginning,” Jablonski told me.

Skin comes in two varieties: with hair and without. Hairless skin is called glabrous, and there isn't much of it. Our only truly hairless parts are lips, nipples and genitalia, and the bottoms of our hands and feet. The rest of the body is covered with either conspicuous hair, called terminal hair, as on your head, or vellus hair, which is the downy stuff you find on a child's cheek. We are actually as hairy as our cousins the apes. It's just that our hair is much wispiest and fainter. Altogether we are estimated to have five million hairs, but the number varies with

age and circumstances, and is only a guess anyway.

Hair is unique to mammals. Like the underlying skin, it serves a multitude of purposes: it provides warmth, cushioning, and camouflage, shields the body from ultraviolet light, and allows members of a group to signal to each other that they are angry or aroused. But some of these features clearly don't work so well when you are nearly hairless. In all mammals, when they are cold, the muscles around their hair follicles contract in a process known formally as horripilation but more commonly as getting goose bumps. In furry mammals, it adds a useful layer of insulating air between the hair and the skin, but in humans it has absolutely no physiological benefit and merely reminds us how comparatively bald we are. Horripilation also makes mammalian hair stand up (to make animals look bigger and more ferocious), which is why we get goose bumps when we are frightened or on edge, but of course that doesn't work very well for humans either.

The two most enduring questions with respect to human hair are when did we become essentially hairless and why did we retain conspicuous hair on the few places we did? As to the first, it isn't possible to state categorically when humans lost their hair, because

hair and skin aren't preserved in the fossil record, but it is known from genetic studies that dark pigmentation dates from between 1.2 and 1.7 million years ago. Dark skin wasn't necessary when we were still furry, so that would strongly suggest a time frame for hairlessness.

Why we retained hair on some parts of our bodies is fairly straightforward with respect to the head but not so clear elsewhere.

Hair on the head acts as a good insulator in cold weather and a good reflector of heat in hot weather. According to Nina Jablonski, tightly curled hair is the most efficient kind "because it increases the thickness of the space between the surface of the hair and the scalp, allowing air to blow through." A separate but no less important reason for the retention of head hair is that it has been a tool of seduction since time immemorial.

Pubic and underarm hair are more problematic. It is not easy to think of a way that armpit hair enriches human existence. One line of supposition is that secondary hair is used to trap or disperse (depending on theory) sexual scents, or pheromones. The one problem with this theory is that humans don't seem to have pheromones. A study published in 2017 in *Royal Society Open Science* by researchers from Australia concluded that human pheromones probably don't

exist and certainly play no detectable role in attraction. Another hypothesis is that secondary hair somehow protects the skin beneath it from chafing, though clearly a lot of people remove hair from all around their bodies without a notable increase in skin irritation. A more plausible theory, perhaps, is that secondary hair is for display—that it announces sexual maturity.

Every hair on your body has a growth cycle, with a growing phase and a resting phase. For facial hair a cycle is normally completed in four weeks, but a scalp hair may be with you for as much as six or seven years. A hair in your armpit is likely to last about six months, a leg hair for two months. Removing hair, whether through cutting, shaving, or waxing, has no effect on what happens at the root. We each grow about twenty-five feet of hair in a lifetime, but because all hair falls out at some point, no single strand can ever get longer than about three feet. Hair grows by one third of a millimeter a day, but the rate of hair growth depends on your age and health and even the season of the year. Our hair cycles are staggered, so we don't usually much notice as our hair falls out.

II

IN OCTOBER 1902, police in Paris were called to an apartment at 157

rue du Faubourg Saint-Honoré, in a wealthy neighborhood a few hundred yards from the Arc de Triomphe in the 8th arrondissement. A man had been murdered and some works of art stolen. The murderer left behind no obvious clues, but luckily detectives were able to call upon Alphonse Bertillon, a wizard at identifying criminals.

Bertillon had invented a system of identification that he called anthropometry but that became known to an admiring public as Bertillonage. The system introduced the concept of the mug shot and the practice, still universally observed, of recording every arrested person full face and in profile. But it was in the fastidiousness of its measurements that Bertillonage stood out. Subjects were measured for eleven oddly specific attributes—height when seated, length of left little finger, cheek width—which Bertillon had chosen because they would not change with age. Bertillon's system was developed not to convict criminals but to catch recidivists. Because France gave stiffer sentences to repeat offenders (and often exiled them to distant, steamy outposts like Devil's Island), many criminals tried desperately to pass themselves off as first-time offenders. Bertillon's system was designed to identify them, and it did that very well. In the first year of operation, he unmasked 241 fraudsters.

Fingerprinting was actually only an incidental part of Bertillon's system, but when he found a single fingerprint on a window frame at 157 rue du Faubourg Saint-Honoré and used that to identify the murderer as one Henri Léon Scheffer, it caused a sensation not just in France but around the world. Quickly, fingerprinting became a fundamental tool of police work everywhere.

The uniqueness of fingerprints was first established in the West by the nineteenth-century Czech anatomist Jan Purkinje, though in fact the Chinese had made the same discovery more than a thousand years earlier and for centuries Japanese potters had identified their wares by pressing a finger into the clay before baking. Charles Darwin's cousin Francis Galton had suggested using fingerprints to catch criminals years before Bertillon came up with the notion, as did a Scottish missionary in Japan named Henry Faulds. Bertillon wasn't even the first to use a fingerprint to catch a murderer—that happened in Argentina ten years earlier—but it is Bertillon who gets the credit.

What evolutionary imperative led us to get whorls on the ends of our fingers? The answer is that nobody knows. Your body is a universe of mystery. A very large part of what happens on and within it happens for reasons that we don't know—very often, no doubt, because there

are no reasons. Evolution is an accidental process, after all. The idea that all fingerprints are unique is actually a supposition. No one can say for absolute certain that no one else has fingerprints to match yours. All that can be said is that no one has yet found two sets of fingerprints that precisely match.

The textbook name for fingerprints is dermatoglyphics. The plow lines that make up our fingerprints are papillary ridges. They are assumed to aid in gripping, in the way tire treads improve traction on roads, but no one has ever actually proved that. Others have suggested that the whorls of fingerprints drain water better, make the skin of the fingers more stretchy and supple, or improve sensitivity, but again no one really knows what they are there for. Similarly, no one has ever come close to explaining why our fingers wrinkle when we have long baths. The explanation most often given is that wrinkling helps them to drain water better and improves grip. But that doesn't really make a great deal of sense. Surely the people who most urgently need a good grip are those who have just fallen in water, not those who have been in it for some time.

Very, very occasionally, people are born with completely smooth fingertips, a condition known as adermatoglyphia. They also have

slightly fewer sweat glands than normal. This would seem to suggest a genetic connection between sweat glands and fingerprints, but what that connection is has yet to be determined. As cutaneous features go, fingerprints are frankly pretty trivial. Far more important are your sweat glands. You might not think it, but sweating is a crucial part of being human. As Nina Jablonski has put it, “It is plain old unglamorous sweat that has made humans what they are today.”

Chimpanzees have only about half as many sweat glands as we have, and so can’t dissipate heat as quickly as humans can. Most quadrupeds cool by panting, which is incompatible with sustained running and simultaneous heavy breathing, especially for furry creatures in hot climates. Much better to do as we do and seep watery fluids onto nearly bare skin, which cools the body as it evaporates, turning us into a kind of living air conditioner. As Jablonski has written, “The loss of most of our body hair and the gain of the ability to dissipate excess body heat through eccrine sweating helped to make possible the dramatic enlargement of our most temperature-sensitive organ, the brain.” That, she says, is how sweat helped to make you brainy.

Even at rest we sweat steadily, if inconspicuously, but if you add in

vigorous activity and challenging conditions, we drain off our water supplies very quickly. According to Peter Stark in *Last Breath: Cautionary Tales from the Limits of Human Endurance*, a man who weighs 155 pounds will contain a little over forty-two quarts of water. If he does nothing at all but sit and breathe, he will lose about one and a half quarts of water per day through a combination of sweat, respiration, and urination. But if he exerts himself, that rate of loss can shoot up to one and a half quarts per hour. That can quickly become dangerous. In grueling conditions—walking under a hot sun, say—you can easily sweat away ten and a half to twelve and a half quarts of water in a day. No wonder we need to keep hydrated when the weather is hot.

Unless the loss is halted or replenished, the victim will begin to suffer headaches and lethargy after losing just three to five quarts of fluid. After six or seven quarts of unrestored loss, mental impairment starts to become likely. (That is when dehydrated hikers leave a trail and wander into the wilderness.) If the loss gets much above ten and a half quarts for a 155-pound man, the victim will go into shock and die. During World War II, scientists studied how long soldiers could walk in a desert without water (assuming they were adequately hydrated at

the outset) and concluded that they could go forty-five miles in 80-degree heat, fifteen miles in 100-degree heat, and just seven miles in 120-degree heat.

Your sweat is 99.5 percent water. The rest is about half salt and half other chemicals. Although salt is only a tiny part of your overall sweat, you can lose as much as three teaspoonfuls of it in a day in hot weather, which can be a dangerously high amount, so it is important to replenish salt as well as water. Sweating is activated by the release of adrenaline, which is why when you are stressed, you break into a sweat. Unlike the rest of the body, the palms don't sweat in response to physical exertion or heat, but only from stress. Emotional sweating is what is measured in lie detector tests.

Sweat glands come in two varieties: eccrine and apocrine. Eccrine glands are much the more numerous and produce the watery sweat that dampens your shirt on a sweltering day. Apocrine glands are confined mostly to the groin and armpits (technically the axilla) and produce a thicker, stickier sweat.

It is eccrine sweat in your feet—or more correctly the chemical breakdown by bacteria of the sweat in your feet—that accounts for their lush odor. Sweat on its own is actually odorless. It needs bacteria

to create a smell. The two chemicals that account for the odor—isovaleric acid and methanediol—are also produced by bacterial actions on some cheeses, which is why feet and cheese can often smell so very alike.

Your skin microbes are exceedingly personal. The microbes that live on you depend to a surprising degree on what soaps or laundry detergents you use, whether you favor cotton clothing or wool, whether you shower before work or after. Some of your microbes are permanent residents. Others camp out on you for a week or a month and then, like a wandering tribe, quietly vanish.

You have about 100,000 microbes per square centimeter of your skin, and they are not easily eradicated. According to one study, the number of bacteria on you actually rises after a bath or shower because they are flushed out from nooks and crannies. But even when you try scrupulously to sanitize yourself, it isn't easy. To make one's hands safely clean after a medical examination requires thorough washing with soap and water for at least a full minute—a standard that is, in practical terms, all but unattainable for anyone dealing with lots of patients. It is a big part of the reason why every year some two million Americans pick up a serious infection in the hospital (and

ninety thousand of them die of it). “The greatest difficulty,” Atul Gawande has written, “is getting clinicians like me to do the one thing that consistently halts the spread of infections: wash our hands.”

A study at New York University in 2007 found that most people had about 200 different species of microbes on their skin, but the species load differed dramatically from person to person. Only four types appeared on everyone tested. In another widely reported study, the Belly Button Biodiversity Project, conducted by researchers at North Carolina State University, sixty random Americans had their belly buttons swabbed to see what was lurking there microbially. The study found 2,368 species of bacteria, 1,458 of which were unknown to science. (That is an average of 24.3 new-to-science microbes in every navel.) The number of species per person varied from 29 to 107. One volunteer harbored a microbe that had never been recorded outside Japan—where he had never been.

The problem with antibacterial soaps is that they kill good bacteria on your skin as well as bad. The same is true of hand sanitizers. In 2016, the Food and Drug Administration banned nineteen ingredients commonly used in antibacterial soaps on the grounds that manufacturers had not proved them to be safe over the long term.

Microbes are not the only inhabitants of your skin. Right now, grazing in the divots on your head (and elsewhere on your oily surface, but above all on your head) are tiny mites called *Demodex folliculorum*. They are generally harmless, thank goodness, as well as invisible. They have lived with us for so long that according to one study their DNA can be used to track the migrations of our ancestors from hundreds of thousands of years ago. At their scale, your skin to them is like a giant crusty bowl of cornflakes. If you close your eyes and use your imagination, you can almost hear the crunching.

One other thing the skin does a lot, for reasons not always understood, is itch. Although a great deal of itching is easily explained (mosquito bites, rashes, encounters with poison ivy), an awful lot of it is beyond explanation. As you read this passage, you may feel an urge to scratch yourself in various places that didn't itch at all a moment ago simply because I have raised the matter. No one can say why we are so suggestible with respect to itches or even why in the absence of obvious irritants we have them at all. No single location in the brain is devoted to itching, so it is all but impossible to study neurologically. Itching (the medical term for the condition is pruritus) is confined

to the outer layer of skin and a few moist outposts—eyes, throat, nose, and anus primarily. No matter how else you suffer, you will never have an itchy spleen. Studies of scratching showed that the most prolonged relief comes from scratching the back but the most pleasurable relief comes from scratching the ankle. Chronic itching occurs in all kinds of conditions—brain tumors, strokes, autoimmune disorders, as a side effect of medications, and many more. One of the most maddening forms is phantom itching, which often accompanies an amputation and provides the miserable sufferer with a constant itch that simply cannot be satisfied. But perhaps the most extraordinary case of unappeasable suffering concerned a patient known as M., a Massachusetts woman in her late thirties who developed an irresistible itch on her upper forehead following a bout of shingles. The itch became so maddening that she rubbed the skin completely away over a patch of scalp about an inch and a half in diameter. Medications didn't help. She rubbed the spot especially furiously while asleep—so much so that one morning she awoke to find a trickle of cerebrospinal fluid running down her face. She had scratched through the skull bone and into her own brain. Today, more than a dozen years later, she is reportedly able to manage the scratch without doing severe damage to