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Introduction by **Alan Lightman**.

In the summer of 1973, I went on a camping trip in Sequoia national Park. I was a graduate student in physics at the time, and my two companions were also physicists. Carved out of granite by retreating glaciers, Sequoia National Park lies in the southern end of the great Sierra Nevada mountain range of California and is most famous for its giant sequoia trees, which attain heights of several hundred feet and ages of two thousand years. In Sequoia, one's sense are overwhelmed. The land tilts and swerves from the ancient shifting of subterranean faults, snow-covered mountains jut into space, shady forests suddenly give way to bright meadows.

During this barrage of sensation, in which it seemed to me that every cubic inch of the world was filled to its maximum capacity, one of my fellow campers, John Schwarz, was at work formulating a new theory of nature–a theory that required seven additional dimensions beyond the usual three. Schwarz's pioneering calculations, called "string theory" and later extended by other theoretical physicists, are not regarded as the best attempt to develop a quantum theory of gravity and to unify all the forces of nature. For technical reasons, such a theory demands more than length, width, and breadth. Fortunately, the extra dimensions are curled up in such tiny circles that they cannot be experienced by macroscopic creatures who are already strained by a mere three.

Almost a century before that excursion into the sequoias of California, in 1884, there quietly appeared in England a little book titled *Flatland*, which invited its readers to consider the outrageous possibility of four dimensions and more. *Flatland* slyly accomplished this suggestion by portraying the highly limited life of a world of only two dimensions, whose inhabitants cannot imagine, and do not want to imagine, a third dimension. In Flatland, all existence and experience is confined to a plane. Nothing has thickness. People come in the shape of triangles, squares, pentagons, and so on, the greater the number of sides, the higher the status. Since all geometrical shapes appear as straight lines when viewed edge on–and edge on is the only possibility in Flatland–inhabitants must feel each other's angles for proper recognition. Interiors of closed figures are invisible. Rain slides across the world plane from the north; consequently each house is oriented so that its "roof" side faces that direction.

The author of this extended fable was the Reverend Edwin Abbott Abbott, born in 1838, educated at St. John's in Cambridge, and ordained in 1862. Abbott was a classicist, Bible scholar, and, from 1865 to 1889, headmaster of the great City of London School, which he himself had attended before university. Abbott came from a line of headmasters, his father, Edwin Abbott, having been headmaster at the Philological School, Marylebone.

In the edition of the British *Dictionary of National Biography* for persons who died in the period of 1922 to 1930, no reference is made to *Flatland, A Romance of many Dimensions* (1884). Abbott is indeed celebrated as a writer, with special notice of his school primer *How to Write Clearly* (1872), his literary criticism such as *Shakespearean Grammar* (1870), and his many theological writings such as *Philochristus* (1878), *Onesimus: Memoirs of a Disciple of Paul* (1882), and *Johannine Grammar* (1906). But his greatest achievement, from the vantage of a few years after his death, was as a teacher. Although frail and delicate in physique, he could keep discipline without effort, for he had the presence of a commander and "the mark of the spiritual leader in that he could impart to others something of the virtue that was in him. He was aflame with intellectual energy: without driving or overtaxing his pupils, he made intellectual effort a kind of religion for them." A number of his students, including H. H. Asquith, went on to Cambridge and Oxford and became leading men of letters and government, of which he was most proud.‘

Today, Abbott is remembered principally as the author of the little book not even mentioned in the *D.N.B.* None of Abbott's now forgotten other forty books hint at anything nearly so imaginative as *Flatland*. Although *Flatland* contains the same moralizing and didactic tone that runs through all of Abbott's writing, the fable manages to break out of its period with the inspiration and eternal meaning of a classic.

In its mathematical underpinnings, fancifulness, and with, once cannot resist comparing Abbott's fable to Lewis Carroll's *Alice in Wonderland*, published only twenty years earlier. Both Abbott and Carroll came out of the English school system, both excelled in the classics, both lent their particularly mathematical and logical minds to the invention of imaginary worlds for the amusement of their readers. Abbott's book is far more pedantic, its geometrical and moral lessons more overt. Although a great deal has been read into Carroll's two *Alice* books, any didacticism, if it exists at all, is well hidden. Perhaps a close comparison to *Flatland* would be the Russian-born physicist George Gamow's *Mr. Tompkins Explores the Atom* (1945). In these books, Gamow creates fantastic worlds in which his hero Mr. C.G.H. Tompkins, "a little clerk of a big city bank," travels at speeds close to the speed of light, or shrinks to the size of subatomic particles. Gamow's explicit purpose is to popularize relativity and quantum theory; he succeeds also in demonstrating the extreme limitation of human sensory perceptions and all intuitive notions of the natural world based on those perceptions. All of these books, including my own *Einstein's Dreams*, constitute a literary tradition in which a fantasy world created by some physical or mathematical conceit invites the reader to ponder philosophical questions in the actual world of human existence.

Flatland is divided into two halves. The first half bristles with the portrait of what today can only be described as a repulsively elitist and sexist society. Priests, who are circles, are the highest class and administrate the two-dimensional realm. Everyone aspires to having the highest number of sides, approaching the exalted circles, and the children of aristocrats are actually fractured to increase their number of corners. Tradesmen and soldiers, among the lowest classes, with a scant three or four sides to themselves, are barely human. Women are not even worthy of three sides. They are one-sided figures–straight lines, in other words–and they must be constantly avoided or handled gingerly so that their two extremely sharp ends will not puncture incautious males in the vicinity. Women talk too much and are so dumb that they aren't even aware of their wretched status at the bottom of the social hierarchy. Occasionally, they go on a berserk rampage and massacre hundreds of males, a practice that is accepted as keeping the population of the lower classes in check (and might have been applauded by a two-dimensional Thomas Malthus).

This description of society is conveyed earnestly by the narrator of the fable, a two-dimensional inhabitant of Flatland. At first, one has the uneasy felling that the narrator stands for Abbott and his own views of society, but the fictional system is so caricatured and ridiculous and witty that it does not seem possible that Abbott could have shared these views, even in his day. I read this first half of *Flatland* as social satire, in the tradition of Jonathan Swift.

Also raised in the beginning section are the venerable philosophical controversies over nature versus nurture, free will versus determinism. Among the lowest of the low in Flatland are the "Irregulars," miserable creatures whose sides are of unequal lengths (as opposed to the equilateral triangles, the squares, the regular pentagons, and so on) and who behave accordingly. Debate rages over whether the Irregulars are natural monsters, born with defective moral constitution, or instead acquire their bitterness and perversion only after being outcast and mistreated by society. The narrator openly confesses that he favors operating on the Irregulars to make them Regulars, and killing them if that process doesn't work. The Priests claim that personal conduct depends completely on immutable Configuration. If one is born bad (irregular), one remains bad. Will, training, and encouragement are useless. Then again, the Priests have a great deal at stake in protecting their exalted position. The practice of operating on Irregulars to make them Regular or of fracturing the children of aristocrats to give them more sides also echoes the controversial idea of eugenics, in which the "best" human beings are segregated and bred together to improve the species. This notion, discussed today in the context of genetic engineering, was put forth most forcefully by Francis Galton in his book *Hereditary Genius* (1869), a book that well could have been read by Abbott.

The second half of Abbott's book takes a sharp turn when the narrator becomes aware of the limited scope of his world and begins conjecturing on three, four, and higher dimensional possibilities. And here begins to emerge the meaning of the book for science. Indeed, in 1920, an article titled "Euclid, Newton, and Einstein," published in the prestigious scientific journal *Nature*, referred to *Flatland* at some length. Einstein's recent theory of General Relativity (1917), based in part on his earlier Special Relativity (1905), treats time as a fourth dimension. Time is not absolute. This fourth dimension is not rigidly marked out like ticks on a ruler but instead can expand and contract depending on gravity and on the motion of the observer through the three spatial dimensions. The *Nature* article compares the motion of our three-dimensional space against a hypothetical fourth dimension to Abbott's description of motion of his two-dimensional Flatland relative to a three-dimensional sphere: If the latter passes through Flatland, it will be witnessed by the two-dimensional creatures as a circle (the intersection of a sphere with a plane) whose diameter starts as a point when the sphere first touches the plane, grows larger and larger to a maximum size, then contracts down to a point and disappears. The analogy between Einstein's relativity and Abbott's Flatland description is striking although not quite exact, since Einstein's fourth dimension of time behaves very differently from an additional dimension of space. Nevertheless, the writer, signing him or herself only as "W.G.," recognized a point of modern scientific significance in Abbott's little book.

For me, the importance of the second part of *Flatland* lies not in its literal geometrical and dimensional discussion, but in its more shrouded warning of too much complacency in the scientific enterprise–and, by extension, all of life. At the time *Flatland* was published, in 1884, much of science, and especially physics, hummed along in a state of self-satisfaction. Newton's celebrated laws of mechanics and gravity were unchallenged. Dalton's and Avogadro's modern concept of the atom provided a good working basis for the understanding of matter and chemical composition. The nature of heat and the laws of thermodynamics had become well established earlier that century by Rumford, Joule, Clausius, Kelvin, and others. In 1865, Maxwell brilliantly elucidated the complete theory of electricity and magnetism, including a fundamental understanding of the properties of light. Soon after, Mendel published his laws for biological heredity; Mendeleyev put into place the periodic table and was successfully predicting new chemical elements. The theory of natural selection, although not unanimously endorsed, offered a scientific explanation of the specialized diversity of species. Science was indeed content with itself.

In an ironical dream, the two-dimensional narrator of Flatland visits Lineland, where the pitifully ignorant Monarch "was persuaded that the Straight Line, which he called his Kingdom and in which he passed his existence, constituted the whole of the world, and indeed the whole of Space."

"Behold me–I am a Line," said the Monarch of Lineland, "the longest in Lineland, over six inches of space."

"Of Length," responded the narrator.

"Fool," said the Monarch. "Space is Length. Interrupt me again and I have done."

The first interruption of nineteenth-century science came with Roentgen's discoveries of X rays, barely a decade after the publication of *Flatland*. X for unknown. nothing had ever been seen like the highly energetic and penetrating radiations that streamed from an electrified gas. Then, the next year, powerful radiations emerged from uranium and radium, which were apparently spitting out tiny pieces of themselves. To the astonishment of scientists, the immortal and indestructible atom could disintegrate of its own accord. In 1905, the twenty-six-year-old Einstein proposed his new theory of time, contradicting all our intuition and experience with the physical world. Two events that are simultaneous to a man on a bench are not simultaneous to a man in a passing train. To Einstein's theory of relativity, W. F. Maggie, Professor of Physics at Princeton (Monarch of Lineland), responded in 1911:

> I do not believe that there is nay man now living who can assert with truth that he can conceive of time which is a function of velocity or is willing to go to the stake for the conviction that his "now" is another man's "future" or still another man's "past."

The final insult to all common sense was delivered by Heisenberg and Schrödinger's quantum theory, which decreed that the position and velocity of an individual particle cannot be completely specified, even in principle. As a result, one cannot predict with certainty the *future* position and velocity of a particle; such predictions can be done only in terms of probabilities, which apply only to the average behavior of a large number of particles. In short, the world hovers in a state of uncertainty. Einstein, once the pioneer of revolutionary scientific ideas, now resisted the new ones and opposed the indeterminancy inherent in quantum physics. In a letter to fellow physicist Max Born, Einstein wrote:

> The idea that an electron exposed to a ray by its own free decision chooses the moment and the direction in which it wants to eject is intolerable to me. If that is so, I'd rather be a cobbler or a clerk in a gambling casino
> than a physicist.

Back in 1884, the narrator of *Flatland*, who has had his worldview shattered by a visit from a three-dimensional Sphere, launches on a personal mission to "arouse in the interiors of Plane and Solid Humanity a spirit of rebellion against the Conceit which would limit our Dimensions to Two or Three or any number short of Infinity." The flatlander begs the Sphere to take him to the "blessed region of the Fourth Dimension." And the sphere, who has previously scoffed at the Flatlander's small worldview, replies: "There is no such land. The very idea of it is utterly inconceivable."

Today, at the end of the twentieth century, scientists are not so complacent as a century ago. We are particularly aware of the limits of human sensory perception. Our instruments detect X rays and radio waves at frequencies that the eye cannot see, measure relativistic time dilation at speeds far greater than human travel, confirm that subatomic particles behave as if they were in two places at once. Biologists now have the ability to alter the cellular instructions of animals, or to clone others from single cells in a test tube. We freely acknowledge that the world is far stranger than it seems. Thus Schwarz's string theory of then spatial dimensions, Stephen Hawking's calculations of the evaporation of black holes, and Alan Guth's theory of an exponentially expanding universe are all taken seriously.

But Abbott, if we read him deeply, has challenged us to question more than our tenets of geometry and physics. If the very dimensionality of space is open to question, then what beliefs remain sacred? What else should we question? For example: Is there really a sharp division between animate and inanimate matter? Could human consciousness be some kind of collective phenomenon, even though each of us has the strong sensation of individual thoughts and minds? Does the earth behave as a single living organism, with all of its physical and biological systems purposefully connected (as proposed in the "Gaia Hypothesis")? Do nonphysical dimensions exist? Does modern technology diminish, rather than enhance, the quality of life? I confess that I do not know how to ask these kinds of questions, or even what areas of thought they involve. I cannot conceive of a world with these possibilities. And that is the point. The inhabitants of Flatland could not conceive of a third dimension. By definition, it is extremely difficult to imagine worlds outside of experience. For that, we are as likely to receive guidance from our artists and philosophers, as from our mathematicians and scientists.